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Research Opportunities at the School of Mathematical Sciences

There are two different schemes across Chemistry, Engineering and Maths:

1. 6 Dalian University of Technology/University of Leicester PhD scholarships funded by CSC (CSC provides stipend and UoL provides international fee waiver)
2. 7 DUT-UoL Collaborative PhD Studentships (DLI provides 20,000 RMB and University of Leicester provides international fee waiver. Only available to DLI students)

We are not considering applications for the two funding sources separately. Shortlisting for interview will be carried out purely on the basis of quality and aptitude for the PhD project for which you have applied. Only at the point of interview and appointment of successful candidates will we begin to consider funding source. If you get through to the interview, you will be asked about your funding preference (only to be considered for CSC, only to be considered for DUT, preference for CSC but also consider DUT, preference for DUT but also CSC, or no preference) and then we will allocate projects at that stage.

A formal application to the University of Leicester is essential (this can be carried out here https://le.ac.uk/study/research-degrees/funded-opportunities/cse-dut-partnership) and the **deadline for applications is: 5th January 2026**. Please choose two research projects and make it clear on your application form which is your first and which is your second choice research project. We will be holding **online interviews from Monday 2nd to Monday 9th February 2026**, so please check your email account regularly to find out if you have been selected for an interview. You should receive an email inviting you to interview by Monday 26th January 2026.

With your application, please provide:

- CV
- Degree certificates and transcripts of study already completed and if possible transcripts to date of study currently being undertaken
- Personal statement
- Evidence of English language, only if you are applying from Dalian University of Technology
- In the references section, please enter the contact details of two academic referees in the boxes provided or upload reference letters if already obtained
- In the funding section, please state **DUT 2026 scholarship**
- In the research proposal section, please provide the names of the **project supervisors and the project titles** you want to be considered for. You can select up to 2 projects. List both in order of preference. (a research proposal is not required)

Please take a look at the 10 different research projects which are available in the School of Mathematical Sciences. The first research project is only available for the CSC funding (project 1), the next 9 research projects are available for both Schemes (projects 2 to 10).

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Only available with CSC funding

1. Validated Numerics for Matrix Functions

Dr Behnam Hashemi – bh241@le.ac.uk

Project Title	**Validated numerics for matrix functions**	
Project Highlights:	1.	Development of self-validated numerical algorithms for matrix functions to monitor the accuracy of solutions obtained by standard floating-point algorithms
	2.	Computing rigorous a posteriori componentwise forward error bounds for matrix functions
	3.	Development of open-source software package for computing guaranteed error bounds for matrix functions

Project Overview (Maximum 350 words)

Matrix functions appear in numerous applications including solution of ODEs and PDEs, probability theory, network science, control theory and particle physics, (see [3]). For instance, when solving the initial value problem

$$\frac{d^2y}{dt^2} + Ay = 0, \quad y(0) = y_0, \quad y'(0) = y'_0$$

where A is a square matrix, the unique solution

$$y(t) = cos\left(\sqrt{A}\,t\right)y_0 + \left(\sqrt{A}\,\right)^{-1} sin\left(\sqrt{A}\,t\right)\,y'_0$$

involves the matrix square root, inverse square root and the matrix sine and cosine. Practical computation of matrix functions relies on floating point arithmetic, a powerful tool whose main limitation is the presence of rounding errors resulting in solutions which are only approximately correct. Indeed, analysis of errors committed in the course of the computation is a central part of numerical computing and various approaches have been developed such as backward error analysis (pioneered by the British mathematician and computer scientist, James Wilkinson) and verified computing based on interval analysis which is the error analysis tool to be employed in this project.

While most verified algorithms for matrix functions explore algebraic functions [2], the aim of this project is to use ideas from approximation theory [4] which potentially open the door to a whole new class of verification algorithms applicable to non-algebraic matrix functions [1]. The goal is to derive new rigorous error bounds for matrix functions which are subsequently used to develop algorithms with automatic result verification. We will then implement, test and compare our algorithms on a wide range of problems.

A strong background in linear algebra, numerical analysis/scientific computing, and proficiency in programming (particularly in MATLAB) is expected.

References:

[1] A. Frommer, B. Hashemi, Computing enclosures for the matrix exponential, *SIAM Journal on Matrix Analysis and Applications* 41 (2020) 1674-1703.

[2] A. Frommer, B. Hashemi, Verified computation of square roots of a matrix, *SIAM Journal on Matrix Analysis and Applications* 31 (2010) 1279-1302.

[3] N. J. Higham, *Functions of Matrices: Theory and Computation*, SIAM, Philadelphia, 2008.

[4] L. N. Trefethen, Approximation Theory and Approximation Practice, SIAM, Philadelphia, 2019.

DUT/UoL CSC PhD studentships and DUT-UoL Collaborative PhD studentships

2. Modelling the effects of transport and communication network structure on street protest dynamics in space and time

Dr Daniel Bearup – djb93@leicester.ac.uk

Project Title	**Modelling the effects of transport and communication network structure on street protest dynamics in space and time**	
Project Highlights:	1.	A novel mathematical modelling approach will be developed to describe street protests dynamics subject to transport network structure and the effect of social media
	2.	The model will be applied to specific case studies and will be parameterised using real data on street protests
	3.	Application of the model will reveal bottlenecks in the local / national transport networks that could be used for protest management and control

Project Overview (Maximum 350 words)

Understanding the **dynamics of social unrest**, e.g. protests, is important to ensure **stable, sustainable development** of social groups and society as a whole. Mathematical models of social dynamics are increasingly recognized as a powerful research tool to facilitate progress in this field. A number of non-spatial, or spatially implicit, systems have been developed to describe how these events develop over time (Morozov et al. 2019, Alsulami et al. 2022). However, **communication and movement** between protest sites can be expected to play an important role in their dynamics (Berestycki et al. 2015, Petrovskii et al. 2020, Cartes et al. 2022). The effects of such spatial processes are largely unexplored.

The goal of the project is to address this important theoretical gap by characterising the **dynamical behaviour of spatially explicit protest models**. The spatial structure will be represented by a network with nodes corresponding to cities and links to railways/motorways. We will begin with the assumption that individuals are fully aware of the protest behaviour within the network, and thus that the primary determinant of spatial dynamics is the structure of the transport network and movement behaviour upon it. The effects of **ease of movement between cities**, determined by the network topology, and **movement preferences regarding protest activity**, modelled as density-dependent dispersal, will be the main focus. Existing data from the Yellow Vests Movement in 2018-2019 in France will support this investigation.

In the second phase of the project, we will consider how **incomplete, biased or limited information** obtained from social or mainstream media may affect the emergent dynamics. Since communication is not necessarily restricted to the transport network, this requires an additional network topology. The effects of this information will be mediated by the density-dependent dispersal process.

Successful implementation of the project will open the possibility of **protest management** by altering the network structure and capacity.

References:

Morozov et al, 2019 SocArXiv, https://doi.org/10.31235/osf.io/tpyux

Alsulami et al, 2022 Scientific Reports, 12:20447, doi:10.1038/s41598-022-23917-z

Berestycki et al, 2015 Netw. Heterogen. Media 10(3), 443–475.

Petrovskii et al, 2020 Mathematics, 8:78; doi:10.3390/math8010078

Cartes et al, 2022 Sci. Rep. 12, 10557.

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3. A sparse spectral element method on the sphere for numerical weather prediction

Dr Marco Fasondini - m.fasondini@leicester.ac.uk

Project Title	**A sparse spectral element method on the sphere for numerical weather prediction**	
Project Highlights:	1.	The computation of vector orthogonal polynomials on subsets of the sphere with optimal complexity algorithms
	2.	Combining multiple subsets of the sphere to design a spectral element method on the whole sphere
	3.	The application of this method to numerical weather prediction, allowing much higher-resolution simulations than was possible before

Project Overview (Maximum 350 words)

The spectral method used by the European Centre for Medium-range Weather Forecasts (ECMWF) uses spherical harmonics (SHs) and vector spherical harmonics (VSHs) as basis functions. The SHs are scalar orthogonal polynomials (OPs) and the VSHs are vector-valued OPs defined on the whole sphere. Since the basis functions are global, the transforms that are required to numerically solve partial differential equations (PDEs) on the sphere can become prohibitively expensive as the degrees of the SHs and VSHs are increased.

The aim of this project is to overcome the parallel scalability bottleneck of this global spectral method by constructing and implementing a sparse spectral element method in which PDEs on the whole sphere are solved by using high-degree scalar and vector-valued OPs on subsets of the sphere such as spherical caps, bands, rectangles and triangles. Since local instead of global basis functions are used, the transforms can be computed much more efficiently.

To ensure the sparsity (and hence computational efficiency) of the method, families of scalar OPs and vector-valued OPs are required on subsets of the sphere. Scalar OPs on spherical caps and bands are known explicitly in terms of univariate classical and semiclassical OPs and these have been used for a sparse spectral method on single elements (i.e., single subsets of the sphere) [1]. The vector-valued OPs that are required on subsets of the sphere are not known explicitly, however these will be computed by combining the recently developed optimal complexity methods in [2] and [3]. These scalar and vector-valued OPs will be combined across multiple elements to yield a sparse spectral element method on the whole sphere. This will allow the use of much higher degree basis functions and therefore higher-resolution simulations of PDEs on the sphere, with applications not only in numerical weather prediction, but also in astrophysics and geosciences.

References:

1. B. Snowball, S. Olver. Sparse spectral methods for partial differential equations on spherical caps, *Trans. Math. Appl.*, 5 (1), 2021.
2. Gutleb, T.S., Olver, S. & Slevinsky, R.M. Polynomial and Rational Measure Modifications of Orthogonal Polynomials via Infinite-Dimensional Banded Matrix Factorizations. *Found Comput Math* (2024). https://doi.org/10.1007/s10208-024-09671-w
3. M. Fasondini, S. Olver, and Y. Xu. Orthogonal polynomials on a class of planar algebraic curves, *Stud. Appl. Math.*,151 (1), 2023.

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4. Data driven inverse techniques for object identification

Professor Paul Ledger - pdl11@leicester.ac.uk

Project Title	**Data driven inverse techniques for object identification**	
Project Highlights:	1.	Use established high-fidelity accelerated computational models to efficiently establish economical characterisations of hidden objects and data-dictionaries
	2.	Develop new types of object features, apply clustering algorithms and assess accuracies of these features in classification approaches for object identification
	3.	Work on a project, which has real-world applications in medical imaging, geophysical surveys, non-destructive testing, materials characterisations and archaeology.

Project Overview (Maximum 350 words)

Inverse problems involve the identification and location of hidden small inclusions from field measurements. New and novel approaches are needed since the field data can only be measured at limited locations and the data is typically noisy and incomplete. For many applications, a rapid decision about the location, shape and material properties of the inclusion is also demanded.

Traditional approaches to the solution of inverse problems involve setting up a functional to be minimised that expresses the difference between measured data and parameterised predicted measurements obtained from the solution of a (set of) partial differential equations (PDEs). The parameters sought typically relate to a discretisation of the material parameters. The approach is expensive (as it requires repeated solution of PDEs and many iterations and can suffer from non-uniqueness). Regularisation may be added, but its choice is often not straightforward. Furthermore, to obtain a reasonable image fidelity, the dimension of the parameters to be sought must be large, but this is at odds with the limited measured data that is available.

This project considers an alternative approach in which the PDE model is replaced by alternative characterisation model where the hidden inclusions are described by tensor coefficients as a function of exciting frequency [1,2]. Such characterisations can be easily found from field measurements and avoid the challenging functional minimisation procedure described above. Computational tools for computing the characterisations of surrogate objects are also available [3]. The approach can be applied to a range of PDEs [1,2] and have applications including medical imaging, understanding ground conditions, non-destructive testing, materials characterisations of composite materials and archaeology.

Key challenges remain as to how best to identify information about the hidden object from the data. To address this, this project will firstly develop large dictionaries of surrogate object characterisations using existing computational tools. Secondly, it will obtain and explore new object features and the extent to which these group characterisations of similar objects by using state-of-the-art clustering approaches. Thirdly, develop probabilistic classifiers, built on the dictionaries of computed characterisations, to provide a data-driven approach to object identification.

References:

1. H. Ammari and H. Kang, Polarization and Moment Tensors: With Applications to Inverse Problems and Effective Medium Theory, Springer 2007

2. P.D. Ledger and W.R.B. Lionheart, The spectral properties of the magnetic polarizability tensor for metallic object characterisation. *Mathematical Methods in the Applied Sciences,* 2020; 43: 78–11.
3. J. Elgy and P.D. Ledger, Efficient computation of magnetic polarizability tensor spectral signatures for object characterisation in metal detection. *Engineering Computations*, 2024; 41: 2472-2503.

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5. Smart rapid design of heat exchangers

Dr Alberto Paganini - admp1@le.ac.uk

Project Title	**Smart rapid design of heat exchangers**	
Project Highlights:	1.	Novel Smart Heat Exchanger Design via PDE-Constrained Optimization
	2.	Massively Parallel, GPU-Accelerated Discontinuous Galerkin Solvers
	3.	Automated realization of orthogonal polynomials on arbitrary domains

Project Overview (Maximum 350 words)

Heat exchangers are the fundamental technology driving energy transfer in every process plant, from petrochemicals to pharmaceuticals. Their efficiency is directly tied to the overall energy consumption and sustainability of the chemical sector. While traditional design relies on decades-old, restrictive geometries, the future of **Smart Chemical Engineering** demands rapid, automated discovery of high-performance, complex architectures. This project aims to deliver this capability.

The research is centered on developing a robust, mathematically principled framework for optimizing heat exchanger designs. This involves pioneering a novel **PDE-constrained level set shape optimization** approach, allowing the system to freely evolve the internal geometry until it achieves peak performance. To accurately solve the underlying computational fluid dynamics and heat transfer equations on these evolving, complex shapes, we will employ high-fidelity **polytopic Discontinuous Galerkin (DG) methods**. These advanced numerical techniques provide the essential accuracy and geometric flexibility needed to capture the physics inside the computer-invented designs.

The ambition of this optimization task requires significant computational power. A key output of the project will be the development of **efficient, GPU-accelerated code,** translating the complex DG algorithms into massively parallel routines suitable for modern high-performance computing hardware. A crucial technical challenge involves devising an **efficient algorithmic construction of orthogonal polynomials on arbitrary geometries**. This fundamental work is necessary to ensure the stability and speed of the DG solver as it adapts to the novel, irregular boundaries generated during the optimization process.

This PhD project offers an exceptional opportunity for a strong computational student to master cutting-edge techniques in applied mathematics, fluid dynamics, and high-performance computing. Graduates of this program will possess a unique, highly marketable skillset, making them prime candidates to establish a successful research career in either industrial R&D environments or academic research positions.

Further reading:

Dong Z, Georgoulis EH, Kappas T. GPU-accelerated discontinuous Galerkin methods on polytopic meshes. SIAM Journal on Scientific Computing. 2021;43(4):C312-334.

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Fernandes RE, Georgoulis EH, Paganini A. Level-set shape optimization via polytopic discontinuous Galerkin methods. SIAM Journal on Scientific Computing. 2025;47(5): B1293-1315.

Fasondini M, Olver S, Xu Y. Orthogonal polynomials on a class of planar algebraic curves. Studies in Applied Mathematics. 2023 Jul;151(1):369-405.

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6. Computational approaches to large deviations in complex systems

Dr Francesco Ragone - fr120@leicester.ac.uk

Project Title	**Computational approaches to large deviations in complex systems**	
Project Highlights:	1.	Large deviation theory (LDT) is concerned with atypical, extreme outcomes and their probability.
	2.	The mathematical principles of LDT enable a shared language for the analysis of rare events in both engineered and natural systems.
	3.	You will employ or develop numerical tools, such as the “cloning” algorithms, to simulate and probe large deviation events in complex systems.

Project Overview (Maximum 350 words)

Extreme events, characterized by their rarity but also their potentially devastating impact, are fundamental to understanding the resilience and performance of complex systems. Quantifying their likelihood is essential across a wide range of domains, including climate modelling, public health, insurance pricing, agriculture, and financial risk management. In engineered systems, rare events can lead to service degradation, making their analysis essential for resource provisioning.

The study of systems from an extreme-event perspective requires advanced mathematical frameworks such as the Large Deviation Theory (LDT). LDT is a branch of probability that studies the occurrence of events that deviate significantly from the average behaviour. LDT is concerned with questions like: How likely is a system to exhibit a large fluctuation away from its typical state? What is the most probable way such a rare event occurs? How can we characterize the "cost" of a deviation? LDT functionals also have analogues in equilibrium and non-equilibrium statistical physics.

We are interested in the application of LDT to models of real-world systems. As these often defy analytical treatment, and their study requires numerical approaches. Our project will address that need by developing Monte Carlo schemes to sample rare trajectories and compute LDT functionals. Another key aspect will be translating deterministic chaotic dynamical systems with metastable states, such as those often encountered in climate science, into probabilistic Markov processes.

Potential applications are in the area of Mathematics of Planet Earth (quantifying extremes like heatwaves, disease outbreaks, or abrupt transitions near climate tipping points) and can include elements of finance or engineering (quantifying system reliability and extreme-loss risk).

The applicants should have preliminary knowledge in at least two of the following areas: dynamical systems, probability, scientific simulations.

References:

Cini et al. (2024). Simulating AMOC tipping driven by internal climate variability with a rare event algorithm. NPJ Clim. Atmos. Sci. 7(31).
Gálfi et al. (2021). Applications of large deviation theory in geophysical fluid dynamics and climate science. Nuovo Cimento 44(6), 291-363.
Cavallaro and Harris (2019). Effective bandwidth of non-Markovian packet traffic. J. Stat. Mech. 2019(8), 083404.
Touchette (2009). The large deviation approach to statistical mechanics. Phys. Rep., 478(1-3), 1-69.

7. Surface Roughness in PDE Transmission Problems

Dr Matias Ruiz - mr447@le.ac.uk

Project Title	**Surface Roughness in PDE Transmission Problems**	
Project Highlights:	1.	A rigorous mathematical framework, based on stochastic geometry, for modelling rough surfaces in 3-dimensional manifolds.
	2.	A set of numerical schemes that can accurately simulate rough-interface transmission problems with high computational efficiency.
	3.	Applications to analyse the effects of surface roughness in metamaterials.

Project Overview (Maximum 350 words)

Transmission problems involve finding solutions to Partial Differential Equations (PDEs) across domains with different material properties, joined by a shared interface. These equations arise in a wide range of applications, including optics, acoustics, and materials science. For example, plasmonic resonances in nanoparticles can be modelled using a Laplace transmission problem, where the interface often has a three-dimensional shape, like a sphere. Understanding the effects of surface roughness poses significant mathematical challenges due to the multiscale nature of the problem and the intricate details of rapidly oscillating surfaces, making direct numerical simulation expensive. To date, all mathematical and numerical studies of this problem assume a smooth interface, which is unrealistic given the manufacturing imperfections often present in nanoparticles.

This PhD project aims to bridge that gap by developing mathematical and computational tools to analyse and simulate the effects of adding surface roughness to an otherwise smooth interface. Specifically, you will:

1- Establish a rigorous procedure for generating surface roughness on three-dimensional manifolds over unstructured meshes.

2- Develop multiscale models, based on stochastic homogenization, to account for surface roughness effects in a broad class of PDE transmission problems, thereby reducing the computational cost of direct numerical simulations.

3- Apply these methods to study wave scattering problems involving rough surfaces in the context of metamaterials.

These results are expected to lead to multiple publications in top applied mathematics journals.

This project will engage a wide range of mathematical topics, including PDEs, finite element methods, differential geometry, homogenization, asymptotic analysis, and spectral theory. It should appeal to students interested in the numerical and theoretical analysis of PDEs.

References:

[1] Biermé, H. (2019). Introduction to Random Fields and Scale Invariance. In: Coupier, D. (eds) Stochastic Geometry. *Lecture Notes in Mathematics*, vol 2237. Springer, Cham. (2019)
[2] J. Nevard and J. B. Keller, Homogenization of Rough Boundaries and Interfaces, *SIAM Journal on Applied Mathematics.* (1997)
[3] H. Ammari, et. al. Mathematical and Computational Methods in Photonics and Phononics, *American Mathematical Society*. (2018)

8. Metastability and Noise-Induced Transitions in Oxygen–Phytoplankton Dynamics

Dr. Larissa Serdukova - ls563@leicester.ac.uk

Project Title	**Metastability and Noise-Induced Transitions in Oxygen–Phytoplankton Dynamics**	
Project Highlights:	1.	**Mathematical Modelling:** Formulation and analysis of deterministic and stochastic oxygen–phytoplankton models based on Petrovskii and Alhassan (2025).
	2.	**Metastability and Transitions:** Investigation of bistability, metastable dynamics, and noise-induced transitions between oxygenated and anoxic regimes.
	3.	**Ecological Implications:** Quantitative interpretation of model outcomes to assess resilience and early-warning indicators of marine oxygen decline.

Project Overview (Maximum 350 words)

Oxygen production by marine phytoplankton plays a fundamental role in sustaining life on Earth. However, increasing ocean temperatures and nutrient stress threaten this delicate balance by altering the rates of photosynthesis and respiration. Large-scale oxygen depletion—*marine anoxia*—has been observed in many oceanic regions and is often associated with abrupt ecological regime shifts. Understanding the mechanisms that govern the stability and transitions between oxygenated and anoxic states is therefore a key challenge in mathematical ecology.

This project focuses on the metastability and stochastic transitions in oxygen–phytoplankton systems. The study is based on the deterministic baseline model of oxygen production proposed by Petrovskii and Alhassan (2025), which describes the temporal dynamics of dissolved oxygen concentration $c(t)$ and phytoplankton biomass $u(t)$ through a pair of coupled nonlinear differential equations. These equations represent oxygen generation via photosynthesis, its consumption through respiration, and phytoplankton mortality and saturation effects. Despite its conceptual simplicity, the model exhibits multiple equilibria, oscillatory behaviour, and bistability, reflecting the potential for critical transitions in marine ecosystems.

The first stage of the project will analyse the deterministic dynamics—examining bifurcations, stability boundaries, and the parameter regimes where metastable states emerge. The second stage will introduce stochastic forcing to account for environmental variability (e.g., temperature or nutrient fluctuations), using stochastic differential equations to study how random perturbations can induce transitions between oxygenated and anoxic states. Analytical methods such as asymptotic approximations, mean first-passage times, and potential landscape analysis will be combined with numerical simulations to characterize noise-induced regime shifts.

Ultimately, the project aims to develop a unified theoretical framework for understanding resilience, tipping behaviour, and early-warning signals in oxygen–phytoplankton systems. The results will provide insights into marine deoxygenation processes and contribute to predictive tools for assessing ecosystem stability under climate variability.

Reference

Petrovskii, S. & Alhassan, F. (2025). *Metastability and transitions in oxygen–phytoplankton dynamics under environmental fluctuations*. **Mathematics**, 13(1): 1–23.

9. Uncovering scientific meaning through semantic analysis of scientific corpora

Dr Neslihan Suzen - ns553@leicester.ac.uk

Project Title	**Uncovering scientific meaning through semantic analysis of scientific corpora**	
Project Highlights:	1.	To develop novel methodologies for semantic analysis that capture conceptual meaning in large-scale scientific corpora.
	2.	To integrate advances in Natural Language Processing (NLP) for enhanced semantic understanding and contextual interpretation of scientific texts.
	3.	To design predictive and explainable models for automated multi-label classification, recommendation, and discovery in English scientific literature.

Project Overview (Maximum 350 words)

Scientific literature represents one of the richest and complex forms of human knowledge, encompassing millions of documents written in highly structured yet semantically nuanced language. As research output grows exponentially, there is an increasing need for automated and interpretable semantic analysis tools capable of extracting meaning patterns, identifying conceptual trends, and supporting evidence-based decision-making. Despite significant progress in text embedding models and large language representations, increasing deployment of NLP and neural language models demands understanding of how models internally encode and manipulate scientific meaning.

The interpretability of texts embeddings and the explainability of semantic similarity derived from them remains a challenge. Current models can measure textual similarity with high accuracy, yet they provide little insight into why two documents are deemed semantically related. Addressing this gap requires mechanistic understanding of how embedding spaces encode meaning and how similarity metrics align (or fail to align) with human scientific reasoning. This project will therefore include employing semantic probing techniques, systematically analysing model representations to determine which semantic properties are encoded in models. These methods will uncover and visualise semantic factors that drive similarity judgments within models trained on scientific texts.

The project proposes comprehensive research uniting semantic representation learning and mechanistic interpretability of large language models and embedding spaces to develop novel techniques for automated analysis of academic corpora. The PhD researcher will design interpretable text representation methodologies and semantic analysis tools that combines information-theoretic, graph-based, and mechanistic approaches to model how language models represent scientific terms, relations, and rhetorical structures. This focus offers insights not only into content of scientific texts, but also into how machines understand science itself.

By combining distributional and structural semantics with transparent interpretability, project aims to develop hybrid models that are both computationally powerful and semantically transparent. The applications will include multi-label classification for citation prediction, semantic drift detection to track conceptual evolution over time, and interpretable recommendation systems for automated literature mapping. Successful completion of this project will lead to advances in processing written academic languages and enhance understanding of semantic relations, generating new computational methods for quantifying meaning and further suggesting support of decision-making.

References
[1] Suzen, N., Gorban, A., Levesley, J. and Mirkes, E., (2022). An Informational Space Based Semantic Analysis for Scientific Texts. 10th International Conference on Foundations of Computer Science & Technology.
[2] Gantla, S. R. (2025, March). Exploring Mechanistic Interpretability in Large Language Models: Challenges, Approaches, and Insights. In 2025 International Conference on Data Science, Agents & Artificial Intelligence (ICDSAAI) (pp. 1-8). IEEE.

10. Analysis of high dimensional functional data using machine learning methods
Dr Bo Wang - Bo.wang@le.ac.uk

Project Title	**Analysis of high dimensional functional data using machine learning methods**	
Project Highlights:	1.	Multi-disciplinary research interweaving statistics and computing
	2.	Develop novel methodologies for functional data analysis
	3.	Applications to real world problems

Project Overview (Maximum 350 words)

Functional data analysis (FDA) studies data in the form of curves or surfaces, and has been a topic of increasing interest, not only in statistics but also in various fields of science. For instance, in energy security, electricity consumption recorded each day by smart meters form functional data and it is hugely important to the authorities and suppliers to make accurate prediction on the electricity demand; in environment satellite images of wild fire over time form functional data and it is crucial to be able to predict the trend of spread of the fire over a short time; in transportation the traffic flows each day form functional data and making short-term traffic prediction is a substantial problem for both drivers and local authorities.

The mainstream methodology for functional data analysis (FDA) is to summarise the information contained in each function into a finite-dimensional vector by using Functional Principal Component Analysis (FPCA) or basis expansions such as B-splines, and then perform the analysis using existing methods for multivariate data. With the fast growing interest in artificial intelligence, in recent years machine learning methods have gained increasing popularity in various fields and applications, due to their capability to fit complex patterns in data and significant improvement in prediction accuracy. An intriguing problem is therefore how the machine learning methods perform for functional data, how they compare with other FDA methods and how these methods can be further adapted and developed for the analysis of functional data.

The overall objective of this project is to explore and develop machine learning methods for the analysis of functional data, in particular, multivariate functional data, mixed functional data and functional data with high dimensional covariate variables. More specifically, the proposed project will

(1) investigate and develop deep neural networks for mixed functional data;
(2) investigate Gaussian processes and deep Gaussian processes methods for multivariate and non-Gaussian functional data;
(3) develop Bayesian neural networks for uncertainty quantification in functional data analysis;
(4) apply the developed models to real-world problems, such as energy security, mortality modelling and forecasting, medical image data.

References

[1] Perdices, D., de Vergara, J.E.L., Ramos, J., 2021. Deep-FDA: Using Functional Data Analysis and Neural Networks to Characterize Network Services Time Series. IEEE Transactions on Network and Service Management 18, 986–999.
[2] Rossi, F., Delannay, N., Conan-Guez, B., Verleysen, M., 2005. Representation of functional data in neural networks. Neurocomputing 64, 183–210.
[3] Yao, J., Mueller, J., Wang, J.-L., 2021. Deep Learning for Functional Data Analysis with Adaptive Basis Layers.

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