DEPARTMENT OF MATHEMATICS
THE CHINESE UNIVERSITY OF HONG KONG

The 4th CAM-ICCM Workshop

Multiscale and Large-scale Scientific Computing

18 – 20 June 2016 • HONG KONG

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Introduction

This international workshop aims to provide a forum for researchers from Hong Kong and Mainland China to exchange ideas with international experts working on Multiscale Methods and Large-scale Computations for scientific computing. It also aims to promote international collaboration on Multiscale Methods and Large-scale Computations. In addition, the workshop is the 4th meeting of the ICCM (International Congress of Chinese Mathematician) Consortium on CAM (Computational and Applied Mathematics). The consortium has the mission of enhancing collaboration among Chinese Mathematicians working on CAM and enhancing their collaboration with international experts. This workshop is jointly organized by the Department of Mathematics and the Institute of Mathematical Sciences at the Chinese University of Hong Kong, and will be held on June 18-20, 2016.

Organizing Committee

Raymond CHAN	The Chinese University of Hong Kong
Eric CHUNG	The Chinese University of Hong Kong
Yalchin EFENDIEV	Texas A&M University
Zhouping XIN	The Chinese University of Hong Kong
Jun ZOU	The Chinese University of Hong Kong

Sponsors

The workshop is generously supported by the following organizations:

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United College,
The Chinese University of Hong Kong

Hong Kong Pei Hua Education Foundation

Hong Kong Mathematical Society

Invited Speakers

Weizhu BAO	National University of Singapore, Singapore
Xiao Chuan CAI	University of Colorado, Boulder, USA
Victor M. CALO	Curtin University, Australia
Li-qun CAO	Chinese Academy of Sciences, China
I-Liang CHERN	National Taiwan University, Taiwan
Jay CHU	National Tsinghua University, Taiwan
Eric CHUNG	The Chinese University of Hong Kong, Hong Kong
Huoyuan DUAN	Wuhan University, China
Bjorn ENGQUIST	University of Texas at Austin, USA
Ivan GRAHAM	University of Bath, UK
Jan HESTHAVEN	Ecole Polytechnique Federale de Lausanne, Switzerland
Viet Ha HOANG	Nanyang Technological University, Singapore
Lijian JIANG	Hunan University, China
Seong LEE	Chevron, USA
Qin LI	University of Wisconsin, USA
Alexei LOZINSKI	University of Franche-Comté, France
Ping-Bing MING	Chinese Academy of Sciences, China
Houman OWHADI	California Institute of Technology, USA
Daniel PETERSEIM	University of Bonn, Germany
Qi WANG	Beijing Computational Science Research Center, China
Xiaoping WANG	Hong Kong University of Science and Technology, Hong Kong
Mary WHEELER	University of Texas at Austin, USA
Jun YAO	China University of Petroleum (East China), China
Lei ZHANG	Shanghai Jiaotong University, China

Schedule Overview

June 18, 2016 (Saturday)

Venue: LT4, YIA

8:30-9:10	Registration
9:10-9:20	Opening
9:20-10:00	Bjorn Engquist
10:00-10:40	Houman Owhadi
10:40-11:10	Coffee Break
11:10-11:50	Ivan Graham
11:50-12:30	Xiao Chuan Cai
12:30-2:30	Lunch
2:30-3:10	Jan Hesthaven
3:10-3:50	Li-qun Cao
3:50-4:20	Coffee Break
4:20-5:00	Victor Calo
5:00-5:40	Huoyuan Duan

June 19, 2016 (Sunday)

Venue: LT4, YIA

8:30-9:20	Registration
9:20-10:00	Mary Wheeler
10:00-10:40	Jun Yao
10:40-11:10	Coffee Break
11:10-11:50	Weizhu Bao
11:50-12:30	Ping Bing Ming
12:30-12:45	Group Photo
12:30-2:30	Lunch
2:30-3:10	Alexei Lozinski
3:10-3:50	Daniel Peterseim
3:50-4:20	Coffee Break
4:20-5:00	Qin Li
5:00-5:40	Lijian Jiang
7:00-9:30	Dinner

June 20, 2016 (Monday)

Venue: LT4, YIA

8:30-9:20	Registration
9:20-10:00	Xiaoping Wang
10:00-10:40	Qi Wang
10:40-11:10	Coffee Break
11:10-11:50	Lei Zhang
11:50-12:30	Seong Lee
12:30-2:30	Lunch
2:30-3:10	I-Liang Chern
3:10-3:50	Viet Ha Hoang
3:50-4:20	Coffee Break
4:20-5:00	Jay Chu
5:00-5:40	Eric Chung

Schedule with Titles of Talks

June 18, 2016 (Saturday)

Venue: LT4, YIA

8:30-9:10	Registration
9:10-9:20	Opening
9:20-10:00	**Bjorn Engquist** Multiscale and Parareal Simulations of Dynamical Systems with Highly Oscillatory Solutions
10:00-10:40	**Houman Owhadi** Multigrid with Rough Coefficients and Multiresolution Operator Decomposition from Hierarchical Information Games
10:40-11:10	Coffee Break
11:10-11:50	**Ivan Graham** The Solution of High Dimensional Elliptic PDEs with Random Data
11:50-12:30	**Xiao Chuan Cai** Numerical Simulation of Blood Flows
12:30-2:30	Lunch
2:30-3:10	**Jan Hesthaven** Multi-Scale Time-Stepping in Particle-in-Cell Methods
3:10-3:50	**Li-qun Cao** Multiscale Analysis and Computation for 3D Time-Dependent Maxwell-Schrödinger System in Heterogeneous Nanostructures
3:50-4:20	Coffee Break
4:20-5:00	**Victor Calo** Local Multiscale Model Reduction for Heterogeneous Transport
5:00-5:40	**Huoyuan Duan** Multiscale Stabilization for Boundary and Interior Layers of Convection-Dominated Problems

June 19, 2016 (Sunday)

Venue: LT4, YIA

8:30-9:20	Registration
9:20-10:00	**Mary Wheeler** Phase-Field Modeling of Proppant-Filled Fractures in a Poroelastic Medium
10:00-10:40	**Jun Yao** Efficient Multiscale Methods for Modeling Flow in Fractured vuggy Reservoirs
10:40-11:10	Coffee Break
11:10-11:50	**Weizhu Bao** Multiscale Methods and Analysis for the Dirac Equation in the Nonrelativistic Limit Regime
11:50-12:30	**Ping Bing Ming** A Hybrid Numerical Method for Multiscale Partial Differential Equations
12:30-12:45	Group Photo
12:30-2:30	Lunch
2:30-3:10	**Alexei Lozinski** Multiscale Finite Element on Perforated Domains
3:10-3:50	**Daniel Peterseim** Numerical Homogenization and the Exponential Decay of the Fine-Scale Green's Function
3:50-4:20	Coffee Break
4:20-5:00	**Qin Li** The Uniform Convergence of Generalized Polynomial Chaos-based Numerical Method for the Transport Equation with Random Input
5:00-5:40	**Lijian Jiang** Sparse Representation for Multiscale Models and its Application for Uncertainty Quantification
7:00-9:30	Dinner

June 20, 2016 (Monday)

Venue: LT4, YIA

8:30-9:20	Registration
9:20-10:00	**Xiaoping Wang** An Efficient Threshold Dynamics Method for Wetting on Rough Surfaces
10:00-10:40	**Qi Wang** Numerical Methods for Generalized Hydrodynamic Models
10:40-11:10	Coffee Break
11:10-11:50	**Lei Zhang** Gamblets for Opening the Complexity-Bottleneck of Implicit Schemes for Hyperbolic and Parabolic PDEs with Rough Coefficients
11:50-12:30	**Seong Lee** Numerical Methods to Solve Non-Linear Transport Equations in Practical Reservoir Simulation
12:30-2:30	Lunch
2:30-3:10	**I-Liang Chern** Coupling Interface Method for Elliptic Interface Problems, Method and Applications
3:10-3:50	**Viet Ha Hoang** A Hierarchical Finite Element Monte Carlo Method for Stochastic Two Scale Elliptic Problems
3:50-4:20	Coffee Break
4:20-5:00	**Jay Chu** A Multiscale Method Coupling Network and Continuum Models in Porous Media
5:00-5:40	**Eric Chung** Adaptive Multiscale Model Reduction using GMsFEM

Titles and Abstracts

Multiscale methods and analysis for the Dirac equation in the nonrelativistic limit regime

Weizhu Bao

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Abstract

In this talk, I will review our recent works on numerical methods and analysis for solving the Dirac equation in the nonrelativistic limit regime, involving a small dimensionless parameter which is inversely proportional to the speed of light. In this regime, the solution is highly oscillating in time and the energy becomes unbounded and indefinite, which bring significant difficulty in analysis and heavy burden in numerical computation. We begin with four frequently used finite difference time domain (FDTD) methods and the time splitting Fourier pseudospectral (TSFP) method and obtain their rigorous error estimates in the nonrelativistic limit regime by paying particularly attention to how error bounds depend explicitly on mesh size and time step as well as the small parameter.Then we consider a numerical method by using spectral method for spatial derivatives combined with an exponential wave integrator (EWI) in the Gautschi-type for temporal derivatives to discretize the Dirac equation. Rigorous error estimates show that the EWI spectral method has much better temporal resolution than the FDTD methods for the Dirac equation in the nonrelativistic limit regime. These methods and results are then extended to the nonlinear Dirac eqaution in the nonrelativistic limit regime. Finally, we present a multiscale time integrator Fourier pseudospectral (MTI-FP) method for the Dirac equation, which is uniformly accurate for the dimensionless paramter. Numerical results demonstrate that our error estimates are sharp and optimal.

Numerical Simulation of Blood Flows

Xiao Chuan Cai

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Abstract

We discuss a parallel domain decomposition algorithm for the simulation of blood flows in compliant arteries by solving a fully-coupled system of nonlinear partial differential equations consisting of an elasticity equation for the artery and an incompressible Navier-Stokes system for the blood flow. The system is discretized with a finite element method on unstructured moving meshes in 3D and solved by a Newton-Krylov algorithm preconditioned with an overlapping Schwarz method. Several mathematical, bio-mechanical, and supercomputing issues will be discussed in detail. We also report the parallel performance of the method on a supercomputer with a large number of processors.

Local Multiscale Model Reduction for Heterogeneous Transport

VM Calo, ET Chung, Y Efendiev, WT Leung

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Abstract

We develop a Petrov–Galerkin stabilization method for multiscale convection–diffusion transport systems. We construct a local reduced-order model for this kind of multiscale transport problems and then develop a systematic approach for finding reduced-order approximations of the solution. We start from a Petrov–Galerkin framework that uses optimal weighting functions. We introduce an auxiliary variable to a mixed formulation of the problem. The auxiliary variable represents the optimal weighting function. The problem reduces to finding a test space (a dimensionally reduced space for this auxiliary variable), which guarantees that the error in the primal variable (representing the solution) is close to the projection error of the full solution on the dimensionally reduced space that approximates the solution. For the test space, we reformulate some recent mixed Generalized Multiscale Finite Element Methods. We introduce snapshots and local spectral problems that appropriately define local weight and trial spaces. In particular, we use energy minimizing snapshots and local spectral decompositions in the natural norm associated with the auxiliary variable. We discuss the stability and its relation to the approximation property of the test space.

Multiscale Analysis and Computation for 3D Time-Dependent Maxwell-Schrödinger System in Heterogeneous Nanostructures

Li-qun Cao

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Abstract

When the size of physical devices reaches the wavelength of an electron, quantum effects become important even dominant and can not be neglected. To analyze and model such physical devices, coupled numerical simulations of Maxwell and Schrödinger equations need to be performed. Maxwell-Schrödinger system with rapidly oscillating discontinuous coefficients originates from the interaction of matter and electromagnetic fields in heterogeneous nanostructures. There are a great number of applications in laser physics, quantum Hall effects, superconductivity and semiconductor optics and transport phenomena in heterogeneous photoelectronic devices. In this talk, we will introduce our recent advances in the multiscale analysis and computation for Maxwell-Schrödinger system in heterogeneous materials. First, we will briefly talk about the fundamental physical questions and the mathematical models such as gauge invariance, topological invariance and so forth. Meanwhile, we will introduce some important studies about the analysis and computation of Maxwell-Schrödinger system. Second, we glance at our results of the multiscale analysis and compu- tation for a stationary Schrödinger-Poisson system in heterogeneous nanostructures, and then we focus on discussing 3D time-dependent Maxwell-Schrödinger system in heterogeneous nanostructures. The homogenization method and the multiscale asymptotic method for the nonlinear coupled system are presented and the convergence results for the electric dipole approximate model are derived. The efficient numerical algorithm based on the above methods and the convergence analysis are advanced. Finally, the numerical results and some unsolved questions are presented.

This talk is based on the joint work with Dr. Chupeng Ma and Dr. Lei Zhang.

Coupling Interface Method for Elliptic Interface Problems, Method and Applications

I-Liang Chern and Yu-Chen Shu

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Abstract

In this talk, I will first review the coupling interface method for solving the elliptic interface problems in arbitrary dimensions. It is a finite difference method on an underlying regular Cartesian grid. The method takes a dimension-splitting approach. In each dimension, it uses piecewise polynomials to approximate the solution from both sides of the interface. The information from different dimensions is linked through jump conditions, leading to a coupled linear equation for the principal second order derivatives. This approach reduces the size of stencil, and thus has mild restriction on the inter- faces. It has more potential to handle complex interface problems. A recent progress on second-order accurate approximation for gradients on interfaces will be reported. Secondly, I will show applications of the coupling interface method, including simulations of macromolecules in ionic solution, surface plasmonic wave propagation on metal/dielectric materials, and a simple tumor simulation.

A multiscale method coupling network and continuum models in porous media

Jay Chu

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Abstract

In this talk, we present a numerical multiscale method for coupling a conservation law for mass at the continuum scale with a discrete network model that describes the pore scale flow in a porous medium. We developed single-phase flow algorithms and extended the methods to two-phase flow, for the situations in which the saturation. Our coupling method for the pressure equation uses local simulations on small sampled network domains at the pore scale to evaluate the continuum equation and thus solve for the pressure in the domain. For local simulation, we introduce a choice of initialization from a optimization problem. We present numerical results for single-phase flows with nonlinear flux-pressure dependence, as well as two-phase flow.

Adaptive Multiscale Model Reduction using GMsFEM

Eric Chung

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Abstract

In this talk, we will present a novel multiscale model reduction technique for solving many challenging problems with multiple scales and high contrast. Our approach systematically and adaptively adds degrees of freedom in local regions as needed and goes beyond scale separation cases. We will focus on the following issues in this talk:

(1) demonstrate the main concepts of our unified approach for local multiscale model reduction;
(2) discuss the method's main ingredients; and
(3) demonstrate its applications to a variety of challenging multiscale problems.

Multiscale Stabilization for Boundary and Interior Layers of Convection-Dominated Problems

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Abstract

Convection-dominated problems arising from convection-diffusion-reaction equation and Navier-Stokes equations which involve physical quantities diffusivity, convection and reaction may have boundary and interior layers in which the solution varies with a very large slope, tending to infinity as the physical parameters vary, for example, as the diffusivity or viscosity tends to zero. Such solution is generally very smooth in the sense of Sobolev spaces, such as $H^2(\Omega)$ regularity, but, the very large slope living in the local regions such as boundary and interior layers would thwart the efficiency and effectiveness of the FEM throughout the entire domain in seeking numerical solutions. Simply speaking, for problems with boundary and interior layers in the above sense, the resolution or accuracy of the finite element solution is very low in the entire domain, mostly serious in boundary and interior layers; even with the refinement of meshes, no improvements are useful within an acceptable computational cost; consequently, the finite element solution would be useless. As is well-known, the presence of the effects of the boundary and interior layers on the finite element solution is due to the loss of the balance among the magnitudes of the physical quantities and the temporal and spatial discretizations. For this reason, the so-called multiscale stabilized finite element method has been extensively employed in computational fluid dynamics and else. The key feature is to augment the standard Galerkin formulation with local residuals of the underlying partial differential equations, featuring a stabilizing parameter, so that no matter how the magnitudes are different among the physical quantities and the temporal and spatial discretizations, the stability and accuracy of the finite element solution can be achieved computationally of reasonable cost (i.e., no too small temporal and spatial discretizations, no special meshes such as adaptive meshes and moving meshes, no special elements, etc). In this talk, I will report new multiscale stabilized finite element methods for Navier-Stokes equations and convection-diffusion-reaction equation. New methods will produce high stable and high accurate finite element solutions. A number of numerical experiments for benchmark problems are performed to illustrate the efficiency and effectiveness of the new methods; comparisons are done with other methods such as DG method, multiscale methods in the sense of Hou and Wu for highly oscillatory coefficients of composite materials, tailored finite point method, adaptive method, and moving mesh method. The numerical results and the comparisons show that the new multiscale stabilized method is advantageous over all the mentioned methods here.

Multiscale and parareal simulations of dynamical systems with highly oscillatory solutions

Bjorn Engquist

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Abstract

The heterogeneous multiscale method is a framework for coupling numerical simulations on different scales. It can be used to design and analyze numerical methods for stiff ordinary differential equations with oscillatory solutions. It can also be used as coarse solver for more accurate simulations of dynamical systems for which the computation is distributed over time intervals.

The solution of high dimensional elliptic PDEs with random data

Ivan Graham

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Abstract

We consider non-uniformly elliptic problems with coefficients given as lognormal random fields. We focus on the forward problem of assessing how uncertainty propagates from data to solution, which leads to very high-dimensional parametrised systems of PDEs. We combine the fast realisation of random fields via circulant embedding techniques with quasi-Monte Carlo methods for dealing with high dimension. We give some recent complexity estimates for the circulant embedding method and also explain why the convergence of the QMC method is independent of dimension. We illustrate the results on some problems motivated by flow in porous media in 2D and 3D.

This is joint work with Rob Scheichl (Bath), Frances Kuo and Ian Sloan (New South Wales) and Dirk Nuyens (Leuven).

Multi-scale time-stepping in particle-in-cell methods

Paul Cazeaux and Jan S Hesthaven

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Abstract

The simulation of problems in kinetic plasma physics are challenging due to strongly coupled phenomena across multiple scales in both time and space. The 6+1 dimensional nature of the Vlasov-Poisson makes the computational modeling very expensive and introduces a substantial bottleneck in effort to model large scale plasma devises such as fusion reactors.

In this talk, we discuss a wavelet-based coarse-grained numerical scheme, based on the framework of equation-free projective Integration, for a kinetic plasma system modeled by the Vlasov-Poisson equations. A kinetic particle-in-cell (PIC) code is used to simulate the micro scale dynamics for short time intervals and extrapolation over long time-steps of the coarse wavelet-based discretization of the system.

To validate the approach and the underlying concepts, we perform numerical experiments: nonlinear propagation and steepening of an ion wave, and the expansion of a plasma slab in vacuum. The direct comparisons to fully resolved PIC simulations show good agreement. We show that the speedup of the projective integration scheme over the full particle scheme scales linearly with the system size, demonstrating efficiency while taking into account fully kinetic, non-Maxwellian effects. This suggests that the approach is potentially interesting for kinetic plasma problems with a large separation of scales, especially in higher dimensions.

A Hierarchical Finite Element Monte Carlo Method for Stochastic Two Scale Elliptic Problems

Viet Ha Hoang

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Abstract

We consider two scale elliptic equations whose coefficient is random and depends on a macroscopic slow variable and a fast variable. We assume that the effective coefficient can be approximated by solving random cell problems in a finite size cube (this is the case, for example, of an ergodic random coefficient, or a random periodic coefficient). This approximated effective coefficient is, however, realization dependent; and we aim to compute its expectation. Straightforward employment of finite element approximation and the Monte Carlo method to compute this expectation with the same level of finite element resolution and the same number of Monte Carlo samples at every macroscopic point is prohibitively expensive. We develop a hierarchical finite element Monte Carlo algorithm to approximate the effective coefficients at a dense hierarchical network of macroscopic points. The method achieves an optimal level of complexity that is essentially equal to that for computing the effective coefficient at one macroscopic point, with essentially the same accuracy. The levels of accuracy for solving cell problems and for the Monte Carlo approximation are chosen according to the level in the hierarchy that the macroscopic points belong to. Solutions at those points at which the cell problems are solved with high accuracy and the number of samples in the Monte Carlo approximation is high are employed as correctors for the effective coefficient at those points at which the cell problems are solved with lower accuracy and fewer Monte Carlo samples are used.

The method combines the hierarchical finite element method for solving cell problems at a dense network of macroscopic points with the optimal complexity developed in D. L. Brown, Y. Efendiev and V. H. Hoang, *Multiscale Model. Simul.* **11** (2013), with a hierarchical Monte Carlo algorithm that uses different number of samples at different macroscopic points depending on the level in the hierarchy that the macroscopic points belong to.

This is a joint work with Donald L. Brown (Nottingham University, UK)

Sparse representation for multiscale models and its application for uncertainty quantification

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Abstract

Stochastic multiscale modeling has become a popular approach to quantify uncertainty in multiscale models. The combination of multiscale features and complex uncertainty in models leads to great challenge to simulate the models and explore the propagation of uncertainty. To treat the difficulty, it is desirable to construct a sparse representation for the outputs of the multiscale models. In the talk, we present a sparse representation based on reduced multiscale basis methods and investigate its applications for uncertainty quantification of subsurface flows in random porous media.

Numerical Methods to Solve Non-Linear Transport Equations in Practical Reservoir Simulation

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Abstract

We first discuss modeling and mathematical issues in developing efficient, accurate numerical methods to solve multi-phase flow in heterogeneous porous media and the current trend and progresses in practical reservoir simulation are reviewed. In this paper we discuss two recent advances in numerical methods for non-linear transport equations in reservoir simulation: (1) multi-scale finite volume method (MSFV) and (2) hybrid-upwinding discretization (HU) for multi-phase flow with gravity. In the first part, we briefly discuss the current status of commercialization of MSFV. For commercial application of MSFV the original algorithm of MSFV has been extended to include iterative methods, well models, fault modeling with non-conformal grids, embedded fracture networks, etc. In the second part we discuss numerical stability in solving coupled nonlinear mass conservation laws, associated with fluid phases switch between co-current and counter-current states as a function of time, or (Newton) iteration. Here, we propose a Hybrid-Upwinding (HU) scheme for the phase fluxes. In the HU scheme, the phase flux is divided into two parts based on the driving force: viscous and buoyancy. The viscous-driven and buoyancy-driven phase fluxes are upwinded differently. Specifically, the viscous flux, which is always co-current, is upwinded based on the direction of the total-velocity. The buoyancy-driven flux across an interface is always counter-current and is upwinded such that the heavier fluid goes downward and the lighter fluid goes upward. It is shown that HU is locally conservative and produces monotone, physically-consistent numerical solutions. In the HU scheme the numerical overall-flux of a fluid phase remains continuous and differentiable as the flow regime changes between co-current and counter-current conditions.

The Uniform Convergence of Generalized Polynomial Chaos-Based Numerical Methods for the Transport Equation with Random Input

Qin Li

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Abstract

Linear transport equation characterizes the dynamics of particles (photons/neutrons etc) on the phase space, and the scattering coefficient in the equation is prescribed by the media. In labs, it is hard to measure the scattering coefficient accurately, and it is natural to ask about the sensitivity of the solution with respect to the scattering coefficient. Unfortunately the standard energy estimate shows that the solution is very sensitive to the measurement, especially in the long time large domain regime with the Knudsen number converging to zero. This result prevents the standard methods like the generalized polynomial chaos method to be applied, which typically require the stability of the solutions. In this talk we bypass the difficulty by passing the equation to the diffusion limit and connect it with the parabolic type equations whose stability results are known. We therefore obtain a uniform convergence in various regimes and justify the validity of generalized polynomial chaos expansion.

Multiscale finite element on perforated domains

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Abstract

We present a multiscale finite element Method (MsFEM) type method in the vein of the classical Crouzeix-Raviart finite elements that is particularly suited for problems on a complex perforated domain. The goal of the method is to approximate the solution on a mesh which is possibly coarse with respect to the perforations and can intersect them in an arbitrary manner, using appropriate precomputed basis functions localized on a small number of the coarse mesh elements. The choice of boundary condition on coarse element edges influences critically the eventual accuracy of any MsFEM approache. The weakly enforced continuity across element edges, as in the Crouzeix-Raviart space, leads to some natural boundary conditions for the multiscale basis functions and relaxes the sensitivity of our method to complex perforation patterns, thus allowing us to get rid of expensive oversampling techniques.

We shall consider first the Poisson equation and demonstrate that the multiscale finite element space should be enriched with appropriate bubble functions. We shall then go on to the Stokes equations and provide another technique for the enrichment of the approximation space using some weighting functions to enforce continuity across the edges. A rigorous numerical analysis will be presented for these two problems in the case of periodic perforations. The performance of our methods in non periodic settings will be illustrated on several numerical test cases.

A Hybrid Numerical Method for Multiscale Partial Differential Equations

Ping-Bing Ming

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Abstract

In this talk, I shall present a new hybrid numerical method for multiscale partial differential equations. Convergence results have been proved, and convergence rate were obtained for problems with various structures. Numerical results have been reported to show the efficiency and accuracy of the proposed method. This is a joint work with Y.F. Huang and J. Lu.

Multigrid with rough coefficients and Multiresolution operator decomposition from Hierarchical Information Games

Houman Owhadi

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Abstract

We introduce a near-linear complexity (geometric and meshless/algebraic) multigrid/multiresolution method for PDEs with rough (L^∞) coefficients with rigorous a-priori accuracy and performance estimates. The method is discovered through a decision/game theory formulation of the problems of (1) identifying restriction and interpolation operators (2) recovering a signal from incomplete measurements based on norm constraints on its image under a linear operator (3) gambling on the value of the solution of the PDE based on a hierarchy of nested measurements of its solution or source term.

The resulting elementary gambles form a hierarchy of (deterministic) basis functions of H_0^1 (Ω) (gamblets) that (1) are orthogonal across subscales/subbands with respect to the scalar product induced by the energy norm of the PDE (2) enable sparse compression of the solution space in H_0^1 (Ω) (3) induce an orthogonal multiresolution operator decomposition. The operating diagram of the multigrid method is that of an inverted pyramid in which gamblets are computed locally (by virtue of their exponential decay), hierarchically (from fine to coarse scales) and the PDE is decomposed into a hierarchy of independent linear systems with uniformly bounded condition numbers. The resulting algorithm is parallelizable both in space (via localization) and in bandwith/subscale (subscales can be computed independently from each other). Although the method is deterministic it has a natural Bayesian interpretation under the measure of probability emerging (as a mixed strategy) from the information game formulation and multiresolution approximations form a martingale with respect to the filtration induced by the hierarchy of nested measurements.

The paper (to appear in SIAM Review) is available at http://arxiv.org/abs/1503.03467

Numerical homogenization and the exponential decay of the fine-scale Green's function

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Abstract

This talk presents a variational approach for the numerical homogenization of elliptic partial differential equations with arbitrary rough diffusion coefficients. The trial and test space in this (Petrov-)Galerkin method are derived from linear finite elements on a coarse mesh of width H by local fine-scale correction. The correction is based on the pre-computation of cell problems on patches of diameter $H \log(1/H)$. The moderate overlap of the patches suffices to prove $O(H)$ convergence of the method without any pre-asymptotic effects. The key step in the error analysis is the proof of the exponential decay of the so-called fine-scale Green's function, i.e., the impulse response of the variational equation in the absence of coarse-scale finite element functions. The method allows the characterization of effective coefficients on a given target scale of numerical resolution.

Among further applications of the approach are the acceleration of solvers for non-linear eigenvalue problems, pollution-free high-frequency scattering, and explicit time stepping on spatially adaptive meshes.

Numerical methods for generalized hydrodynamic models

Qi Wang

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Abstract

I will discuss the Onsager theory for nonequilibrium thermodynamics and then generalize it to develop generalized hydrodynamic theories for a variety of complex fluids/soft matter systems. For the generalized hydrodynamics, we can clearly identify its variational structure and dissipative structure using Onsager Theory. Based on the mathematical structure, I will discuss a set of methods to discretize them semi-discretely in time and fully discrete in both space and time in order to preserve their variational and dissipative strcutures in numerical schemes. Finally, I will present some results for applications to multiphase complex fluid flows and cell dynamics.

An efficient threshold dynamics method for wetting on rough surfaces

Xiaoping Wang

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Abstract

The threshold dynamics method developed by Merriman, Bence and Osher (MBO) is an efficent method for simulating the motion by mean curvature flow when the interface is away from the solid boundary. Direct generalization of the MBO type method to the wetting problems with interface intersecting the solid boundary is not easy because solving heat equation on general domain with wetting boundary condition is not as efficient as that for the original MBO method. The dynamics of the contact point also follows a different dynamic law compared to interface dynamics away from the boundary. In this paper, we develop an efficient volume preserving threshold dynamics method for wetting on rough surfaces, which is based on minimization of the weighted surface area functional over a extended domain that includes the solid phase. The method is simple, stable with the complexity $O(N \log N)$ per time step and it is not sensitive to the inhomogeneity or roughness of the solid boundary.

Phase-field modeling of proppant-filled fractures in a poroelastic medium

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Abstract

This work presents proppant and fluid-filled fracture with quasi-Newtonain fluid in a poroelastic medium. Lower-dimensional fracture surface is approximated by using the phase field function. The two-field displacement phase-field system solves fully-coupled constrained minimization problem due to the crack irreversibility. This constrained optimization problem is handled by using active set strategy. The pressure is obtained by using a diffraction equation where the phase-field variable serves as an indicator function that distinguishes between the fracture and the reservoir. Then the above system is coupled via a fixed-stress iteration. The transport of the proppant in the fracture is modeled by using a power-law fluid system.

The numerical discretization in space is based on Galerkin finite elements for displacements and phase-field, and an Enriched Galerkin method is applied for the pressure equation in order to obtain local mass conservation. The concentration is solved with cell-centered finite elements. Nonlinear equations are treated with Newton's method. Predictor-corrector dynamic mesh refinement allows to capture more accurate interface of the fractures with reasonable number for degree of freedoms.

Efficient Multiscale Methods for Modeling Flow in Fractured vuggy Reservoirs

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China University of Petroleum (East China)

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Abstract

Fractures and vugs play a significant effect on the macro-scale flow, thus should be described exactly. Accurate modeling of flow in fractured media is usually done by discrete fracture model (DFM). For accurate modeling of flow in fractured vuggy reservoirs, we proposed a discrete fractured vuggy network model (DFVN). Both models can provide detailed representation of flow characteristic. However, considering the computational efficiency and accuracy, traditional numerical methods are not suitable for DFM and DFVN. In our work, multiscale methods, including multiscale finite element method (MsFEM) and multiscale mixed finite element method (MsMFEM), are proposed for detailed modeling of fluid flow in fractured vuggy reservoirs. In multiscale methods, the governing equations are solved on coarse grid. The interaction between the fractures, vugs and the matrix is captured through multiscale basis functions calculated numerically by solving DFM or DFVN on the local fine grid. Through multiscale basis functions, multiscale methods can not only reach a high efficiency as upscaling technology, but also finally generate a more accurate and conservative velocity field on the full fine-scale grid. In our approach, oversampling technique is applied to get more accurate small-scale details. Triangular fine-scale grid is applied, making it possible to consider fractures in arbitrary directions. Comparisons of the multiscale solutions with the full fine-scale solutions indicate that the later one can be replaced by the former one. The results showed that the multiscale technology is a promising numerical method for multiscale flows in high-resolution fractured media.

Gamblets for opening the complexity-bottleneck of implicit schemes for hyperbolic and parabolic PDEs with rough coefficients

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Abstract

Implicit schemes are popular methods for the integration of time dependent PDEs such as hyperbolic and parabolic PDEs. However the necessity to solve corresponding linear systems at each time step constitutes a complexity bottleneck in their application to PDEs with rough coefficients. We present a generalization of gamblets introduced in \cite{OwhadiMultigrid:2015} enabling the resolution of these implicit systems in near-linear complexity and provide rigorous a-priori error bounds on the resulting numerical approximations of hyperbolic and parabolic PDEs. These generalised gamblet's induce a multiresolution decomposition of the solution space that is adapted to both the underlying (hyperbolic and parabolic) PDE and to the time-steps of the numerical scheme. This is a joint work with Houman Owhadi.

Directions

A. Between Airport and Accommodation

1) Royal Park Hotel (帝都酒店)

Address: 8 Pak Hok Ting Street, Sha Tin, New Territories, Hong Kong

香港新界沙田白鶴汀街八號

Telephone: +852- 2601 2111

Website: http://www.royalpark.com.hk/hongkong/eng/index.html

By Public Airport Bus

(Not recommended for guests who have bulky luggage)

Public Airport Bus No. A41 goes from the airport to Royal Park Hotel bus stop (帝都酒店巴士站), for HK$22.3 per person. It runs from 06:00 to 24:00 and departs every 20 min at Airport Bus Terminus. The journey takes approx. 65 min.

Details of Airport Bus No. A41:http://m.kmb.hk/en/result.html?busno=a41#desDetail

By Taxi

A direct taxi ride from the airport to the hotel would cost about HK$300 per car (max 5 persons each), depending on the traffic.

*For your easy communication with taxi driver, you may show the following Chinese note card:

請送我到 (Please drive me to):

新界沙田白鶴汀街八號帝都酒店

Royal Park Hotel,
8 Pak Hok Ting Street, Sha Tin, N.T.

2) Regal Riverside Hotel (麗豪酒店)

Address: 34-36 Tai Chung Kiu Road, Sha Tin, New Territories, Hong Kong

香港沙田大涌橋路 34-36 號

Telephone: +852- 2649 7878

Website: http://www.regalhotel.com/regal-riverside-hotel/tc/home/home.html

By Public Airport Bus

(Not recommended for guests who have bulky luggage)

Public Airport Bus No. A41 goes from the airport to Regal Riverside Hotel bus stop (麗豪酒店巴士站), for HK$22.3 per person. It runs from 06:00 to 24:00 and departs every 20 min at Airport Bus Terminus. The journey takes approx. 65 min.

Details of Airport Bus No. A41:http://m.kmb.hk/en/result.html?busno=a41#desDetail

By Taxi

A direct taxi ride from the airport to the hotel would cost about HK$300 per car (max 5 persons each), depending on the traffic.

By Free Hotel Shuttle Bus

Please send your request to aggie@math.cuhk.edu.hk before your arrival.

*For your easy communication with taxi driver, you may show the following Chinese note card:

請送我到 (Please drive me to):

香港沙田大涌橋路 34-36 號麗豪酒店

Regal Riverside Hotel,
34-36 Tai Chung Kiu Road, Sha Tin,
New Territories, Hong Kong

B. Between Accommodation & Conference Venue

The workshop will take place at LT4, Yasumoto International Academic Park (YIA), The Chinese University of Hong Kong.

Step 1: From your hotel to **Shatin MTR station**

From **Royal Park Hotel (帝都酒店)**, you can walk to Shatin MTR station through the New Town Plaza (新城市廣場). It takes about 10 minutes.

From **Regal Riverside Hotel (麗豪酒店)**, you can take buses.

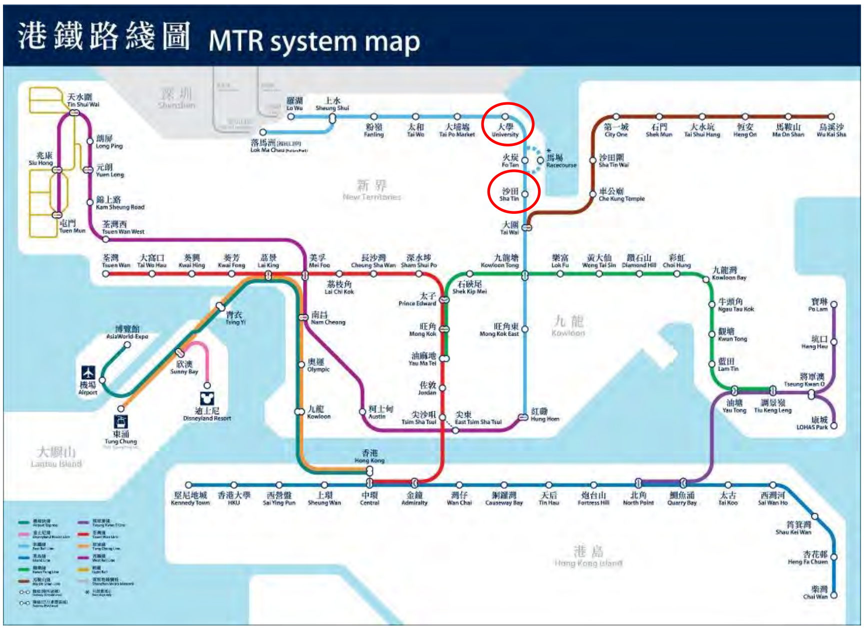
No.	Get in	Get off	Service hours	Frequency	Duration	Fee
KMB **86K**	REGAL RIVERSIDE HOTEL	SHA TIN RAILWAY STATION BUS TERMINUS	Normal 5:30 to 0:05 / Holiday 5:30 to 0:05	every 5 to 10min.	5mins	$6.1
KMB **89X**	REGAL RIVERSIDE HOTEL	SHA TIN RAILWAY STATION BUS TERMINUS	Normal 5:50 to 0:00 / Holiday 5:50 to 0:00	every 6 to 10min.	5mins	$5.4

When you return from Shatin MTR station to Regal Riverside Hotel, the routes vary a little.

No.	Get in	Get off	Service hours	Frequency	Duration	Fee
KMB **86K**	SHA TIN RAILWAY STATION BUS TERMINUS	REGAL RIVERSIDE HOTEL	Normal 5:40 to 0:45 / Holiday 5:40 to 0:45	Every 5 to 10min.	5mins	$6.1
KMB **89X**	SHA TIN RAILWAY STATION BUS TERMINUS	REGAL RIVERSIDE HOTEL	Normal 5:40 to 0:00 / Holiday 5:40 to 0:00	Every 6 to 12min.	5mins	$7.5

Step 2: From Shatin MTR station to **University MTR Station**

Take the train to University MTR station, which is two stops away from Shatin MTR station.



Step 3: From University MTR Station to **YIA**

The YIA building is next to the University MTR station. It is a 2-5 min walk from the University Station. You may choose either Exit A, C or D when heading to YIA.
However, please note that only Exit A or B can access to trains going towards Shatin when you are leaving the University. Please also note that the train ticket booth is located at Exit B.

Meals

We will provide tea breaks, lunches and a dinner during the workshop.

Dinner Venue: Jasmine Room II, Level 2, Royal Park Hotel Date: 19 June 2016 Time: Start at 7:00pm

Wi-Fi Account

Wi-Fi SSID:	**CUguest**
User ID:	**camiccm4@conference.cuhk.edu.hk**
Password:	**cuhkmath**

Useful Information

1. Contact Persons

   Prof. Eric Chung: 9385 9985 (mobile) or 3943 7972 (office)

   Ms. Aggie Law: 9159 3151 (mobile) or 3943 7946 (office)

   Ms. Suki Chan: 3943 7989

   Ms. Cynthia Chen: 5494 2874 (mobile)

   Mr. Ivan Au Yeung: 5137 4129 (mobile)

2. Travel Card

   Octopus Card, an electronic fare card that is accepted by almost all forms of public transport, and at many fast food chains and stores. It's convenient and eliminates the need for small change.

   Add money to it whenever you need to, and any unspent value in On-Loan Octopus is refundable along with the HKD50 deposit at any MTR Station.

   *minus HKD9 handling fee for cards returned within three months.

   For more details, please refer to: http://www.octopus.com.hk/home/en/index.html

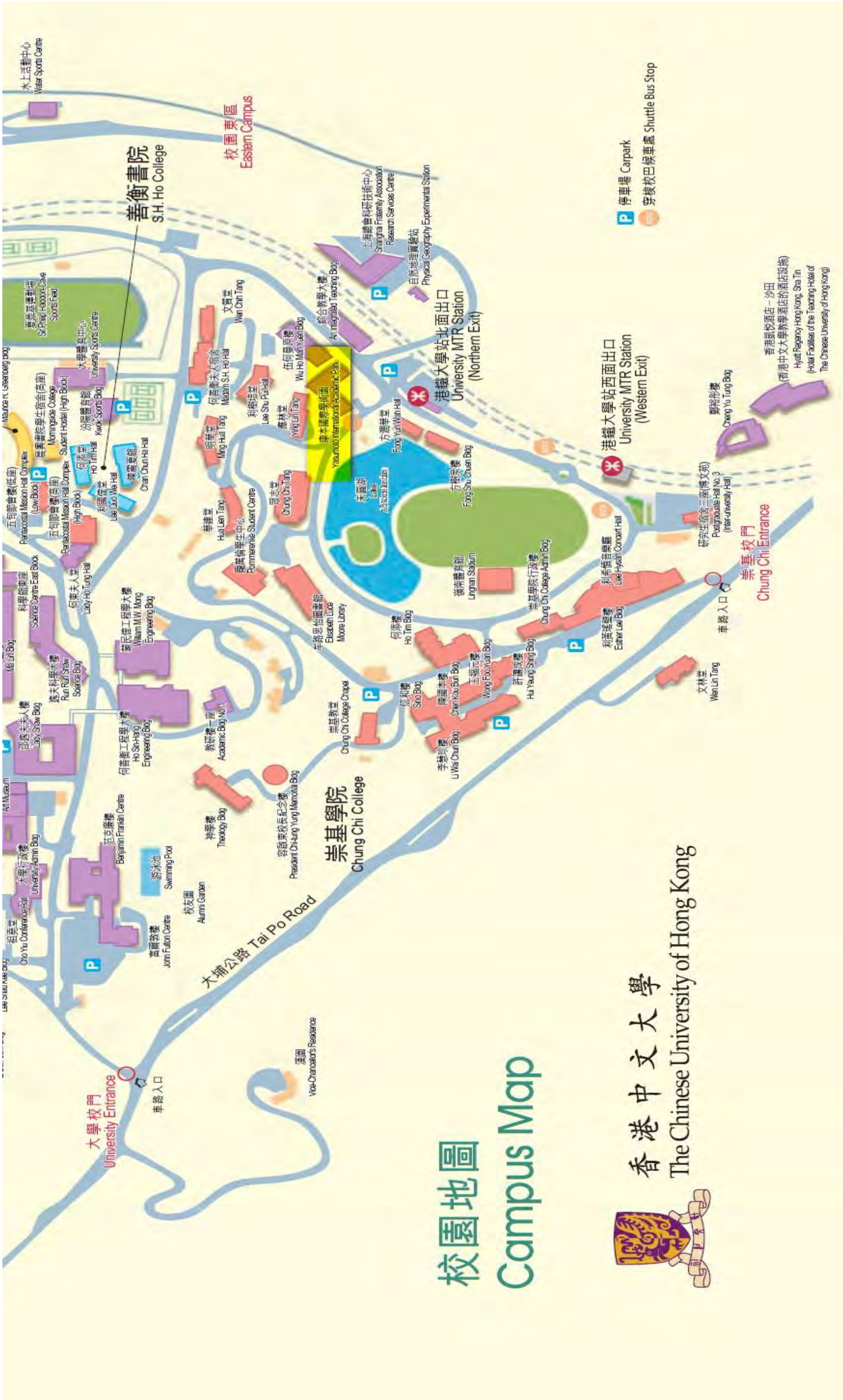
3. Emergency Numbers

   For any kind of emergency, please contact the Security Unit

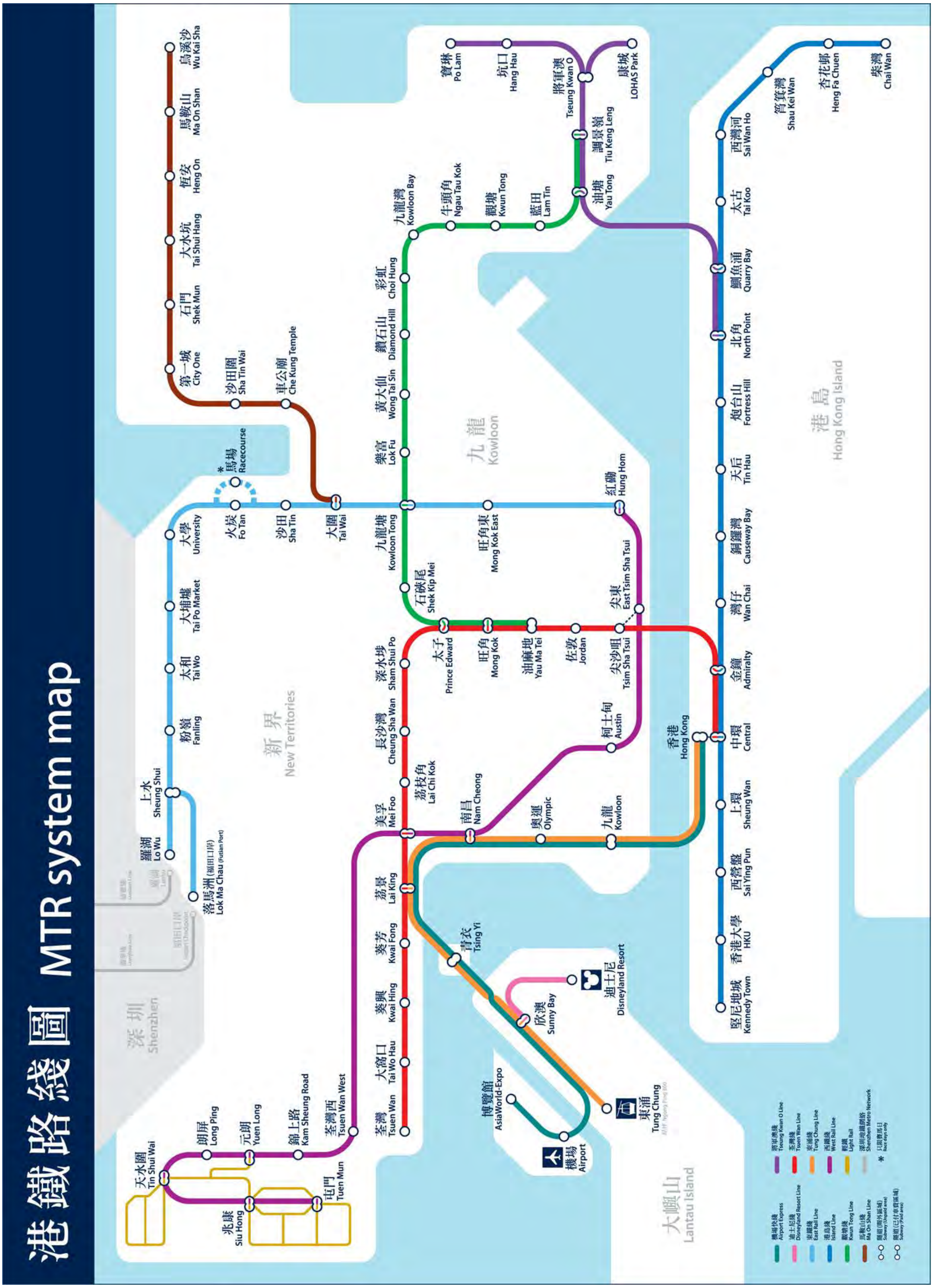
   Telephone: 3943 7999

   Email: security_unit@cuhk.edu.hk

CUHK Campus Map



MTR System Map



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Seong LEE	Chevron
Qiuqi LI	Hunan University
Tiexiang LI	Southeast University
Jingshi LI	Jilin University
Guo LI	Sun Yat-Sen University
Yonglin LI	Nanjing University
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Qin LI	University of Wisconsin

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