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Mathematics at the Core of Applied Research: Where Theory Meets Practice

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Applied research increasingly relies on mathematics to translate fundamental theory into practical solutions. This internvention will highlight how mathematical modeling and computation can describe complex systems, forecast behavior, and support efficient decision-making across real-world applications. Building on advances in non-Newtonian fluid dynamics and nanofluid transport, a concise model-to-computation pipeline connecting governing equations, non-dimensional analysis, and validated numerical simulation is presented. Some representative case studies are discussed, spanning bio-inspired transport in micro-scale environments and electroosmotic hybrid nanofluid flow in diseased arterial geometries, illustrating how quantitative results can guide practical, design-oriented insights. The intervention also concludes with a brief outlook on emerging opportunities where AI-enhanced modeling can accelerate analysis and strengthen the impact of applied mathematics across disciplines.

Algebraic Tools for Coding Theory and Cryptography

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Modern algebra plays a central role in the development of coding theory and cryptography. This talk introduces algebraic tools that play a key role in coding theory and cryptography. We discuss how algebraic structures such as finite fields, finite rings and polynomial rings are used to construct error-correcting codes and cryptographic schemes, and how their algebraic properties enable efficient algorithms and security guarantees. The goal of this talk is to highlight the unifying role of modern algebra in both areas through simple examples.

The unfinished equation:
Why our Mathematics has Failed Nature

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Classical mathematics has achieved extraordinary precision by idealizing nature into rigid structures: fixed dimensions, immutable geometries, associative algebras, and linear notions of change. Yet natural phenomena rarely conform to such constraints. Living systems bend, deform, evolve, bifurcate, and occasionally annihilate, exhibiting behaviors that transcend Euclidean geometry and conventional algebraic closure. This work argues that the persistent mismatch between mathematical formalism and natural reality arises from an incomplete foundational framework, one that privileges static objects over dynamic transformation.

Motivated by a geometry of continuous deformation and a vectorial invariance beneath mutable forms, the paper introduces a conceptual paradigm in which dimensions are not fixed but flow, algebraic operations may transition between commutativity and non-commutativity, and structural stability coexists with critical degeneration. Within this perspective, zero divisors, singularities, and breakdowns of association are not pathologies but boundary phenomena marking phase transitions in natural systems.

By reframing mathematics as an evolving language rather than a closed axiomatic monument, the study seeks to bridge analysis, geometry, and algebra into a unified, deformable framework more faithful to nature's intrinsic variability. The unfinished equation is thus not a failure of rigor, but an invitation to extend mathematical thought toward a living, adaptive formalism capable of capturing the true dynamics of the natural world.

Chebyshev Finite Integration Method for Solving Heat Conduction with Nonlocal and Moving Boundaries

Ratinan Boonklurb

Chulalongkorn University, Thailand

In this talk, we propose numerical algorithms based on the Chebyshev finite integration method to find approximate solutions to the heat conduction equation, specifically addressing both nonlocal and moving boundary conditions. We examine one- and two-dimensional heat equations under nonlocal boundaries. For moving boundaries, we focus on the one-dimensional heat equation with both one-phase and two-phase moving boundary conditions. Additionally, we provide numerical examples to demonstrate the efficiency and accuracy of our proposed algorithms in comparison to other methods. The results highlight the robustness and potential applications of these algorithms in solving complex boundary problems in heat conduction.

A Priori and a Posteriori Error analyses of a Pressure-robust Virtual Element Method for the two-Dimensional Brinkman problem

Yanping Chen

Nanjing University of Posts and Telecommunications College of Science, China

This talk investigates both a priori and a posteriori error estimates for a pressure-robust and divergence-free virtual element method to approximate the incompressible Brinkman problem on polygonal meshes. The exactly divergence-free property of virtual space preserves the mass-conservation of the system. By extending the lowest-order Raviart–Thomas element to polygonal meshes, we construct a divergence-preserving reconstructor for the discretization of the right-hand side. A rigorous a priori error analysis is developed, showing that the velocity error is independent of both the continuous pressure and the viscosity. Taking advantage of the virtual element method's ability to handle more general polygonal meshes, we design an adaptive mesh refinement approach and construct a residual-type a posteriori error indicator. This indicator is proven to provide global upper and local lower bounds for the discretization error. Finally, some numerical experiments demonstrate the robustness, accuracy, reliability and efficiency of the method.

Concave Certificates: Geometric Framework for Distributionally Robust Risk and Complexity Analysis

Hong Chu

Vin University, Vietnam

Distributionally Robust (DR) optimization aims to certify worst-case risk within a Wasserstein uncertainty set. Current certifications typically rely either on global Lipschitz bounds, which are often conservative, or on local gradient information, which provides only a first-order approximation. In this talk, we introduce a novel geometric framework based on the least concave majorants of the growth rate function. Our proposed concave certificate establishes a tight bound of DR risk that remains applicable to non-Lipschitz and non-differentiable losses. We extend this framework to complexity analysis, introducing a deterministic bound that complements standard statistical generalization bound. For practical application in deep learning, we introduce the adversarial score as a tractable relaxation that enables efficient and layer-wise analysis of neural networks.

Identification of some Water Quality Models

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One of the earliest water quality models was developed by Streeter and Phelps for the Ohio River in 1925. They proposed a 1-D steady-state model which describes the variation of dissolved oxygen (DO) and biochemical oxygen demand (BOD) along a river section. DO and BOD are among the most widely used water quality indicators. DO is the amount of oxygen present in a unit volume of water. Maintaining sufficient DO is critical for the preservation of the aquatic ecosystem in rivers and lakes. The term BOD is used to quantitatively describe the amount of DO per unit volume required to decompose organic waste. The BOD can be used as an indicator of water pollution. The Streeter-Phelps model was later extended to the case of time-varying DO and BOD. More complex models, such as QUAL2E and WASP, include more state variables such as ammonia, nitrites, nitrates, organic nitrogen, organic phosphorus, and orthophosphates.

In this talk, we focus on advection-reaction (AR) equations or advection-diffusion-reaction (ADR) equations which are used as a water quality model describing the evolution of BOD and DO in a river or stream. In these models, the coefficients representing the deoxygenation and reaeration rates are not known, and there are some empirical formulas for the reaeration rate, but none for the deoxygenation one. Furthermore, it is difficult to confirm the validity of these formulas for an arbitrary river stretch because this coefficient depends on geological factors of the river. We consider the inverse problem of determining these coefficients from additional measurements (learning water quality models). First, based on available data, we use sparse regularization techniques to determining some water quality models. Second, based on the Carleman estimates technique, we prove Lipschitz-type stability estimates for DO-BOD models with respect to data. For numerical computation, the coefficient identification problem is reformulated as an optimization problem using the least-squares method coupled with the adjoint equation method for computing the gradient of the objective functional. Error estimates are derived and numerical examples are provided for demonstrating the performance of the proposed algorithm.

(In collaboration with Nguyen Trung Thanh, Nguyen Van Duc, and Nguyen Van Thang.)

Approximate Controllability for some Integrodifferential Equations

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Control theory is a multidisciplinary domain focused on understanding the behavior of dynamic systems, primarily aimed at managing their outputs. A specific area within this field is mathematical control theory, which emphasizes the use of mathematical techniques to assess system behavior and develop controllers. This entails employing tools such as differential equations, linear algebra, and optimization to analyze, model, and govern system dynamics. These systems find broad applications in fields like robotics, automation, aerospace, electrical engineering, mechanical systems, as well as biological and social contexts. Characterized by complex representations including partial differential equations and functional differential equations among other infinite-dimensional models, these systems present significant challenges that make analyzing their behaviors a crucial and complex research domain. Recently, there has been considerable interest in applying control theory to evaluate and manage the dynamics of these systems. The purpose of this discussion is to explore the approximate controllability of specific infinite-dimensional dynamical systems defined by integrodifferential equations.

Explicit Symmetric Low-Regularity Integrator for the Nonlinear Schrodinger Equation

Yue Feng

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The numerical approximation of low-regularity solutions to the nonlinear Schrodinger equation (NLSE) is notoriously difficult and even more so if structure-preserving schemes are sought. Recent works have been successful in establishing symmetric low-regularity integrators for NLSE. However, so far, all prior symmetric low-regularity algorithms are fully implicit, and therefore require the solution of a nonlinear equation at each time step, leading to significant numerical cost in the iteration. In this work, we introduce the first fully explicit (multi-step) symmetric low-regularity integrators for NLSE. We demonstrate the construction of an entire class of such schemes which notably can be used to symmetrise (in explicit form) a large amount of existing low-regularity integrators. We provide rigorous convergence analysis of our schemes and numerical examples demonstrating both the favourable structure preservation properties obtained with our novel schemes, and the significant reduction in computational cost over implicit methods.

Rank Inspired Neural Network for Solving PDEs

Yunqing Huang

Xiangtan University, China

Neural network methods such as Physics-Informed Neural Networks (PINNs) and Extreme Learning Machines (ELM) offer advantages including strong universality, user-friendliness, and well-developed code ecosystem. However, they suffer from uncertainties like poor interpretability and parameter sensitivity. In this report, we introduce a rank-inspired neural network method to address the issue that the solution performance of physics-informed extreme learning methods (PIELM) is sensitive to weight initialization. The training process of RINN consists of two stages. In the first stage, the optimization is performed to train the weight parameters of the hidden layers, ensuring that the output functions of the last hidden layer satisfy orthogonality constraints. This further enhances the function representation and approximation capabilities of the spanned linear space. In the second stage, the hidden layers parameters are frozen, and the least squares method is used to determine the output layer parameters for solving partial differential equations. Numerical results show that compared with PIELM, RINN significantly reduces performance differences caused by parameter initialization while maintaining high accuracy in solving PDEs.

Transmission Dynamics of Soil-Transmitted Helminths Incorporating Human and Animal Hosts

Editha Jose

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Soil-transmitted helminths (STHs), one of the most common neglected tropical diseases, pose a serious threat to public health in tropical and subtropical regions. These parasites infect both humans and animals through soil contact or ingestion. This talk focuses on the dynamics of STH transmission model incorporating the roles that humans, animals, and the environment play as reservoirs for the spread of STH. The sensitivity analysis reveals key parameters influencing infection rates, as ingestion rate, disease progression rate, and shedding rate, all of which increase infection. Conversely, higher clearance and recovery rates decrease infection. The study also highlights the potential for cross-species transmission of STH infections between humans and animals, underscoring the One Health concept, which acknowledges the interdependence of human, animal, and environmental health. Ongoing studies focus on recommended interventions such as the implementation of WASH to prevent infection, reduce environmental contamination by parasites' eggs, and anthelmintic drug administration for both humans and animals to lower shedding rates.

Generation of Aesthetic Curves: Integrability and Self-Affinity

Kenji Kajiwara

Kyushu University, Japan

We consider the log-aesthetic curve (LAC) and its generalisation from the viewpoint of the underlying integrable structure and symmetry called "self-affinity". LAC is a family of planar curves developed in industrial design as those car designers regard as "aesthetic". LAC can be formulated as shape-invariant curves with respect to integrable deformations in similarity geometry. We also discuss the symmetry called the self-affinity, which is a similar notion to self-similarity characterising the fractals. We present genelisation of LAC based on the integrability and symmetry in the framework of Klein geometry.

Directional Variational Convergence, Directional Equilibrium Problems

Phan Quoc Khanh

Ton Duc Thang University, Vietnam

We introduce notions of directional variational convergence and directional equilibrium problems in normed spaces, inspiring that directional versions of most concepts and problems in mathematics have been studied in the literature but no ones are seen for such important concepts and problems in optimization and variational analysis. Next, we consider main variational properties of the new notions of convergence. They are about the preservation of directional variational objects through directional variational convergence. Then, we apply this preservation to approximations of directional equilibrium problems.

Excitability and Feedback: to Pulse or not to Pulse?

Bernd Krauskopf

The University of Auckland, New Zealand

Excitability is a very common phenomenon in many natural and engineered systems; examples are neurons, certain chemical reactions and laser systems. Being at equilibrium, an excitable system reacts to a sufficiently large perturbation by suddenly releasing a pulse of stored energy. The system then needs some time to recover its energy level before the next pulse can be triggered. When an excitable system is coupled to itself via a feedback loop with a sufficiently large delay time then very interesting pulsing dynamics may occur. Our mathematical analysis of relevant delay differential equation models shows when and how one can trigger different trains of sustained pulses in such systems. We demonstrate this with two examples: an excitable micropillar laser with an optical feedback loop generated by a regular mirror, and an actual live cell that receives voltage feedback from itself.

Reaction Networks Approach of
Modeling Biological and Disease Dynamics

Angelyn Lao

De La Salle University, Philippines

Reaction network theory offers a compelling alternative to traditional methods for modeling biological and disease-related dynamical systems. Unlike approaches that rely heavily on precise parameter values—often difficult to measure or estimate in complex biological contexts—reaction network theory allows for qualitative analysis of system behavior based solely on network structure. This makes it particularly well-suited for studying systems where data is sparse or uncertain. One of the key strengths of this framework is its ability to decompose complex systems into meaningful subsystems. By analyzing the dynamics of these subsystems independently and then recombining them, researchers can gain insight into the behavior of the overall network. This modular approach not only improves interpretability but also enhances scalability, enabling systematic exploration of intricate biological phenomena. In this talk, we will demonstrate how reaction network theory can be used to uncover fundamental principles underlying biological regulation and disease progression, offering a pathway to robust, mechanism-driven modeling without the need for exhaustive parameterization.

Hybrid Least Squares/Gradient Descent Methods for DeepONets

Chang-Ock Lee

Korea Advanced Institute of Science & Technology, South Korea

We propose an efficient hybrid least squares/gradient descent method to accelerate DeepONet training. Since the output of DeepONet can be viewed as linear with respect to the last layer parameters of the branch network, these parameters can be optimized using a least squares (LS) solve, and the remaining hidden layer parameters are updated by means of gradient descent form. However, building the LS system for all possible combinations of branch and trunk inputs yields a prohibitively large linear problem that is infeasible to solve directly. To address this issue, our method decomposes the large LS system into two smaller, more manageable subproblems - one for the branch network and one for the trunk network - and solves them separately. This method is generalized to a broader type of L^2 loss with a regularization term for the last layer parameters, including the case of unsupervised learning with physics-informed loss.

Learning Macroscopic Dynamics from Data

Qianxiao Li

National University of Singapore, Singapore

We discuss some recent work on constructing stable and interpretable macroscopic dynamics from trajectory data using deep learning. We adopt a modelling approach: instead of generic neural networks as functional approximators, we use a model-based ansatz for the dynamics following a suitable generalisation of the classical Onsager principle for non-equilibrium systems. This allows the construction of macroscopic dynamics that are physically motivated and can be readily used for subsequent analysis and control. We discuss applications in the analysis of polymer stretching in elongational flow. Moreover, we will also discuss some algorithmic challenges associated with learning (macroscopic) dynamics for scientific applications.

Stability and Adaptive Enhancement of SPRING in Wavefunction Optimization

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Variational Monte Carlo (VMC) combined with expressive neural network wavefunctions has become a powerful route to high-accuracy ground-state calculations, yet its practical success hinges on efficient and stable wavefunction optimization. While stochastic reconfiguration (SR) provides a geometry-aware preconditioner motivated by imaginary-time evolution, its Kaczmarz-inspired variant, subsampled projected-increment natural gradient descent (SPRING), achieves state-of-the-art empirical performance. However, the effectiveness of SPRING is highly sensitive to the choice of a momentum-like parameter mu. The origin of this sensitivity, particularly the instability observed at mu=1 has remained unclear. In this work, we clarify the distinct mechanisms governing the regimes mu¡1 and mu=1. We establish convergence guarantees for 0¡=mu¡1 under mild assumptions, and construct a counterexample showing that mu=1 can induce divergence via uncontrolled growth along kernel-related directions when the step-size is not summable. Motivated by this theoretical insight and extensive numerical experiments, we further propose a parameter-free adaptive strategy for selecting mu based on spectral flatness and subspace overlap. This approach achieves performance comparable to optimally tuned SPRING, resulting in a more robust and theoretically grounded optimization framework for VMC.

Quantifying the Effectiveness of Mangroves, Seagrass, and Eco-Structures in Coastal Wave Attenuation

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Institut Teknologi Bandung, Indonesia

Coastal regions worldwide are increasingly exposed to wave-induced hazards as a consequence of climate change, sea-level rise, and ecosystem degradation. Nature-based solutions, such as mangroves and seagrass meadows, together with eco-engineered structures, have emerged as promising alternatives or complements to conventional hard coastal defenses. This study quantitatively evaluates the effectiveness of mangroves, seagrass, and eco-structures in attenuating surface waves under shallow-water conditions. A depth-averaged hydrodynamic framework based on the shallow water equations is employed, incorporating vegetation-induced drag and structural resistance terms to represent different protection mechanisms. Wave attenuation performance is quantified exclusively using the wave transmission coefficient. Numerical simulations are conducted for a range of vegetation patch lengths and structural configurations, enabling systematic comparison between purely nature-based, purely structural, and hybrid eco-structural defenses. The results demonstrate that mangroves and seagrass significantly reduce wave transmission when sufficient spatial extent is present, while eco-structures provide more immediate attenuation over shorter distances. Hybrid configurations exhibit synergistic behavior, achieving lower transmission coefficients than single-mechanism defenses. These findings provide quantitative insights for the design and optimization of sustainable coastal protection strategies and support the integration of green–grey infrastructure in climate-resilient shoreline management.

Breaking Nonlinearity Barriers in Science and Engineering with a Hermite–Padé Computational Framework

Oluwole Daniel Makinde

Stellenbosch University, South Africa

Nonlinear phenomena are central to many problems in science and engineering, yet they often resist accurate analytical treatment and pose significant challenges for conventional numerical methods. This study presents a novel computational framework based on Hermite–Padé techniques aimed at overcoming key limitations associated with the approximation and solution of nonlinear systems. The proposed framework systematically combines series representations with Hermite–Padé rational approximants to enhance convergence, improve stability, and extend the validity of solutions beyond the radius of traditional perturbation methods. By reformulating nonlinear governing equations into a computationally efficient structure, the approach enables accurate resolution of strong nonlinearities, singular behaviors, and multi-scale dynamics. The effectiveness and robustness of the framework are demonstrated through representative problems drawn from applied mathematics, physics, and engineering, highlighting its superior performance compared with standard numerical and semi-analytical techniques. The results indicate that the Hermite–Padé computational framework provides a powerful and flexible tool for breaking nonlinearity barriers and advancing the analysis of complex scientific and engineering systems.

TBA

Stéphane Mangouala

African Society for Industrial and Applied Mathematics, Gabon

Pending

A Novel Fractional Binary Model for Option Pricing: Market Completeness and Convergence

Martin Le Doux Mbele Bidima

African Society for Industrial and Applied Mathematics, Cameroon

Pending

Discrete-Time Optimal Control of Species Augmentation in Interacting Population Models

Stephen Moore

University of Cape Coast, Ghana

In this talk, we present a unified discrete-time optimal control framework for biodiversity conservation in systems where demographic fragility and interspecific interactions jointly shape extinction risks. Across two complementary settings; (i) multi-species competition and (ii) predator–prey dynamics; we model conservation "augmentation" (translocation from reserve to target populations) under strong Allee effects, capturing thresholds below which populations may fail to recover.

In the first part, i.e. for multi-species competition, we formulate a four-population discrete interaction model with controls and compare objective functionals that balance population recovery against augmentation costs under both linear and nonlinear cost structures.

In the second part, i.e. for predator–prey systems, we study how the order of discrete ecological events (growth and interaction versus augmentation timing) alters qualitative outcomes, by analyzing two augmentation models that differ in whether translocation occurs before or after growth and predation. In all cases, optimality conditions are derived using a discrete-time generalization of Pontryagin's Maximum Principle, and optimal strategies are computed numerically using discrete forward–backward sweep methods and sequential quadratic programming. Simulations across parameter regimes (competition intensity, augmentation efficacy, and cost weights) demonstrate that optimal augmentation can yield substantial improvements in target and reserve population levels, but that optimal policies are sensitive to cost nonlinearities and, critically, to event ordering in discrete-time predator–prey dynamics. The results obtained provide guidance for designing appropriate time-stepped translocation strategies that are robust to interaction structure, demographic thresholds, and operational timing constraints.

Topological Data Analysis for COVID-19 Classification from 5 Lung CT-Scan Images

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We study a topological approach for classifying COVID-19 and non-COVID-19 lung CT scan images. Each image is mapped to a three-dimensional point cloud and reduced to a feature point cloud (FPC) using an intensity cover. Persistent homology is then computed using Vietoris–Rips filtrations, producing homology groups H0, H1, and H2, and a lower-star filtration on the original image, producing H0-LSF. Each persistence diagram is vectorized using persistence landscapes with five layers and 100 sample points, resulting in a 2000-dimensional feature vector for each image. Experiments are conducted on a dataset of 1000 images (500 COVID-19 and 500 non-COVID) taken from a subset of the SARS-CoV-2 CT-scan dataset. Using Support Vector Machine and Random Forest classifiers, we achieve accuracies of 95.10% (ROC-AUC 98.38%) and 93.40% (ROC-AUC 97.70%), respectively. Among the homological features, H1 provides the strongest discriminative signal.

Control Chart for Monitoring Fraction Nonconforming based on the Generalised Beta of the First Kind Distribution

Kok Haur Ng

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The Shewhart p-chart is widely used in statistical process control to monitor fraction nonconforming (p), assuming a binomial distribution and employing a normal approximation for the chart's formation. However, this approximation degrades when the true fraction nonconforming is small. A more flexible p-chart based on the generalised Beta of the first kind (GB3) distribution is introduced for improved monitoring of fraction nonconforming. The GB3 p-chart captures the first three moments of non-normally distributed fraction data, retaining its control limits within the [0,1] interval. This study assesses the GB3 p-chart's shift detection efficiency against competing charts, including Shewhart, Beta and Kumaraswamy p-charts, in terms of average run length, median run length and standard deviation of the run length. The numerical results indicate superior performance for the GB3 p-chart when the fraction nonconforming is small (p0.05) across various sample sizes. For larger shifts, all charts show comparable run length performances. Two real-world applications demonstrate the empirical use of the GB3 p-chart in scrutinising production data.

A Global Structure-preserving Kernel Method for the Learning of Hamiltonian Systems

Juan-Pablo Ortega

Nanyang Technological University, Singapore

In this talk, I will present a structure-preserving kernel ridge regression method that allows the recovery of globally defined, potentially high-dimensional, and nonlinear Hamiltonian functions on Poisson manifolds out of datasets made of noisy observations of Hamiltonian vector fields. The proposed method is based on finding the solution of a non-standard kernel ridge regression where the observed data is generated as the noisy image by a vector bundle map of the differential of the function that one is trying to estimate. Additionally, it is shown how a suitable regularization solves the intrinsic non-identifiability of the learning problem due to the degeneracy of the Poisson tensor and the presence of Casimir functions. A full error analysis is conducted that provides convergence rates using fixed and adaptive regularization parameters. The good performance of the proposed estimator is illustrated with several numerical experiments. This talk is joint work with Jianyu Hu and Daiying Yin.

From Pseudo-Differential to Fourier Integral: Boundedness of Operators on $L^{p(\cdot)}(\mathbb{T}^n)$ Spaces

Marie Françoise Ouedraogo

University Joseph KI-ZERBO, Burkina Faso

Pseudo-differential operators play a fundamental role in harmonic analysis and the theory of PDE. They can often be represented or approximated by Fourier integral operators, allowing their functional properties to be studied using Fourier transform tools. This presentation explores the link between pseudo-differential operators and Fourier integral operators on the torus, focusing on the boundedness of the latter in the context of variable exponent spaces. The study illustrates how the spectral structure of the torus and variations in the exponent influence the regularity and bound of the operators, offering perspectives for applications in harmonic analysis and in PDE theory on spaces with periodic geometry.

Random Walks and Algorithms on Graphs

Thi Ha Duong Phan

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Random walks on graphs are fundamental tools in both theory and algorithms for complex networks such as the internet, social networks, author networks, protein system, etc . From a simple rule - moving randomly to a neighboring vertex, random walk model provide powerful ways to explore large graphs and uncover hidden structures.

Using linear algebraic tools like the Laplacian and graph spectra, random walks lead to efficient algorithms for ranking, clustering, and navigation. Key notions such as stationary distributions and hitting times connect them to discrete dynamical systems and applications like community detection.

This talk presents these ideas from theory to practice, showing how simple random processes yield effective algorithms for real world networks.

Computational Mathematics of Kilometer-Scale Regional Climate Downscaling over Borneo

Nurul Huda binti Mohd Ramli

Universiti Brunei Darussalam, Brunei

High-resolution climate information is essential for understanding local-scale climate variability and extremes in Borneo, yet available global and regional datasets remain too coarse to resolve the complex interactions between topography, land-sea contrast, and mesoscale atmospheric processes. This talk presents the computational mathematics underpinning the high-resolution climate downscaling project, which focuses on the design of a kilometre-scale (˜1 km) regional climate downscaling system for Brunei Darussalam and northern Borneo.

We outline the governing equations of regional atmospheric models and examine how numerical discretisation, domain nesting, and lateral boundary forcing influence stability, accuracy, and computational cost at fine spatial resolutions. Key challenges associated with multi-scale dynamics, time-step constraints, and high-performance computing scalability are discussed in the context of long-term historical simulations over the Borneo region.

While dynamical downscaling provides physically consistent representations of atmospheric processes, its application at kilometre scales highlights practical limitations related to resolution, bias, and uncertainty. From a computational mathematics perspective, these challenges motivate the exploration of hybrid approaches in which data-driven or AI-based methods may complement physics-based models. The talk briefly outlines the mathematical considerations involved in such hybrid frameworks, including physical consistency, interpretability, and uncertainty propagation.

The presentation concludes with lessons learned from developing a high-resolution downscaling framework for Borneo and identifies open computational and mathematical questions that will guide subsequent stages of the project.

Thinking in Networks:
Mathematical Perspectives on Connected Systems

Fatimah Abdul Razak

Universiti Kebangsaan Malaysia, Malaysia

Networks provide a unifying mathematical framework for studying complex systems composed of interacting components. Many phenomena across disciplines can be naturally represented as networks, enabling structure and dynamics to be analysed within a common language.

This talk adopts a network-centric perspective on complex systems, focusing on how structural properties—such as degree distributions, centrality, clustering, and modularity—shape system-level behaviour. I will discuss how these features influence dynamical processes including diffusion, contagion, and coordination, and highlight key modelling considerations in applied network analysis.

By viewing networks as a general mathematical tool rather than a domain-specific model, the talk aims to illustrate their value for bridging theory and application, and for supporting cross-disciplinary research in applied and computational mathematics.

Advancing Scientific Machine Learning in Industry

Wil Schilders

Einhoven University of Technology, Netherlands

Scientific machine learning (SciML) has been taking the academic world by storm as an interesting blend of traditional scientific modeling with machine learning (ML) methodologies like deep learning. While traditional machine learning methodologies have difficulties with scientific issues like interpretability, and enforcing physical constraints, the blend of ML with numerical analysis and differential equations has evolved into a novel field of research which overcome these problems while adding the data-driven automatic learning features of modern machine learning. Many successes have already been demonstrated, with tools like physics-informed neural networks, universal differential equations, deep backward stochastic differential equation solvers for high dimensional partial differential equations, and neural surrogates showcasing how deep learning can greatly improve scientific modeling practice. Consequently, SciML holds promise for versatile application across a wide spectrum of scientific disciplines, ranging from the investigation of subatomic particles to the comprehension of macroscopic systems like economies and climates.

However, despite notable strides in enhancing the speed and accuracy of these methodologies, their utility in practical and specifically industrial settings remain constrained. Many domains within the scientific community still lack comprehensive validation and robustness testing of SciML approaches. This limitation is particularly pronounced when confronted with complex, real-world datasets emanating from interactions between machinery and environmental sensors as usually addressed in industry. Still if appropriately addressed, SciML with its promise to accelerate innovations and scientific discoveries by orders of magnitudes, offers unique opportunities to address the insatiable desire for faster and more accurate predictions in many fields. This presentation is dedicated to exploring recent advancements in the implementation of SciML techniques. We will discuss how methodologies can be refined to ensure their practical viability and scalability, particularly in industrial sectors where digital and physical components converge.

Threshold quantities and Lyapunov functions for Ordinary differential equations Epidemic models with Mass action and Standard incidence functions

Baba Seidu

C. K. Tedam University of Technology and Applied Sciences, Ghana

This paper presents a novel algebraic method for the construction of Lyapunov functions to study global stability of the disease-free equilibrium points of deterministic epidemic ordinary differential equation models with mass action and standard incidence functions. The method is named as **Jacobian-Determinant method**. In our method, a direct algebraic procedure that also relies only on determinant of the Jacobian matrix of the infected subsystem is developed to determine a threshold quantity, $\mathcal{R}'_0$ akin to the basic reproduction number, $\mathcal{R}_0$ of such class of models. The developed technique is applied on a wide variety of models to construct Lyapunov functions to study the global stability of the infection-free critical points. Further, implementation of our method reveals that the threshold quantity is the same as (or the square) of the basic reproduction numbers as obtained using the next-generation matrix method. It is further observed that even for models that do not use the standard or mass action incidence, the threshold quantity is still related to the basic reproduction numbers as obtained with the next-generation matrix method.

Particle migration and Focusing in Microfluidic ducts

Yvonne Stokes

The University of Adelaide, Australia

Neutrally-buoyant spherical particles of sufficient size suspended in flows through microfluidic ducts will migrate in the cross-section due to the forces acting on them and may focus to specific regions. Particle trajectories are influenced by particle size, duct geometry, flow rate, initial conditions and, in the case of active particles, because of their own activity. As will be shown in this talk, mathematical modelling reveals a landscape of interesting and complex dynamics, which might be exploited for a variety of different applications. For example, cancer cells can be isolated from a blood sample, a process known as "liquid biopsy", which is attractive for diagnosis of cancer; sperm might be separated from pyospermic semen (containing a large number of white blood cells) to improve assisted reproduction technologies. The goal is to develop models that might be used to determine a duct geometry and other criteria for a specific application.

This is joint work with Drs Brendan Harding and Rahil Valani.

Sums of Three Fibonacci Numbers as Concatenations of Repdigits in Base b

Pagdame Tiebekabe

University of Kara, Togo

We study a Diophantine problem involving the Fibonacci sequence and digital representations in integer bases. More precisely, for an integer base $b \geq 2$, we investigate the equation

$$F_{n_1} + F_{n_2} + F_{n_3} = \overline{d_1 \cdots d_1, \ d_2 \cdots d_2, \ d_3 \cdots d_3}_b,$$

where the right-hand side denotes the concatenation, in base b, of three repdigits of lengths $\ell_1 \geq \ell_2 \geq \ell_3 \geq 1$, with digits $d_1, d_2, d_3 \in \{0, \ldots, b-1\}$ and $d_1 > 0$, and where $n_1 \geq n_2 \geq n_3 \geq 0$.

Using lower bounds for linear forms in logarithms in the sense of Baker–Wüstholz, combined with refined height estimates and a reduction method based on continued fractions, we prove that, for any fixed base $b \geq 2$, the above equation admits only finitely many solutions in non-negative integers. In particular, we obtain an explicit upper bound for n_1 depending logarithmically on b.

As an application, we completely determine all solutions for bases $2 \leq b \leq 10$. This work extends earlier results on Fibonacci numbers subject to digital constraints and highlights the effectiveness of transcendence techniques in Diophantine problems linking recurrence sequences and numeral systems.

A Mathematical Framework for Within-Host Mycobacterium Tuberculosis Infection and Host Immune Dynamics

Getachew Teshome Tilahun

Haramaya University, Ethiopia

Trimming is a ubiquitous operation in computer-aided-design whereby parts of a geometry are merged, intersected or simply discarded. While it grants virtually unlimited flexibility in geometric design, it introduces a plethora of other difficulties when such geometries are used within immersed finite element methods. In particular, small cut elements cause severely ill-conditioned system matrices requiring dedicated penalization, stabilization or preconditioning techniques. In this talk, after highlighting the limitations of existing preconditioning strategies, we explore deflation-based preconditioners for immersed finite element methods.

Adam-family Methods with Decoupled Weight Decay

Kim Chuan Toh

National University of Singapore, Singapore

We investigate the convergence properties of a general class of Adam-family methods for minimizing quadratically regularized nonsmooth nonconvex optimization problems, especially in the context of training nonsmooth neural networks with weight decay. Motivated by AdamW, we propose a novel framework for Adam-family methods with decoupled weight decay. Within our framework, the estimators for the first-order and second-order moments of stochastic subgradients are updated independently of the weight decay term. Under mild assumptions and with non-diminishing stepsizes for updating the primary optimization variables, we establish the convergence properties of our proposed framework. In addition, we show that our framework encompasses a wide variety of well-known Adam-family methods, hence offering convergence guarantees for these methods in the training of nonsmooth neural networks. As a practical application of our framework, we propose a method named AdamD (Adam with Decoupled Weight Decay). Numerical experiments demonstrate that AdamD outperforms Adam and is comparable to the popular AdamW, in both the aspects of generalization performance and efficiency.

Based on joint work with Kuangyu Ding and Nachuan Xiao

Deflation-based Preconditioning for Immersed Finite Element Methods

Cornelis Vuik

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Trimming is a ubiquitous operation in computer-aided-design whereby parts of a geometry are merged, intersected or simply discarded. While it grants virtually unlimited flexibility in geometric design, it introduces a plethora of other difficulties when such geometries are used within immersed finite element methods. In particular, small cut elements cause severely ill-conditioned system matrices requiring dedicated penalization, stabilization or preconditioning techniques. In this talk, after highlighting the limitations of existing preconditioning strategies, we explore deflation-based preconditioners for immersed finite element methods.

Numerical Software Packages from the FASTMath Institute and Their Applications

Carol Woodward

Lawrence Livermore National Laboratory, USA

The Frameworks, Algorithms, and Scalable Software Technologies for Mathematics (FASTMath) Institute funded by the United States Department of Energy (DOE) develops numerical methods and software and deploys them to scientific applications running on large-scale computing systems. The FASTMath software, including the AMReX, MFEM, PUMI, and SUNDIALS discretization packages, the PETSc, SuperLU, hypre, Kokkos Kernels, and FASTEig solvers libraries, and the libEnsemble, PyTUQ, Dakota, and IBCDFO optimization / uncertainty quantification packages, is some of the most used numerical software around the world. A strong component of the FASTMath activities is to steward this software ensuring its usability and relevance to the scientific and artificial intelligence communities. This talk will give a brief introduction to the FASTMath Institute, introduce some of its most used software, and show highlights of that software use in applications.

Stability and Growth in Incompressible Euler Equations

Yao Yao

National University of Singapore, Singapore

The incompressible Euler equations describe how the velocity field of an incompressible, inviscid fluid evolves over time. In this talk, I will discuss some recent results on long-time dynamics and infinite-in-time growth for the Euler equations. These include the nonlinear stability of vortex quadrupoles with odd-odd symmetry (joint work with Kyudong Choi and In-Jee Jeong), and infinite-in-time growth for the three-dimensional axisymmetric Euler equations without swirl (joint work with Khakim Egamberganov).

Overcoming Spectral Bias via Cross-Attention

Tao Zhou

Chinese Academy of Sciences, China

Neural networks often exhibit spectral bias, a phenomenon where high-frequency components may converge substantially more slowly than low-frequency ones. To address this imbalance, we propose a cross-attention architecture that adaptively reweights a multiscale random Fourier feature (RFF) bank. Cross-attention residual blocks provide an input-dependent mechanism to emphasize the most informative frequencies, accelerating high-frequency convergence over baselines built on the same bank. The cross-attention module also enables incremental spectral enrichment: dominant Fourier modes extracted from intermediate approximations via discrete Fourier analysis can be appended to the feature bank and used in subsequent training, without changing the backbone architecture. We further extend this framework to PDE learning by introducing a linear combination of two sub-networks: one targeting high-frequency components and the other focusing on low-frequency components, with a learnable (or optimally chosen) mixing factor that balances their contributions and improves training efficiency in oscillatory regimes. Numerical experiments on high-frequency and discontinuous regression problems, image reconstruction tasks, as well as representative PDE examples, demonstrate the effectiveness and robustness of the proposed method.

Two-level Domain Decomposition-type Preconditioners for the Helmholtz Equation with High Wavenumber

Jun Zou

The Chinese University of Hong Kong, Hong Kong SAR

In this talk, we will address two novel two-level domain decomposition-type preconditioners for solving the Helmholtz equation with high wavenumber. Both preconditioners are defined over a set of overlapping subdomains, with each preconditioner formed by a global coarse solver and one local solver on each subdomain. The global coarse solver is based on the localized orthogonal decomposition (LOD) technique. The local subproblems are Helmholtz problems in subdomains with homogeneous boundary conditions or impedance boundary conditions. Both preconditioners are shown to be optimal under some reasonable conditions, that is, a uniform upper bound of the preconditioned operator norm and a uniform lower bound of the field of values are established in terms of all the key model parameters. This is the first time to show the rigorous optimality of a two-level domain decomposition-type preconditioner with respect to all the key model parameters and that the LOD solver can be a very effective coarse solver for multilevel domain decompositions for the Helmholtz equation with high wavenumber. Numerical experiments are presented to confirm the optimality and efficiency of the two proposed preconditioners.