UNIVERSITY OF CAMBRIDGE

Summer Research Festival 2024

Monday 14 October 2024, Centre for Mathematical Sciences

Click on the talk title to jump to abstract

	Meeting Room 4	Meeting Room 2
14:00	**Asymptotic Decomposition of a Charged Scalar Field in de Sitter Space** *Ryan Wong (supervisor: Grigalius Taujanskas)*	**The 'Distance' Between Brain Network States** *Haruka Watanabe (supervisor: Ioannis Kontoyiannis)*
14:20	**Horizon Merger in Schwarzschild-de Sitter Space** *Hangzhi Wang (supervisor: Harvey Reall)*	**On low frequency inference for diffusions without the hot spots conjecture (Part 1)** *Douglas Barnes (supervisor: Richard Nickl)*
14:40	**Bosonic String in Anti-de Sitter Space** *Ruoxin Bai (supervisor: Bob Knighton)*	**On low frequency inference for diffusions without the hot spots conjecture (Part 2)** *Aditya Jambhale (supervisor: Richard Nickl)*

Tea & Coffee (Central Core), 15:00 - 15:30

	Meeting Room 4	Meeting Room 2
15:30	**LION: A toolkit for neural network enhanced computer tomography** *Charlie Shoebridge (supervisor: Ander Biguri)*	**Surfaces, Graphs, and Commutators (Part 1)** *Andrew Florescu (Supervisor: Henry Wilton)*
15:50	**Parameters learning enhancement on Biophysics informed Brain Tumour Segmentation** *Yizhen Chen (supervisor: Angelica Aviles-Rivero)*	**Surfaces, Graphs, and Commutators (Part 2)** *Rose Conway (Supervisor: Henry Wilton)*
16:10	**Learned Regularisation using Bregman - Moreau envelope** *Sheng Han (supervisors: Zak Shumaylov & Carola-Bibiane Schönlieb)*	**Surfaces, Graphs, and Commutators (Part 3)** *Aaron Kim (Supervisor: Henry Wilton)*

Tea & Coffee (Central Core), 16:30 - 17:00

	Meeting Room 4	Meeting Room 2
17:00	**Investigation of Regularization by Discretization for the Reconstruction of Randomly Rough Surfaces** *Adam Khan (supervisor: Orsola Rath Spivack)*	**Modelling the stabilities and trajectories of uniflagellar bacteria** *Jay Manson-Whitton (supervisor: John Lister)*
17:20	**Measuring Butterfly Velocity in the XY Model on Emerging Quantum Computers** *Calum McCartney (supervisor: Subhayan Roy Moulik)*	**Modelling Ocean Carbon Solutions** *Ciadh Takahashi (supervisor: John Taylor)*
17:40		**Cosmic Strings and Boson Stars** *Katrina Ng (supervisor: Amelia Drew)*

Click on the talk title to jump to abstract

UNIVERSITY OF CAMBRIDGE

Summer Research Festival 2024

Monday 14 October 2024, Centre for Mathematical Sciences

Click on the talk title to jump to abstract

	Meeting Room 5	Meeting Room 3
14:00	**Get out from Underneath** *Ben Gillott (supervisor: Imre Leader)*	**Intersection theory on the moduli space of curves** *Dylan Toh Shan Hong (supervisor: Dhruv Ranganathan)*
14:20	**Structure of Graphs with Extremal Third Eigenvalue (Part 1)** *Giacomo Leonida (supervisors: Jan Petr & Imre Leader)*	**Tannaka Duality: Reconstructing Groups from Representations** *Amy Needham (supervisor: Martin Hyland)*
14:40	**Structure of Graphs with Extremal Third Eigenvalue (Part 2)** *Sida Li (supervisors: Jan Petr & Imre Leader)*	**Consistency strength hierarchies** *Robert Simpson (supervisor: Benedikt Löwe)*

Tea & Coffee (Central Core), 15:00 - 15:30

	Meeting Room 5	Meeting Room 3
15:30	**Private Estimation of SBMs (Part 1)** *Ethan D'souza (supervisor: Po-Ling Loh)*	**The Range of Random Walk Bridges** *Marios Stamoulis (supervisor: Andjela Sarkovic)*
15:50	**Private Estimation of SBMs (Part 2)** *Tomáš Flídr (supervisor: Po-Ling Loh)*	**Majority Dynamics in Graphs** *Sean Jaffe (supervisor: Marcelo Campos)*
16:10	**Probability Bounds on Persistent Centroid Appearance in Random Growing Trees** *Ryan Hu (supervisor: Po-Ling Loh)*	**The Codegree Density - A Turán Problem in Hypergraphs** *James Sarkies (supervisor: Oliver Janzer)*

Tea & Coffee (Central Core), 16:30 - 17:00

	Meeting Room 5	Meeting Room 3
17:00	**Efficient Probabilistic Machine Learning using Newton's Identities** *Kishan Sharma (supervisor: Henry Moss)*	**Otto Calculus and Gradient Flows on the Infinite-Dimensional Manifold of Probability Measures** *Mara-Ioana Postolache (supervisors: Clément Mouhot and Amélie Loher)*
17:20	**Climate-Teleconnections** *Romeo Passaro (supervisor: Pietro Lio, Department of Computer Science and Technology)*	**Spectral methods for time-dependent PDEs** *Maria Osmova (supervisor: Arieh Iserles)*

Click on the talk title to jump to abstract

Meeting Room 4, 2:00pm - 3:00pm

2:00pm

Ryan Wong

Asymptotic Decomposition of a Charged Scalar Field in de Sitter Space

DAMTP

General Relativity and Cosmology

Astronomical observations indicate that the cosmological constant in our universe is positive. We study the asymptotic behaviour of a scalar field in 4 dimensional de Sitter space, which is the maximally symmetric solution of a space time with positive cosmological constant. In this talk, we explore how this can be done using several different methods, including the conformal method.

2:20pm

Hangzhi Wang

Horizon Merger in Schwarzschild-de Sitter Space

DAMTP

General Relativity and Cosmology

We explore the merger of a black hole with a cosmological horizon in Schwarzschild-de Sitter space. We study how the merger occurs, determine how the area changes as a function of time and investigate the contribution of a Gauss-Bonnet term in the entropy.

2:40pm

Ruoxin Bai

Bosonic String in Anti-de Sitter Space

DAMTP

General Relativity and Cosmology

High Energy Physics

String theory is a theoretical framework that unites quantum mechanics with gravity, offering a promising path towards the unification of all fundamental forces of nature. In this presentation, we will first explore string theory in three-dimensional Anti-de Sitter (AdS) spacetime. We will then extend our discussion to generalize the Wakimoto representation and the current algebra to higher-dimensional AdS spacetimes.

Meeting Room 4, 3:30pm - 4:30pm

3:30pm

DAMTP

Machine Learning

Charlie Shoebridge

LION: A toolkit for neural network enhanced computer tomography

LION is a tool kit for computed tomography integrated with deep learning practices. This talk covers a few of the methods used in LION for reconstructing CT images with limited and dirty data.

3:50pm

DAMTP

Applied and Computational Analysis

Yizhen Chen

Parameters learning enhancement on Biophysics informed Brain Tumour Segmentation

This study builds on previous work by Lipei et al. that used a Partial Differential Equation (PDE) model of brain tumor growth to regularize deep learning in brain tumor segmentation. We refine the earlier model by enhancing the biophysics neural network architecture through inserting two Multi-layer Perceptrons (MLP) networks for parameters learning and improving the loss function to better capture biophysical priors and pathological information. The model is further fine-tuned by optimizing activation functions, hidden layer sizes, and the number of hidden layers for optimal performance. When tested on the BraTS21 dataset, these improvements resulted in higher precision and reliability in tumor segmentation.

4:10pm

DAMTP

Applied and Computational Analysis

Sheng Han

Learned Regularisation using Bregman - Moreau envelope

By tapping into the relationship between Hamilton-Jacobi PDE and Moreau envelop, this project seeks to find better ways to optimise variational problems containing a learned regulariser. Utilising physics-informed neural networks (PINNs) to solve the underlying HJ equation alongside learning the regulariser, thus recovering the Moreau envelope of the regulariser at no cost during inference, provides ways of finding global solutions to non-convex problems at a low computational cost.

Meeting Room 4, 5:00pm - 5:40pm

5:00pm

DAMTP

Applied and Computational Analysis

Adam Khan

Investigation of Regularization by Discretization for the Reconstruction of Randomly Rough Surfaces

In this project, we numerically investigate the stability and convergence of a pre-existing method for reconstructing the profile of randomly rough surfaces by systematically varying step-size and measurement plane height. The effect on reconstruction accuracy is then analysed quantitatively using both the L2 norm and cross correlation. Finally, the technique of ‘surface padding’ is introduced which significantly improves reconstruction accuracy.

5:20pm

DAMTP

Quantum Information

Calum McCartney

Measuring Butterfly Velocity in the XY Model on Emerging Quantum Computers

The butterfly velocity is commonly used to understand information transport properties in quantum dynamical systems. In this project an IBM Q processor is used to demonstrate a quantum teleportation-based protocol for estimating the butterfly velocity in the XY spin lattice model. The numerical simulation results are then compared with analytical calculations and found to be in agreement.

Meeting Room 2, 2:00pm - 3:00pm

2:00pm

Haruka Watanabe

The ‘Distance’ Between Brain Network States

DPMMS

Statistics

The goal is to determine dynamic brain networks from resting-state fMRI data. Last summer, networks were clustered into distinct clusters. This process allowed the identification of networks with varying densities and properties. Building upon these results, I employed the NetOTC method (network optimal transition coupling) to quantify the distance between these networks. In conclusion, both approaches show evidence of dynamic connectivity networks.

Douglas Barnes & Aditya Jambhale

On low frequency inference for diffusions without the hot spots conjecture

DPMMS

Analysis & Partial Differential Equations

Statistics

A 'diffusion process' describes the motion of a diffusing particle on a domain over time. The physical nature of the domain is described by a 'diffusivity function' which is unknown to us and our goal is to infer it statistically given equally spaced samples of a diffusing particle. We removed the dependence on the 'hot-spots' conjecture from two main theorems in a recent paper of Nickl.

2:20pm

Douglas Barnes

On low frequency inference for diffusions without the hot spots conjecture (Part 1)

2:40pm

Aditya Jambhale

On low frequency inference for diffusions without the hot spots conjecture (Part 2)

Meeting Room 2, 3:30pm - 4:30pm

Andrew Florescu, Rose Conway, and Aaron Kim

Surfaces, Graphs, and Commutators

DPMMS

Differential Geometry & Topology

Consider the supremum, taken over all elements of the free group on two generators that are commutators, of the number of 'non-equivalent' ways that such an element can be expressed as a commutator. Our project used a combination of algebraic, topological, geometric, and combinatorial arguments to establish the first known finite upper bound on this quantity.

3:30pm

Andrew Florescu

Surfaces, Graphs, and Commutators (Part 1)

3:50pm

Rose Conway

Surfaces, Graphs, and Commutators (Part 2)

4:10pm

Aaron Kim

Surfaces, Graphs, and Commutators (Part 3)

Meeting Room 2, 5:00pm - 6:00pm

5:00pm

DAMTP

Fluid and Solid Mechanics

Jay Manson-Whitton

Modelling the stabilities and trajectories of uniflagellar bacteria

Uniflagellar bacteria can be modelled as a rigid cell body and a rigid helical flagellum connected by a short flexible hook. A biological motor rotates the flagellum, producing a propulsive force which drives the bacterium forward. Using a simplified model, we examine how the mechanics of the bending hook affects the dynamics of the swimming bacterium.

5:20pm

DAMTP

Fluid and Solid Mechanics

Ciadh Takahashi

Modelling Ocean Carbon Solutions

There is growing consensus that carbon dioxide removal (CDR) is necessary to mitigate climate change. The ocean, with its vast area and long-term carbon sequestration potential, is a focus for CDR strategies. One proposed method is through biology (eg. growing kelp forests), but ocean dynamics and interactions remain poorly understood. Modelling these interactions is crucial to determine the effectiveness of these methods.

5:40pm

DAMTP

General Relativity and Cosmology

Katrina Ng

Cosmic strings and boson stars

Cosmic strings are a class of topological defect, found from solutions to the wave equation for a complex scalar field with a 'wine bottle' potential, and a potential source of axion dark matter. Boson stars are gravitationally-bound compact objects, and are solitonic solutions of the Einstein-Klein-Gordon equations with a similar potential. This project will investigate the mathematical links between these two phenomena.

Meeting Room 5, 2:00pm - 3:00pm

2:00pm

Ben Gillott

Get out from Underneath

DPMMS

Combinatorics

Get out from Underneath' is a pursuit evasion game played on the n by n grid: how big a team of cops do we need to remain on top of a fast robber at all times? The question in 1D is simple, but these strategies give vastly different bounds in 2D - n and n^2. I show improvements to these bounds.

Giacomo Leonida & Sida Li

Structure of Graphs with Extremal Third Eigenvalue

DPMMS

Combinatorics

For a graph G on n vertices, how large can the third eigenvalue of its adjacency matrix be? To answer this, we look at the opposite end of the spectrum and introduce a new graph operation. By studying a family of invariant regular graphs, we sculpt what the algebraically worst-case scenario has to look like and break it apart.

2:20pm

Giacomo Leonida

Structure of Graphs with Extremal Third Eigenvalue (Part 1)

2:40pm

Sida Li

Structure of Graphs with Extremal Third Eigenvalue (Part 2)

Meeting Room 5, 3:30pm - 4:30pm

Ethan D'souza and Tomáš Flídr

Private Estimation of SBMs

DPMMS

Statistics

Many real-life networks can be modelled as random graphs, often as Stochastic Block Models describing the relations between communities. With no restrictions, we can precisely estimate the communities from a given network using linear algebra methods. However, as the data often corresponds to private information about individuals, a natural problem is to develop algorithms which respect privacy constraints.

3:30pm

Ethan D'souza

Private Estimation of SBMs (Part 1)

3:50pm

Tomáš Flídr

Private Estimation of SBMs (Part 2)

4:10pm

Ryan Hu

Probability Bounds on Persistent Centroid Appearance in Random Growing Trees

DPMMS

Probability, Applied Probability, & Mathematical Finance

In the uniform attachment model of randomly growing trees, it is known that the centroid—the most central vertex (if defined appropriately)—stabilizes, almost surely, after a finite time (Po-Ling Loh and Varun Jog, 2016). In this talk, we will describe novel probabilistic bounds on the time required for this stabilization to occur. This result is particularly relevant for practical applications, as it helps determine the likelihood that the current centroid is already the persistent one.

Meeting Room 5, 5:00pm - 5:40pm

5:00pm

DAMTP

Applied and Computational Analysis

Kishan Sharma

Efficient Probabilistic Machine Learning using Newton's Identities

Gaussian processes are powerful probabilistic machine learning models: one reason being that they can encode prior scientific knowledge into otherwise purely data-driven machine learning tasks. In particular, the Gaussian processes' kernel function controls the covariance of the learned processes. When constructing predictive models for systems with high-dimensional inputs, the necessity arises to incorporate additional structural assumptions through the kernel function.

5:20pm

Department of Computer Science and Technology

Romeo Passaro

Climate-Teleconnections

In this talk, I will introduce state-of-the-art deep learning techniques, such as Graph Neural Networks and Attention Mechanisms, applied to Weather Seasonal Forecasting. The focus is on climate modes, recurring weather patterns, particularly exploring and explaining the influences of climate oscillators on Earth, teleconnections.

Meeting Room 3, 2:00pm - 3:00pm

2:00pm

DPMMS

Algebraic Geometry

Dylan Toh Shan Hong

Intersection theory on the moduli space of curves

The moduli space of curves is one of the cornerstones of modern algebraic geometry: it parameterises all algebraic curves at once. One may access its intrinsic geometry via intersection theory, which identifies characteristic numbers of the space. In this project, I use intersection theory to study the double-double ramification cycle, a certain geometric sublocus of the moduli space.

2:20pm

DPMMS

Number Theory & Algebra

Amy Needham

Tannaka Duality: Reconstructing Groups from Representations

When we use representations to study groups, a natural question may arise asking how much information can we get from representations, and in particular, do we lose any information in passing from a group to its representations? Tannaka duality provides an answer to this question in a wide range of cases, namely those in which we can put a “geometric” structure on the group.

2:40pm

DPMMS

Foundations

Consistency strength hierarchies

Robert Simpson

Consistency strength is a method of ordering logical statements according to the consistency statements that they prove. However, the definition used varies between authors, in ways that seem very similar but turn out not to be equivalent. What is known about this hierarchy and do the different definitions have similar properties?

Meeting Room 3, 3:30pm - 4:30pm

3:30pm

- DPMMS
- Combinatorics
- Probability, Applied Probability, & Mathematical Finance

Marios Stamoulis

The Range of Random Walk Bridges

Random walks are amongst the most commonly used stochastic processes, with applications in a wide variety of algorithms. One feature of interest is their range - the number of vertices reached in a given time. In this talk, we prove a result which gives general bounds for the range of closed random walks - also known as random walk bridges.

3:50pm

- DPMMS
- Combinatorics

Sean Jaffe

Majority Dynamics in Graphs

We study the evolution of majority dynamics on Erdős-Rényi G(n,p) random graphs. In this process, each vertex of a graph is assigned one of two initial states. Subsequently, on every day, each vertex simultaneously updates its state to the most common state in its neighbourhood. In this project, we focused on the question of unanimity: Given an initial coloring, what is the probability for each color to win, meaning it covers the whole graph at some point. In doing so, we resolve several conjectures by various mathematicians.

4:10pm

- DPMMS
- Combinatorics

James Sarkies

The Codegree Density - A Turán Problem in Hypergraphs

The minimum codegree of a k-uniform hypergraph G is the largest integer m such that any (k-1)-subset of V(G) is contained in at least m edges. The codegree threshold of a k-uniform hypergraph F is the largest possible minimum codegree of an n-vertex F-free hypergraph. I will discuss my results on this problem, which includes determining a class of hypergraphs with sublinear codegree threshold.

Meeting Room 3, 5:00pm - 6:00pm

5:00pm

DPMMS

Analysis & Partial Differential Equations

Mara-Ioana Postolache

Otto Calculus and Gradient Flows on the Infinite-Dimensional Manifold of Probability Measures

We discuss Otto calculus: by giving the set of probability measures a Riemannian manifold structure, we can relate solutions to some evolution PDEs to gradient flows of a certain functional. Since gradient flows minimise the functional with a controlled convergence to the minimum, we obtain convergence rates of arbitrary solutions to the unique steady-state solution of the system (the global minimiser).

5:20pm

DAMTP

Applied and Computational Analysis

Analysis & Partial Differential Equations

Maria Osmova

Spectral methods for time-dependent PDEs

A spectral method starts by specifying an orthonormal basis of the underlying Hilbert space – once this is done, we can convert a time-dependent PDE into an infinite-dimensional ODE system by Galerkin conditions and solve its finite-dimensional truncation. The project surveyed a number of contemporary approaches in the choice of orthonormal bases, in particular T-systems and W-systems.