# Program at a Glance

| Time | 22 Aug 2024, Thursday |
|---|---|
| 9:00 - 9:30 | Registration |
| 9:30 - 9:45 | LT-10<br>Opening Ceremony & Group Photo |
| 9:45 - 10:30 | LT-10<br>(Chair: Jonathan James WYLIE)<br>**PLENARY TALK I: Xiaoming YUAN** |
| 10:30 - 10:50 | Coffee Break |
| 10:50 - 11:20 | INVITED TALK 1: Lijun YUAN |
| 11:20 - 11:50 | INVITED TALK 2: Jianquan LU |
| 11:50 - 12:20 | INVITED TALK 3: Jun FAN |
| 12:20 - 14:00 | Lunch Break |
| | LT-10<br>(Chair: Weifeng QIU) |
| 14:00 - 14:45 | **PLENARY II: Buyang LI** |
| 14:45 - 15:15 | INVITED TALK 4: Ting WEI |
| 15:15 - 15:35 | Coffee Break |
| 15:35 - 16:05 | INVITED TALK 5: Yuan YAO |
| 16:05 - 16:35 | INVITED TALK 6: Yuhui DENG |
| 16:35 - 17:05 | INVITED TALK 7: Huaian DIAO |
| | City Chinese Restaurant<br>Academic Exchange Building, City University of Hong Kong |
| 18:30 – 21:00 | **Conference Banquet (By Invitation)** |
| **LT-10: Lecture 10, Level 4, Yeung Kin Man Academic Building (Academic 1)** | |

# Program at a Glance

| Time | 23 Aug 2024, Friday |
|---|---|
| 9:15 - 9:45 | Registration |
| 9:45 - 10:30 | LT-10<br>(Chair: Xiaosheng ZHUANG)<br>**PLENARY TALK III: Ming LIU** |
| 10:30 - 10:50 | Coffee Break |
| 10:50 - 11:20 | INVITED TALK 8: Wenjun XIONG |
| 11:20 - 11:50 | INVITED TALK 9: Lei SHI |
| 11:50 - 12:20 | INVITED TALK 10: Jilu WANG |
| 12:20 - 14:00 | Lunch Break |
| | LT-10<br>(Chair: Dan DAI) |
| 14:00 - 14:45 | **PLENARY IV: Lun ZHANG** |
| 14:45 - 15:15 | INVITED TALK 11: Wenying XU |
| 15:15 - 15:35 | Coffee Break |
| 15:35 - 16:05 | INVITED TALK 12: Xiaoyi CHEN |
| 16:05 - 16:35 | INVITED TALK 13: Zheng-Chu GUO |
| | City Chinese Restaurant<br>Academic Exchange Building, City University of Hong Kong |
| 18:30 – 21:00 | **Conference Dinner (By Invitation)** |
| **LT-10: Lecture 10, Level 4, Yeung Kin Man Academic Building (Academic 1)** | |

# Abstracts

## Conference on Frontiers in Applied Mathematics

**Celebrating 30th City University of Hong Kong**

22 August - 23 August, 2024
City University of Hong Kong

Co-organized by
Liu Bie Ju Centre for Mathematical Sciences
Department of Mathematics

# Contents

# 1 Plenary Talks

## Artificial tangential motions for surface evolution

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We review the development of parametric finite element methods for approximating surface evolution under external velocity field or geometric flows, as well as efforts in developing artificial tangential motions on the surfaces to improve the mesh quality of the computed approximate surfaces. Then we discuss some new parametric finite element methods, with new artificial tangential motions constructed at the continuous level, for approximating surface evolution under external velocity fields and geometric flows. Convergence of these methods for approximating surface evolution will also be discussed.

## Data-driven based fault diagnosis and life prediction for modern satellites

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With the widespread application of satellite technology across various fields, society's reliance on satellite systems has significantly increased. Consequently, the safety, reliability and effectiveness of satellite components and equipment have garnered substantial attention. The development of data-driven intelligent fault diagnosis (IFD) and intelligent life prediction (ILP) methods offers new solutions to ensure and enhance the safety and reliability of these systems. In this prersentation, we explore the design of IFD and ILP methods for dynamic systems in modern satellite infrastructure. Our focus is on the challenges associated with applying data mining technology in the satellite realm. To tackle these complex issues, we propose a systematic approach to IFD and ILP. This involves diagnostic methods based on attention mechanisms, the symmetric dot pattern (SDP) method, graph networks, and

long short-term memory (LSTM) networks. Additionally, we develop fault diagnosis strategies anchored in deep learning and satellite life prediction schemes leveraging LSTM techniques. Finally, we will discuss the practical application of these advanced fault diagnosis and life prediction methods on orbiting satellites, which includes the construction and utilization of digital satellite twin platforms.

## How optimization helps industry: some real applications in the era of AI and cloud computing

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We will showcase some completely new optimization problems arising recently in the AI and Cloud Computing industries, such as live streaming, virtual machine, digital human, physics engines, large language models, and AI-chip design. These problems have been rarely studied in academia, hence neither rigorous theory nor efficient algorithms could be found. We will show how to understand and represent these problems mathematically, and briefly discuss their difficulties and/or recent progresses mainly from the optimization and OR perspectives.

## On the gap probability of the tacnode process

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The tacnode process is a universal determinantal point process arising from non-intersecting particle systems and tiling problems. It is the aim of this talk to explore the integrable structure and asymptotics for the gap probability of the thinned/unthinned tacnode process over $(-s, s)$. We establish an integral representation of the gap probability in terms of the Hamiltonian associated with a system of differential equations. With the aids of some remarkable differential identities for the Hamiltonian, we also compute large gap asymptotics, up to and including the constant term in the thinned case. As direct applications, we obtain expectation, variance and a central limit

theorem for the associated counting function. Based on a joint work with Luming Yao.

# 2 Invited Talks

## A novel shell formulation for large deformations of compressible biological structures

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This study presents the development of an asymptotically consistent morphoelastic shell model for describing finite deformations in biological tissues, utilizing an energy-based approach. Recognizing the significant compressibility that biological materials can exhibit under large deformations, we incorporate this factor to enhance the accuracy of morphoelastic change predictions. Our model integrates Rodriguez et al.'s growth model with a novel shell formulation we've developed. We begin with a three-dimensional (3D) morphoelastic model and derive the optimal shell energy through a series expansion around the middle surface. Employing a two-step variational method, we retain the leading-order expansion coefficient while eliminating higher-order terms. The result is a two-dimensional (2D) shell energy that depends on the stretching and bending strains of the middle surface. The derived morphoelastic shell model maintains asymptotic consistency with three-dimensional morphoelasticity and can reproduce various existing shell models in the literature. To demonstrate its applicability, we employ this model to investigate the invagination process during the inversion of the Volvox embryo.

## VSG-GAN: A high-fidelity image synthesis method with semantic manipulation in retinal fundus image

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In recent years, advancements in retinal image analysis, driven by machine learning and deep learning techniques, have enhanced disease detection and

diagnosis through automated feature extraction. However, challenges persist, including limited dataset diversity due to privacy concerns and imbalanced sample pairs, hindering effective model training. To address these issues, we introduce the Vessel & Style Guided Generative Adversarial Network (VSG-GAN), an innovative algorithm building upon the foundational concept of GAN. In VSG-GAN, a generator and discriminator engage in an adversarial process to produce realistic retinal images. Our approach decouples retinal image generation into distinct modules: the vascular skeleton and background style. Leveraging style transformation and GAN inversion, our proposed Hierarchical Variational Autoencoder (HVAE) module generates retinal images with diverse morphological traits. Additionally, the Spatially-Adaptive De-normalization (SPADE) module ensures consistency between input and generated images. We evaluate our model on MESSIDOR and RITE datasets using various metrics, including Structural Similarity Index Measure (SSIM), Inception Score (IS), Fréchet Inception Distance (FID), and Kernel Inception Distance (KID). Our results demonstrate the superiority of VSG-GAN, outperforming existing methods across all evaluation assessments. This underscores its effectiveness in addressing dataset limitations and imbalances. Our algorithm provides a novel solution to challenges in retinal image analysis by offering diverse and realistic retinal image generation. Implementing the VSG-GAN augmentation approach on downstream diabetic retinopathy classification tasks has shown enhanced disease diagnosis accuracy, further advancing the utility of machine learning in this domain.

## Unique and stable determination of the obstacle by finitely many far-field measurements

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In this talk, I will discuss the uniqueness and stability aspects of identifying obstacles using a finite number of far-field measurements. Uniqueness is primarily contingent upon the unique geometric structure exhibited by Laplacian eigenfunctions near corners. We achieve stable determination of convex polygonal impedance obstacles through a single far-field measurement. Our stability estimates establish explicit relationships between the geometric characteristics of the obstacle and the order of vanishing of the

wave field at specific corner points.

## Functional neural network on infinite-dimensional data

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Neural networks have proven their versatility in approximating continuous functions, but their capabilities extend far beyond. In this talk, we delve into the realm of functional neural networks, which offer a promising approach for approximating nonlinear smooth functionals defined on Lp spaces. By investigating the convergence rates of approximation and generalization errors under different regularity conditions, we gain insights into the theoretical properties of these networks. This analysis contributes to a deeper understanding of functional neural networks and opens up new possibilities for their effective application in diverse domains such as dynamic system identification, distribution regression, and functional data analysis.

## Online learning in reproducing kernel Hilbert space

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Analyzing and processing large-scale data sets is becoming ubiquitous in the era of big data. Online learning has attracted increasing interest in recent years due to its low computational complexity and storage requirements, it has been applied to various learning tasks. In this talk, we will present some results of online learning algorithms in Reproducing Kernel Hilbert space. This talk is based on joint work with Prof. Lei Shi and Prof. Andreas Christmann and Prof. Yunwen Lei.

## Impulsive dynamic systems: analysis, control and applications

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This talk focuses on the dynamic analysis, control and applications of impulsive systems. The method of average impulsive interval will be introduced, and then a unified criterion is established for synchronization of impulsive dynamical networks. Furthermore, a new concept of average impulsive delay is introduced to characterize impulsive delays from a holistic perspective. In addition, unlike previous results on the "negative" effect of delay on the stability of impulsive systems, this talk will show the potential "positive" effect of delay on the stability of impulsive systems. Finally, impulsive control is successfully applied to stabilization of networked systems under denial-of-service (DoS) attacks. These applications demonstrate that impulsive controllers are very robust to a wide range of DoS attackers, even if their attack parameters (DoS duration and DoS frequency) are previously unknown to the control designer.

## Learning theory of classification with deep neural networks

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Deep neural networks (DNNs) trained with the logistic loss (also known as the cross entropy loss) have made impressive advancements in various binary classification tasks. Despite the considerable success in practice, generalization analysis for binary classification with deep neural networks and the logistic loss remains scarce. The unboundedness of the target function for the logistic loss in binary classification is the main obstacle to deriving satisfying generalization bounds. In this talk, we aim to fill this gap by developing a novel theoretical analysis and using it to establish tight generalization bounds for training fully connected ReLU DNNs with logistic loss in binary classification.

## Optimal $L^2$ error estimates of unconditionally stable FE schemes for the Cahn–Hilliard–Navier–Stokes system

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The work is concerned with the analysis of a popular convex-splitting finite element method for the Cahn–Hilliard–Navier–Stokes system, which has been widely used in practice. Since the method is based on a combined approximation to multiple variables involved in the system, the approximation to one of the variables may seriously affect the accuracy for others. Optimal-order error analysis for such combined approximations is challenging. The previous works failed to present optimal error analysis in $L^2$-norm due to the weakness of the traditional approach. Here we first present an optimal error estimate in $L^2$-norm for the convex-splitting FEMs. We also show that optimal error estimates in the traditional (interpolation) sense may not always hold for all components in the coupled system due to the nature of the pollution/influence from lower-order approximations. Our analysis is based on two newly introduced elliptic quasi-projections and the superconvergence of negative norm estimates for the corresponding projection errors. Numerical examples are also presented to illustrate our theoretical results. More important is that our approach can be extended to many other FEMs and other strongly coupled phase field models to obtain optimal error estimates.

## Simultaneous determination of the order and a coefficient in a fractional diffusion-wave equation

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This talk is focused on an inverse problem for recovering the order of fractional derivative and a time-dependent potential coefficient in a time-fractional diffusion wave equation by an integral condition or one single point measurement on the boundary. The Lipschitz continuity of the forward operators from the unknown order and coefficient to the given data are achieved in terms of the integral equation held by the solution of the direct problem. We also obtain the uniqueness for the considered inverse problems in terms of

somewhat general conditions to the given functions. Moreover, we propose a Tikhonov-type regularization method and prove the existence of the regularized solution and its convergence to the exact solution under a suitable regularization parameter choice. Then we use a linearized iteration algorithm to recover numerically the order and time-dependent potential coefficient simultaneously. Three numerical examples for one- and two-dimensional cases are provided to display the efficient of the proposed method.

## The design of iterative learning control in the tracking problem of complex networks

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Induced by the random access protocol (RAP), a kind of iterative learning schemes with cooperative-antagonistic interactions are designed to achieve tracking of a network system, in which each node is described by a two-time-scale system to deal with heterogeneous type of information in the node. Considering that the mutual relationships may be cooperative and also competitive among nodes in many real-world networks, iterative learning controllers are designed to be cooperative-antagonistic. Furthermore, in order to prevent data collision in the process of signal transmissions, the RAP is introduced into the design of the iterative learning controllers. Considering both known and unknown transition probabilities in the RAP, the next objective is to obtain conditions to guarantee the tracking of the network system by adjusting some changeable parameters in the designed iterative learning controllers.

## Fully distributed adaptive dynamic event-triggered schemes of multi-agent systems

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This talk will present recent advances on adaptive dynamic event-triggered

(ADET) schemes of multi-agent systems. First, we will discuss the state-based and observer-based consensus control problem of multi-agent systems with general linear dynamics under event-triggered communication (ETC), respectively. Two novel event-triggered strategies named adaptive dynamic event-triggered (ADET) schemes for one-to-all and one-to-one ETC are well developed, in which on-line triggering parameters associated with each node or edge and dynamic thresholds with updating laws are introduced, respectively. Second, the hybrid Nash equilibrium (NE) seeking problem over a network in a partial-decision information scenario. In order to save communication cost, a novel event-triggered scheme, namely, edge-based adaptive dynamic event-triggered (E-ADET) scheme, is proposed with on-line-tuned triggering parameter and threshold, and such a scheme is proven to be fully distributed and free of Zeno behavior. Then, a hybrid NE seeking algorithm, which is also fully distributed, is constructed under the E-ADET scheme. By means of the Lipschitz continuity and the strong monotonicity of the pseudo-gradient mapping, we show the convergence of the proposed algorithms to the NE. Compared with the existing distributed algorithms, our algorithms remove the requirement on global information, thereby exhibiting the merits of both flexibility and scalability.

## Controlling the false discovery rate in transformations: split knockoffs

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Controlling the False Discovery Rate (FDR) in a feature selection procedure is critical for reproducible discoveries and trustworthy research, which receives an extensive study in sparse linear models with finite samples. However, it remains largely open in the scenarios where the sparsity constraint is not directly imposed on the parameters, but on a linear transformation of the parameters to be estimated. Examples include total variations, wavelet transforms, fused LASSO, and trend filtering, etc. In this paper, we propose a data adaptive FDR control in this transformational sparsity setting, the Split Knockoff method. The proposed scheme exploits both variable and data splitting. The linear transformation constraint is relaxed to its Eu-

clidean proximity in a lifted parameter space, yielding an orthogonal design for improved power and orthogonal Split Knockoff copies. To overcome the challenge that exchangeability fails due to the heterogeneous noise brought by the transformation, new inverse supermartingale structures are developed for provable the FDR control with directional effects. Simulation experiments show that the proposed methodology achieves desired (directional) FDR and power. An application to Alzheimer's Disease study is provided that atrophy brain regions and their abnormal connections can be discovered based on a structural Magnetic Resonance Imaging dataset (ADNI). This is a joint work with CAO, Yang and SUN, Xinwei.

## Spectra approximations and the existence of real reflection and transmission zeros near a bound state in the continuum

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A linear scattering problem for which incoming and outgoing waves are restricted to a finite number of radiation channels can be precisely described by a frequency-dependent scattering matrix. The entries of the scattering matrix, as functions of the frequency, give rise to the transmission and reflection spectra. To find the scattering matrix rigorously, it is necessary to solve the partial differential equations governing the relevant waves. In this talk, we firstly consider how to approximate the reflection and transmission spectra near a resonance. We develop a method to approximate the scattering matrix by using the information of the resonance and the exact scattering matrix at the real part of the resonant frequency. Secondly, we study the exist of real reflection and transmission zeros near a bound state in the continuum (BIC). We present a theory on the existence of real transmission and reflection zeros that correspond to the zero dips in the transmission and reflection spectra.

# Index