CSRC Summer School on Applied Inverse Problems

August 7-11, 2017

Conference Room I, 1st Floor,

CSRC Home Building

http://www.csrc.ac.cn/en/event/workshop/2017-04-14/72.html

Sponsorship:Beijing Computational Science Research Center

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Contents

Introduction

Inverse problems have wide application in optics, radar, acoustics, nondestructive testing, geophysics and many other fields. This meeting aims at bringing together researchers from mathematical, physical and engineering communities to exchange ideas and discuss new trends. It will provide an interdisciplinary forum to inspire graduate students, post-docs and young researchers to cooperate in a wide range of applied inverse problems. Topics of this summer school include (but not limited to):

(i) regularization theory for ill-posed and inverse problems

(ii) inverse electromagnetic scattering with applications in imaging science

(iii) inverse problems arising from geophysics and seismology

Organizing Committee

Guanghui Hu	Beijing Computational Science Research Center (CSRC)
Bo Zhang	Academy of Mathematics and Systems Science (AMSS) Chinese Academy of Sciences (CAS)

Scientific Committee

Gang Bao	Zhejiang University
Jin Cheng	Fudan University
Qiang Du	Beijing Computational Science Research Center
Jijun Liu	Southeast University
Bo Zhang	Academy of Mathematics and Systems Science

Schedule Overview

	August 7 (Monday)	August 8 (Tuesday)	August 9 (Wednesday)	August 10 (Thursday)	August 11 (Friday)
8:20-8:30	Opening				
8:30-10:00	Jijun Liu (刘继军)	Jijun Liu (刘继军)	Haiwen Zhang (张海文)	Lianlin Li (李廉林)	Lianlin Li (李廉林)
10:00-10:20	Photo	Break	Break	Break	Break
10:20-11:50	Lingyun Qiu (邱凌云)	Lianlin Li (李廉林)	Jianwei Ma (马坚伟)	Haiwen Zhang (张海文)	Jiaqing Yang (杨家青) Wenzhao Zhang (张闻钊)
11:50-12:30	Lunch	Lunch	Lunch	Lunch	Lunch
12:30-14:30	Break	Break	Break	Break	
14:30-15:30	Haiguang Liu (刘海广)	Yanfei Wang (王彦飞)	Xiang Xu (徐翔)	Xiaodong Liu (刘晓东)	
15:30-15:50	Break	Break	Break	Break	
15:50-16:50	Haibing Wang (王海兵)	Hao Wu (吴昊)	Ju Ming (明炬)	Yikan Liu (刘逸侃)	
17:00-17:30		Pengfei Wang (汪鹏飞)			
17:30	Dinner	Dinner	Dinner	Dinner	
18:00		Banquet (lecturers and speakers)			

Schedule with Titles and Talks
August 7, 2017 (Monday)

8:20-8:30	**Opening**
8:30-10:00	**Jijun Liu (刘继军)** Regularization schemes for ill-posed problems
10:00-10:20	**Photo and break**
10:20-11:50	**Lingyun Qiu (邱凌云)** Introduction to the mathematics of seismic inversion
11:50-12:30	**Lunch**
12:30-14:30	**Break**
14:30-15:30	**Haiguang Liu (刘海广)** Computational problems in high resolution imaging using X-ray lasers
15:30-15:50	**Break**
15:50-16:50	**Haibing Wang (王海兵)** Green function and its applications to inverse boundary problems
17:00-17:30	**Break**
17:30	**Dinner**

August 8, 2017 (Tuesday)

8:30-10:00	**Jijun Liu (刘继军)** Regularization schemes for ill-posed problems
10:00-10:20	**Break**
10:20-11:50	**Lianlin Li (李廉林)** Inverse electromagnetic scattering theory
11:50-12:30	**Lunch**
12:30-14:30	**Break**
14:30-15:30	**Yanfei Wang (王彦飞)** Selected topics on geophysical data imaging
15:30-15:50	**Break**
15:50-16:50	**Hao Wu (吴昊)** Some recent results for waveform based earthquake location
17:00-17:30	**Pengfei Wang (汪鹏飞)** Introduction of the computing resource at CSRC and a visit to Tianhe 2-JK
17:30	**Dinner**
18:00	**Banquet (lecturers and speakers)**

August 9, 2017 (Wednesday)

8:30-10:00	**Haiwen Zhang (张海文)** Fundamentals of radar imaging
10:00-10:20	**Break**
10:20-11:50	**Jianwei Ma (马坚伟)** Compressed sensing
11:50-12:30	**Lunch**
12:30-14:30	**Break**
14:30-15:30	**Xiang Xu (徐翔)** Carleman estimate and applications for piezoelectric equations
15:30-15:50	**Break**
15:50-16:50	**Ju Ming (明炬)**
17:30	**Dinner**

August 10, 2017 (Thursday)

8:30-10:00	**Lianlin Li (李廉林)** Inverse electromagnetic scattering theory
10:00-10:20	**Break**
10:20-11:50	**Haiwen Zhang (张海文)** Fundamentals of radar imaging
11:50-12:30	**Lunch**
12:30-14:30	**Break**
14:30-15:30	**Xiaodong Liu (刘晓东)** Sampling methods for acoustic scattering problems
15:30-15:50	**Break**
15:50-16:50	**Yikan Liu (刘逸侃)** Inverse problems for the acoustic equation with a time-dependent principal part
17:30	**Dinner**

August 11, 2017 (Friday)

8:30-10:00	**Lianlin Li (李廉林)** Inverse electromagnetic scattering theory
10:00-10:20	**Break**
10:20-11:05	**Jiaqing Yang (杨家青)** Some selected topics on inverse scattering by unbounded rough surfaces
11:05-11:50	**Wenzhao Zhang (张闻钊)** Introduction of quantum radar
11:50-12:30	**Closing and lunch**

Titles and Abstracts

Computational problems in high resolution imaging using X-ray lasers

Haiguang Liu
Beijing Computational Science Research Center, China

X-ray free electron lasers (XFELs) provide super brilliant femtosecond X-ray pulses, opening doors for high resolution imaging using single particles or nanocrystals. In this talk, I will give a brief introduction of X-ray lasers and explain why it is so powerful. Then I will focus on the computational problems in the analysis of XFEL data, including the single particle imaging and serial nano crystallography. For single particle imaging, the major challenge is the restoration of image orientations and phase retrieval, especially for the sample with heterogeneous conformations. For serial nano crystallography, we need to deal with indexing of diffraction peaks and model reconstructions. If time allows, I would like to provide an alternative approach to solve structures without restoring the orientations. The take-home message is that XFEL offers some unique features to allow us to see molecular movies at ultrashort time scale in the microscopic world, and the problems need joint efforts from multidisciplinary.

Inverse problems for the acoustic equation with a time-dependent principal part

Yikan Liu
The University of Tokyo

In this talk, we investigate the theoretical stability and the numerical reconstruction of two inverse problems for the general acoustic equation with a time-dependent principal part. For the inverse source problem on determining the spatial component,we prove the local Hölder stability in both cases of partial boundary and interior observation data based on a

newlyestablished Carleman estimate for general hyperbolic operators. For the coefficient inverse problem on determining space-dependent wave propagation speed, we apply a similar argument to prove the same local stability of Hölder type with the aid of an auxiliary first order Carleman estimate. Numerically, we adopt the classical Tikhonov regularization to reformulate both problems into related optimization problems, for which we develop iterative thresholding algorithms by deriving the respective variational equations. Numerical examples up to three spatial dimensions are presented to demonstrate the accuracy and efficiency of the proposed iteration.

Green function and its applications to inverse boundary problems

Haibing Wang
Southeast University

Green function plays a central role in the theory of partial differential equations. Especially, in many non-iterative reconstruction methods for inverse boundary problems, the indicator functions constructed from measurement data are closely related to the corresponding Green functions. In this talk, taking inverse boundary problem for the diffusion equation as an example, we show how the Green function is linked to the inverse boundary problem. In addition, we also show how to construct the Green function and analyze its local asymptotic behavior.

Fundamentals of radar imaging

Haiwen Zhang
Chinese Academy of Sciences

The aim of this lecture is to present the state of the art of the mathematical theory of radar imaging.We will talk about radar systems, Doppler effect, radar ambiguity function, scattering theory and so on. If

time permits, we will give an introduction of synthetic aperture radar. We hope this lecture will enable students to have a better mathematical understanding of radar imaging and to be interested inthis field.

Introduction of quantum radar

Wenzhao Zhang
Beijing Computational Science Research Center, China

20 世纪 50 年代末以来，雷达获得了广泛的应用和发展，它不仅成为军事上必不可少的电子装备，而且深入到社会经济发展的各个领域，如气象预报、资源探测、安全预警、环境监测等，同时也推动着科学研究的进程，如天体研究、大气物理、电离层结构研究等。随着科技的蓬勃发展，对雷达提出了更高精度、更远距离、超高分辨率以及多目标测量等要求。现有的雷达系统越来越难以满足人们日益增长的需求。另一方面，量子技术对通信领域以及超精密测量方面的巨大影响，使得人们期望通过量子的技术手段提升雷达的性能。2008 年，麻省理工学院的 Seth Lloyd 提出了利用纠缠增强目标识别的量子照明协议使得这一期望成为了可能，随后，很多课题组便展开了对量子雷达的探索。诸多利用量子手段增强目标探测的协议也被相继提出，这也使得人们逐渐看到了将量子技术应用于雷达系统的广阔前景。这里，我将首先对传统雷达系统做一些简单的介绍，包括雷达的分类、应用、雷达方程以及雷达散射截面等，然后对比经典雷达计算给出的量子雷达的雷达方程、散射截面。之后我们还介绍几种常用的量子测量方式，最后，结合目前的研究现状介绍几种潜在的量子雷达方案：量子照明、量子成像等。

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[2].S. Barzanjeh et al., Microwave Quantum Illumination. Physical Review Letters. 114, 80503 (2015).

[3].G. Brida, M. Genovese, I. Ruo Berchera, Experimental realization of sub-shot-noise quantum imaging. Nature Photonics. 4, 227–230 (2010).

[4].S. Lloyd, Enhanced Sensitivity of Photo detection via Quantum

Illumination. Science. 321, 1463–1465 (2008).
[5].Y. Cai, S.-Y. Zhu, Ghost imaging with incoherent and partially coherent light radiation. Physical Review E. 71, 56607 (2005).

Some recent results for waveform based earthquake location

Hao Wu
Tsinghua University

The waveform based earthquake location is essentially a PDE-constraint optimization problem. In this talk, we will present some newly developed techniques. (i) We convert the original optimization problem into the problem of finding the zero point of the auxiliary functions. But the computational cost is significantly less than that of the iterative methods. (ii) We apply the famous Wasserstein metric to locate the earthquake. The convexity of the misfit function with respect to the earthquake hypocenter and the origin time can be observed. Even for large data noise, these methods could locate the earthquake with reasonable accuracy. These approaches provide fast and accurate methods to locate the earthquakes, which may be useful for the earthquake real-time locating and the earthquake relocation.

Selected topics on geophysical data imaging

Yanfei Wang
Institute of Geology and Geophysics
Chinese Academy of Science

In this talk, I address about inverse problems in geophysics and the related solution methods. Inverse problems in geophysics mainly refer to using the observations with various detectors to infer the unknowns, e.g., albedos, temperature distribution, LAI, layer reflectivity, impedance, velocity, density, magnetization, electroconductibility, anisotropic

parameters, data completion and imaging of an object section. Generally, inverse problems are ill-posed in the sense that one of the three items "existence, uniqueness or stability" of the solution may be violated. In geophysics, nearly all inverse problems are ill-posed because of the limitations of observations and instability during inversion computation. For instance, a direct effect of the limitations of acquisition is the sub-sampled data will generate aliasing in the frequency domain; therefore, it may affect the subsequent processing such as filtering, de-noising, amplitude versus offset analysis, multiple eliminating and migration imaging.In our recent work, we develop some sparse optimization methods for the geophysical data regularization and imaging problems. We consider sparsity-constrained regularization modeling and related solving methodology. Numerical experiments based on theoretical data and field data are performed and interpreted.

Sampling methods for acoustic scattering problems

Xiaodong Liu
Chinese Academy of Sciences

This talk aims to give a short review of the sampling methods for inverse acoustic scattering problems. In particular, a novel direct sampling method will be introduced. The same as the classical sampling methods (e.g., linear sampling method or factorization method), our novel sampling method makes no explicit use of boundary conditions or topological properties of the underlying scattering system. Only matrix multiplication has been used in the novel sampling method, thus it is much more direct and more robust to noises.

Compressed sensing

Jianwei Ma
Harbin Institute of Technology

压缩感知描述的是如何用不完备的测量高精度重够未知目标。本报告主要讲压缩感知的基本概念和步骤：稀疏变换，随机采样和凸优化重构，并结合地球物理信号处理和反问题的背景来具体展开。

Introduction to the mathematics of seismic inversion

Lingyun Qiu
Petroleum Geo-Services Company

The goal of this lecture is to give an introduction of the mathematical background of the seismic inverse problem, focusing on the robust misfit metric and variational regularization method.The seismic inverse problem appears in the applications of the exploration geophysics and consists in determining the geophysical information of an un-derneath region using the data measured on the surface. It is formulated as a PDE constrained inverse medium problem: given the values of a family of solutions in a hyperbolic system, find the coe cients of the system. A data fitting scheme is usually employed to solve it in mathematics and engineering. In most realistic situations, solving this inverse problem is challenging due to the large scale and ill-posedness of the problem(noisy measurement, lack of stability and non-uniqueness).The analysis and numerical scheme of this nonlinear problem has been ex-tensively studied by both mathematician and geophysicist in the past decades. The main mathematical obstacle remaining is on the appearance of many local minima in the data-misfit function. I will show two approaches to mitigate the ill-posedness – One is via a generalized version of the TV-L1 regularization and the other one is to use the quadratic Wasserstein metric.

Inverse electromagnetic scattering theory

Lianlin Li
Peking University

课程（一）：从电磁成像到电磁感知
讨论电磁感知的最新研究进展，包括面向对象数据处理算法和智能数据采集方法。
课程（二）：无相位逆散射成像的一些方法
讨论电子工程领域的无相位逆散射成像方法，包括无相位 Rytov 方法，无相位迭代 Born/Rytov 方法，无相位对比源方法。
课程（三）：压缩相位复原理论与方法
讨论压缩相位复原的近似信息传递理论与算法。

Regularization schemes for ill-posed problems

Jijun Liu
Southeast University

Most of the inverse problems are ill-posed, and consequently the regularization techniques are required to solve the inverse problems for getting the stable solutions . In these talks, we will firstly introduce the framework of regularization for linear ill-posed problems, focusing on the choice strategies of regularizing parameters and the convergence rate of the corresponding regularizing solution. Then we will show the applications of the regularization techniques for some important inverse problems such as inverse scattering problems and diffusion problems.

Carleman estimate and applications for piezoelectric equations

Xiang Xu
Zhejiang University

In this talk, Carleman estimate for piezoelectric equations in one dimension is established. Utilizing this estimate, a local Holder stability for an inverse source problem is obtained on determining a spatial component. Consequently, we show a uniqueness and Lipschitz stability result on an inverse coefficient problem in case of interior observation data.Moreover, the inverse source and coecient problems are numerically solved via an iterative algorithm based upon regularization methods. Numerical examples are presented to validate the effectiveness of the proposed algorithms.

Some selected topics on inverse scattering by unbounded rough surfaces

Jiaqing Yang
Xi'an Jiaotong University

The inverse scattering theory aims to recover unknown informations suchas the shape, location and parameters on the bounded or unboundedobstacles by means of far-field or near-field data of scattered waves.In this talk, I this talk, I shall address some interesting inverse problems arising in the inverse unbounded surface scattering including the periodical case. A short review will be introduced on the uniqueness issue and numerical solutions methods obtained recently for the related inverse problems. In addition, I will also present several challenging topics in the field of the inverse scattering associated with the unbounded rough surfaces.

List of Participants

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Useful Information to Beijing CSRC

Here are *Some Important Tips:*

1 CSRC Address:

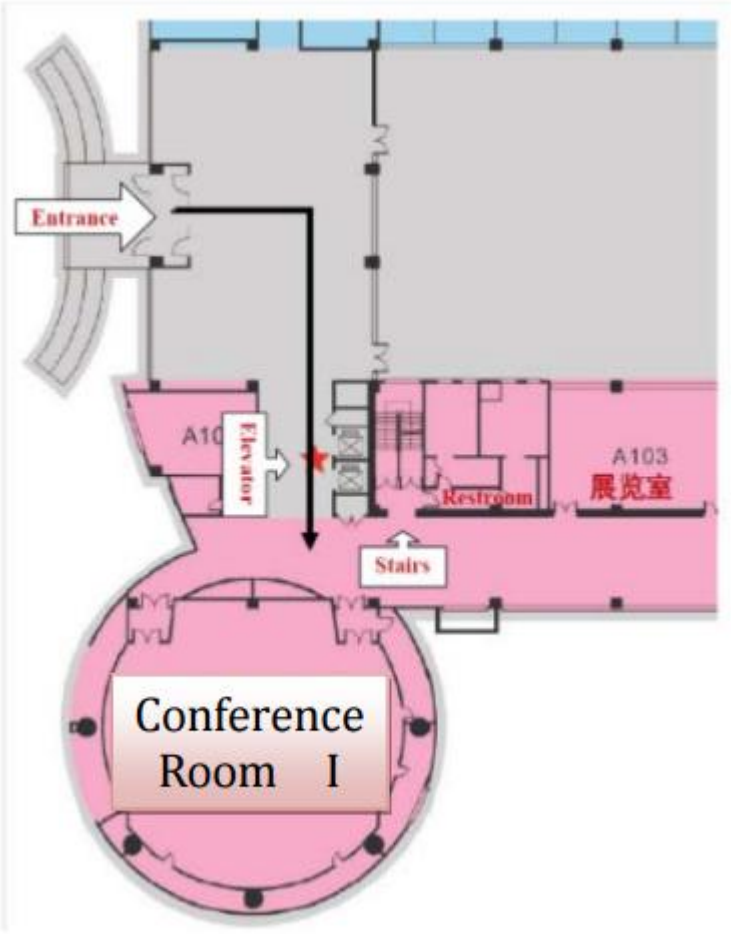
◊ Building 9,East Zone, ZPark Ⅱ, No.10 Xibeiwang East Road, Haidian District, Beijing 100094, China

◊ 北京市海淀区西北旺东路 10 号院东区 9 号楼

◊ Telephone: +86-10-56981800

2 Summer School Venue: Conference Room I, 1st Floor

3 Free Wi-Fi: csrc_guest, password: csrc20150308



Recommended Route

Taxi:

1) From Capital International Airport (首都国际机场): the cost is about 130 RMB (50mins).

2) From Beijing Railway Station (北京站): the cost is about 100 RMB (80 mins).

3) From Beijing West Railway Station (北京西站): the cost is about 70 RMB (60mins).

4) From Beijing South Railway Station (北京南站): the cost is about 105

RMB (90mins).

Local Bus:

Bus #205 (Software Park West Stop/软件园西区站)

Bus #333 (Houchangcun East Stop/后厂村东站)

Bus #963/#982 (Dongbeiwang West Road North Stop/东北旺西路北口站)

Subway:

Take Subway Line 13 to "SHANG DI Station(上地站)", take Exit A to catch Bus #205 to "Software Park West Stop(软件园西区站)". Enter the park and proceed toward in the north direction, CSRC will be to your right in 400 meters.