International Workshop

on

Inverse Problems

April 23-24, 2010

LT2 & LT4, Teaching Complex at Western Campus
The Chinese University of Hong Kong

Program and Abstracts

Department of Mathematics
The Institute of Mathematical Sciences
The Chinese University of Hong Kong

Contents

Objective

Inverse Problems has become a very active, interdisciplinary and well-established research area over the past two decades. It has found wide applications in engineering, industry, medicine, as well as life and earth sciences.

The aim of this international workshop is to bring together some leading computational and applied mathematicians from around the world to present and discuss recent developments in inverse problems and their applications.

Organizing Committee

- Raymond Chan, *The Chinese University of Hong Kong, HKSAR*
- Eric Chung, *The Chinese University of Hong Kong, HKSAR*
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Sponsors

- The Institute of Mathematical Sciences
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- The Department of Mathematics
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Invited speakers

- H.T. Banks, *North Carolina State University, USA*
- Xudong Chen, *National University of Singapore, Singapore*
- Eric Chung, *Chinese University of Hong Kong, HKSAR*
- Bernd Hofmann, *Chemnitz University of Technology, Germany*
- Kazufumi Ito, *North Carolina State University, USA*
- Bangti Jin, *University of Bremen, Germany*
- Michael Klibanov, *University of North Carolina at Charlotte, USA*
- Rainer Kress, *University of Goettingen, Germany*
- Karl Kunisch, *University of Graz, Austria*
- Jijun Liu, *Southeast University, China*
- Ya Yan Lu, *City University of Hong Kong, HKSAR*
- Peter Monk, *University of Delaware, USA*
- Gen Nakamura, *Hokkaido University, Japan*
- Roland Potthast, *University of Reading, UK*
- William Rundell, *Texas A&M University, USA*
- Gunther Uhlmann, *University of Washington, USA*
- Masahiro Yamamoto, *University of Tokyo, Japan*

Schedule

Program-at-a-Glance

Date / *Time*	**22-April (Thursday)**	**23-April (Friday)**	**24-April (Saturday)**
8:30 – 9:00 am		Opening Ceremony	
9:00 – 9:45 am		G. Uhlmann	H.T. Banks
9:45 – 10:30 am		W. Rundell	M. Yamamoto
10:30 – 11:00 am		*Tea Break*	*Photo and Tea Break*
11:00 – 11:45 am		P. Monk	G. Nakamura
11:45 – 12:30 pm		X.D. Chen	R. Potthast
12:30 – 2:30 pm	*Lunch*		
2:30 – 3:15 pm		M. Klibanov	K. Kunisch
3:15 – 4:00 pm		B. Hofmann	K. Ito
4:00 – 4:30 pm	*Tea Break*		
4:30 – 5:15 pm		Y.Y. Lu	J.J. Liu
5:15 – 6:00 pm		E. Chung	B.T. Jin
6:30 pm	Reception	Banquet	Dinner

Friday, April 23, 2010

8:30 – 9:00 am	Opening Ceremony
Session Chair	***Jun Zou***
9:00 – 9:45 am	*G. Uhlmann* 30 Years of Calderón's Problem
9:45 – 10:30 am	*W. Rundell* Rational Approximation Methods for Inverse Source Problems
10:30 – 11:00 am	*Tea Break*
Session Chair	***H.T. Banks***
11:00 – 11:45 am	*P. Monk* The Determination of Anisotropic Surface Impedance in Electromagnetic Scattering
11:45 – 12:30 pm	*X.D. Chen* Subspace-based Optimization Method for Solving Inverse Scattering and EIT problems
12:30 – 2:30pm	*Lunch*
Session Chair	***Masahiro Yamamoto***
2:30 – 3:15 pm	*M. Klibanov* Blind Imaging from Experimental Data Using a Globally Convergent Inverse Algorithm
3:15 – 4:00 pm	*B. Hofmann* The Variational Inequality Approach for Obtaining Convergence Rates in Regularization
4:00 – 4:30 pm	*Tea Break*
Session Chair	***Gunther Uhlmann***
4:30 – 5:15 pm	*Y.Y. Lu* Diffraction and Scattering Problems on a Slab
5:15 – 6:00 pm	*E. Chung* A New Phase Space Method for Recovering Index of Refraction from Travel Times
6:30 pm	**Banquet**

Saturday, April 24, 2010

Session Chair	***William Rundell***
9:00 – 9:45 am	*H.T. Banks* `Standard Error Computations for Uncertainty Quantification in Inverse Problems: Asymptotic Theory vs. Bootstrapping`
9:45 – 10:30 am	*M. Yamamoto* `On Fractional Diffusion Equations: Physical Background, Novelties on Forward Problems and Some Inverse Problems`
10:30 – 11:00 am	*Photo and Tea Break*
Session Chair	***Peter Monk***
11:00 – 11:45 am	*G. Nakamura* `Green Function for Interior Transmission Problem`
11:45 – 12:30 pm	*R. Potthast* `Inverse Problems in Neural Field Theory`
12:30 – 2:30 pm	*Lunch*
Session Chair	***Roland Potthast***
2:30 – 3:15 pm	*K. Kunisch* `Identification and Control of Variational Inequalities`
3:15 – 4:00 pm	*K. Ito* `A Regularization Parameter for Nonsmooth Tikhonov Regularization`
4:00 – 4:30 am	*Tea Break*
Session Chair	***Karl Kunisch***
4:30 – 5:15 pm	*J.J. Liu* `On the Reconstruction of Biotissue Conductivity by MREIT`
5:15 – 6:00 pm	*B.T. Jin* `Sparse Reconstruction in Electrical Impedance Tomography`
6:30 pm	Dinner

Titles & Abstracts

Standard Error Computations for Uncertainty Quantification in Inverse Problems: Asymptotic Theory vs. Bootstrapping

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Abstract: We computationally investigate two approaches for uncertainty quantification in inverse problems for nonlinear parameter dependent dynamical systems. We compare the bootstrapping and asymptotic theory approaches for problems involving data with several noise forms and levels. We consider both constant variance absolute error data and relative error which produces non-constant variance data in our parameter estimation formulations. We compare and contrast parameter estimates, standard errors, confidence intervals, and computational times for both bootstrapping and asymptotic theory methods. These findings represent collaborative efforts with Kathleen Holm and Danielle Robbins

Subspace-based Optimization Method for Solving Inverse Scattering and EIT problems

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Abstract: This talk presents a numerical method to solve inverse scattering problem (ISP) and electric impedance tomography (EIT) problem. Although these two problems deal with different PDEs and boundary conditions, they can be both written as two types of equations after introducing a physical concept, the secondary source. The two types of equations can be solved by the recently proposed subspace-based optimization method (SOM). The essence of the SOM is that a part of the secondary source is determined from the spectrum analysis without using any optimization, whereas the rest is determined by an optimization method. Since the optimization is carried out in a smaller dimensional space, the algorithm significantly speeds up the convergence. There is a great flexibility in partitioning the space of secondary source into two orthogonally complementary subspaces: the signal subspace and the noise subspace. This flexibility enables the algorithm to perform robustly against noise. Numerical simulations validate the efficacy of the proposed method: robustness against noise, fast convergence, high resolution, and the ability to deal with scatterers of special shapes.

A New Phase Space Method for Recovering Index of Refraction from Travel Times

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Abstract: We develop a new phase space method for reconstructing the index of refraction of a medium from travel time measurements. The method is based on the so-called Stefanov-Uhlmann identity which links two Riemannian metrics with their travel time information. We design a numerical algorithm to solve the resulting inverse problem. The new algorithm is a hybrid approach that combines both Lagrangian and Eulerian formulations. In particular the Lagrangian formulation in phase space can take into account multiple arrival times naturally, while the Eulerian formulation for the index of refraction allows us to compute the solution in physical space. Numerical examples including isotropic metrics and the Marmousi synthetic model are shown to validate the new method.

The Variational Inequality Approach for Obtaining Convergence Rates in Regularization

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Abstract: Convergence rates for the Tikhonov regularization of nonlinear ill-posed operator equations in abstract function spaces require the handling of both smoothness conditions imposed on the solution and structural conditions expressing the character of nonlinearity. Recently, in [1, 2, 3] the distinguished role of variational inequalities holding on some level sets for this purpose was outlined. When lower rates are expected such inequalities combine the smoothness properties of solution and forward operator in a sophisticated manner. In this talk, we will present some ex- tensions of the variational inequality approach from Hölder rates to more general cases including logarithmic convergence rates (cf. [4]). To formulate the results in a Banach space setting we use Bregman distances for measuring the regularization error. In this context, we also exploit the method of approximate source conditions (cf. [5]) and develop ideas for the treatment of non-metric misfit functionals (cf. [6]).

References:

[1] B. Hofmann, B. Kaltenbacher, C. Pöschl, O. Scherzer: A convergence rates result for Tikhonov regularization in Banach spaces with non-smooth operators. Inverse Problems 23 (2007), 987-1010.

[2] O. Scherzer, M. Grasmair, H. Grossauer, M. Haltmeiner, F. Lenzen: Variational Methods in Imaging. New York: Springer 2009.

[3] B. Hofmann. M. Yamamoto: On the interplay of source conditions and variational inequalities for nonlinear ill-posed problems. Applicable Analysis 89. To appear.

[4] R. I. Bot, B. Hofmann: An extension of the variational inequality approach for obtaining convergence rates in regularization of nonlinear ill-posed problems. Journal of Integral Equations and Applications 22 (2010). To appear.

[5] T. Hein, B. Hofmann: Approximate source conditions for nonlinear ill-posed problems - chances and limitations. Inverse Problems 25 (2009), 035003 (16pp).

[6] J. Geissler, B. Hofmann: A new approach to source conditions in regularization with general residual term. Published electronically 2009 as: arXiv:0906.3438 [math.NA].

A Regularization Parameter for Nonsmooth Tikhonov Regularization

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Abstract: A novel criterion for choosing regularization parameters for nonsmooth Tikhonov functionals is discussed. The proposed criterion is solely based on the value function and applicable to a broad range of fidelity and regularization functionals. An efficient numerical algorithm for computing the minimizer for the criterion is developed, and its convergence properties are also derived. Numerical results for several common nonsmooth functionals are presented. to demonstrate the capability.

Sparse Reconstruction in Electrical Impedance Tomography

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Abstract: In this talk we discuss a variational formulation for the electrical impedance tomography (EIT) problem of reconstructing conductivity from boundary measurements. The sparsity of the "inhomogeneity" with respect to a certain basis is a priori assumed. The proposed approach is based on a Tikhonov functional by incorporating a sparsity-promoting l1-term. This allows us to obtain quantitative results and overcomes the classical problem of over-smoothing in EIT reconstructions. Some theoretical results of the forward problem and differentiability of the functional with respect to the conductivity parameter are provided. An efficient algorithm, which utilizes adjoint operators in appropriate Sobolev spaces as well as shrinkage operators for realizing the sparsity-promoting regularization, is proposed. Numerical results for several two-dimensional problems are presented.

Blind Imaging from Experimental Data Using a Globally Convergent Inverse Algorithm

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Abstract: Recently the first and the third authors have developed a new globally convergent algorithm for a coefficient inverse problem for the equation $c(x)u_{tt} = \triangle u, x \in R^3$ with single measurement data [1,2]. While a global convergence theorem was proven and numerical experiments with computationally simulated data were successful, the team of co-authors of the current presentation has felt that a much better way to verify this new algorithm was via working with experimental data. These data were acquired in the picoseconds regime and then the algorithm of [1,2] was applied to reconstruct the spatially distributed refractive index $n(x) = \sqrt{c(x)}$. Recall that $1ps = 10^{-12}s = 10^{-3}ns$. It is important that only **BLIND** experiments were made from the start: the team had no advanced knowledge about values of refractive indexes in dielectric inclusions. First, these indexes were computed via the algorithm [1,2]. Next, they were directly and independently measured a posteriori by two well established techniques. Subsequent comparison with computational results has revealed an excellent accuracy provided by the algorithm of [1,2].

Acknowledgment: This work was supported by the U.S. Army Research Laboratory and U.S. Army Research Office grants number W911NF-08-1-0470 and W911NF-09-1-0409.

1. L. Beilina L and M.V. Klibanov, A globally convergent numerical method for a coefficient inverse problem, SIAM J. Sci. Comp., 31, 478-509, 2008

2. L. Beilina L and M.V. Klibanov, Synthesis of global convergence and adaptivity for a hyperbolic coefficient inverse problem , J. Inverse and Ill-Posed Problems, 18, issue 1, 2010.

3. M.V. Klibanov, M.A. Fiddy, L. Beilina, N. Pantong and J. Schenk, Picosecond scale experimental verification of a globally convergent algorithm for a coefficient inverse problem, Inverse Problems, 26, issue 3, 2010.

Conformal mapping and impedance tomography

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Abstract: Akduman, Haddar and Kress [1, 2, 3] have employed a conformal map- ping technique for the inverse problem to recover a perfectly conducting or a nonconducting inclusion in a homogeneous background medium from Cauchy data on the accessible exterior boundary. We propose an extension of this approach to two-dimensional inverse electrical impedance tomography with piecewise constant conductivities. A main ingredient of our method is the incorporation of the transmission condition on the unknown interior boundary via a nonlocal boundary condition in terms of an integral equation. We present the foundations of the method, a local convergence result and exhibit the feasibility of the method via numerical examples.

This is joint work with Houssem Haddar, Palaiseau, France

References:

[1] Akduman, I. and Kress, R.: Electrostatic imaging via conformal map- ping. Inverse Problems 18, 1659-1672 (2002).

[2] Haddar, H. and Kress, R.: Conformal mappings and inverse boundary value problems. Inverse Problems 21, 935-953 (2005).

[3] Kress, R.: Inverse Dirichlet problem and conformal mapping. Mathematics and Computers in Simulation 66, 255-265 (2004).

Generalized Total Variation Regularisation

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Abstract: In the first part of this talk it is demonstrated how classical total variation regularization can be reformulated as a bilateral obstacle problem. For the latter, semismooth Newton methods can readily be applied and lead to a superlinearly convergent algorithm.

The second part of the talk is devoted to the novel concept of generalized total variation (TGV-)regularization.

On the Reconstruction of Biotissue Conductivity by MREIT

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Abstract: Magnetic Resonance Electrical Impedance Tomography (MREIT) is a new medical imaging technique that aims to provide electrical conductivity image with sufficiently high spatial resolution and accuracy. This new method takes advantage of internal information to solve its nonlinear inverse problem of recovering a conductivity distribution inside an imaging object. Compared with the classical electrical impedance tomography (EIT), the ill-posedness of the problems is weakened due to the application of internal information of the electrical potential. In this talk, we will introduce some recent development on the mathematical analysis in this area, including the realization of harmonic B_z algorithm, reconstruction scheme based on nonlinear integral equation method, error analysis. The numerical implementations are also presented.

Diffraction and Scattering Problems on a Slab

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Abstract: Photonic crystals (PhCs) are periodic structures with a period on the scale of the wavelength of the light. An important class of PhCs is the PhC slab, where the periodic structure (typically, a triangular lattice of air-holes) is fabricated on a thin dielectric slab. In this talk, we present our recently developed numerical methods for analyzing diffraction and scattering problems associated with PhC slabs. The first problem involves a finite number of arrays of circular air-holes on a slab, where each array is periodic and infinite, and all air-holes are located on a triangular lattice. For such a structure, we specify an incident wave which is a propagating mode of the slab (as a waveguide), then calculate the reflected and transmitted waves. Based on an eigenmode expansion in the vertical direction (perpendicular to the slab) and Fourier-Bessel expansions in the horizontal directions, we construct a Dirichlet-to-Neumann (DtN) map for each unit cell, and then develop an efficient numerical method that avoids repeated calculations in identical unit cells. The second problem involves a single air-hole of arbitrary shape on a slab. For a given incident wave (a propagating mode of the slab), we calculate the scattered waves based on vertical eigenmode expansions and boundary integral equations. This is a joint work with Lijun Yuan and Yumao Wu.

The Determination of Anisotropic Surface Impedance in Electromagnetic Scattering

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Abstract: Anisotropic material constants can cause significant issues for inverse scattering algorithms. For example it is impossible to identify general anisotropic permittivity and permeability in Maxwell's equations from far field data because the far field pattern is invariant to local changes of variables within the scatterer. Such changes of variables result in different anisotropic coefficients and so the coefficients can only be determined up to such changes of variables. Nevertheless the support of the scatterer can still be identified.

However, once the anisotropy is limited to a lower dimensional manifold, the question arises if uniqueness is still lost. In this presentation (with F. Cakoni) I shall consider a scattering problem for the time harmonic Maxwells equations with an anisotropic surface impedance. We prove that this impedance can be uniquely determined, and provide an integral equation for the solution. We also provide some numerical results.

Green Function for Interior Transmission Problem

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Abstract: The construction of Green function for interior transmission problem and its estimate are given. Assuming that the interior transmission boundary and all the coefficients of the operators are smooth, the key is to construct a local parametrix near the interior transmission boundary. This is achieved by using the Poisson type pseudo-differential operators.

Inverse Problems in Neural Field Theory

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Abstract: Inverse problems in computational neuroscience comprise the determination of synaptic weight matrices or kernels for neural networks or neural fields respectively. Here, we reduce multi-dimensional inverse problems to inverse problems in lower dimensions which can be solved in an easier way or even explicitly through kernel construction. In particular, we discuss a range of embedding techniques and analyze their properties. We study the Amari equation as a particular example of a neural field theory. We obtain a solution of the full 2D or 3D problem by embedding 0D or 1D kernels into the domain of the Amari equation using a suitable path parametrization and basis transformations. Pulses are interconnected at branching points via path gluing. As instructive examples we construct logical gates, such as the persistent XOR and binary addition in neural fields. In addition, we compare results of inversion by dimensional reduction with a recently proposed global inversion scheme for neural fields based on Tikhonov-Hebbian learning. The results show that stable construction of complex distributed processes is possible via neural field dynamics. This is an important first step to study the properties of such constructions and to analyze natural or artificial realizations of neural field architectures.

Rational Approximation Methods for Inverse Source Problems

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Abstract: The basis of most imaging methods is to detect hidden obstacles or inclusions within a body when one can only make measurements on an exterior surface. Such is the ubiquity of these problems, the underlying model can lead to a partial differential equation of any of the major types, but here we focus on the case of steady-state electrostatic or thermal imaging and consider boundary value problems for Laplace's equation. Our inclusions are interior forces with compact support and our data consists of a single measurement of (say) voltage/current or temperature/heat flux on the external boundary. We propose an algorithm that under certain assumptions allows for the determination of the support set of these forces by solving a simpler "equivalent point source" problem.

30 Years of Calderón's Problem

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Abstract: In 1980 A. P. Calderón wrote a short paper entitled "On an inverse boundary value problem". In this seminal contribution he initiated the mathematical study of the following inverse problem: Can one determine the electrical conductivity of a medium by making current and voltage measurements at the boundary of the medium? There has been substantial progress in understanding this inverse problem in the last 30 years or so. In this lecture we will survey some of the most important developments.

On Fractional Diffusion Equations: Physical Background, Novelties on Forward Problems and Some Inverse Problems

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Abstract: For simulations of diffusion of contaminants in the porous media, one can use a fractional diffusion equation as model. There have been many works on the fractional calculus but very few results on the fractional diffusion equation. After description of some properties on ordinary fractional equations, I present results on the forward problems and on several inverse problems for fractional diffusion equations, on the basis of joint works with

Prof. K. Ito (North Carolina State University),

Prof. J. Cheng, Mr. Xu Xiang (Fudan University),

Mr. Junichi Nakagawa, Dr. Kenichi Sakamoto (Nippon Steel Corporation).

Directions

Directions
for International Workshop on Inverse Problems
April 23-24, 2010, Hong Kong

All invited speakers are arranged to stay at the CUHK campus guesthouse:
Chan Kwan Tung.

(1) You can find the detailed information from the airport to our campus at our website:

http://www.math.cuhk.edu.hk/gerinfo/cuhk.html

(2) You can find the detailed information to our department at our website:

http://www.math.cuhk.edu.hk/gerinfo/dept.html

(3) You can find our campus map at

http://www.cuhk.edu.hk/english/campus/cuhk-campus-map.html

The guest house you will stay is called **Chan Kwan Tung**, next to the Yali Guesthouse and the University Health Centre, near the Central Campus in the campus map.
For enquiries,

Tel: (852) 2603-6422 Fax: (852) 2603-5272
Email: guest-house@cuhk.edu.hk
Website: www.cuhk.edu.hk/ugh/guesthouse/enq.html (see a map there)

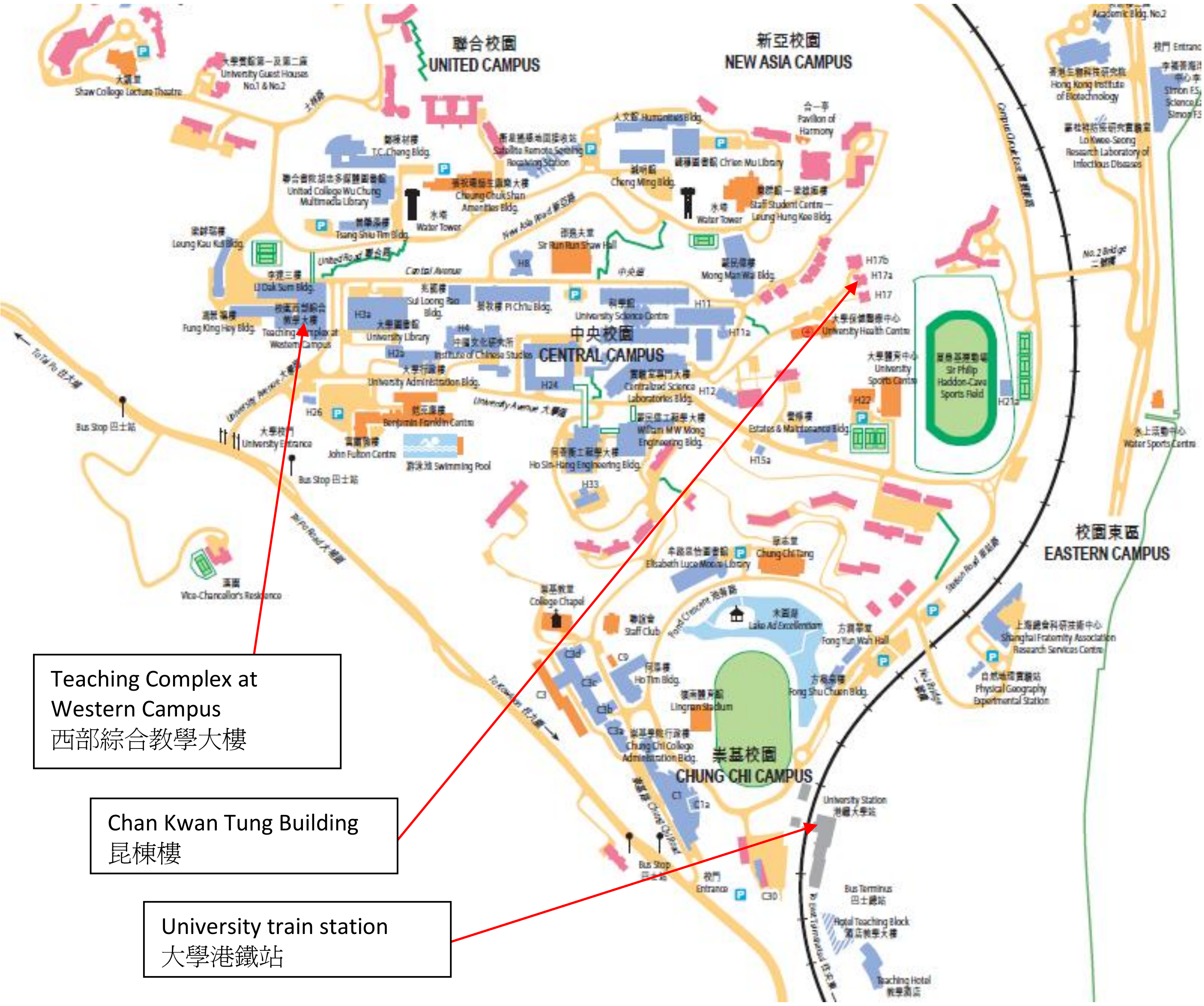
If you can print out an enlarged copy of the map and show to your tax driver, the Chinese names of the university and the guesthouse there should be extremely helpful.

(4) Contact persons and phone numbers

You may call the following numbers when you need assistance in Hong Kong:

Jun Zou : 852-26097985 (office), 62854948 (mobile)
Eric Chung : 852-26097972 (office), 63837350 (mobile)

CUHK Map & Locations



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