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# Mini Workshop on Bayesian Inverse Problems and Imaging

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May 26, 2017

601 Pao Yue-Kong Library



Institute of Natural Sciences, Shanghai Jiao Tong  
University

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# 1 General Information

## Introduction

This one-day mini-workshop aims at bring together researchers on Bayesian inverse problems and imaging. The topics include Bayesian and variational models, numerical algorithms and application in diverse medical imaging. The mini-workshop is supported by Institute of Natural Sciences and School of Mathematical Sciences.

## Date

May 26, 2017

## Venue

601 Pao Yue-Kong Library

## Organizers

- Jinglai Li, Shanghai Jiao Tong University
- Xiaoqun Zhang, Shanghai Jiao Tong University

# 2 Schedule

**2017-05-26**

Time	Speaker	Title
09:00 - 09:40	Samuli Siltanen	Shearlet-sparsity regularisation for sparse tomography
09:40 - 10:20	Matthias J. Ehrhardt	Faster PET Reconstruction with a Stochastic Primal-Dual Hybrid Gradient Method
10:20 - 10:40		Coffee Break
10:40 - 11:20	Tan Bui-Thanh	Towards Large-Scale Computational Science and Engineering with Quantifiable Uncertainty
11:20 - 12:00	Lukas F. Lang	Optical Flow on Evolving Sphere-Like Surfaces
12:00 - 13:30		Lunch Break
13:30 - 14:10	Heikki Haario	Parameter uncertainty of chaotic systems
14:10 - 14:50	Alex Thiery	Optimal Transportation methods for Bayesian Inverse Problems
14:50 - 15:30	Joana Sarah Grah	Learning Filter Functions in Regularisers by Minimising Quotients

15:30 - 15:50		Coffee Break
15:50 - 16:30	Veronica Corona	Joint reconstruction and segmentation from under-sampled MRI data
16:30 - 17:10	Tatiana Bubba	A nonsmooth regularization approach based on
17:10 - 17:50	Jae Kyu Choi	PET-MRI Joint Reconstruction by Joint Sparsity Based Tight Frame Regularization

## 3 Abstract

### 3.1 2017-05-26

#### 3.1.1 Shearlet-sparsity regularisation for sparse tomography (Samuli Siltanen)

*Samuli Siltanen, University of Helsinki*  
 2017-05-26 09:00 - 09:40

Tomographic reconstruction from comprehensive projection data is a mildly ill-posed inverse problem which is already well-understood. By comprehensive projection data we mean a large number of radiographs taken from essentially all directions around the target. However, many practical imaging situations allow only sparsely collected data. Reasons for this may include desire to reduce radiation dose or data collection time, or mechanical restrictions on imaging directions. Tomographic reconstruction from sparsely collected data is a severely ill-posed problem, and it needs to be regularized by complementing the measurement information by a priori knowledge about the target. The shearlet transform provides a flexible and computational efficient way for enforcing piecewise smoothness in the attenuation coefficient. This is relevant in many practical applications of tomography. For example, the examination of bone samples for detecting osteoarthritis can be speeded up by a factor of 20 using shearlet-based methods.

#### 3.1.2 Faster PET Reconstruction with a Stochastic Primal-Dual Hybrid Gradient Method (Matthias J. Ehrhardt)

*Matthias J. Ehrhardt, Cambridge University*  
 2017-05-26 09:40 - 10:20

In this talk we revisit the problem of PET reconstruction with non-smooth and convex priors. As the data fidelity term in PET is the Poisson likelihood there are not many algorithms that can solve this problem. A very popular choice to solve this problem is the Primal-Dual Hybrid Gradient method proposed by Chambolle and Pock. The system matrix for clinical PET scanners is very large and cannot be stored in the memory of most computers and thus an expensive algorithm to compute

matrix vector products has to be employed. In this talk we extend the Primal-Dual Hybrid Gradient method to the subset setting (like in ART, Kaczmarz or OSEM). By choosing subsets randomly we can prove that the algorithm is convergent for all sensible random subset selections. Examples based on synthetic and real data show that it is much faster (in terms of actual time) than the standard Primal-Dual Hybrid Gradient method.

### **3.1.3 Towards Large-Scale Computational Science and Engineering with Quantifiable Uncertainty (Tan Bui-Thanh)**

*Tan Bui-Thanh, The University of Texas at Austin  
2017-05-26 10:40 - 11:20*

We present our recent efforts towards uncertainty quantification for large-scale computational sciences and engineering. The talk has three parts.

In the first part we present a systematic FEM-based discretization of function-space Markov chain Monte Carlo (MCMC) methods to obtain dimension-independent MCMC methods. This class of MCMC methods are important for PDE-constrained Bayesian inverse problems because they ensure the convergence of the computation as the mesh is refined.

In the second part, we present several particle methods to compute (approximate) posterior samples without the need for a Markov chain. We present theory, computational experiments, and comparisons among the methods.

In the last part, we present dimension-reduction techniques to reduce the data, the parameter, and the state for large-scale data-driven inverse problems in high dimensional parameter spaces.

Numerical results for several inverse problems, including inverse electromagnetic scattering and seismic inversions, will be discussed.

### **3.1.4 Optical Flow on Evolving Sphere-Like Surfaces (Lukas F. Lang)**

*Lukas F. Lang, Cambridge University  
2017-05-26 11:20 - 12:00*

We consider optical flow on evolving surfaces which can be parametrised from the 2-sphere. Our main motivation is to estimate cell motion in time-lapse volumetric microscopy images depicting fluorescently labelled cells of a live zebrafish embryo. We exploit the fact that the recorded cells float on the surface of the embryo and allow for the extraction of an image sequence together with a sphere-like surface. We solve the resulting variational problem by means of a Galerkin method based on compactly supported vectorial basis functions and present numerical results.

### 3.1.5 Parameter uncertainty of chaotic systems (Heikki Haario)

*Heikki Haario, LUT, Lappeenranta University of Technology*  
2017-05-26 13:30 - 14:10

The challenge of estimating parameters in chaotic systems is related to the fact that a fixed model parameter does not correspond to a unique long-time model integration, but to a set of quite different solutions as obtained by setting, e.g., slightly different initial values or solver settings. But while all such trajectories are different, they approximate the same underlying attractor. We show how this idea can be used to create a well-defined statistical likelihood that enables model identification even in the chaotic regime where other methods fail. The approach is verified with various chaotic ODE and PDE systems, together with an extension to SDE.

### 3.1.6 Optimal Transportation methods for Bayesian Inverse Problems (Alex Thiery)

*Alex Thiery, National University of Singapore*  
2017-05-26 14:10 - 14:50

We present an ensemble transform algorithm for Bayesian inverse problems that is rooted from a discretization of the Monge-Kantorovich transport problem. The approach borrows the strength of Sequential Monte Carlo (SMC) methods but replaces the re-sampling step by a transportation optimization problem. The method transforms a set of particles distributed according to the prior distribution into a particle approximation of the Bayesian posterior. Numerical results for large-scale Bayesian inverse problems governed by PDEs will be presented.

### 3.1.7 Learning Filter Functions in Regularisers by Minimising Quotients (Joana Sarah Grah)

*Joana Sarah Grah, Cambridge University*  
2017-05-26 14:50 - 15:30

Learning approaches have recently become very popular in the field of inverse problems and a large variety of methods has been established. However, most learning approaches only aim at fitting parametrised models to favourable training data whilst ignoring misfit training data completely. In contrast to that, we present a learning framework for parametrised regularisation functions based on quotient minimisation, where we allow for both fit- and misfit-training data in the numerator and denominator, respectively. We present results resembling behaviour of well-established derivative-based sparse regularisers like total variation or higher-order total variation in one-dimension. Moreover, we introduce novel families of non-derivative-based regularisers. This is accomplished by learning favourable scales and geometric properties while at the same time avoiding unfavourable ones.

### 3.1.8 Joint reconstruction and segmentation from undersampled MRI data (Veronica Corona)

*Veronica Corona, Cambridge University*  
2017-05-26 15:50 - 16:30

Magnetic resonance imaging (MRI) is widely used in medical and non-medical applications. It often deals with fast acquisition techniques and incomplete measurements, posing challenges in the reconstruction and further analysis of the data. One common imaging task is segmentation, which is typically posterior to acquisition. However, it has been shown for different imaging techniques (x-rays, SPECT, PET) that solving both problems simultaneously can improve performances. We propose a method to jointly reconstruct and segment undersampled data from MRI. We derive a variational model that consists of a total variation regularised reconstruction from undersampled k-space and a Chan-Vese based segmentation. We develop an algorithm based on a splitting approach that solves efficiently the two minimisation subproblems. We present our method and its performance for synthetic and real data.

### 3.1.9 A nonsmooth regularization approach based on (Tatiana Bubba)

*Tatiana Bubba, University fo Helsinki*  
2017-05-26 16:30 - 17:10

Region-of-interest tomography (ROI CT) is among the "hot topics" in the field of X-ray tomographic imaging, due to its potential to lower exposure to X-ray radiation and reduce the scanning time. This is particularly appealing for a wide range of biomedical application, such as contrast-enhanced cardiac imaging or positioning of intracranial stents.

However, the truncation of projection measurements results in a severe ill-posedness, and the presence of noise compromises the stability of traditional CT reconstruction algorithms. In order to obtain stable reconstructions, we introduce a nonsmooth convex optimization approach based on shearlets, a recent multiscale method especially designed to sparsely approximate images with edges. For the solution of this problem, we analyze the very recently proposed variable metric inexact line-search algorithm (VMILA), a proximal-gradient method that enables the inexact computation of the proximal point defining the descent direction.

By using both Poisson noisy simulated data and real data from fan-beam CT geometry, we evaluate the reconstruction performance of our approach and we compare it with the same framework with total variation (TV) as regularization term. In particular, we investigate which technique is more effective in recovering the desired features of the image and avoids unwanted artifacts. The results show that for real data the texture is reconstructed more accurately with the proposed nonsmooth shearlet-based approach, compared to the TV-based approach, without biasing the

image towards a piecewise constant image model. Also, the proposed approach reveals to be insensitive to the location and the size of the ROI.

### **3.1.10 PET-MRI Joint Reconstruction by Joint Sparsity Based Tight Frame Regularization (Jae Kyu Choi)**

*Jae Kyu Choi, Shanghai Jiao Tong University  
2017-05-26 17:10 - 17:50*

Recent technical advances lead to the coupling of PET and MRI scanners, enabling to acquire functional and anatomical data simultaneously. In this talk, we present a tight frame (wavelet frame and data driven tight frame) based PET-MRI joint reconstruction model which exploits the structural similarity between two modalities. To exploit the structural similarity, our model inflicts the joint sparsity of tight frame coefficients. Our model adopts the balanced approach in the tight frame based image restoration to further take the different sparsity of different modality images into account. A proximal alternating minimization algorithm is proposed to solve the nonconvex and nondifferentiable model, and the global convergence is presented based on the Kurdyka-Lojasiewicz property.