OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

School of Mathematical and Statistical Sciences

14th Annual Research Day

10 April 2024

Programme

	Talks take place HBB-G019 Coffee, lunch, posters, and reception take place TBA
9:20–9:30	**Cathal Seoighe**, Head of School: Opening Remarks
9:30–10:00	**Joshua Maglione**, (University of Galway) *Zeta functions and hyperplane arrangements*
10:00–10:30	**Yueyun Zhu** (University of Galway) *Derivative multivariate functional principal component analysis and its application to coronary artery disease*
10:30–11:00	**Frances Fahy** (Ryan Institute) *Interrelations between mathematics and environmental research: the Role of the Ryan Institute*
11:00–11:30	**Tea and coffee**
11:30–12:00	**Griffen Small** (University of Galway) *Modelling the Non-Linear Viscoelastic Behaviour of Brain Tissue in Torsion*
12:00–13:00	**Lightning talks** person 1 • person 2 • person 3
13:00–14:10	**Lunch and Poster Session**
14:10–14:40	**Lars Jermiin** (University of Galway) *TBA*
14:45–15:30	**Eimear Byrne** (UCD) *Codes and Matroids*
15:30–17:00	**Poster session, reception, and prizes**

Contents

1 Introduction

...

Welcome to...

2 Abstracts of invited talks

Joshua Maglione (University of Galway): *Zeta functions and hyperplane arrangements*

Abstract:

We define a class of multivariate rational functions associated with hyperplane arrangements called flag Hilbert–Poincaré series. We show how these rational functions are connected to local Igusa zeta functions and class counting zeta functions for certain graphical group schemes studied by Rossmann and Voll. We report on a general self-reciprocity result and a non-negativity result of the numerator polynomial under a coarsening, and we explore other connections within algebraic combinatorics. We report on joint works with Christopher Voll and with Galen Dorpalen-Barry and Christian Stump.

Griffen Small (University of Galway): *Modelling the Non-Linear Viscoelastic Behaviour of Brain Tissue in Torsion*

Abstract: Brain tissue accommodates non-linear deformations and exhibits time-dependent mechanical behaviour. The latter is one of the most pronounced features of brain tissue, manifesting itself primarily through so-called viscoelastic effects. One key effect is stress relaxation, where the stress decreases over time when brain tissue is deformed and then held in place. While the literature is replete with non-linear viscoelastic models, they are generally cumbersome and computationally expensive, making model fitting and the estimation of brain tissue's material parameters difficult. The modified quasi-linear viscoelastic (MQLV) model, recently reappraised by De Pascalis et al. [1] and Balbi et al. [2], offers a simpler alternative for modelling brain tissue's viscoelastic behaviour but remains underutilised and has yet to be validated with experiments.

Torsion is one of the most robust deformation modes for measuring brain tissue's mechanical properties. It can be readily implemented using a rotational rheometer, which measures both the torque and normal force required to twist a cylindrical sample [3]. However, previous studies on brain tissue's viscoelasticity have focused on measuring only on torque, overlooking the additional insights provided by normal force measurements [4].

In this presentation, we present a novel protocol for characterising the viscoelastic properties of brain tissue, based on the torsion deformation mode and the MQLV model. We performed ramp-and-hold relaxation tests on freshly slaughtered cylindrical ovine brain samples (25 mm diameter and 10 mm height). The tests were conducted using a commercial rheometer at varying twist rates of $\{40, 240, 400\}\,\mathrm{rad\,m^{-1}\,s^{-1}}$, with a fixed twist of $88\,\mathrm{rad\,m^{-1}}$. The viscoelastic material parameters were estimated by simultaneously fitting the measured torque and normal force to the MQLV model's analytical predictions [5]. The model's predictions were further validated through finite element simulations of the experiments using the open-source software FEniCS [6]. Our results demonstrate that the model accurately fits the experimental data, with the estimated elastic material parameters aligning well with those reported in previous studies on brain samples under torsion [3]. By allowing us to obtain two independent datasets (torque and normal force) from a single test, our proposed protocol provides us with a much more efficient and accessible alternative to traditional multi-mode protocols, which often rely on expensive, custom-made experimental rings or multiple testing devices; in contrast, our protocol can be easily implemented in any commercially available rheometer.

Beyond advancing brain tissue's mechanical characterisation and validating the efficacy of the MQLV model, our results have broader implications. When coupled with bespoke finite element models, the material parameters estimated in this study could enhance our understanding of the forces and deformations associated with traumatic brain injury, which could contribute to the design of improved headgear for sports such as boxing and motorsports. Additionally, our novel

protocol offers new insights into the mechanical behaviour of soft tissues beyond the brain.

This work has emanated from research jointly funded by Taighde Éireann – Research Ireland under grant number GOIPG/2024/3552 (Griffen Small), and by the College of Science and Engineering at the University of Galway under the Millennium Fund scheme for the project "Modelling Brain Mechanics" (Valentina Balbi).

References

[1] R. De Pascalis, D. I. Abrahams, W. J. Parnell, *On nonlinear viscoelastic deformations: a reappraisal of Fung's quasi-linear viscoelastic model*, Proc. R. Soc. A: Math. Phys. Eng. Sci. 470 (2166) (2014) 20140058.

[2] V. Balbi, T. Shearer, W. J. Parnell, *Tensor decomposition for modified quasi-linear viscoelastic models: Towards a fully non-linear theory*, Math. Mech. Solids 0 (0) (2023) 1–25.

[3] V. Balbi, A. Trotta, M. Destrade, A. Ní Annaidh, *Poynting effect of brain matter in torsion*, Soft Matter 15 (25) (2019) 5147–5153.

[4] S. Chatelin, A. Constantinesco, R. Willinger, *Fifty years of brain tissue mechanical testing: from in vitro to in vivo investigations*, Biorheology 47 (5–6) (2010) 255–276.

[5] M. Righi, V. Balbi, *Foundations of viscoelasticity and application to soft tissue mechanics*, in: J. Málek, E. Süli (Eds.), Modeling Biomaterials, Springer, 2021, Ch. 3, pp. 71–103.

[6] M. Alnæs, J. Blechta, J. Hake, A. Johansson, B. Kehlet, A. Logg, C. Richardson, J. Ring, M. E. Rognes, G. N. Wells, *The FEniCS project version 1.5*, Archive of Numerical Software 3 (100) (2015) 9–23.

Yueyun Zhu (University of Galway): *Derivative multivariate functional principal component analysis and its application to coronary artery disease*

Abstract: With the development of wearable monitoring devices and sensors, increasingly large and complex datasets are being recorded. Such data often exhibit non-linear patterns and estimating the rate of change (i.e, derivatives) is particularly informative for understanding the underlying dynamics.

Functional principal component analysis (FPCA) is a powerful tool, which represents the infinite-dimensional functional data into the Karhunen-Loève expansion with a set of orthogonal functional principal components (FPCs) and functional principal component scores (FPC-scores). Multivariate FPCA (MFPCA) is an extension of FPCA to accommodate multiple correlated features. The multivariate FPCs (MFPCs) capture the joint variation between different features and the associated multivariate FPC-scores (MFPC-scores) summarize this variation as numerical values.

To estimate the derivatives of multivariate functional data, we proposed a new method, namely the derivative of multivariate functional principal component analysis (DMFPCA). Analogously to MFPCA, the derivative MFPCs (DMFPCs) capture the joint variation for the derivatives of different features and the derivative MFPC-scores (DMFPC-scores) summarize this joint variation as numerical values.

We applied MFPCA and DMFPCA to the quantitative flow ratio (QFR) and vessel diameter obtained from angiograms. MFPCA was employed to estimate MFPC-scores, which were used as predictors in a penalized logistic regression to classify physiological patterns of coronary artery disease. DMFPCA was employed to investigate the underlying dynamics between diameter and QFR, providing guidance for selecting the optimal stent location during percutaneous coronary intervention.

3 Abstracts of lightning talks

Title

Speaker One

This is my abstract.