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 2025**. 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 6th to 13th February 2025**, 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 Friday 24th January 2025.

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 if available
- 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 2025 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 two research projects are only available for the CSC funding (projects 1 and 2), the next 7 research projects are available for both Schemes (projects 3 to 9), whilst the last research project is only available for DLI funding (project 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

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

where A is a square matrix, the unique solution

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

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.

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[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.

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2. Mathematical models of mass extinctions and climate tipping points accounting for the interplay between biotic and abiotic feedbacks

Professor Sergei Petrovskii - sp237@le.ac.uk

Project Title	**Mathematical models of mass extinctions and climate tipping points accounting for the interplay between biotic and abiotic feedbacks**	
Project Highlights:	1.	Mass extinctions is a phenomenon that has several times during the Earth history greatly perturbed the course of macroevolution by wiping out more than one half of the whole life on the planet.
	2.	The project aims to develop novel mathematical and computational models to study mass extinctions causes and mechanisms.
	3.	Successful implementation of the project will greatly contribute to the understanding of mass extinctions of the past as well as the effects of climate change across multiple time scales.

Project Overview (Maximum 350 words)

Mass extinctions have been in the focus of research for several decades [1,2]. Species get extinct all the time; however, several times through the 550 Ma of the recorded history of life on Earth, the extinction rates exceeded the average background rate by more than an order of magnitude, resulting in 50-90% loss in the global biodiversity. Remarkably, the current extinction rate (over the last 150 years) is estimated to be about two orders of magnitude higher than the background rate, suggesting that we may be witnessing the beginning of the “6th mass extinction”.

Species do not only adapt to a climate change, going extinct if the change is too large or too fast. They can attenuate the change and/or modify the environment according to their needs. This has long been known in the climate science as the Gaia hypothesis [3] but is overlooked by modelling studies on mass extinctions. In order to bridge this gap, recently a novel conceptual modelling approach was developed [4] to couple the zero-dimensional global energy budget model (the so called Budyko-Sellers equation) to a generic model of population dynamics [5].

This PhD project will develop and extend the new conceptual approach to include important factors such as species evolutionary response to the environmental change, the dependence of population functioning on the ambient temperature, the effect of other taxa (e.g. as preys or predators), the effect of environmental and demographic stochasticity.

In order to ensure the efficient work on the project, the applicants are expected to have a good degree in applied mathematics with at least some preliminary knowledge of ordinary differential equations, basics of nonlinear dynamics, basics of the probability theory. Some experience in computer programming (e.g. in Matlab) and numerical simulations is desirable, although not mandatory.

[1] Alvarez L.W., et al. (1980). Science 208: 1095-1108.
[2] Sudakow I., et al. (2022). Physics of Life Reviews 41: 22-57.
[3] Lovelock J.E., Margulis L. (1974). Tellus 26(1-2): 2-10.
[4] Vakulenko S.A., et al. (2021). Physical Review E 103: 022202.
[5] Alsulami A., Petrovskii S. (2023) Chaos, Solitons & Fractals 175, 114018.

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

3. 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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4. 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.
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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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5. Exploiting spectral data for small object identification using polarizability tensors

Professor Paul Ledger - pdl11@leicester.ac.uk

Project Title	**Exploiting spectral data for small object identification using polarizability tensors.**	
Project Highlights:	1.	Polarizability tensors provide an economical object characterisation of hidden inclusions and provide a characterisation in terms of a small number of parameters.
	2.	Exploiting measurements as a function of frequency provides spectral data, which contains additional information for identifying objects.
	3.	Applications include medical imaging, understanding ground conditions, 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. Such problems are challenging 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 where PDE model is replaced by an asymptotic expansion, which describes the field perturbation due to the presence of an inclusion as its size tends to zero [1]. Expansions are available for a range of PDEs [1] and have applications including medical imaging, understanding ground conditions, non-destructive testing, materials characterisations of composite materials and archaeology. In common, they describe the hidden inclusion using an economical characterisation called a polarizability tensor. The coefficients of the tensor can easily be obtained from the measured field measurements avoiding the costly and challenging functional minimisation procedure described above.

Explicit formulae [1,2] are available for computing polarizability tensors for different applications and the characterisations can be efficiently obtained by numerical approximation of transmission problems [3]. The characterisations are a function of the exciting frequency [2] and dictionaries of these so-called spectral characterisations can be obtained. The task then reduces to one of identifying the nature of the inclusion by classification of the spectral characterisation of the hidden inclusion to those of the dictionary. The project will investigate different approaches for this.

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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. *Math Meth Appl Sci*. 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, arXiv:2307.05590v2 (2024).

6. 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 modeled 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 tools to analyze 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)

7. Vibroimpact dynamical systems (VIS) for energy harvesting

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Project Title	Vibroimpact dynamical systems (VIS) for energy harvesting	
Project Highlights:	1.	Studying different types of vibro-impact motions that deliver the maximum amount of converted electrical energy
	2.	Exploring period doubling bifurcations, grazing behavior, and potential regions of bi-stability and chaotic behavior in VIS
	3.	Studying the influence of the stochastic effects on the weakly stable solutions or near the critical values where the stochastic noise likely to cause transitions that influence energy outputs.

Project Overview (Maximum 350 words)

A vibroimpact systems, their dynamics and applications as energy sinks keep attracting attention of scientists around the world [1, 2]. A VIS is one of the most colourful representatives of nonlinear dynamics. Despite its relatively simple mechanical structure that can be realized by a mass-spring system with a barrier, various nonlinear effects can be observed in VI systems [3, 4]. The difficulty in analysing the VI systems is related to the fact that a VI system's velocity is discontinues in real life applications where the impact cannot be treated as ideally elastic (restitution coefficient $r = 1$). To overcome this difficulty a number of approaches have been developed for deterministic and stochastic systems [3, 4, 5]. Nevertheless, there are several issues related to the dynamics of VI systems end their applications that have not yet been studied sufficiently. A relatively small number of research publications are focused on efficient VI system design for Energy Harvesting from ambient vibrations into high density electrical energy at low cost. The main reasons for the lack of results is the difficulty in predicting their performance and optimizing their design.

This project focuses on studying dynamics of a novel mechanical system for energy harvesting from vibrations. The system comprises an external mass M with a slot allowing a free rolling-type motion of an internal mass (a ball). Whereas the external mass is subjected to a harmonic excitation $f(t)$ the inner mass motion due to gravity g is engaged by an impact interaction against dielectric membranes, covering the bottom ∂B and top ∂T of the slot. The deformation of the membranes results in capacitance change and therefore can be used for energy harvesting.

The current analytical results [6, 7] point to other types of behavior to be explored in future studies, in terms of phase and impact velocity. This includes period doubling bifurcations, grazing behavior, and potential regions of bi-stability and chaotic behavior. The analytical results for stability and bifurcations also suggest parameter regimes to explore within the stochastic context. For example, in cases where the solutions are weakly stable or near the critical values stochastic effects are likely to cause transitions that influence outputs. The future studies of other types of stable periodic motions, which can be observed in this vibroimpact system, are essential for comparison and identification of those motions that are realistic and deliver the maximum amount of harvested energy.

References:

[1] M. A. Al-Shudeifat, N. Wierschem, D. D. Quinn, A. F.Vakakis, L. A. Bergman, J. B. Spencer, Numerical and experimental investigation of a highly effective single-sided vibro-impact non-linear energy sink for shock mitigation, Int. J. Non Lin. Mech. 52 (2013), pp. 96-109.

[2] O. V. Gendelman, A. Allon, Dynamics of forced system with vibro-impact energy sink, J. Sound Vib., 358 (2015), pp. 301-314.
[3] R. A. Ibrahim, Vibro-impact dynamics: modeling, mapping and applications, Springer Science and Business Media, 2009.
[4] V. I. Babitsky, Theory of Vibro-impact Systems and Applications, Springer Science and Business Media, 2013.
[5] M. F. Dimentberg, D. V. Yurchenko, Random vibrations with impacts: a review, Nonlinear Dynamics, 36 (2004), pp. 229-254.
[6]. L. Serdukova, R. Kuske, D. Yurchenko, Post-grazing dynamics of a vibro-impacting energy generator, Journal of Sound and Vibration, Journal of Sound and Vibration, February 2020, DOI: 10.1016/j.jsv.2020.115811.
[7]. L. Serdukova, R. Kuske, D. Yurchenko, Stability and bifurcation analysis of the period-T motion of a vibro-impacting energy harvester, Nonlinear Dynamics, October 2019, DOI: 10.1007/s11071-019-05289-8.

8. Advancing Machine Learning Based Missing Data Imputation in Medical Practice

Dr Neslihan Suzen - ns553@leicester.ac.uk

Project Title	**Advancing Machine Learning Based Missing Data Imputation in Medical Practice**	
Project Highlights:	1.	To develop novel and interdisciplinary approach to constructing missing data imputation methodology.
	2.	To exploit the capabilities of advances in Machine Learning to conduct missing data analysis.
	3.	To develop predictive models for patient trajectory.

Project Overview (Maximum 350 words)

This project aims to enhance clinical decision making through machine learning-based missing data analysis in electronic patient records (EPRs).

EPRs contain a rich source of information, capturing comprehensive details on patients' medical histories [1]. However, clinical data is referred to as 'dirty data', which signifies data may be inconsistent, incomplete or inaccurate. The dirty data can undermine the quality of patient care, complicate data analysis for research, and limit the potential of EPRs to drive improvements in healthcare outcomes.

Missing data, in particular, poses a significant barrier to accurately modelling patient trajectories— the progression of a patient’s health status over time. This trajectory modelling is crucial for predicting patient outcomes, identifying potential health risks, and informing timely interventions. However, incomplete or inconsistent data hinders this process by introducing uncertainty into models and reducing their predictive accuracy.

Previous studies have highlighted that incomplete data limits the ability to predict patient outcomes and inform interventions [2,3]. To address this, machine learning methods, such as imputation algorithms and predictive modelling, have emerged as effective solutions for handling missing data, filling in gaps with statistically likely values and thereby enhancing the accuracy of patient trajectory models [4].

This project will explore how influence of the missing data in estimating patient trajectories. By leveraging advance machine learning to manage and analyse these gaps, this project aims to maximize the value of EPRs and ultimately improve clinical decision-making by providing healthcare providers with a more complete view of a patient’s health trajectory, supporting a more accurate clinical decision.

The project proposes comprehensive research on the analysis of missingness patterns in large sets of clinical records, and the development and validation of advanced machine learning techniques for imputing missing data. The PhD researcher will design novel advance methodologies for handling missing data and mitigating bias within clinical records and machine learning models, helping to create a more inclusive foundation for decision-support systems in healthcare.

[1] Suzen, Neslihan, et al. "What is Hiding in Medicine’s Dark Matter? Learning with Missing Data in Medical Practices." 2023 IEEE International Conference on Big Data (BigData). IEEE, 2023.
[2]Zhou, X., et al. (2020). "Challenges and solutions in dealing with missing data in clinical research." *Journal of Biomedical Informatics*, 102(1), 104-112.

[3] Kumar, S., et al. (2018). "Impact of Missing Data on Healthcare Predictive Models." *Computational Medicine Journal*, 15(3), 201-212.
[4] Yoon, J., et al. (2018). "GAIN: Missing Data Imputation using Generative Adversarial Nets." *Proceedings of the 35th International Conference on Machine Learning*, 32(2), 5689-5697.

9. 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.

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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.

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Only available with DLI funding

10. Building an intelligent clinical concierge: adaptive decision support using multi-modal data

Dr. Robert Free – rob.free@leicester.ac.uk

Project Title	Building an intelligent clinical concierge: adaptive decision support using multi-modal data	
Project Highlights:	1.	Developing approaches to enable an AI-driven agent to dynamically filter and display relevant patient information to support decision-making at critical points in a clinical workflow.
	2.	Integrating contextual, guideline-driven recommendations dynamically into the agent without predefined structures.
	3.	Exploring transparency, accountability and interpretability to increase trust and understanding in an agent's real-time decision-support recommendations.
Project Overview (Maximum 350 words)		

Clinical decision support (CDS) tools are software applications that support doctors when making decisions related to patients' conditions, by optimising and standardising their diagnostic options. Most CDS tools are expert systems driven by a defined set of logical steps focused on decision making - resulting in a patient moving down a particular "patient pathway". While in recent years artificial intelligence (AI) models have been integrated into these systems, the models still essentially sit within these logical pathways.

There are several limitations to the current approach. First, pathways need to be manually defined and maintained so they can keep up with current patient management approaches. Second, most current CDS tools use only structured data (e.g. electronic patient records) and do not consider information from patient consultations or notes, which often provide invaluable information for informed clinical decision making. Third, CDS tools can be poorly designed. They often provide doctors with irrelevant notifications making it difficult to identify the most important information based on the patient's current state. This reduces the doctor's ability to identify and categorise patients who need to be prioritised.

In this project you will build an AI-based CDS concierge that provides more dynamic and adaptive approaches to decision support. The project will involve designing novel AI models that incorporate and make sense of patient consultations and disease management guidelines. You will also produce responsible approaches for dealing with these data sources to dynamically, but safely include these guidelines in support tools. Furthermore, you will explore how best to incorporate transparency, accountability and interpretability into the assistant so that the AI approaches embedded can be trusted by doctors.

This project will produce new CDS technologies which move the paradigm away from simple logical approaches towards dynamic and adaptive tools. Outputs will include: i) a prototype CDS agent which adjusts information displayed according to relevancy, based on guideline recommendations; ii) novel insights into the viability and impact of dynamically filtered, context-aware agent-based CDS based on real-time patient data and clinician input; iii) contributions to best practice for transparency and trust-building within agent-driven CDS tools.