ICMU

INTERNATIONAL CENTRE FOR MATHEMATICS IN UKRAINE

INTERNATIONAL CONFERENCE

MATHEMATICS FOR THE REAL WORLD

Co-organised by

International Centre for Mathematics in Ukraine (ICMU), Kyiv

Centre for Quantum Mathematics of the University of Southern Denmark (SDU), Odense

Dates

24–28 August 2026

Schedule

The schedule is shown in Kyiv time (UTC +3).

Monday, 24 August

Time	Speaker / Event	Section / Title	Location
9:45–10:00	Welcome Remarks		
10:00–10:50	Valerie Isham	Maths in Biology – Epidemic Modelling: past successes and future challenges	Odense
10:50–11:00	Q&A session		
11:00–11:30	Coffee break		
11:30–12:00	Asger Hobolth	Maths in Biology – Advanced posterior analyses of hidden Markov models for improved inference of Neanderthal introgression in modern humans	Odense
12:10–12:40	Julia Palacios	Maths in Biology – Novel coalescent point process approaches for Bayesian inference of disease and molecular dynamics	Odense
12:45–13:15	Fabian Freund	Maths in Biology – Ancestral tree height estimation and applications to whole genome data	Odense
13:15–15:00	Lunch		
15:00–15:50	Jørgen Ellegaard Andersen	Maths in Quantum Computations	Odense
15:50–16:00	Q&A session		
16:00–16:30	Coffee break		
16:30–17:00	Mingsheng Ying	Maths in Quantum Computations – Invariants of Quantum Programs	Odense
17:10–17:40	Steven Rayan	Maths in Quantum Computations – Quantum Computing in Negative Curvature	Odense
17:50–18:20	Aaron Lauda	Maths in Quantum Computations – How Topology Shapes Quantum Information	Odense

Tuesday, 25 August

Time	Speaker / Event	Title / Section	Location

10:00–10:50	Jan Obłój	Maths in Finance – Optimal Transport Methods in Finance: from robust pricing, through non-parametric sensitivities to calibration	Odense
10:50–11:00	Q&A session		
11:00–11:30	Coffee break		
11:30–12:00	Oleksii Mostovyi	Maths in Finance – Second-Order Envelope Theorems for Preference Perturbations and Their Applications to Indifference Greeks	Odense
12:10–12:40	Mykhaylo Shkolnikov	Maths in Finance – Relative arbitrage problem under eigenvalue lower bounds	Odense
12:45–13:15	Alexander Gnedin	Maths in Finance – Sequential Selection with a View to Finance	Odense
13:15–15:00	Lunch		
15:00–15:50	Jane-Ling Wang	Maths in Data Science – Statistics in the Age of AI	Odense
15:50–16:00	Q&A session		
16:00–16:30	Coffee break		
16:30–17:00	Jason Xu	Maths in Data Science – Distance-to-set regularization	Odense
17:10–17:40	Cynthia Rush	Maths in Data Science – Spectral Geometry and the Limits of Convex Regularization in High-Dimensional Regression	Zoom
17:50–18:20	Hau-Tieng Wu	Maths in Data Science – Nonstationary physiological time series to clinical biorhythms via hidden-state manifold diffusions	Kyiv

Wednesday, 26 August

Time	Speaker / Event	Title / Section	Location
10:00–11:00	Maryna Viazovska	Formal and informal mathematics of sphere packing	Odense
11:00–11:15	Q&A session		
11:15–11:45	Coffee break		
11:45–12:45	Anna Nagurney	Networks, Supply Chains, and Variational Inequalities	Odense
12:45–13:00	Q&A session		
13:00–15:00	Lunch		
15:00–15:30	Mykola Maksymenko	Quantum Computations in Practice	

15:30–15:45	Q&A session		
15:45–16:00	Break		
16:00–16:30	Oleksii Kuchaiev	Artificial Intelligence in Practice – Artificial Intelligence & Math	Odense
16:30–16:45	Q&A session		
16:45–17:15	Coffee break		
17:15–17:30	ICMU Highlights		
17:30–18:45	Panel Discussion	Maths-Driven Innovations	

Thursday, 27 August

Time	Speaker / Event	Title / Section	Location
10:00–10:40	Karol Życzkowski	Maths in Quantum Theory – An invitation to quantum combinatorics	Kyiv
10:50–11:30	Paweł Horodecki	Maths in Quantum Theory – From quantum thermodynamics to energy transfer: charging quantum batteries via reservoir engineering	Zoom
11:30–12:00	Coffee break		
12:00–12:40	Enrico Brehm	Maths in Quantum Theory – Symmetry in quantum field theory	Odense
12:45–13:25	Erik Aurell	Maths in Quantum Theory – Operators with spectral density increasing as $\Omega(E) \sim e^{cE^2}$	Kyiv
13:25–15:00	Lunch		
15:00–15:50	Serge Belongie	Maths in Machine Learning – Challenges in Fine-Grained Image Analysis	Odense
15:50–16:00	Q&A session		
16:00–16:30	Coffee break		
16:30–17:00	Maria Han Veiga	Maths in Machine Learning – Reinforcement learning in control problems	Kyiv
17:10–17:40	Peter Orbanz	Maths in Machine Learning – Biasing Machine Learning Toward Geometry and Symmetry	Odense
17:50–18:20	Ritabrata 'Rito' Dutta	Maths in Machine Learning – Prequential posteriors	Odense

Friday, 28 August

Time	Speaker / Event	Title / Section	Location
10:00–10:50	Stefan Dziembowski	Maths in Cryptography	Odense
10:50–11:00	Q&A session		

11:00–11:30	Coffee break		
11:30–12:00	Oleksandra (Sasha) Lapiha	Maths in Cryptography – Postquantum Cryptography	Kyiv
12:10–12:40	Yevhen Perehuda	Maths in Cryptography - What to Guess in Key-Recovery Attacks?	Odense
12:45–13:15	Brice Minaud	Maths in Cryptography	Kyiv
13:15–15:00	Lunch		
15:00–15:50	Dominique Unruh	Maths in Quantum Cryptography	Odense
15:50–16:00	Q&A session		
16:00–16:30	Coffee break		
16:30–17:00	Giulio Malavolta	Maths in Quantum Cryptography	Odense

Abstracts

Valerie Isham
University College London, Department of Statistical Science

Maths in Biology - Epidemic Modelling: past successes and future challenges

Mathematical modelling of epidemics has been one of the big success stories in mathematical biology over the last century, with mathematical methods developed to gain insight into the complexities and non-linearities of infection dynamics and to bring possibilities for control. While much of the work has involved generic models, recent work has often focused on a wide range of specific infections, and epidemic modelling of the COVID pandemic was fundamental to the scientific advice for official response both in the UK and worldwide. As a result, the field has expanded rapidly, driven by novel interactions with other fields, both within the mathematical and statistical sciences, and with a range of other disciplines such as genomics, virology, behavioral sciences, and economics.

In this talk, I will start with some introductory remarks about approaches to epidemic modelling, its purposes and strategy. I will then outline some simple generic mechanistic transmission models, their threshold behavior, and the role of stochasticity, before discussing their extension to more complex state spaces, incorporating population structure and heterogeneity of mixing. Finally, I will discuss current work in which the dynamics of behaviour and responses to treatment interventions are included.

Asger Hobolth
Aarhus University, Department of Mathematics

Maths in Biology - Advanced posterior analyses of hidden Markov models for improved inference of Neanderthal introgression in modern humans

Hidden Markov models constitute a tremendously popular and important class of mathematical models for time series analysis. Two major tasks in applications of hidden Markov models are to (i) compute distributions of summary statistics of the hidden state sequence, and (ii) decode the hidden state sequence. We describe finite Markov chain imbedding (FMCI) and hybrid decoding to solve each of these two tasks. We apply the methods to the problem of classifying and identifying Neanderthal fragments in modern humans.
This is joint work with Zenia Elise Damgaard Baek (Aarhus, Denmark), Moises Coll Macia (Barcelona, Spain) and Laurits Skov (Copenhagen, Denmark).

Julia Palacios
Standord University, Departments of Statistics and Biomedical Data Science

Maths in Biology - Novel coalescent point process approaches for Bayesian inference of disease and molecular dynamics

Coalescent models provide a principled framework for inferring disease and cellular population dynamics from samples of molecular sequences. Typically, these models are derived as scaling limits of simple discrete-generation population models and interpretation of model parameters is challenging. In this talk, we derive two coalescent models by viewing them as thinnings of continuous-time population processes, yielding genealogical models parameterized directly in terms of epidemiologically and biologically meaningful quantities. We then present efficient Bayesian algorithms for posterior inference and assess performance in simulation studies. Finally, we illustrate the approach by reanalyzing sequence data from the 2014 Ebola outbreak in Liberia.

Fabian Freund
University of Leicester, Department of Genetics and Genome Biology

Maths in Biology - Ancestral tree height estimation and applications to whole genome data

An important building block in modelling the genetic diversity of a sample of n DNA sequences is a model for the ancestral relationship of the sample. Locally in the genome, these objects are modelled as realisations of a random tree model, the genealogy of the sample in this genomic region.

We revisit a general pathwise identity between the height of a random tree and other branch lengths properties. We use this duality to establish an estimator of the average time to the most recent common ancestor (TMRCA) of a sample's genealogy across the whole genome from genomic data under different evolutionary scenarios (governed by standard or time-changed Kingman and Λ/Ξ-n-coalescents, which are random tree models used in population genetics). As a side-product, we establish ergodic properties of the underlying genealogical processes across the genome.

We then compare this estimator with other current methods to estimate genome-wide TMRCA estimates, on simulated and on real genomic data. This is joint work with Arno Siri-Jégousse (UNAM Mexico City), Emilien Joly (CIMAT, Guanajuato, Mexico), and Daniel Teofilov (Leicester).

Mingsheng Ying
University of Technology Sydney

Maths in Quantum Computations - Invariants of Quantum Programs

As quantum hardware advances from prototypes to practical platforms, reliable software becomes increasingly critical. Verification is indispensable for ensuring the correctness, safety, and security of quantum software. Program invariants play a key role in program verification. In this talk, we introduce the notion of invariants for quantum programs and develop an effective technique for invariant generation, enabling the verification and analysis of quantum programs.

Steven Rayan
Centre for Quantum Topology and Its Applications (quanTA) and Department of Mathematics and Statistics, University of Saskatchewan

Math in Quantum Computing - Quantum Computing in Negative Curvature

I will present a project of mine that has been unfolding over the past decade — one that intimately involves pure mathematical structures in the discovery and design of quantum materials and quantum processors. The resulting devices simulate, and leverage, a particular mathematical feature: negative curvature. These technologies are identical in crucial ways to currently available noisy intermediate scale quantum (NISQ) devices, yet also support new types of gate synthesis and advanced error correction not normally inherent in, say, superconducting platforms. As such, I will situate these developments within the framework of the pursuit of fault-tolerant, scalable quantum computing. The work here spans pure mathematics, applied mathematics, condensed matter physics, quantum information and computation, and ultimately experiments in the form of device physics and nanofabrication.

Aaron Lauda
University of Southern California - Los Angeles

Math in Quantum Computing - How Topology Shapes Quantum Information

Modern physiological monitoring produces continuous, high-frequency, multimodal signals that replace sparse clinical measurements with richly structured time series. These signals are inherently nonstationary, exhibiting evolving oscillatory patterns, nonlinear dynamics, and latent physiological states that challenge conventional statistical models. We propose a hidden-state manifold diffusion framework for learning from such data. A kernel-based drift and diffusion estimates with theoretical guarantees and some open problems will be discussed. We discuss statistical properties of the estimators, establish theoretical guarantees, and highlight several open mathematical questions. Applications to physiological waveform analysis illustrate how the proposed framework recovers clinically meaningful biorhythms and provides interpretable summaries of complex temporal behavior. The framework offers a statistically principled approach to transforming raw physiological time series into representations suitable for clinical analysis and decision support.

Jan Obłój

University of Oxford, Mathematical Institute

Maths in Finance - Optimal Transport Methods in Finance: from robust pricing, through non-parametric sensitivities to calibration

I present some recent developments where methods from the optimal transport (OT) theory powers novel approaches in mathematical finance. And reversely, where mathematical finance inspires new variants of the classical OT problem. I first discuss robust pricing and hedging and its link to the OT problems with an additional martingale constraint. I highlight how additional market information can be easily incorporated and led to sharper no-arbitrage pricing bounds. I then discuss how methods from Wasserstein distributionally robust optimization (DRO) yields insights into constructing sensitivities, also known as the Greeks in quantitative finance. We propose a new non-parametric Greek, Upsilon, which captures generic first-order sensitivity of an optimisation problem to model misspecification. It is obtained via first order analysis of model perturbations in the Wasserstein space of probability measures. I will describe theoretical results, as well as applications in image recognition (adversarial attacks and robust training methods) and in finance (delta-Upsilon hedging, robustness of deep hedging methods). Finally, I discuss the problem of calibrating a math finance model to market data. I show that the problem can be formulated as a semimartingale optimal transport problem under a finite number of discrete constraints, and introduce a PDE formulation along with its dual counterpart. The solution, a calibrated diffusion process, can be represented via the solutions of Hamilton–Jacobi–Bellman equations arising from the dual formulation. I present tests on both simulated data and market data, including for the joint calibration problem of SPX options and VIX options or futures, a problem known to be difficult. I also comment on analytically tractable calibrations giving raise to the Arithmetic and Geometric Benamou-Brenier problems. This talk is based on many joint works and I will acknowledge my collaborators during my talk.

Oleksii Mostovyi
University of Connecticut, Department of Mathematics

Maths in Finance - Second-Order Envelope Theorems for Preference Perturbations and Their Applications to Indifference Greeks

Preferences of economic agents may evolve over time due to learning, changing attitudes toward risk, or the incorporation of additional information. Motivated by this observation, we develop second-order envelope theorems for utility maximization under small perturbations of preferences. As an application, we introduce a framework for the Greeks of indifference prices, describing how these prices respond to evolving preferences.

Our approach leads to a number of auxiliary results of independent interest. In particular, we obtain second-order expansions of the primal and dual value functions and first-order expansions of the corresponding optimal wealth and supermartingale deflator. The expansion coefficients are characterized by quadratic optimization problems and possess a transparent representation in terms of orthogonal projections under the risk-tolerance measure when the latter exists.

The resulting formulas suggest that the first-order sensitivities of indifference prices are determined exclusively by the nonhedgeable component of the preference perturbation under the optimal numéraire.

Mykhaylo Shkolnikov
Carnegie Mellon University, Department of Mathematical Sciences

Maths in Finance - Relative arbitrage problem under eigenvalue lower bounds

We will discuss a new formulation of the relative arbitrage problem from stochastic portfolio theory that asks for a time horizon beyond which arbitrage relative to the market exists in all ”sufficiently volatile” markets. In our formulation, ”sufficiently volatile” is interpreted as a lower bound on an ordered eigenvalue of the instantaneous covariation matrix, a quantity that has been extensively studied in the empirical finance literature. Upon framing the problem in the language of stochastic optimal control, we characterize the time horizon in question through the unique (upper semicontinuous) viscosity solution of a fully nonlinear elliptic partial differential equation related to the Ambrosio-Soner co-dimension mean curvature flow. Based on joint work with Jou-Hua (Erica) Lai and H. Mete Soner.

Alexander Gnedin
Queen Mary University of London

Maths in Finance - Sequential Selection with a View to Finance

In this talk, we will review classical online optimal selection models in the context of trading strategies for buyers and sellers. The interest in such models has arisen recently in connection with high-frequency trading, posted-price auctions, and dynamic inventory management under capital constraints. We also propose a new approach to the construction of optimal strategies under constraints not covered by familiar dynamic programming techniques, addressing situations with non-Markovian dynamics and path-dependence.

Jane-Ling Wang
University of California, Davis, Department of Statistics

Maths in Data Science - Statistics in the Age of AI

Contemporary research in statistics is increasingly influenced by developments in AI. I will briefly relate my own journey from more traditional to AI-influenced statistical research in the areas of functional data and survival data analysis, focusing on challenges and opportunities. A key feature of functional data is their infinite-dimensional nature, which creates challenges when harnessing neural networks and when incorporating functional covariates in statistical models, leading to an ill-posed inverse problem. A key feature of survival data is their incomplete nature, which challenges the theory and implementation of many machine learning approaches, such as conformal prediction and hypothesis testing for black-box models. I will discuss these challenges and propose some solutions.

Jason Xu
University of California, Los Angeles, Department of Biostatistics

Maths in Data Science - Distance-to-set regularization

We consider a penalty framework based on regularizing the squared distance to set-based constraints for several core statistical tasks. These distance-to-set penalties provide a simple and flexible way to cast constrained optimization problems in more tractable unconstrained forms. We will see that they often avoid drawbacks that arise from popular alternatives such as shrinkage methods. We discuss a general strategy for eliciting effective algorithms in this framework using majorization-minimization (MM), the general principle behind EM that transfers difficult problems onto a sequence of more manageable subproblems. We focus on overviewing the main ideas, and include a few applications including sparse covariance estimation on classical cell signaling data and to spatial transcriptomics. We discuss inroads to Bayesian inference: in particular, analogous ideas lead to constraint relaxation and generalized profile likelihood to include optimization subproblems, leading to methods that are amenable to gradient-based posterior computation.

Cynthia Rush
Columbia University, Department of Statistics

Maths in Data Science - Spectral Geometry and the Limits of Convex Regularization in High-Dimensional Regression

In this talk I will demonstrate how the spectrum of a high-dimensional design controls the best asymptotic risk achievable by convex regularization. For iid Gaussian designs, Celentano and Montanari (2022) established a related convex lower bound, but the spectral shape is then fixed by the sample-to-dimension ratio. We instead study right-rotationally invariant designs with an otherwise arbitrary limiting squared-singular-value distribution. Our main result shows that every estimator in a broad class of separable convex penalized least-squares procedures has asymptotic mean-squared error at least that of a corresponding Bayes message-passing estimator. The resulting lower bound depends on the full spectrum, not only on the sample-to-dimension ratio or average measurement strength. In particular, at fixed average measurement strength, a mean-preserving spread of the squared singular values worsens the best possible convex risk: weakly measured directions are more damaging than strongly measured directions are beneficial. I will explain the main ideas behind this spectral comparison and how vector approximate message passing separates the effects of the signal prior from those of the design spectrum. This is joint work with Audrey Yang and Baichen Tan.

Hau-Tieng Wu
New York University, Courant Institute of Mathematical Sciences

Maths in Data Science - Nonstationary physiological time series to clinical biorhythms via hidden-state manifold diffusions

Modern physiological monitoring produces continuous, high-frequency, multimodal signals that replace sparse clinical measurements with richly structured time series. These signals are inherently nonstationary, exhibiting evolving oscillatory patterns, nonlinear dynamics, and latent physiological states that challenge conventional statistical models. We propose a hidden-state manifold diffusion framework for learning from such data. A kernel-based drift and diffusion estimates with theoretical guarantees and some open problems will be discussed. We discuss statistical properties of the estimators, establish theoretical guarantees, and highlight several open mathematical questions. Applications to physiological waveform analysis illustrate how the proposed framework recovers clinically meaningful biorhythms and provides interpretable summaries of complex temporal behavior. The framework offers a statistically principled approach to transforming raw physiological time series into representations suitable for clinical analysis and decision support.

Anna Nagurney
University of Massachusetts Amherst

Networks, Supply Chains, and Variational Inequalities

Our economies and societies depend on networks from transportation and logistical networks, as well as supply chains, to energy and telecommunication networks, including the Internet. The modeling of such complex systems requires capturing the behavior of their users. In this presentation, I will discuss challenges and opportunities associated with the real-world modeling of network systems, including that of supply chains, and will overview the Braess Paradox. I will highlight the powerful, unifying theory of variational inequalities, and its relationship to projected dynamical systems, for the formulation, analysis, and solution of a wide range of equilibrium problems, including those in which policies such as tariffs and subsidies are incorporated. I will then delve more deeply into our agricultural and food supply chain modeling research, which includes aspects of perishability and commodity quality, and will describe a supply chain international trade model inspired by Ukraine. Finally, I will discuss how to get research out in front of policy-makers and decision-makers to influence positive change.

Oleksii Kuchaiev
NVIDIA, Applied Research

Maths in AI Practice - Artificial Intelligence & Math

Modern frontier AI systems are, at their core, large mathematical objects brought to life by engineering — and the mathematics behind them is readily accessible to a mathematical audience. This talk consists of two parts. In the first, I will give a high-level overview of the mathematics underlying today's frontier AI systems: the linear algebra and probability at the heart of transformer architectures, the optimization theory behind training at scale, and the statistical ideas driving techniques such as reinforcement learning from human feedback and from verifiable rewards. In the second part, I will survey recent milestones of AI in mathematics — from performance on olympiad problems and formal proof assistants to first contributions to research-level questions — and discuss where these systems still fail and why. I will conclude with practical thoughts on how mathematicians can use AI productively today: as a collaborator for exploration, literature search, and formalization, while remaining fully in control.

Karol Życzkowski
Institute of Theoretical Physics Jagiellonian University, Cracow,
Center for Theoretical Physics, Polish Academy of Sciences, Warsaw

Maths in Quantum Theory – An invitation to quantum combinatorics

A classical combinatorial design is an arrangement of elements from a finite set satisfying certain balance and symmetry conditions. A quantum combinatorial design is instead built from pure quantum states — elements of a finite-dimensional Hilbert space — arranged with an analogous symmetry and balance. Simple examples include quantum Latin squares and quantum Sudoku designs [1]. The negative solution to Euler's famous problem of the 36 officers implies that no two orthogonal Latin squares of order six exist. We show that the problem does admit a solution [2] once the officers are allowed to be entangled [3], and we construct a quantum orthogonal Latin square of this order [4]. The solution can be visualized on a six-by-six chessboard, which shows the 36 officers splitting into nine groups of four entangled states each [5].

These results can be seen as an invitation to explore quantum analogues of classical combinatorial problems more broadly.

[1] J. Paczos, M. Wierzbiński, G. Rajchel-Mieldzioć, A. Burchardt, K. Życzkowski, Genuinely quantum SudoQ and its cardinality, Phys. Rev. A 104, 042423 (2021).

[2] S.A Rather, A.Burchardt, W. Bruzda, G. Rajchel-Mieldzioć, A. Lakshminarayan and K. Życzkowski, Thirty-six entangled officers of Euler, Phys. Rev. Lett. 128, 080507 (2022).

[3] S. Ball and R. Simoens, Thirty-Six quantum officers are entangled, Phys. Rev. Lett. 137, 050202 (2026)

[4] D. Garisto, Euler's 243-Year-Old 'Impossible' Puzzle Gets a Quantum Solution, Quanta Magazine, Jan. 10, 2022; https://www.quantamagazine.org/

[5] K. Życzkowski, W. Bruzda, G. Rajchel-Mieldzioć, A. Burchardt, S. A. Rather, A. Lakshminarayan, $9 \times 4 = 6 \times 6$: Understanding the quantum solution to the Euler's problem of 36 officers, J. Phys.: Conf. Series 2448, 012003 (2023).

Pawel Horodecki

International Centre for Theory of Quantum Information Technologies – University of Gdansk, Faculty of Applied Physics and Mathematics – Gdansk University of Technology

Maths in Quantum Theory – From quantum thermodynamics to energy transfer: charging quantum batteries via reservoir engineering

We shall discuss the main concepts of quantum thermodynamic [1] and explain the concept of the thermodynamically useful energy called ergotropy [2]. Subsequently we shall present some results on charging quantum batteries [3] the systems where the energy in the form of ergotropy is stored, focused especially on the improvement with help of reservoir engineering. Typically the charger-battery system is coupled by a Hamiltonian term. It turns out that if, however, two oscillatory batteries have a qubit in between, than there is a catalysis effect – qubit does not store the energy, but helps in charging [4]. Using different technique, recently it has been shown that when interaction involves also the environment that acts collectively the charging can be improved [5,6]. We shall present those findings and also discuss recent results on some modification of the above paradigm.

[1] R. Alicki, The quantum open system as a model of the heat engine, J. Phys. A, 12(5), L103 (1979); J. Oppehneim, M. Horodecki, Fundamental limitations for quantum and nanoscal thermodynamics, Nat. Comm. 4, 2059 (2013); P. Skrzypczyk, A. J. Short, S. Popescu, Work extraction and thermodynamics for individual quantum systems, Nat. Comm. 5, 4185 (2014)]

[2] A.E. Allahverdyan, R. Balian, Th.M. Nieuwenhuizen, Maximal work extraction from quantum systems EPL 67 565 (2004)

[3] F. Campaioli, S. Gherardini, J. Q. Quach, M. Polini, G. M. Andolina, Colloquium: Quantum Batteries, Rev. Mod. Phys. 96, 031001 (2024).

[4] R. R. Rodríguez, B. Ahmadi, P. Mazurek, S. Barzanjeh, R. Alicki, and P. Horodecki, Catalysis in charging quantum batteries, Phys. Rev. A 107, 042419 (2023)

[5] B. Ahmadi, P. Mazurek, P. Horodecki, S. Barzanjeh, Nonreciprocal Quantum Batteries, Phys. Rev. Lett. 132, 210402 (2024)

[6] B. Ahmadi, P. Mazurek, S. Barzanjeh, and P. Horodecki, Superoptimal charging of quantum batteries via reservoir engineering: Arbitrary energy transfer unlocked, Phys. Rev. Applied 23, 024010 (2025)

Enrico Brehm

DESY Research Centre

Maths in Quantum Theory – Symmetry in quantum field theory

Symmetry is one of the most powerful tools to understand physics and very often makes them computational tractable - it tells you which finite-dimensional problem to solve to obtain physically relevant results. I will trace this idea through the ways symmetry appears in quantum field theory, from spacetime symmetry, where irreducible representations classify the particle content, to internal and gauge symmetry, and finally to generalised symmetries described by topological defects and fusion categories rather than groups. I then make the point concrete with recent work on $U(N)$ matrix models, where Schur–Weyl duality supplies an orthogonal basis of the gauge-invariant sector labelled by Young diagrams. Matrix elements of the interacting Hamiltonian can be computed exactly through characters of the symmetric group, and come out as closed-form polynomials in the rank N. This gives access to finite-N, finite-coupling dynamics, and leaves a well-posed combinatorial open problem.

Erik Aurell

KTH Royal Institute of Technology, Stockholm

Maths in Quantum Theory – Operators with spectral density increasing as $\Omega(E) \sim e^{cE^2}$

Quantum black holes (if such objects exist) have an entropy usually given as proportional to the black hole horizon area. From a statistical physics perspective, and for all black holes so far observed, this basically translates to an entropy proportional to the square of the black hole mass. If entropy is the logarithm of the number of microstates corresponding to a macrostate, here black holes of approximately the same mass, the spectral density hence grows super-exponentially. I will discuss what mathematical operators with such spectra there can be, and present a simple example, which however cannot describe a physical black hole. The talk is based on joint work with Satya N. Majumdar, available as Phys. Rev. Research 7:043165 (2025).

Serge Belongie

University of Copenhagen, Department of Computer Science

Maths in Machine Learning - Challenges in Fine-Grained Image Analysis

Fine-grained image analysis (FGIA) is a longstanding and fundamental problem in computer vision and pattern recognition, underpinning a diverse set of real-world applications. The task of FGIA concerns visual objects from subordinate categories, e.g., species of birds or models of cars. Capitalizing on advances in Large Vision-Language Models (LVLMs), in recent years we have witnessed remarkable progress on a variety of FGIA problems. In this talk we review representative examples in the context of recognition and retrieval alongside other key issues such as publicly available benchmark datasets, domain-specific applications, and connections with other modalities including text and audio. We conclude by highlighting several research directions and open problems.

Maria Han Veiga
Ohio State University, Department of Mathematics

Maths in Machine Learning - Reinforcement learning in control problems

Traditional optimal control frameworks, such as dynamic programming and the calculus of variations, typically rely on full knowledge of system dynamics and cost functions. While theoretically rigorous, these methods lack the notion of learning, as they do not adapt from data or experience, making the applicability of the method reduced when requiring real-time control. Reinforcement learning (RL) introduces a learning-based perspective to control, where agents improve their policies through trial and error. In this talk, I will present some recent work on Model-free Reinforcement Learning methods to solve (PDE based) control problems. These methods are particularly advantageous in continuous control settings, allowing for the incorporation of awkward (i.e. non-differentiable) objective functions and a real-time deployment of the control.

Peter Orbanz
University College London, Gatsby Computational Neuroscience Unit

Maths in Machine Learning - Biasing Machine Learning Toward Geometry and Symmetry

There is a range of machine learning problems in which mathematical structure, such as symmetries, geometric constraints, or differential relations, is known before any data is observed. How to integrate such structure in learning and inference raises a range of questions. Some of these are answered, and many are not. I will give a short overview of such problems and illustrate them with specific examples.

Ritabrata 'Rito' Dutta
University of Warwick, Department of Statistics

Maths in Machine Learning - Prequential posteriors

Data assimilation is a fundamental task in updating forecasting models upon observing new data, with applications ranging from weather prediction to online reinforcement learning. Deep generative forecasting models (DGFMs) have shown excellent performance in these areas, but assimilating data into such models is challenging due to their intractable likelihood functions. This limitation restricts the use of standard Bayesian data assimilation methodologies for DGFMs. To overcome this, we introduce prequential posteriors, based upon a predictive-sequential (prequential) loss function; an approach naturally suited for temporally dependent data which is the focus of forecasting tasks. Since the true data-generating process often lies outside the assumed model class, we adopt an alternative notion of consistency and prove that, under mild

conditions, both the prequential loss minimizer and the prequential posterior concentrate around parameters with optimal predictive performance. For scalable inference, we employ easily parallelizable wastefree sequential Monte Carlo (SMC) samplers with preconditioned gradient-based kernels, enabling efficient exploration of high-dimensional parameter spaces such as those in DGFMs. We validate our method on both a synthetic multi-dimensional time series and a real-world meteorological dataset; highlighting its practical utility for data assimilation for complex dynamical systems.
(joint work with Shreya Sinha-Roy, Richard Everitt, Christian Roberts)

Yevhen Perehuda

Ruhr University Bochum

Maths in Cryptography - What to Guess in Key-Recovery Attacks?

Determining the precise parts of the key that need to be guessed in a block cipher's key-recovery attack is fundamental for judging its cost: if the same attack can be executed by guessing less key material, then the cipher's resistance against this attack is overestimated. Although a multitude of prior works provide upper bounds on the key material required, and although these bounds might be tight in some special cases, a precise evaluation of the required key material and the tightness of these bounds is still missing. We remedy this by enumerating linear trails to iteratively compute the affine hull of the support of the Fourier transform of the key-recovery map. This leads to a generic and practical algorithm that identifies the smallest subspace of key material to be guessed. This algorithm is ready to be used in virtually any attack and for a large variety of cipher structures. We demonstrate its impact by showcasing improvements on several published integral, linear, differential-linear, and zero-correlation attacks on the block ciphers PRESENT, SIMON, SKINNY, and GIFT.