



Computational Science Summer School (CSSS) 2026

Mathematical Modelling in Finance, Medical Science, and Weather Forecast

Book of Abstracts

Mar 16–27, 2026

M202 M Building, Faculty of Science
Mahidol University, Bangkok, Thailand



IWR
Interdisciplinary Center
for Scientific Computing



Mahidol University
Faculty of Science



CSSS2026: Book of Abstracts

Computational Science Summer School (CSSS) 2026
Mathematical Modelling in Finance, Medical Science, and Weather Forecast
March 16–27, 2026 — Bangkok, Thailand

In Collaboration with:

- Interdisciplinary Center for Scientific Computing (IWR), University of Heidelberg
- Centre of Excellence in Mathematics (CEM)
- Research Center in Data Science for Health Study (RC-DSHS)
- Department of Mathematics, Faculty of Science, Mahidol University

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Invited Talks

Singular Stochastic Control in Real Investments

Arnon Archankul¹

¹Department of Mathematics, University of York, York, UK YO10 5GH
Walailak University, Thailand
arnon.archankul@gmail.com

Abstract

Real investment and financing decisions are often gradual rather than “all-or-nothing”: firms adjust cash through payouts or injections, and investors rebalance portfolios only occasionally because trading is costly. Singular stochastic control provides a natural framework for such problems, modelling interventions as cumulative actions applied when the state process reaches economically meaningful thresholds.

This talk gives an accessible introduction to the intuition and mathematics of singular control, illustrated through cash management and optimal portfolio allocation with transaction costs. I outline the diffusion-based model setup, the associated value functions, and how optimal policies are characterised by Hamilton-Jacobi-Bellman variational inequalities with free boundaries. I also describe an equivalent Dynkin game formulation that offers further analytical comparative statics analysis. Finally, time permitting, I will discuss some comparative statics and briefly indicate how the framework extends to ambiguity (model uncertainty) via maxmin utility, leading to Hamilton-Jacobi-Bellman-Isaccs-type variational inequalities and altered intervention thresholds.

Keywords: singular stochastic control, cash management, portfolio allocation, transaction costs.

Virus Host Shifts from a Niche Evolution Perspective

Peter Fransson¹

¹Modelling and Ecology Group Leader at Heidelberg Planetary Health Hub
Heidelberg University, Heidelberg, Germany
peter.fransson@iwr.uni-heidelberg.de

Abstract

Emerging pathogens, resulting from a zoonotic spillover, constitute a major health burden. This includes pathogens like HIV, H1N1, SARS-CoV, and SARS-CoV-2 (Covid-19), and many more. An estimated 75% of emerging diseases originate from zoonoses. Evolutionary host shifts—the evolutionary change in a pathogen’s natural host—are rare events and require the pathogen to overcome a number of barriers, including ecological and evolutionary barriers. For example, a direct jump from a reservoir host species to a novel host species may constitute a fitness reduction for the pathogen, the severity of which depends on the degree of differences between the hosts. However, the pathogen could adapt to the novel host environment (niche evolution), at the loss of adaptiveness to the original natural host. The interplay between host similarity and interaction, and adaptiveness trade-off are important factors which determine pathogen evolution and possible evolutionary host shift.

Here we present an epi-niche-evolutionary model to investigate the combined effect of host species similarity and intra- and interspecific interactions on pathogen evolutionary host shifts.

Identifying Redundant Rainfall Stations in Northern Thailand by Comparing Ordinary Kriging and Universal Kriging with Adaptive Simulated Annealing

Adsadang Himakalasa^{1*}, Thaned Rojsiraphisal¹

¹Department of Mathematics, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
adsadang1@gmail.com; thaned.r@cmu.ac.th

Abstract

This study addresses redundant station identification in Northern Thailand's spatial monitoring network through integrated graph-theoretic analysis and stochastic optimization. The network is formulated as a weighted correlation graph where vertices represent stations and edge weights quantify spatial dependence derived from climate data. A constrained station selection algorithm generates candidate removal sets by prioritizing highly correlated vertices, while geostatistical interpolation via Ordinary Kriging (OK) and Universal Kriging (UK) evaluates information loss through optimal linear prediction at removed locations. The optimization employs Simulated Annealing with adaptive objective weighting to dynamically balance correlation-based selection against kriging reconstruction error throughout the annealing process. Computational experiments are conducted across reduction scenarios involving the removal of 5 to 30 stations. Performance metrics, including kriging variance, confirm enhanced preservation of spatial structure, particularly under intensive reduction regimes. Results demonstrate distinct performance characteristics between OK and UK, with implications for network design strategies. Additionally, the adaptive weighting strategy improves candidate solution quality during the annealing process. This framework provides methodological guidance for selecting appropriate geostatistical techniques in network optimization applications.

Keywords: monitoring network optimization, climate data, correlation graph, minimum spanning tree, simulated annealing, kriging interpolation.

*Corresponding author.

Interacting Particle Systems and Complex Dynamics

Watthanan Jatuviriyapornchai¹

¹Department of Mathematics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand
watthanan.jat@mahidol.ac.th

Abstract

Interacting particle systems are continuous-time Markov processes that describe the evolution of configurations of locally interacting components. They constitute a central class of stochastic models for non-equilibrium dynamics and for the emergence of macroscopic structure from simple microscopic rules.

Key theoretical themes include invariant measures, scaling limits, and condensation phenomena, where a positive fraction of the total mass concentrates on a vanishing fraction of sites in the thermodynamic limit. The structure of condensation can be analysed for classical models such as the Inclusion Process and the Zero-Range Process using size-biased sampling techniques. In the Inclusion Process, the condensed phase may occupy multiple sites and exhibits a hierarchical structure related to the Poisson–Dirichlet distribution. In the Zero-Range Process, condensation may be induced by a single site with an atypically large rate, and size-biased methods clarify how the resulting structure depends on the scaling of transition rates.

Mechanisms of this type also arise in applied contexts, including traffic flow, financial systems, and collective decision dynamics such as elections. These examples illustrate how interacting particle models provide a common mathematical description for large-scale behaviour emerging from local stochastic interactions.

Parameter Estimation for Forward Kolmogorov Equation with Application to Nonlinear Exchange Rate Dynamics

Ekaterina Kostina¹

¹Head of Numerical Optimization Group at Heidelberg University, Germany
ekaterina.kostina@iwr.uni-heidelberg.de

Abstract

We present a general framework for estimating unknown parameters of diffusion processes, which are widely used in mathematical finance, for example in the modeling of asset prices. The proposed approach is based on solving a parameter estimation problem subject to the forward Kolmogorov (Fokker–Planck) partial differential equation describing the time evolution of the probability density function of the underlying stochastic system.

This framework enables the incorporation of nonlinear effects in both drift and volatility, as well as their dependence on observed economic data. We discuss the associated modelling and numerical methods in detail and demonstrate the approach on nonlinear exchange rate dynamics. Based on joint work with S. Jaeger.

Role of Dynamical Modelling in Advancing Bio-medical Science: A Case study of Modelling Diabetes Mellitus

Yongwimon Lenbury¹

¹Member of the Royal Society of Thailand
Centre of Excellence in Mathematics, PERDO, MHESI, Thailand
Department of Mathematics, Faculty of Science, Mahidol University, Thailand
yongwimon.len@mahidol.ac.th

Abstract

In several aspects, dynamical modelling has played a transformative role in advancing bio-medical science. Most notable is how it shifted the focus of bio-medical research from static snapshots of biological data to understanding the temporal, functional, and mechanistic behavior of living systems. It is true that the ability of a system, machine, or process to rapidly and automatically handle, process, or produce a large volume of data, samples, or items within a specific time frame signifies high efficiency and speed, often utilizing automation to outperform conventional methods, widely used in computing, biology, and manufacturing. However, by integrating mathematical equations, such as ODEs and PDEs, with high-throughput experimental data, these models simulate how biological systems respond to internal and external stimuli, contributing significantly to disease understanding, drug discovery, and personalized medicine.

The number of people living with diabetes rose from 200 million in 1990 to 830 million in 2022. Prevalence has been rising more rapidly in low- and middle-income countries than in high-income countries. Here, recent research results concerning diabetes, will be discussed by way of examples of how mathematical modelling can yield valuable and practical conclusions that helps the decision makers in their drive towards achieving optimum management and control.

Multi-Conditional Expression Mapping to Metabolic Flux Modeling for Precision and Systems Biology Insights

Kitiporn Plaimas¹

¹Department of Mathematics and Computer Science, Chulalongkorn University, Bangkok, Thailand
kitiporn.p@chula.ac.th

Abstract

Understanding how cellular metabolism adapts across different biological conditions is a central challenge in systems and precision biology. In this talk, I present Integrated Gene-expression Modeling (IGM), a framework for multi-conditional expression mapping to metabolic flux modeling, which integrates gene expression profiles from diverse conditions into genome-scale metabolic models. By systematically linking transcriptional changes to metabolic flux variations, this approach enables comparative analysis of condition-specific metabolic states and reveals functional shifts underlying phenotypic differences. Applied to *Escherichia coli*, this approach reduces ambiguity in flux solutions, improves agreement with experimentally measured fluxes, and captures condition-specific metabolic adaptations. Overall, IGM provides a practical bridge between gene expression and metabolic function, offering new opportunities for systems-level and precision biology insights.

Computational Modelling of Osteoporosis Risk in Postmenopausal Thai Women Using Machine Learning Approaches

Pornsarp Pornsawad¹

¹Department of Mathematics, Faculty of Science, Silpakorn University, Nakhon Pathom, 73000, Thailand
pornsawad_p@silpakorn.edu

Abstract

Osteoporosis is a major health concern among postmenopausal women, and early risk identification is important for effective prevention and treatment. However, clinical datasets used for screening often contain missing values, high-dimensional variables, and imbalanced class distributions. This talk presents a computational approach for modeling osteoporosis risk in postmenopausal Thai women using machine learning techniques. The study uses retrospective clinical data collected from patients at Ramathibodi Hospital. Several classification algorithms—including k-nearest neighbors, neural networks, naïve Bayes, Bayesian networks, support vector machines, decision trees, and random forests—are evaluated. To improve predictive performance, preprocessing methods such as missing data imputation, feature selection, and synthetic minority oversampling are applied. The results demonstrate that appropriate preprocessing significantly enhances model performance and supports the development of reliable decision-support tools for osteoporosis risk screening.

4TaStiC: Time and Trend Traveling Time Series Clustering for Classifying Long-Term Type 2 Diabetes Patients

Onthada Preedasawakul¹, Nathakhun Wiroonsri^{1*}

¹Statistics, Probability, and Data Science with R programming (SPiDeR) research group, Department of Mathematics, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
o.preedasawakul@gmail.com; nathakhun.wir@kmutt.ac.th

Abstract

Diabetes is one of the most prevalent diseases worldwide, capable of damaging various internal systems. Diabetes patients require routine check-ups, resulting in a time series of laboratory records such as hemoglobin A1c (HbA1c), which reflect each patient's health behavior over time. Clustering patients into groups based on their entire time series data assists doctors in making recommendations and choosing treatments without the need to review all records. However, clustering this type of dataset introduces some challenges; patients visit their doctors at different time points, making it difficult to match levels, trends, peaks, and patterns of their time series. To address these challenges, we introduce a novel method: Time and Trend Traveling Time Series Clustering (4TaStiC), using a base dissimilarity combined with Euclidean and Pearson correlation metrics. We evaluated this algorithm on labeled artificial datasets, comparing its performance with that of eight existing methods including a representation learning-based deep learning method. 4TaStiC outperformed the other methods based on both accuracy and Adjusted Rand Index. Finally, we applied 4TaStiC to cluster 1,989 type 2 diabetes patients at Siriraj Hospital using their HbA1c time series data. Each group of patients exhibits clear characteristics that will benefit doctors in making efficient clinical decisions.

Keywords: cross-correlation, hierarchical clustering, HbA1c, healthcare, time series.

*Corresponding author.

Solving Stochastic Climate-Economy Models Using Least-Squares Monte Carlo Method

Pavel Shevchenko¹

¹Department of Actuarial Studies and Business Analytics, Macquarie University, Sydney, NSW, Australia
pavel.shevchenko@mq.edu.au

Abstract

Global integrated assessment models like the iconic dynamic integrated climate-economy (DICE) model treating the world as one region became a standard tool for studying policy decisions in climate change area. Extension to multiple regions, like regional integrated climate-economy (RICE) models, is possible though numerical solution is more difficult due to increased dimensionality. These models are solved as deterministic optimal control problems producing deterministic future trajectories of temperature, economic capital, social cost of carbon, and other climate-economy variables. Solving these models with stochastic shocks added requires solution of the corresponding optimal stochastic control problems which is much more challenging. There are only few studies attempting to solve the DICE and RICE models with simple stochastic extensions. At the same time, the least-squares Monte Carlo method (LSMC) has become a popular in quantitative finance for solving optimal stochastic control problems due to its effectiveness in dealing with high dimensional problems and because it imposes fewer restrictions on the constraints and allows for flexibility in the dynamics of the underlying stochastic processes. In this talk we present how the LSMC method can be used to solve stochastic DICE and stochastic 12 region RICE models. To address the complexity and high dimensionality of these models, we incorporate deep neural network approximations in place of standard regression techniques within the LSMC framework. We solve the RICE model under cooperation and noncooperation between the regions. The latter corresponds to finding Cournot-Nash equilibrium. Our results demonstrate that the LSMC method can be used to efficiently derive optimal policies for climate-economy models in the presence of uncertainty.

This talk is based on the following papers:

- Arandjelović, A., Shevchenko, P.V., Matsui, T., Murakami, D., Myrvoll, T.A. (2024). Solving stochastic climate-economy models: A deep least-squares Monte Carlo approach. arXiv preprint arXiv:2408.09642.
- Shevchenko, P.V., Arandjelovic, A., Matsui, T., Murakami, D., Myrvoll, T.A. (2025). Solving stochastic regional climate-economy models using least-squares Monte Carlo method: cooperative and non-cooperative scenarios. Preprint in progress.
- Shevchenko, P.V., Murakami, D., Matsui, T., Myrvoll, T.A. (2022). Impact of covid-19 type events on the economy and climate under the stochastic dice model. *Environmental Economics and Policy Studies* 24, 459–476.

A Piecewise Deterministic Approach for Parameter Estimation in Multi-Dimensional Stochastic Differential Equation Models

Andreas Sommer¹

¹Head of IFDIFF/PErFDiff Group at the Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University, Im Neuenheimer Feld 205, 69259 Heidelberg, Germany
andreas.sommer@iwr.uni-heidelberg.de

Abstract

Many biological and other natural processes follow basic deterministic laws but are shaped by intrinsic stochasticity, which can markedly alter system behaviour. Such processes can often be modelled using systems of nonlinear stochastic differential equations (SDEs)

$$dX_t = f(t, X_t, p) dt + D dW_t, \quad X_0 = x_0(p)$$

with state vector $X_t \in \mathbb{R}^{n_x}$, influenced by constant-intensity diagonal diffusion $D \in \mathbb{R}^{n_x \times n_x}$, driven by denotes an n_x -dimensional white noise process dW_t . Drift function f and initial state X_0 may depend on parameters $p \in \mathbb{R}^{n_p}$ that are to be estimated from measurements.

On short time scales, SDE trajectories resemble those of the corresponding ordinary differential equations (ODEs) if diffusion is not dominating. This motivates a piecewise deterministic approximation by dividing the time horizon into intervals where the drift-only ODE governs the dynamics. The jumps (discontinuities) between intervals can be interpreted as accumulated stochasticity. However, a simple concatenation of interval ODE solutions completely decouples the interval processes and, in general, leads to wrong conclusions. Instead, the jumps can and must be used for regularization in the parameter estimation problem.

This approach leverages efficient ODE solvers and derivative-based optimization, supports equality and inequality constraints, and accommodates arbitrary, possibly noisy measurement data. It is applicable to multidimensional systems and enables hidden state or trajectory reconstruction (see Figure 1). A convergence result and applications to problems in systems biology and finance will be presented.

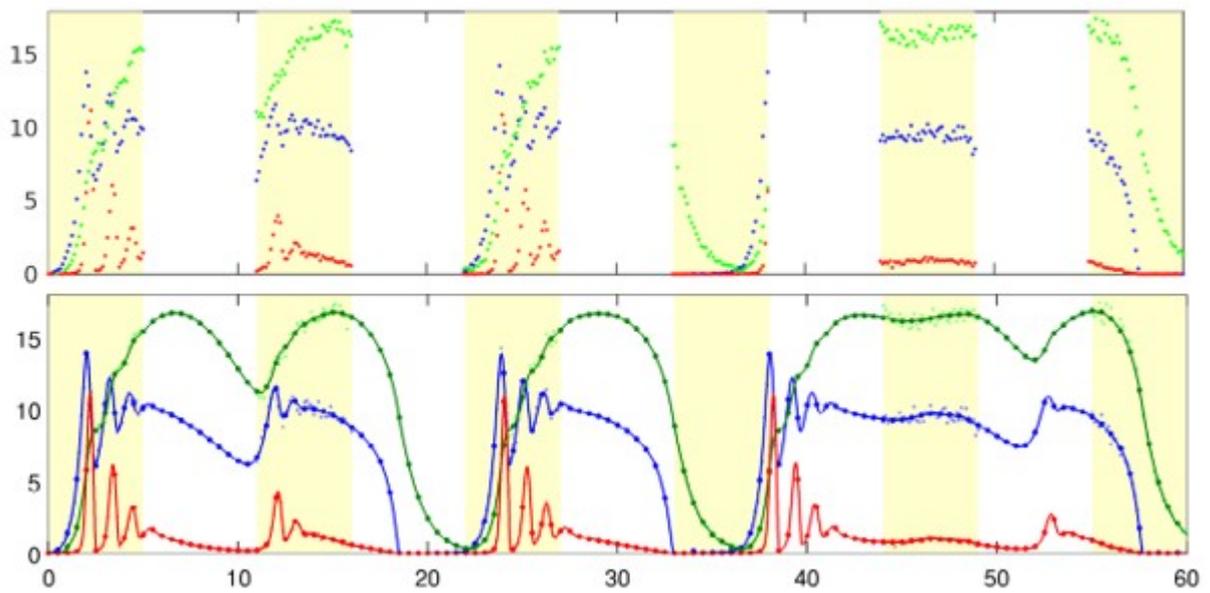


Figure 1: Calcium oscillator model (in a.u., Kummer et al, 2005). The observed oscillations are due to intrinsic stochasticity. Top: Intermittent observations (yellow background) with measurement errors. Bottom: Reconstructed trajectory. Enlarged dots mark the beginning of a new approximation interval. The "bump" in the last unobserved time range (white background) is a successful reconstruction of the original trajectory.

Algorithmic Treatment of Filippov-Type Switched and Sliding-Mode ODE Systems with IFDIFF [1]

Andreas Sommer¹

¹Head of IFDIFF/PErFDiff Group at the Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University, Im Neuenheimer Feld 205, 69259 Heidelberg, Germany
andreas.sommer@iwr.uni-heidelberg.de

Abstract

Ordinary differential equations (ODEs) and differential-algebraic equations (DAEs) with implicit (state-dependent) switches—common in applications like mechanics and disease modelling—challenge general-purpose integrators, often producing unnoticed incorrect solutions.

Filippov theory [2] application requires extensive manual effort to derive switching planes, convex combinations, and manifold dynamics. This talk recaps key aspects of Filippov theory before presenting the IFDIFF Toolbox for MATLAB, which automates this entirely: Given model code with non-differentiable operators (min, max, abs, sign, if-branching), IFDIFF generates switching functions, detects switching and sliding manifold entry/exit up to machine precision, and outputs differentiable MATLAB code for precise simulation and sensitivities. No model or integrator changes required.

We demonstrate IFDIFF's capabilities on selected prototypical examples from mechanics and disease modelling, and show how accurate simulations and model sensitivities can be generated.

[1] <https://ifdiff.github.io>

[2] A. F. Filippov: "Differential Equations with Discontinuous Righthand Sides" (in Russian), Mat. Sb. (N.S.), 1960, Vol 93(1)

Multi-Modal Geodata for Public Health & Humanitarian Aid

Alexander Zipf¹

¹Chair of GIScience (Geoinformatics) at University of Heidelberg, Germany
Scientific Director of the Heidelberg Institute for Geoinformation Technology (HeiGIT)
zipf@uni-heidelberg.de

Abstract

This talk explores the integration of multi-modal geodata—combining satellite and street view imagery, geospatial sensor data, crowdsourced geodata (aka VGI, such as OpenStreetMap), and further geographic information—to support public health interventions and humanitarian aid. We use computational methods for fusing heterogeneous data sources across geographic scales. This enables disease surveillance, risk mapping, and resource allocation in crisis settings. Selected case studies will demonstrate how multi-modal geodata analytics can improve situational awareness, enhance decision-making, and support data-driven responses to public health emergencies and humanitarian challenges.

GeoAI for Disaster Management

Alexander Zipf¹

¹Chair of GIScience (Geoinformatics) at University of Heidelberg, Germany
Scientific Director of the Heidelberg Institute for Geoinformation Technology (HeiGIT)
zipf@uni-heidelberg.de

Abstract

This talk examines the role of GeoAI—the integration of geospatial data with artificial intelligence—in disaster management. Leveraging advances in machine learning, computer vision, and spatial modeling, we develop methods for analyzing remote sensing data like satellite imagery and street view imagery together with further crowdsourced data and sensor streams to support disaster preparedness and response. Case studies from our work at HeiGIT.org illustrate how GeoAI enables situational awareness and scalable decision support, contributing to more resilient and effective disaster management.

Participation Talks

Analysis and Computation of Low Order Conditional Moments of Extended Cox-Ingersoll-Ross Processes with 3-State Regime Switching

Phattharaphon Boonsaem^{1*}, Benjawan Rodjanadid¹, Eckart Schulz¹

¹School of Mathematics and Geoinformatics, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand
M6600228@g.sut.ac.th; benjawan@sut.ac.th; eckart@sut.ac.th

Abstract

The Cox–Ingersoll–Ross (CIR) model and its extensions are widely used to describe short-term interest rates. However, models with constant parameters often fail to capture abrupt structural changes in financial markets. To address this limitation, this study considers the Regime-Switching Extended Cox–Ingersoll–Ross (RS-ECIR) model, in which model parameters depend on a finite-state continuous-time Markov chain with three regimes. This research focuses on the analytical computation of low-order conditional moments of the RS-ECIR process. Using the Feynman–Kac framework, the conditional moments are shown to satisfy a hybrid system of coupled partial differential equations, which can be transformed into a system of linear matrix ordinary differential equations through a polynomial expansion approach. The main objective is to derive explicit closed-form solutions for the first and second conditional moments in the three-state regime-switching case. The analytical results are illustrated and validated by numerical examples and symbolic computations using Wolfram Mathematica.

Keywords: cox–ingersoll–ross process, hybrid pdf system, markov chains, regime switching.

*Corresponding author.

An Analytical Formula for the Transition Density of a Conic Combination of Independent Squared Bessel with Time-Dependent Dimensions and Financial Applications

Nopporn Thamrongrat¹, Chhaunny Chhum², Sanae Rujivan^{1*},
Boualem Djehiche³

¹Research Center in Data Science for Health Study, Division of Mathematics and Statistics, School of Science, Walailak University, Nakhon Si Thammarat 80161, Thailand

nopporn.th@mail.wu.ac.th; rsanae@wu.ac.th

²Research Center in Data Science for Health Study, School of Science, Walailak University, Nakhon Si Thammarat 80161, Thailand

chhaunny.ch@mail.wu.ac.th

³Department of Mathematics, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden

boualem@kth.se

Abstract

The squared Bessel process plays a central role in stochastic analysis, with wide-ranging applications in mathematical finance, physics, and probability theory. While explicit expressions for its transition probability density function (TPDF) under constant parameters are well established, analytical results for the case of time-dependent dimensions remain limited. In this paper, we address this challenging problem by deriving an analytical formula for the TPDF of a conic combination of independent squared Bessel processes with time-dependent dimensions, expressed as a Laguerre series expansion. Based on this representation, we obtain closed-form expressions for the conditional moments in terms of hypergeometric functions. As a practical application, we provide an analytical valuation of an interest rate swap, where the underlying short rate follows a conic combination of independent squared Bessel processes with time-dependent dimensions. The accuracy and computational efficiency of the proposed formulas are validated through Monte Carlo simulations.

Keywords: conditional moments, financial applications, laguerre series expansion, squared bessel process, time-dependent dimension, transition probability density function.

*Corresponding author.

Advanced Computational Framework for Surface/Subsurface Flow Simulation

Panasun Manorost¹

¹Interdisciplinary Center for Scientific Computing, Heidelberg University, Im Neuenheimer Feld 205,
D-69120 Heidelberg, Germany
panasun.manorost@stud.uni-heidelberg.de, panasun.pu@gmail.com

Abstract

This presentation introduces a robust computational framework designed to address complex topological challenges in hydrological research, utilizing the Diffusive Wave Equation (DWE) as its mathematical core to model diverse physical regimes through adaptable friction laws and fully coupled systems, such as surface-groundwater interactions and multi-layer urban flooding. Built upon the Distributed and Unified Numerics Environment (DUNE), the software offers two distinct numerical solvers capable of handling both structured and unstructured meshes—a Vertex-Centered Finite Volume (VFVM) scheme optimized for rapid, large-scale flood mapping, and a Discontinuous Galerkin (DG) method together with a Cut-Cell approach for high-fidelity simulation. A critical feature of the framework is its robust handling of wet/dry interfaces, strictly enforcing positivity preservation to ensure numerical stability and non-negative water depth solutions across both solvers. To handle heterogeneous bathymetry efficiently, the system integrates automated river network delineation based on flow accumulation thresholds and employs Adaptive Mesh Refinement (AMR) to locally increase resolution along river channels, with validation through standard benchmarks demonstrating the framework’s stability and accuracy in simulating flow evolution over complex terrain.

Keywords: coupled surface-subsurface flow, vertex-centered finite volume (VFVM), discontinuous Galerkin (DG) Method, cut-cell method, positivity preservation, adaptive mesh refinement (AMR), diffusive wave equation (DWE), unstructured mesh, DUNE Framework, urban flooding, water management.

Double-Scale Stochastic Volatility and Stochastic Correlation in Cross-Inverse Options and its Application to Crypto-Assets

Angelo E. Marasigan^{1*}

¹Institute of Mathematical Sciences, College of Arts and Sciences, University of the Philippines Los Baños, Laguna 4033, Philippines
aemarasigan@up.edu.ph

Abstract

This study proposed a pricing model for cross-inverse options that incorporated double-scale stochastic volatility and mean-reverting stochastic correlation. Standard valuation frameworks often fail to capture the extreme volatility clustering and dynamic correlation breakdown observed in cryptocurrency markets. To address this, the stochastic differential equations for the underlying asset and settlement currency were modeled using a multi-factor variance process to capture short- and long-term dynamics. The characteristic function for the log-price ratio was derived to enable a semi-analytical pricing solution via Fourier transform methods. To validate the theoretical findings, a numerical simulation was conducted to test the stability of the model parameters. The model was then applied to a sample of cryptocurrency option prices, and its performance was assessed. Finally, the results were compared against the standard Heston model. Results demonstrated the superiority of the double-scale framework in capturing the volatility skew and valuing correlation-sensitive derivatives.

Keywords: cross-inverse options, double-scale stochastic volatility, stochastic correlation, cryptocurrency derivatives, fourier transform pricing, heston model.

*Corresponding author.

Unveiling PM2.5 Dynamics in Northern Thailand through Higher-Order Network Clustering

Supawan Nanta^{1*}, Sompop Moonchai¹, Kanyuta Pochinapan¹

¹Department of Mathematics, Faculty of Science, Chiang Mai University, Chiang Mai 50100, Thailand
nanta.supawan@gmail.com; sompop.m@cmu.ac.th; kanyuta.p@cmu.ac.th

Abstract

Standard environmental analyses are effective at pinpointing pollution hotspots, but they often fall short of explaining how pollutants move across regions or which areas most strongly influence others. When interactions between regions are not explicitly considered, these important connections remain obscured, limiting the effectiveness of transboundary pollution management. To address this, our study identifies interconnected regions by tracing the directed movement of PM2.5 from areas of higher concentration to those of lower concentration. Our analysis covers 112 districts in Thailand's Upper North region, including Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, Phrae, and Uttaradit. By applying motif analysis within a complex network framework, we uncover two key aspects of PM2.5 transmission. First, the approach identifies major potential pollution contributors within each regional cluster by capturing specific source-to-target movement patterns. Second, it reveals clear PM2.5 transport pathways, highlighting the dominant routes through which pollutants spread across these nine provinces.

Keywords: PM2.5 transport, complex networks, motif analysis, spectral clustering, northern Thailand.

*Corresponding author.

Equitable Auction Design: With and Without Distributions

Ruiqin Wang¹, Çağıl Koçyiğit², Napat Rujeerapaiboon^{3*}

¹Shanghai University of Finance and Economics, Shanghai, China
wangruiqin@mail.shufe.edu.cn

²University of Luxembourg, Luxembourg, Luxembourg
cagil.kocyigit@uni.lu

³National University of Singapore, Singapore, Singapore
napat.rujeerapaiboon@nus.edu.sg

Abstract

We study a mechanism design problem where a seller aims to allocate a good to multiple bidders, each with a private value. The seller supports or favors a specific group, referred to as the minority group. Specifically, the seller requires that allocations to the minority group are at least a predetermined fraction (equity level) of those made to the rest of the bidders. Such constraints arise in various settings, including government procurement and corporate supply chain policies that prioritize small businesses, environmentally responsible suppliers, or enterprises owned by historically disadvantaged individuals. We analyze two variants of this problem: stochastic mechanism design, which assumes bidders' values follow a known distribution and seeks to maximize expected revenue, and regret-based mechanism design, which makes no distributional assumptions and aims to minimize the worst-case regret. We characterize a closed-form optimal stochastic mechanism and propose a closed-form regret-based mechanism, and establish that the ex-post regret under the latter is at most a constant multiple (dependent on the equity level) of the optimal worst-case regret. We further quantify that this approximation constant is at most 1.31 across different equity levels. Both mechanisms can be interpreted as set-asides, a common policy tool that reserves a fraction of goods for minority groups. Furthermore, numerical results demonstrate that the stochastic mechanism performs well when the bidders' value distribution is accurately estimated, while the regret-based mechanism exhibits greater robustness under estimation errors.

Keywords: auction design, mechanism design, robustness, regret minimization.

*Corresponding author.

Parameter Estimation Problem in Pharmacokinetic Model for the Treatment of Type II Diabetes Mellitus Using Metformin

Narayan Thapa¹

¹Department of Mathematics, School of STEM, Dallas College, Dallas Texas, United States
nthapa@dallascollege.edu

Abstract

Type II diabetes mellitus is a metabolic disorder in which a person has highly elevated blood glucose levels resulting from bodily tissues being resistant to the insulin that is produced in the pancreas. Metformin is an anti-hyperglycemic drug that is widely used for treating type II diabetes mellitus. Metformin works to reduce blood glucose levels by decreasing the rate of hepatic glucose output, decreasing the rate of intestinal glucose absorption, and increasing the rate of glucose uptake by muscle cells and fat tissue. In this work, an identification problem was investigated using an existing pharmacokinetic compartmental model for type II diabetes mellitus where the effects of oral administration of metformin are considered. The parameters of the model were estimated

Keywords: parameter estimation, pharmacokinetic model, optimal parameters, type II diabetes mellitus, Laplace transform

Robust Ensembling: Limited Data & Unlimited Queries

Napat Rujeerapaiboon^{1*}, Shuting Yang¹, Qingxuan Yang²

¹Department of Industrial Systems Engineering and Management, National University of Singapore, Singapore, Singapore

napat.rujeerapaiboon@nus.edu.sg; e1521029@u.nus.edu

²Imperial College Business School, Imperial College London, London, United Kingdom
qingxuan.yang25@imperial.ac.uk

Abstract

In predictive modeling with limited training data, ensemble learning methods based on empirical risk minimization often suffer from overfitting and unstable out-of-sample performance. This issue becomes more pronounced when heterogeneous predictive models are combined using data-driven weights estimated from small samples, a setting commonly encountered in data-scarce forecasting problems such as those arising in financial and weather-related applications. In this work, we study a robust satisficing-based framework for ensemble learning that aims to improve the stability of ensemble predictions under limited and uncertain data.

We formulate ensemble construction as a robust satisficing problem that balances predictive performance and robustness. Distributional uncertainty is incorporated using a Wasserstein-based robustness formulation. The resulting framework remains computationally tractable for complex predictive models and is applicable to ensemble forecasting tasks in finance and other complex systems where uncertainty plays a central role.

Our empirical study compares three ensemble strategies: a standard sample-average approximation (SAA)-based ensemble, a robust satisficing (RS) formulation, and a benchmark satisficing (BM) variant. We evaluate these ensemble strategies using real-world predictive data and analyze the resulting ensemble behavior under varying levels of uncertainty. We find that both RS and BM exhibit more stable and favorable out-of-sample performance than SAA under elevated uncertainty, highlighting the robustness advantages of satisficing-based ensemble approaches in practical forecasting settings.

Building on these results, ongoing work focuses on a systematic comparison between robust satisficing and benchmark satisficing, with particular emphasis on their relative performance in the presence of outliers. In addition, we are exploring extensions within the satisficing framework that allow ensemble weights to adapt across prediction instances based on input features, which is particularly relevant for dynamic forecasting problems such as those encountered in financial and weather prediction. Together, these directions aim to further enhance the flexibility and robustness of satisficing-based ensemble learning for decision-making under uncertainty.

Keywords: benchmark satisficing, distributional uncertainty, limited data, out-of-sample stability, robust satisficing.

*Corresponding author.

Poster Presentations

Resolution of an Open Problem on the Metallic Ratios of the Multi-Component Pulsating Fibonacci Sequence

Kittipong Laipaporn¹, Suriya Decharan^{2*}

¹School of Science , Walailak University, Nakhon Si Thammarat 80160, Thailand

lai.kittipong@gmail.com

²Data science and Artificial intelligence, School of Science , Walailak University, Nakhon Si Thammarat 80160, Thailand

suriya.hog2545@gmail.com, suriya.de@mail.wu.ac.th

Abstract

This paper investigates and resolves a significant open problem concerning the asymptotic behavior of the generalized multi-component pulsating Fibonacci sequence, as proposed in recent literature. This sequence is characterized by a system of m interrelated components governed by alternating recurrence relations that vary between even and odd indices, influenced by a positive parameter k . The study focuses on the open problem limits of the ratios of consecutive terms within this pulsating structure, which are hypothesized to converge to specific constants derived from the sequence's parameters. By employing the principle of mathematical induction as the primary analytical tool, we derive the explicit general terms for the sequence components. This systematic approach enables a rigorous proof of the convergence ratios for both odd-indexed to even-indexed terms and even-indexed to odd-indexed terms. Our findings provide a complete resolution to the stated open problem, establishing the precise limiting values and further clarifying the fundamental connection between multi-component pulsating recurrence systems and the broader spectrum of generalized metallic ratios.

Keywords: pulsating Fibonacci sequence, metallic ratio, mathematical induction, asymptotic behavior, recurrence relation.

*Corresponding author.

Utilizing Markov Chains to Analyze State Transitions and Predict Event Probabilities: A Quantitative Risk Analysis Approach

Bhubess Niemnum¹, Amma Phuhada¹, Noppadol Wichitsongkram¹

¹Department of Mathematics, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
bessy.niemnun@gmail.com; starbladeed@gmail.com; noppadonw@g.swu.ac.th

Abstract

Stochastic modeling is a fundamental tool in Quantitative Finance, commonly used to forecast market regimes and credit risk migration. This project adapts these financial mathematical frameworks, specifically Markov Chains, to model dynamic systems with absorbing states in a sports context. While traditionally applied to asset pricing or default prediction, this methodology is equally effective in quantifying the probability of the "First Goal", a critical metric in sports betting markets and risk analysis. The proposed model categorizes the system into five distinct states: two absorbing states (Goals) and three transient states (Defensive Zone, Midfield, Offensive Zone), mathematically analogous to credit rating migration matrices. Key parameters p (transition probability), α (offensive efficiency), and β (defensive efficiency) are introduced to quantify the "performance volatility" of each team. Using linear algebra techniques, specifically the Transition Matrix P , Eigenvalues, and the Fundamental Matrix $N = (I - Q)^{-1}$, we calculate long-term state probabilities and the expected number of transitions before an event realization. The model was empirically tested using data from the AFF Mitsubishi Electric Cup 2024. The results demonstrate that financial modeling techniques can be effectively transposed to sports analytics to quantify event probability and support decision-making under uncertainty.

Keywords: markov chain, football analysis, first goal prediction, risk assessment, stochastic modeling.

Compact Linear Difference Schemes for the Time-Fractional Burgers' Equation: Analysis and Long-Time Behavior

Sivaporn Phumichot^{1*}, Ben Wongsaijai¹

¹Department of Mathematics, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
sivaporn_phum@cmu.ac.th; ben.wongsaijai@cmu.ac.th

Abstract

Weather evolution in atmospheric systems is governed by nonlinear transport and diffusion processes that arise in many climate-related flow phenomena. Mathematical models are widely used to investigate the fundamental mechanisms of such transport processes, among which the time-fractional Burgers' equation provides a natural framework for modeling memory-dependent atmospheric transport. In this work, we focus on the numerical analysis of the one-dimensional time-fractional Burgers' equation. A compact linear difference scheme based on the L_1 -discretization of the Caputo time-fractional derivative is proposed. The existence and uniqueness of the numerical solution are rigorously established, and convergence in the maximum norm is proven. Numerical experiments are conducted to validate the theoretical analysis, demonstrating $2 - \alpha$ accuracy in time and fourth-order accuracy in space. In addition, the long-time behavior of the time-fractional Burgers' equation is investigated numerically, leading to the identification of a suitable decay rate. The proposed framework can be extended to higher-dimensional problems and to other time-fractional transport models arising in atmospheric and climate-related flow studies.

Keywords: finite difference method, compact difference operator, Caputo fractional derivative, L_1 -discretization formula, long-time behavior

*Corresponding author.

Relational Fixed Point Theorems with Applications to Mathematical Finance

Sitthipon Phumsamud¹

¹Program in Data Science and Artificial Intelligence, School of Science, Walailak University, Nakhon Si Thammarat 80160, Thailand
sitthipon4069@gmail.com

Abstract

In this work, we investigate fixed point theorems for mappings defined on relational metric spaces, a generalized framework introduced by Charoensuk (2022), where a metric structure is combined with an underlying relation. We first study the notion of relational continuity and establish several equivalent characterizations in terms of relational convergence and inverse images of relationally open and closed sets, providing a foundational tool for analyzing iterative processes. We then introduce relational contraction maps, relational expanding maps, and their F-type generalizations, and prove corresponding fixed point theorems under suitable assumptions of relational completeness, extending classical Banach-type results to a broader setting. Beyond the theoretical development, we demonstrate that the proposed relational fixed point framework is well suited for applications in mathematical finance. In particular, pricing problems arising from Black–Scholes-type models and stochastic differential equations can be reformulated as fixed point problems for nonlinear pricing operators, which often fail to be contractive in the classical metric sense but exhibit monotonicity or admissibility properties. By equipping the space of price functions with an appropriate relational structure induced by order or comparison principles, these operators satisfy relational contractive conditions. Consequently, the fixed point results developed in this work can be applied to establish the existence and uniqueness of pricing solutions under weaker assumptions than those required in standard metric frameworks, providing a flexible analytical tool for studying nonlinear financial models.

Keywords: relational metric spaces, fixed point, relational expanding maps, relational contraction maps, f-expanding maps, f-contraction maps.

Improvement of the Complex Pulsating $(a_1, a_2, \dots, a_m, c, d)$ -Fibonacci Sequence with Financial Applications

Sattawat Rotphirun^{1*}, Kittipong Laipaporn¹,
Prathomjit Khachorncharoenkul¹

¹School of Science, Walailak University, Nakhon Si Thammarat 80160, Thailand
Sattawat.ro@mail.wu.ac.th; lai.kittipong@gmail.com; prathomjit.kh@wu.ac.th

Abstract

Mathematical modeling of cyclical fluctuations is essential in financial time series analysis, particularly for capturing market volatility and economic cycles. In this study, we present the closed form of a new generalization of the Fibonacci sequence, termed the complex pulsating $(a_1, a_2, \dots, a_m, c, d)$ -Fibonacci sequence. This sequence extends previous versions of pulsating sequences by incorporating complex numbers and a real scaling factor d applied to the sum of imaginary parts of terms with odd subscripts, offering a novel approach to modeling multi-dimensional oscillating trends in financial data. To determine the closed form, we employ matrix theory techniques, specifically focusing on the analysis of eigenvalues and eigenvectors of associated block matrices. We also restructure the matrix representation to simplify the process of finding the closed form compared to prior structural approaches. Our results provide a direct formula for calculating the real and imaginary parts of any term in the sequence for both even and odd subscripts, which can theoretically serve as a discrete tool for predicting pulsating behaviors in asset pricing and risk assessment models.

Keywords: pulsating fibonacci sequence, financial modeling, closed form, matrix method, volatility analysis.

*Corresponding author.

Rabies Epidemic Modeling with Neural Networks and Fractional Calculus

Ramsha Shafqat¹

¹Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University
Rangsit Center, Pathum Thani 12120, Thailand
ramshawarriach@gmail.com

Abstract

Rabies remains a major public health concern in regions where dog-mediated transmission sustains human infection risk. Classical integer-order models often fail to capture the long incubation periods and delayed responses characteristic of rabies dynamics. In this study, we propose an eight-compartment human–dog rabies transmission model governed by the Atangana–Baleanu–Caputo fractional derivative with a non-singular Mittag–Leffler kernel and a harmonic-mean incidence rate to account for contact saturation effects. To efficiently approximate the resulting fractional system, a Levenberg–Marquardt-based deep neural network surrogate is developed and trained using reference solutions generated by a fractional Adams–Bashforth–Moulton scheme. The surrogate accurately reproduces all state variables with low numerical error. Numerical simulations reveal that fractional memory significantly influences outbreak timing, peak magnitude, and persistence, with dog-related transmission parameters exerting the strongest impact. The proposed framework provides an efficient and biologically meaningful tool for analyzing rabies dynamics with memory effects.

Keywords: Rabies transmission modeling, infectious-disease spread, numerical simulation, neural-network methods, Levenberg–Marquardt training, fractional calculus.

Deep Neural Network Model for Fractional-Order Cancer Chemotherapy Dynamics

Ramsha Shafqat¹

¹Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University
Rangsit Center, Pathum Thani 12120, Thailand
ramshawarriach@gmail.com

Abstract

We study a fractional-order cancer chemotherapy model describing the coupled dynamics of normal cells, tumor cells, immune effectors, and chemotherapeutic drug concentration via Caputo reaction diffusion equations. High-fidelity reference data are generated using a fractional Adams–Bashforth–Moulton (ABM) predictor–corrector scheme and used to train a hyperbolic tangent sigmoid deep neural network (HTS–DNN) model. The network has four hidden layers with (50, 30, 20, 10) neurons, employs HTS activations, and is optimized with Levenberg–Marquardt (LM) backpropagation under an 80%/10%/10% train/validation/test split. Across several fractional orders and initial conditions, the HTS–DNN accurately reproduces the numerical solutions, with mean squared errors below 10^{-3} and uniformly small time-resolved errors. Once trained, the DNN model is more than five orders of magnitude faster than the fractional solver, enabling rapid exploration of parameter sets and therapy schedules. Phase portraits and regression diagnostics confirm that key biological features memory driven tumor suppression, chemotherapy-induced immune activation, and concentration-dependent tumor killing are preserved. The proposed HTS–DNN achieves the best trade-off between accuracy and computational cost, providing an efficient framework for modeling fractional tumor–immune–drug dynamics.

Keywords: Mathematical model, Caputo fractional derivative, cytotoxic therapy modeling, tumor and normal cell populations, immune response, radial-basis networks, hidden-layer design, Levenberg–Marquardt Backpropagation.

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