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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.

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

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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.

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.

Rank Inspired Neural Network for Solving PDEs

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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.

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

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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.

Reaction Networks Approach of Modeling Biological and Disease Dynamics

Angelyn Lao

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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

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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

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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.

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

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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.

Monotone Projection Algorithm and Machine Learning Model For Backward-Facing Step Navier-Stokes Flows

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Understanding flow structures in sudden expansions is crucial due to their applications in heat exchangers, micro-fluidic devices, cooling systems, and many others. Simulating such systems requires a stable and divergence-free solution of the Navier-Stokes equations (NSEs). Monotone schemes are methods with non-oscillatory and stable behavior, while projection methods (PM) ensure divergence-free solution of the NSEs. However, a projection method may lack monotonicity. The current work proposes the Theorem of Monotone Projection Navier-Stokes Solvers (TMPNSS), which gives the conditions under which a PM is monotone, bounded and stable. A PM is designed on a staggered grid, and the TMPNSS is applied to establish its monotonicity and other key properties. Then a detail parametric study of backward facing step flow is undertaken using the reattachment length and pressure drop as quantitative monitors. To make the results of the parametric study reasonably reproducible and accessible to wider audience, we consider that computational fluid dynamics (CFD) simulations can be computationally intensive - requiring lots of electrical energy and computing resources. Consequently, we use machine learning techniques to develop a surrogate model of the reattachment length as a function of inlet velocity and step height. The results show that (i) the reattachment length varies non-monotonically with step height - initially increasing to a maximum, then decreasing beyond a critical step height, (ii) the critical step height, at which maximum reattachment length occurs, depends on the fixed inlet average velocity, and (iii) in the entire parameter space, the maximum reattachment length (of 1.35) occurs at average inlet velocity 1.5 and step height 0.6. (iv) the machine learning model can serve as reliable substitute of the full CFD code.

Random Walks and Algorithms on Graphs

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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

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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

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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

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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

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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

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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 $d_1, d_2, d_3 \in \{0, \dots, b-1\}$ 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.

Deflation-based Preconditioning for Immersed Finite Element Methods

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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.

Overcoming Spectral Bias via Cross-Attention

Tao Zhou

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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.