Workshop on Mathematical and Computational Challenges of Medical Imaging and Inverse Problems

August 13 – 16, 2018

Organized by

Fudan University

Shanghai University of Finance and Economics (SUFE)

School of Mathematics, SUFE
No.777 Guoding Road, Yangpu District, Shanghai, China

Sponsors

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Fudan University

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Introduction

The aim of this workshop is to provide a forum for mathematicians and engineers who are working in the areas of medical imaging and related inverse problems to share their recent research progress and develop further collaborations in this field.

Topics of the workshop will include

1. New engineering technology in medical imaging such as Photo-Acoustic, Optical Tomography, CT, MRI and Ultrasound;
2. Mathematical and numerical modelling of medical imaging;
3. Theoretical and numerical inversion of medical imaging.

Scientific Committee

Jin Cheng

Fudan University, Shanghai University of Finance and Economics, China

Jianliang Qian

Michigan States University, USA

Invited Speakers

Mark Anastasio

Washington University in Saint Louis, USA

Gang Bao

Zhejiang University, China

Yoko Hoshi

School of Medicine, Hamamatsu University, Japan

Shingyu Leung

Hong Kong University of Science and Technology, Hongkong

Jijun Liu

Southeast University, China

Manabu Machida

School of Medicine, Hamamatsu University, Japan

Goro Nishimura

Hokkaido University, Japan

Xiaochuan Pan

University of Chicago, USA

Chunqi Qian

Michigan State University, USA

Hotel Information

Howard Johnson Caida Plaza Shanghai

No.188 Wudong Road, Yangpu District, Shanghai, China

Conference Information

Conference Hall

1st Floor, Administrative Building, SUFE

Program at a glance

	Aug. 12 (SUN)	**Aug. 13** (MON)	**Aug. 14** (TUE)	**Aug. 15** (WED)	**Aug. 16** (THU)
08:30 – 09:00		**Opening Ceremony**			
09:00 – 09:45		Gunther Uhlmann	Mark Anastasio	Hong-Kai Zhao	Chunqi Qian
09:45 – 10:30		Eric Todd Quinto	Ge Wang	Shingyu Leung	Xiaotong Zhang
10:30 – 11:00		**Coffee Break**			
11:00 – 11:45		Kui Ren	Masahiro Yamamoto	Jijun Liu	Yu Jiang
11:45 – 13:30		**Lunch**			**Closing Ceremony** **Lunch**
13:30 – 14:15		Xiaochuan Pan	Yoko Hoshi	**Symposium**	
14:15 – 15:00		Yang Yang	Goro Nishimura		
15:00 – 15:30	**Registration**	**Coffee Break**			
15:30 – 16:15		Haibing Wang	Manabu Machida		
16:15 – 17:00		**Free Discussion**			
17:00 – 19:00		**Dinner**	**Banquet**	**Dinner**	

Registration

August 12 (Sunday)

15:00 – 19:00 **Room 723**, Red Tile Building, SUFE

August 13 (Monday)

08:00 – 08:30 **Lobby** of Administrative Building, SUFE

Program

August 13, 2018
Monday

08:30 – 09:00 **Opening Ceremony**

Welcoming Remarks

Group Photo

09:00 – 11:45 **Plenary Talk**

09:00 Gunther Uhlmann
Title: TBA

09:45 Eric Todd Quinto
Title: Artifacts in tomography

10:30 **Coffee Break**

11:00 Kui Ren
Title: Quantitative Photoacoustics with Additional Optical Measurements

11:45 – 13:30 **Lunch**

August 13, 2018
Monday

13:30 – 16:15 Plenary Talk

13:30 Xiaochuan Pan
Title: Investigation of Non-Linear Problems in X-ray CT

14:15 Yang Yang
Title: TBA

15:00 **Coffee Break**

15:30 Haibing Wang
Title: TBA

16:15 – 17:00 Free Discussion

17:00 – 19:00 Dinner

August 14, 2018

Tuesday

09:00 – 11:45 **Plenary Talk**

09:00 Mark Anastasio

Title: Photoacoustic Computed Tomography in Heterogeneous Acoustic Media: Status and Open Challenges

09:45 Ge Wang

Title: Machine Learning for Biomedical Imaging

10:30 **Coffee Break**

11:00 Masahiro Yamamoto

Title: TBA

11:45 – 13:30 **Lunch**

August 14, 2018
Tuesday

13:30 – 16:15 **Plenary Talk**

13:30 Yoko Hoshi

Title: Toward next generation diffuse optical tomography: the issue of internal refractive index variations

14:15 Goro Nishimura

Title: Time-domain optical tomography for fluorescence objects

15:00 **Coffee Break**

15:30 Manabu Machida

Title: Spatial-frequency optical tomography in the radiative-transport regime

16:15 – 17:00 **Free Discussion**

17:00 – 19:00 **Banquet**

August 15, 2018
Wednesday

09:00 – 11:45 **Plenary Talk**

09:00 Hong-Kai Zhao

Title: A hybrid adaptive phase space method for reflection traveltime tomography

09:45 Shingyu Leung

Title: Some Numerical Methods for Inverse Problems from Traveltime Tomography and Gravimetry

10:30 **Coffee Break**

11:00 Jijun Liu

Title: TBA

11:45 – 13:30 **Lunch**

13:30 – 17:00 **Symposium**

Title: Challenges of Medical Imaging and Inverse Problems

17:00 – 19:00 **Dinner**

August 16, 2018
Thursday

09:00 – 11:45 Plenary Talk

09:00 Chunqi Qian

Title: MRI detection and inverse problems

09:45 Xiaotong Zhang

Title: Computational Electromagnetic Problems in 7T MRI

10:30 **Coffee Break**

11:00 Yu Jiang

Title: Inversion Analysis for Magnetic Resonance Elastography

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11:45 – 12:15 Closing Ceremony

Closing Remarks

12:15 – 13:30 Lunch

Abstract

Photoacoustic Computed Tomography in Heterogeneous Acoustic Media: Status and Open Challenges

Mark Anastasio

Washington University in St. Louis

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Photoacoustic computed tomography (PACT) is an emerging soft-tissue imaging modality that has great potential for a wide range of preclinical and clinical imaging applications. It can be viewed as a hybrid imaging modality in the sense that it utilizes an optical contrast mechanism combined with ultrasonic detection principles, thereby combining the advantages of optical and ultrasonic imaging while circumventing their primary limitations. In this talk, we review our recent advancements in image reconstruction approaches for PACT in acoustically heterogeneous fluid and elastic media.

Toward next generation diffuse optical tomography: the issue of internal refractive index variations

Yoko Hoshi

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Diffuse optical tomography (DOT) is a technique to reconstruct images of absorption and scattering coefficient distribution in turbid media. The main applications of DOT have been breast, neonatal brain, joint, limb and fluorescence imaging over the last 30 years. However, image quality is still far from widespread clinical use, which is attributed to difficulty in accurate numerical modeling of light propagation in biological tissue as well as ill-posed nature of inverse problems. The

radiative transfer equation (RTE) describes light propagation in biological tissue correctly, whereas knowledge about optical properties, including refractive index and anisotropy factor, which are parameters of the RTE, is incomplete. Although it is widely accepted that refractive indices vary with each tissue, these values are generally assumed to be homogeneous throughout the imaging region. This assumption is supported by the previous simulation study reporting that the effect of internal refractive index variations on boundary measurements was slight in a two-layered slab model[1]. However, our some recent studies have suggested that refractive-index mismatch conditions should be taken into account when reconstructing DOT images. In this workshop, firstly I will talk about the general aspects of DOT briefly, and then talk about the issue of the internal refractive index variations.

1. Dehghani H, et al. Phys. Med. Biol. 48 (2003) 2713-2727.

Inversion Analysis for Magnetic Resonance Elastography

Yu Jiang

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A diagnosing modality called MRE (Magnetic Resonance Elastography) whose hardware consists of a MRI and vibration system can measure the displacement vector of a shear wave inside a human tissue. The so called elastogram of MRE is to recover viscoelasticity of human tissue from the *MRE measured data*. This is an inverse problem with single interior measurement.

The importance of MRE is that it can realize doctors' palpation inside a human boday which had been dreamed by doctors for a long time. Although the hardware of MRE is developing very quickly, the elastogram has not yet developed enough and there are so many challenging questions for elastogram.

I will introduce the fundamental principal and mathematical model of MRE in the talk. Some inversion sheme to recover the unknown viscoelastic coefficients will also be present.

This is a joint work with Prof. Gen Nakamura in Hokkaido University, Japan.

Some Numerical Methods for Inverse Problems from Traveltime Tomography and Gravimetry

Shingyu Leung

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We discuss various numerical methods to some inverse problems originated from traveltime tomography and inverse gravimetry. We first formulate these inverse problems in variational formulations. To minimize the energy in the variational formulation, we derive the gradient of the nonlinear functional which can be efficiently computed using the adjoint state method. We also propose an operator splitting approach to some of these inverse problems. We will also show various numerical examples to demonstrate the feasibility and the robustness of these new formulations.

TBA

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Spatial-frequency optical tomography in the radiative-transport regime

Manabu Machida

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It has been reported that noncontact optical tomography is improved by the use of illumination with sinusoidal intensity pattern. Although this imaging method of using spatial frequency is promising, most research so far has relied on the diffusion approximation to the radiative transport equation. In this talk, I will present numerical algorithms of optical tomography with spatially sinusoidal illumination for the radiative transport equation. With the help of the technique of rotated reference frames, the forward problem, i.e., the three-dimensional radiative transport equation is solved in two ways: the spherical-harmonic expansion and the FN method. Then the inverse problem is solved by making use of the Green's function, which is the solution to the forward problem.

Time-domain optical tomography for fluorescence objects

Goro Nishimura
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Fluorescence imaging technique is very common to assess the biological samples. However, it is really difficult to image the fluorescence from thick samples, like human tissues. The fluorescence photons are strongly scattered and the spatially localized information is spreading in the whole space and lost. The image is obtainable from data with a reconstruction based on the mathematical model of photon transport. We have employed the time-domain photon diffusion (PD) model instead of the steady state PD model because time-domain method is a method to increase the spatial information. In this talk, I introduce our approach and experimental results. I also discuss the effect of the contaminations in time-domain data.

Investigation of Non-Linear Problems in X-ray CT

Xiaochuan Pan

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Non-linear data models arise in X-ray computed tomography (CT). Current CT imaging applications are based largely on a linear data model. While the linear data model can be of sufficient utility for a wide variety of CT imaging applications, it is recognized also that non-linear effect can result in artifacts in CT images, which could distract the visualization/detection of subtle, low-contrast structures of application significance. There has been a renewed, strong interest in research on and application of multi-spectral (or photon-counting) CT in the field. In multi-spectral CT, accurate image reconstruction remains challenging because its appropriate data model is highly non-linear due to the polychromatic nature of X-ray spectra used. Also, in realistic CT imaging, the presence of non-linear partial volume (NLPV) effect can lead to artifact that obscure low-contrast signals especially when they embedded within an environment of high contrast structures. Both multi-spectral and NLPV can lead to non-linear data models in CT. In the presentation, I will discuss recent advances in the development of methods, with a focus on a non-convex optimization-based image reconstruction (OBIR) method, for solving non-linear data model in realistic CT through considering the effect of multi spectra or NLPV. Following the discussion, specific examples will be used to illustrate the applications of the methods to CT imaging and to demonstrate their effectiveness in compensation for the effect of multi spectra or NLPV.

MRI detection and inverse problems

Chunqi Qian

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Magnetic Resonance Imaging (MRI) is a powerful and versatile technique for diseases diagnosis and preclinical research. The applicability of MRI, however, is often limited by its detection sensitivity, which determines the achievable spatial resolution. Although the detection sensitivity of MRI has steadily increased over the last four decades of its existence, I will introduce a complementary method that can further improve its detection sensitivity. This method benefits from the well-known fact that a miniaturized detector has better local sensitivity when it is placed in vicinity to the detection object. But unlike the traditional micro-coils that need wired connections, the wireless amplified detector can maintain the superior local sensitivity by amplifying signals in situ before wirelessly coupling them to the external receiver. The detector has an integrated amplifier that doesn't require an internal power source. After going through the operation principles, I will demonstrate the detection capabilities of Wireless Amplified NMR Detectors (WAND) with high resolution kidney and vascular images obtained on animal models. Such high resolution capability has enabled the in vivo observation of kidney functions at near histological level. Finally, I will address inverse problems related to the future development of the wireless amplifier technology.

Artifacts in tomography

Eric Todd Quinto

Tufts University

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In this talk, we will describe how artifacts are generated in limited data X-ray tomography. We characterize artifacts both by their shape and their cause. We will explain the artifacts using Fourier and microlocal analysis. We will provide examples from real and simulated data that illustrate our results for X-ray CT and, if time, photoacoustic CT and sonar.

Quantitative Photoacoustics with Additional Optical Measurements

Kui Ren

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We study here an inverse problem in quantitative photoacoustic tomography (QPAT) where we supplement photoacoustic data with additional boundary optical data as measured in optical tomography (OT). We demonstrate computationally the benefits of such combination of QPAT and OT. In particular, we show that this combination can improve the separation of the absorption and scattering coefficients in numerical image reconstructions.

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Machine Learning for Biomedical Imaging

Ge Wang

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Computer vision and image analysis are great examples of machine learning especially deep learning. While computer vision and image analysis deal with existing images and produce features of these images (images to features), tomographic reconstruction produces images of internal structures from externally measured data which are various features of the underlying images (features to images). Recently, deep learning techniques are being actively developed worldwide for tomographic reconstruction, with encouraging results at RPI and other institutions. We believe that deep reconstruction is a next frontier of machine learning, has a revolutionary potential to improve tomographic solutions, and promises major impacts on development of imaging methods and their applications. Along this direction, we have been working on data-driven algorithms based on modern analytic and iterative reconstruction algorithms, for optimized workflow with multi-stages and/or in multi-modes, and toward superior performance in clinical and preclinical applications. In addition to my general perspective of "deep imaging" (https://ieeexplore.ieee.org/document/7733110), our recent results will

be reported on methodological exploration, learning-based reconstruction, and hybrid imaging.

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Computational Electromagnetic Problems in 7T MRI

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The RF receive coil array has become increasingly vital in current MR imaging practice due to its extended spatial coverage, maintained high SNR, and improved capability of accelerating data acquisition. The performance of a coil array is intrinsically determined by the current patterns generated in coil elements as well as by the induced electromagnetic fields inside the object. Through numerical electromagnetism computation, investigations of the ultimate performance constrained by a specific coil space, which defines all possible current patterns flowing within, offers the opportunity to evaluate coil-space parameters without the necessity of considering the realistic coil element geometry, coil elements layout, and number of receive channels in modeling. In this talk, I will introduce our recent studies of the influences of coil-space design parameters through evaluating the corresponding spatial constrained ultimate intrinsic SNR (UISNR) and ultimate g-factor (uGF), and provide our insights on to what extent, the ultimate coil performance can be achieved by using practical coil designs. We hope the present analysis will offer important implications in novel receive array design for primate brain MR imaging at ultra-high field (UHF).

A hybrid adaptive phase space method for reflection traveltime tomography

Hong-Kai Zhao

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We present a hybrid imaging method for travel time tomography problem which includes both unknown medium and unknown scatterers in a bounded domain. The goal is to recover both the medium and the boundary of the scatterers from the scattering relation data on the domain boundary. Our method is composed of three steps: 1) preprocess the data to classify them into three different categories of measurements corresponding to non-broken rays, broken-once rays, and others, respectively, 2) use the the non-broken ray data and an effective data-driven layer stripping strategy–an optimization based iterative imaging method–to recover the medium velocity outside the convex hull of the scatterers, and 3) use selected broken-once ray data to recover the boundary of the scatterers–a direct imaging method. We show that our hybrid method can recover both the unknown medium and the not-too-concave scatterers efficiently and robustly.

School of Mathematics (SoM)

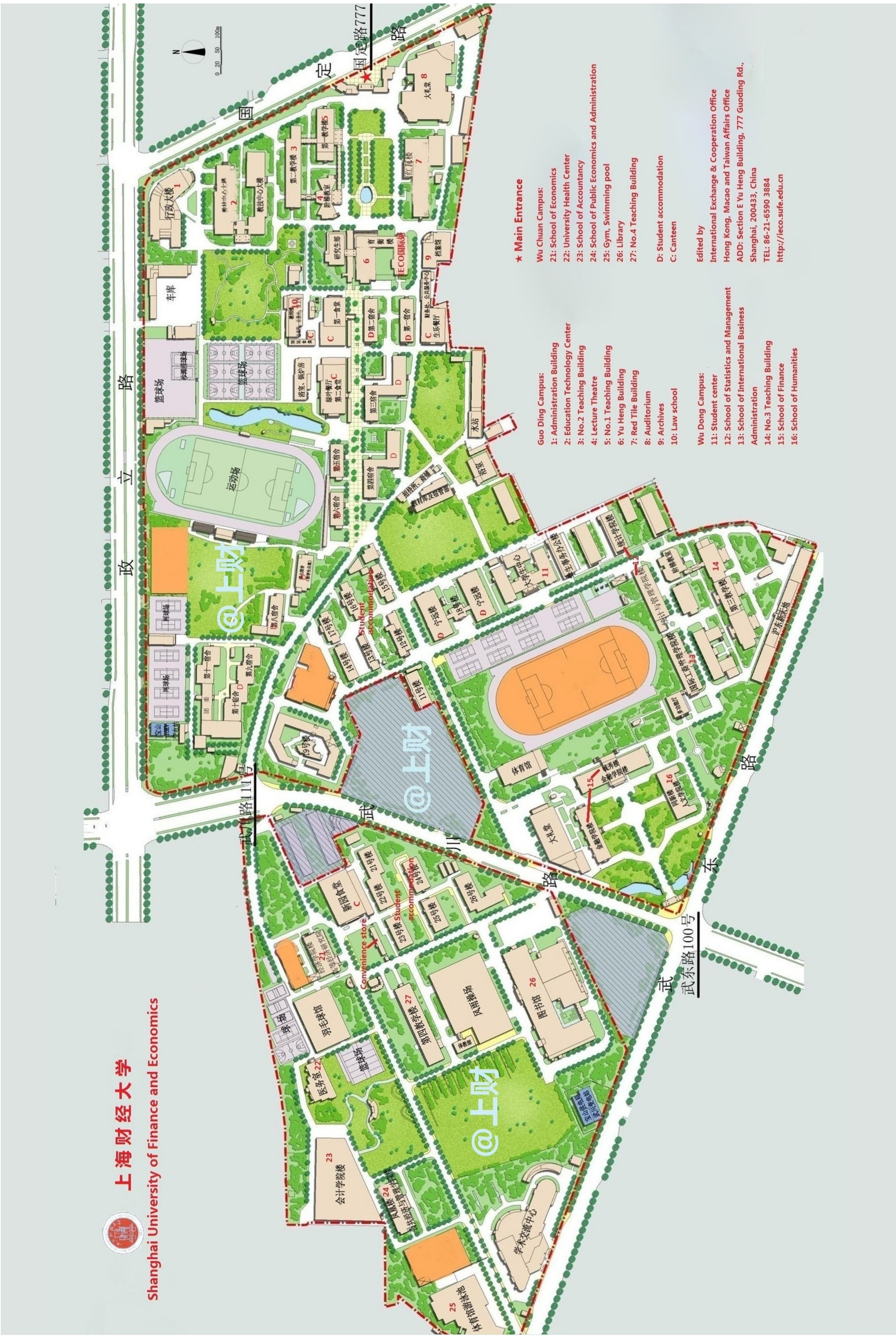
Shanghai University of Finance and Economics (SUFE)

Formerly named as Department of Applied Mathematics, the School of Mathematics at SUFE was founded in July 2014. The school currently offers a doctoral degree program in Applied Probability. By collaborating with the School of Finance and Economics, SoM also trains Ph.D. candidates in the major of Financial Mathematics and Financial Engineering. As for the Master's Degree programs, it provides several research areas, namely, Pure Mathematics, Computational Mathematics, Operational Research and Cybernetics, Applied Mathematics, Applied Probability and Financial Mathematics. SoM also has Bachelor's Degree programs in Pure Mathematics and Applied Mathematics, and, Informational and Computing Science. It owns the Computational Mathematics Laboratory and the Mathematical Modeling Laboratory. Most importantly, the school established the Institute of Scientific Computation and Financial Data Analysis in 2016, providing innovative and frontier researches for modeling and computing of financial data. The school established in 2017 the Economics-Mathematics Program under the special configurations for undergraduates to fully satisfy the demand for cultivating outstanding talents in the fields of mathematical finance and data science.

The School of Mathematics is proud of its promising faculty group. The faculty members focus on the international engagements and have partnered with worldwide prestigious universities and institutions, making their great effort to the students' all-around development.

Being of the solid fundamental knowledge in mathematics, the undergraduates and postgraduates students in SoM also have a good mastery of applied disciplines, such as economics, finance, and management. Consequently they are highly praised by employers after graduation with complete employment.

The graduated students from SoM own diversified and promising career future. In 2016, more than 70% of the graduates pursued further study in prestigious domestic and foreign institutions, including Harvard University, University of Cambridge, the London School of Economics and Political Science, Columbia University, etc. Most of the postgraduate students take on challenging jobs in financial institutions, as well as educational and research institutions.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