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An overview of Tomography and Applications

Preface

1. Introduction

This special issue of Fundamenta Informaticae follows the Meeting on Tomography and Applications which took place from March 21 to March 23, 2016 at the Department of Mathematics of Politecnico di Milano. It consists of seven invited papers, which went through a refereeing process. They provide a good representation of the topics discussed at the meeting.

The event, that reached its 10^{th} edition, is by now an established meeting forum for the tomographic research community to present overviews of current developments taking place in both theoretical research and applications. The meeting provided an opportunity to discuss the state of the art of tomographic research from various points of view, taking into account a broad spectrum of expertise of the audience which included pure mathematicians, experimentalists and applied researchers.

In the internet era, when most recent original results are easily accessible from the web, keeping the tradition of meetings such as this one is very important, as they provide forums for direct, personal contacts which are beneficial for solving challenging problems, defining new research directions, and for initiating new as well as strengthening established cooperations.

Before presenting the papers, we provide a concise summary of the contributions of all the speakers of the meeting.

2. Meeting on Tomography and Applications, March 21-23, 2016, Mathematics Department, Politecnico di Milano.

The program of the meeting contained the following lectures.

MAIN LECTURES

- Claudio Ferrero, ESRF Grenoble

  Tomography at the ESRF and its applications: current techniques and outlook.

  ABSTRACT A brief overview is given of the main tomography reconstruction tools used at the ESRF and their supported geometries (parallel and conic beams, helical scans) along with

the associated distributed computation scheme and the most used phase retrieval algorithms. In addition, some iterative methods which have been more recently implemented are outlined. Tentative guidelines are given to help choose the most appropriate algorithms targeting convergence rate, cost per iteration, scalability and numerical stability. Some examples are given of the most outstanding results. The issue of automatic tuning of regularization is briefly discussed as well as numerical techniques for the removal of ring artifacts. The challenges posed by local tomography problems are mentioned and possible solutions are outlined. To conclude, some examples of applications are shown in areas as diverse as materials science and cultural heritage.

- Peter Gritzmann TU München

  On grain indexing and reconstruction.

  ABSTRACT The problem of identifying granular structures is of basic interest in material sciences. The present talk deals with two fundamental problems in this field.

  First, we develop a mathematical model for grain indexing, i.e., for identifying the position and orientation of small crystals (grains) within bulk materials from their images (spots) under X-ray diffraction tomography. We establish and then use the connection of the underlying tasks to problems from the geometry of numbers and combinatorial optimization to give various results on the uniqueness and computational complexity of reconstruction. We also outline algorithms that are based on hypergraph matchings.

  Second, we show how to handle the discrete inverse problem of detecting the geometry of polycrystals (grain maps), based only on few measured parameters (volume, center and, possibly, moments) for each grain. We develop anisotropic diagrams based on geometric clusterings that turn out to provide appropriate tools.

  (The first part is joint work with A. Alpers, G. Heise and A. Taraz; the second part is joined work with A. Alpers, A. Brieden, A. Lyckegaard and H. Poulsen)

- Samuli Siltanen University of Helsinki

  Dynamic sparse X-ray tomography.

  ABSTRACT In recent years, mathematical methods have enabled three-dimensional medical X-ray imaging using much lower radiation dose than before. One example of products based on such approach is the 3D dental X-ray imaging device called VT, manufactured by Palodex Group. The idea is to collect fewer projection images than traditional computerized tomography machines and then use advanced mathematics to reconstruct the tissue from such incomplete data. The idea can be taken further by placing several pairs of X-ray source and detector "filming" the target from many directions at the same time. This allows in principle recovering the three-dimensional inner structure as a function of time. From the biological point of view, one could observe the internal organs of a living and un-sedated organism such as a laboratory mouse. Tentative computational results are shown, based on both simulated and measured data. The results suggest that the new imaging modality is promising for biological applications.

OTHER TALKS

- Sara Brunetti University of Siena

  Q-convexity-based shape descriptors

  ABSTRACT In Discrete Tomography, several classes of binary images presenting different kind of convexity have been studied. These classes arise inherently from the pixel-based representation of the digital image, and give rise to a one dimensional convexity (for instance, h- or v-convexity) or to a two-dimensional convexity (for instance, hv-convexity and Q-convexity). The latter permits to generalize hv-convexity to any two or more directions, and provides similar properties to the class of convex binary images. Moreover, this kind of convexity has been mostly studied in Discrete Tomography for its attractive properties: the reconstruction problem for this class can be done in polynomial time and a random generation algorithm is known.

  In this talk, we propose to define an immediate two-dimensional convexity measure, based on the concept of Q-convexity. Convexity estimators are among the most important shape descriptors in digital image analysis. Shape feature extraction and representation plays an important role in many categories of applications like for example shape retrieval, shape recognition and classification, shape approximation and simplification, and so on. Various continuous and discrete convexity measures have been proposed which can be grouped into different categories, and among them area-based measures and boundary-based ones are frequently used. In the definition of the new Q-convexity estimator we exploit the geometrical description of a binary image provided by the so called salient and generalized salient points, and the definition of Q-convex hull, combining in this way both boundary and area information. Moreover, the advantages of this approach are that normalization is straightforward, the computation of the measure can be done efficiently, and the generalization to any two or more directions should be easy.

  This is a joint work with Pter Balzs.

- Roberto Fedele, Politecnico di Milano

  A new system for X-ray computed microtomography at Politecnico di Milano.

  ABSTRACT A new system for X-ray microtomography has been recently acquired at Politecnico di Milano in the framework of a intramural grant. The system is used by numerous researchers for 3D inspection on several materials and structures seeking diverse engineering applications and achieving resolutions of 2-3 micrometers. Main features of the systems are outlined and the problems encountered so far are specified envisaging possible collaborations.

- Andrea Frosini University of Firenze

  A tomographical interpretation of a sufficient condition on h-graphical sequences.

  ABSTRACT The notion of hypergraph generalizes that of graph in the sense that each hyperedge is a nonempty subset of the set of vertices, without constraints on its cardinality. A fundamental and widely investigated notion related both to graphs and to hypergraphs is the characterization of their degree sequences, that is the lists of their vertex degrees. Concerning graphs, this problem has been solved in a classical study by Erdös and Gallai, while no efficient solutions are known for hypergraphs. If we restrict the (degree sequences) characterization to uniform hypergraphs, several necessary conditions are provided in the literature, but only few

sufficient ones: among the latter, a recent one requires to split a sequence into suitable subsequences whose graphicality has to be recursively tested. Unfortunately, such an approach does not allow a direct efficient implementation. We study this problem under a tomographical perspective by adapting an already known reconstruction algorithm that has been defined for regular h-uniform degree sequences to the proposed instances, providing efficiency to the sufficient condition. Furthermore, we extend the set of h-uniform degree sequences whose graphicality can be efficiently tested. This tomographical approach seems extremely promising for further developments.

- Nicolas Gac, CNRS, Paris

  Multi-GPU parallelization of 3D X-Ray Reconstruction.

  ABSTRACT In this talk, parallelization on GPU of iterative algorithm for 3D X-ray reconstruction will be presented. Our forward and backward operators and our laplacian operator (used for quadratic regularization) has been parallelized on a 8 GPUs server. A special focus will be on optimization of memory transfers between the host PC and the GPU board. Asynchronous transfers and half float compression of data has been used for this purpose. Results will be presented concerning 1024^3 and 2048^3 volumes.

- Lajos Hajdu University of Debrecen

  Some applications of an algebraic framework for discrete tomography.

  ABSTRACT In the talk we present some applications using an algebraic framework for discrete tomography. We start with briefly outlining the underlying algebraic framework, worked out together with R. Tijdeman. We mention that the original setting concerned rectangular sets only, however, later on we extended the theory to any convex set. Then we give some applications relying on these settings. We shall focus on two directions: the geometric placement of the solutions (related results of Batenburg, van Dalen, Fortes, Tijdeman, Hajdu and others) and the question of uniqueness (results of Brunetti, Dulio, Peri, Hajdu and others, in comparison with the fundamental theorems of Lorentz for arbitrary and Gardner and Gritzmann for convex sets, and results of Katz and others in connection with the Mojette transform).

- Federica Marone Paul Scherrer Institut, Villigen

  Regridding for efficient tomographic reconstruction algorithms.

  ABSTRACT At third generation synchrotron sources, typical acquisition times range from few minutes for high-resolution tomographic datasets to just few hundreds of milliseconds in time resolved experiments (e.g. 20 Hz tomography). To efficiently reconstruct this large amount of data (of the order of several tens of TBs per experiment) without need for dedicated GPU hardware, we exploit regridding, guaranteeing high computational performance without loss in accuracy. In this talk we first introduce the basics of projectors based on regridding, also highlighting their versatility, and then discuss their application both in analytic and iterative reconstruction algorithms. We show that the projector accuracy in iterative schemes does not influence neither the algorithm convergence nor the final reconstruction quality. The speed increase provided by these operators compared to other state-of-the art approaches is at least of one order of magnitude while the memory requirements remain moderate. These latest algorithmic developments make iterative approaches very attractive to tackle the reconstruction of

strongly under-constrained datasets, typical in emerging 4D studies, and bring real-time 3D previewing of time-resolved experiments closer to reality.

- Ali Mohammad-Djafari, CNRS, Paris

  Bayesian Tomography from a few number of projections.

  ABSTRACT In Computed Tomography (CT), when the number of projections is very low or limited in angles, the problem becomes very ill-posed. The discretized version will also be ill-posed, in the sense that the problem may still have infinite number of solutions. We need then to add constraints or prior information. We propose to use a basis such as Haar Transform and a sparsity enforcing prior to be able to obtain a satisfactory solution.

- Rosa Maria Moresco, University of Milano-Bicocca

  New insight of in vivo imaging in the understanding of brain disorders.

  ABSTRACT In the last few years the development of biotechnology has increased our knowledge of the structural and molecular modification attending brain disorders which are relevant not only for a better understanding and classification of diseases but also for the development of novel therapeutic interventions. In this era of targeted based therapy and personalized medicine, in vivo imaging techniques represent a unique tool for the early identifications of specific subset of patients on the basis of specific structural, functional and molecular regional brain features. The most advance approach, actually limited to oncology, is represented by radiomics that, in analogy to other omics techniques, transform data into specific imaging signature capturing tissue heterogeneity of patients. However other innovative analysis, like functional MRI (resting state or during task) or diffusion tensor MRI imaging (DTI), has permitted to map at macroscopic levels the structural or functional networking present in brain. In addition, the use of positron tomography techniques (PET) allows to image and quantify the distribution of neuroreceptors, transporter and enzyme or the abnormal presence of activated immune cells or misfolded protein present at regional level in central nervous system. Integration of molecular information with structural and functional data related to normal and pathological brain networking might provide in the near future new insights for the building of new neuropathological models of brain disorders. Here some representative example of structural, functional, molecular and multimodal imaging approach to the classification of brain disorders will be presented.

- Antal Nagy, University of Szeged

  What can influence the effectiveness of the Discrete Tomography?

  ABSTRACT There are many things that one should take into account during the reconstruction of discrete objects. Previously we have shown that the angle set also determines the quality of the reconstruction when the number of projections is low. We will present a framework which can be used to test different kind of tomographic reconstruction methods for multivalued discrete phantoms using a special metric. We will also present the possible improvements of Discrete Algebraic Reconstruction Technique. Finally we will present conclusions of our results.

- Matteo Santacesaria, Politecnico di Milano

  Edge detection in Electrical Impedance Tomography.

  ABSTRACT In this talk we will present a new imaging method which is able to reconstruct discontinuities (e.g., edges of inclusions) of an electrical conductivity from boundary voltage and current measurements. The method combines the high contrast sensitivity of Electrical Impedance Tomography with improved spatial resolution obtained through introduction of a nonphysical (virtual) variable. This talk presents the theoretical background of the method as well as numerical reconstructions. This is a joint work with A. Greenleaf, M. Lassas, S. Siltanen, and G. Uhlmann.

- Maurizio Santini, Universit di Bergamo and Wim van Aarle, University of Antwerp

  On the challenging application of a fast scanning protocol applied on multiphase objects subject to heat transfer.

  ABSTRACT Applications of X-ray tomography at the microscale level on multiphase and heat transfer experiments offer researchers challenging problems in which the relatively slow scanning protocol of conventional micro-CT setups is unsatisfactory for the matching of unsteady problems, e.g., for oscillating or evaporating surfaces such as water droplets. Combining high X-ray flux and/or utilizing faster acquisition units is usually not sufficient due to several technological problems, i.e., scintillator decay time and sensitivity, instability of the higher X-ray flux and the consequent focal spot thermal drifting. Instead, the acquisition time must also be restricted by reducing the number of projection measurements. This, however, leads to limited reconstruction problems in which the available information is insufficient to create an accurate representation of the scanned object. To overcome this problem, prior knowledge regarding the objects density distributions can be exploited.

- Robert Tijdeman, Leiden University

  On the structure of global dependencies.

  ABSTRACT In discrete tomography there is redundancy in the data. For example, the sum of the line sums in one direction is equal to the sum of the line sums in another direction. A dependency is called global if it is valid for all objects. The global dependencies form a linear space. In 2007 Van Dalen made a conjecture on the rank of the space of the global dependencies and a more precise one on the rank of the space of the global dependencies of a given power. Van Dalen proved both conjectures in case of at most four given directions. The former conjecture was proved for any number of directions by Stolk and Batenburg in 2010. The second is still open. In the lecture we discuss the progress with respect to the second conjecture.

- Laszlo Varga University of Szeged

  Decomposition of projections and materials in CT imaging.

  ABSTRACT In the classical sense of tomographic imaging one can gather X-ray projections of an object from different directions. Different types of materials have different absorption properties, which enables one to reconstruct the different materials in the image. Still these classical types of projections have a drawback, viz., they respond to all the materials at once. What if we

could use new projection acquisition techniques - like prompt gamma neutron activation tomography - to get decomposed projections. Such projections would have values which do not only tell the summed attenuation of the materials, but the proportion of the materials along the beam lines. Such projections could bring an interesting new aspect to the reconstruction process. The presentation will give simulation studies for such scenarios.

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