Annual Mathematics PhD Day 2023

Norman, Daniel; Hakami, Abdulrahman; Micik, Milos; Ayodele, Victoria; Xie, Yihang; Jovanovic, Filip

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School of Science and Engineering
University of Dundee

A celebration of PhD Research in Mathematics

Annual Mathematics PhD Day 2023

Friday 17 November 2023, 12:30-17:30
Baxter Suite 1.36 & Lamb Gallery, Tower Building
Mathematics, SSEN

Organised by: Dumitru Trucu, Karen Meyer, and Eric Hall

School of Science
and Engineering
University of Dundee

Annual Mathematics PhD Day 2023

Friday 17th November, 12:30-17:30
Venue: ***Baxter Suite 1.36****, in the Tower Building,* ***with Lamb Gallery for lunch and coffees***

Event Schedule:

12:30 – 13:30 Arrival and lunch

13:30 – 15:50 Scientific Session 1:

- 13:30-13:35: Welcome (Dumitru) 5 mins

- 13:35-13:50: 3 x 5 min from new PhD students:
  - 13:35-13:40 Daniel Norman
  - 13:40-13:45 Abdulrahman Hakami
  - 13:45-13:50 Milos Micik

- 13:50-14:35: 3 x 10 min talks (5 mins between talks):
  - 13:50-14:00 Victoria Ayodele
  - 14:05-14:15 Yihang Xie
  - 14:20-14:30 Filip Jovanovic

- 14:35-15:50: 3 x 20 min talks (5 mins between talks):
  - 14:35-14:55 Nader Alharbi
  - 15:00-15:20 Zhihao Tao
  - 15:25-15:45 Jonathan Miller

15:50 – 16:20 Coffee

16:20 – 17:30 Scientific Session 2:

- 3 x 20 min talks (5 mins between talks):
  - 16:20-16:40 Martin Sanner
  - 16:45-17:05 Andrei Macarie
  - 17:10-17:30 Andrew Fraser

Evening: optional unsubsidised dinner and drinks at St Andrews Brewing Co from 6pm.

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Abstracts

Daniel Norman

Talk Title:
AI probabilistically predicting severe solar weather

Abstract:
Introducing myself and my area of research around training neural networks to predict, probabilistically, where severe solar weather may occur on our sun.

Abdulrahman Hakami

Talk Title: *Introducing myself: newly arrived 1st year PhD student*

Abstract:
My first steps as PhD student in Applied Mathematics in University of Dundee

Milos Micik

Talk Title: *Machine learning based image analysis for phenotyping*

Abstract:
Automated image-based plant phenotyping allows high throughput quantification of plant traits by analysing images captured by sensors and cameras in controlled environments or in the fields at any defined time interval. Visible light, fluorescent, near infrared, infrared and hyperspectral images can be captured from different viewing angles allowing the construction of 2D and 3D model of plants and their components, e.g. leaves, stems, flowers, and spikes etc. I will investigate how supervised deep learning methods and segmentation algorithms can be used to develop systems that provide accurate measurements of a list of plant traits.

Victoria Iyadunni Ayodele

Talk Title:
Energy Law Preserving C^0 Finite Element Schemes for Phase Field Models in Two-Phase Flow Computations

Abstract:

The concept introduced in “An energy law preserving C^0 finite element scheme for stimulating the kinetics effects in liquid crystal flow dynamics” was utilized for the development of an energy law preserving method and compute the diffuse interface models of Allen-Cahn and Cahn-Hilliard, which describe the movement of two-phase incompressible flows at the diffusive interface (phase-field). The two models are discretized using a C^0 finite element method in space and a modified midpoint scheme in time. We address the divergence-free condition by employing a penalty formulation to enhance stability in the pressure variable, which allows the derivation of the discrete energy law for these diffusive interface models.
Currently, we want to show through an illustrative example that the method is beneficial for computing multiphase models, we will finally present the results of several computations of two-phase incompressible flow examples to showcase the excellent performance of the proposed method.

Reference:
P. Lin, C. Liu, H. Zhang (2007). An energy law preserving C^0 finite element scheme for stimulating the kinetics effects in liquid crystal flow dynamics. Journal of Computational Physics, 227 (2):1411-1427.

Yihang Xie

Talk Title: *Alveolar bone cutting on noisy cleft dental mesh*

Abstract:
Computer-aided techniques have gained popularity in the field of dental research and treatment. However, their application in addressing cleft lip/palate (CLP) cases has been limited due to the substantial variability in the shapes of such cases and the presence of significant noise in the data.

My research aimed to development an innovative algorithm to segment the alveolar bone in cleft dental meshes, a crucial step in virtual CLP treatment. This partitioning process enables us to assess essential information such as the shape, height, and width of the alveolar bone defect, which is vital for alveolar bone grafting procedures.

So far, I have been trying to automate the algorithm. I have tried region-growing method and use different metrics like surface curvature field, gradient of height function. However, fully automating this process seems challenging, primarily due to the complexity of defining a measure to captures the intricate shape of the alveolar bone.

In the future, I will continue to explore alternative automatic segmentation methods to determine if a fully automated partitioning of the alveolar bone is feasible. Otherwise, I will adapt my strategy to incorporate interactive segmentation methods to enhance the accuracy of the segmentation process.

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Filip Jovanovic

Talk Title: *Structures and dynamics in a periodically forced Lorenz system*

Abstract:
Skin friction drag causes substantial energy loss in transport systems. A promising method to reduce drag is to oscillate the surfaces of the flow transversely to the flow direction, leading to drag reduction of up to 25% (Quadrio, 2011). The wall oscillation leads to drag reduction via altering the flow structure in the near-wall region. However, a detailed description and understanding of the effect of periodic forcing on these structures is missing. It is well known (see e.g. Kawahara et al., 2012) that exact coherent structures, such as equilibria and periodic orbits form a 'skeleton' about which turbulent dynamics organise; therefore, the reaction of these exact coherent structures to periodic forcing is of interest. As a first step towards understanding how periodic forcing impacts means of turbulent motion, such as drag, we study how such forcing impacts other low-dimensional chaotic processes, starting with the Lorenz system (Lorenz, 1963). We demonstrate how periodic forcing impacts averages in this system and relate this to structural changes of its unstable periodic orbits. These orbits have a direct impact on the averages in the Lorenz system (Eckhardt & Ott, 1994) and we demonstrate to what extent this remains true in a periodically forced version by examining the effect on chaotic averages, dynamics, and unstable periodic orbits. The methodology is applicable to a wider range of chaotic systems including turbulence, so that optimised strategies for drag reduction may be designed.

Nader Al Harbi

Talk Title:
The Effectiveness of Blended Learning in Mathematics for Secondary School Students and their Teachers and Parents in Saudi Arabia

Abstract:
Great strides have been made across the globe in the development of effective teaching approaches and methodologies for improving the efficiency of the learning process and catering to students' diverse learning styles. Blended learning has emerged as a promising teaching approach, integrating online and face-to-face learning strategies to enhance learning outcomes. In Saudi Arabia, the Ministry of Education has introduced the Madrasati platform to support distance learning and achieve the country's economic and digital transformation goals. Despite the increasing popularity of blended learning, there is a dearth of research on the effectiveness of the platforms such as the Madrasati platform in a blended learning approach for mathematics education in secondary schools.
In this study, a systematic literature review was conducted on blended learning in secondary mathematics. After the inclusion and exclusion process, as shown in figure 1, the process involved identifying studies through databases, removing duplicates, screening titles and abstracts, and analysing full articles based on inclusion and exclusion criteria. The quality of

the selected studies was then assessed based on research methodology and analysis, resulting in a reduced number of full-text papers.

This study aims to investigate the effectiveness of blended learning by using the Madrasati platform on students' mathematics performance and students, teachers, and parents' perceptions and acceptance of the platform. A mixed-methods research design was utilising to collect data, including open-ended questionnaires, semi-structured interviews, and analysis of students' final results from four secondary schools in Qassim city. The study sample includes male and female government secondary school students, their parents, and teachers from different socio-economic areas. This factor might influence the effectiveness of blended learning using the platform, which could be caused by the differences in the accessibility, motivation, or other factors between these two areas, such as internet access, infrastructure, and income variation.
The Technology Acceptance Model (TAM) was employed to analyse the data and test hypotheses related to perceived usefulness, ease of use, and mathematics information quality regarding the Madrasati platform. The study aims to contribute to the growing body of knowledge on blended learning in mathematics and offer new insights into the Saudi Arabian context. The findings will be of significant value to the Ministry of Education in achieving its long-term goals of utilising the Madrasati platform to improve the classroom setting and enhance students' mathematics skills.

The study's outcomes will provide valuable insights to learning institutions that are striving to implement technology in the teaching and learning process. The study's results will also encourage other countries to adopt national learning platforms to ensure the continuity of education and mitigate the risks of educational losses in the future. In conclusion, this study contributes to the literature on blended learning and provides empirical evidence on the effectiveness of the platforms such as the Madrasati in a blended learning approach for mathematics education in secondary schools.

Zhihao Tao

Talk Title: *Cross-adhesion and cross-diffusion in cancer dynamics*

Abstract:
In this talk we focus on establishing an extensive computational modelling and analysis framework for the invasion of a solid tumour in the human body that accounts for the interplay between the cross-adhesion and cross-diffusion cells sub-populations processes that are involved within the underlying cancer cells migration. Specifically, we will explore the non-local spatio-temporal evolution of an invading tumour that assumes two cancer cells sub-populations (namely, a primary cancer cell population as well as a mutated one) that proliferate and at the same time exercise both random movement and directed migration. In particular, the directed movement is assumed to be driven here by the naturally arising interplay between cell-adhesion and cross-diffusion cells populations processes, and in this context, this talk will explore three cell migration scenarios. These will be accompanied by

numerical simulation (based on finite volume) as well as a novel functional analysis approach for the cross-diffusion parameters sensitivity.

Jonathan Miller

Talk Title: *Exploring survival requirements for Type Six Secretion System aided attack on host cells*

Abstract:
Cellular competition plays an important role in diverse biological settings. Protein secretion systems, mechanisms to interact with and respond to the environment, are a crucial cellular utility in bacterial populations. Serratia marcescens, an opportunistic pathogen, operates an aggressive system called the Type VI Secretion System (T6SS). Urinary tract and ocular lens infections, endocarditis, osteomyelitis and septicaemia have all been linked to S. Marcescens. T6SS is a flexible transmembrane macromolecular machine, capable of offering strong competitive edges in population dynamics. Governed by a post translational regulation network the T6SS uses a reusable inverted bacteriophage-like structure to make repeated attacks, reorientating between each one, to gain adversarial niches. A mathematical model was developed and shows that by varying attacking rates, reorientation, and number of T6SSs, critical population sizes of targeted cells emerge such that survival is always possible.

Martin Sanner

Talk Title:
SolARE – Solar Active Region Extractor - A statistical approach

Abstract:
Solar Active Regions play a crucial role in Space Weather prediction. However, forecasting their complete evolution remains challenging due to the underlying dependence on the solar dynamo. Our project aims to understand the evolution of physical parameters of Active Regions over their lifetime, contributing to improved Space Weather prediction and Space Situational Awareness. Active Regions are commonly observed through data sets of single view Magnetograms or Synoptic Maps, which provide a comprehensive surface view and reveal newly emergent magnetic Flux. We study datasets by Mackay (Mackay 2003) and Yeates (Yeates 2016). In such data sets, Active Regions may be defined through a variety of features (encoded as a database entry). These regions may switch between bipolar and multipolar configurations and generally depend on what the original reviewer found relevant. Features chosen and the parameters to calculate them are often subjective, making comparisons between approaches more difficult. To address this challenge and the prediction of parameters of a region, we propose a pipeline that defines bipolar Active Regions in an algorithmic fashion, using a given database and identifies the bipoles in Magnetogram data sets, with an initial focus on synoptic maps. We employ a probabilistic model to match bipoles and form Active Regions based on the information available in the underlying database. Our

approach automatically retrieves physical parameters for individual polarities and the resulting total Active Region. Our pipeline can compare systematic predictions of Active Regions with underlying databases of Active Region parameters. We employ both custom and classical metrics, utilising the provided parameters, system measurements for the same, and probabilistic comparisons between the resulting Active Region and the database statistics. Additionally, strides are taken in linking Active Regions through a sequence of maps (where possible), allowing for headway in the prediction of Active Region evolution to be made.
In this talk, I am presenting the current stage of the work, as well as giving a look into the next steps.

Andrei Macarie

Talk Title: *Post-operative glioblastoma cancer cell distribution in the peritumoural oedema*

Abstract:
Glioblastoma multiforme (GBM), the most aggressive primary brain tumour, exhibits low survival rates due to its rapid growth, infiltration of surrounding brain tissue, and resistance to treatment. One major challenge is oedema infiltration, a fluid build-up that provides a path for cancer cells to invade other areas. MRI resolution is insufficient to detect these infiltrating cells, and despite chemotherapy and radiotherapy, this results in tumour relapses.
In this work, we propose a new multiscale mathematical modelling and computational approach to explore the oedema infiltration and predict tumour relapses. To address tumour relapses, we explored several possible scenarios for the distribution of remaining GBM cells within the oedema after surgery. Furthermore, in this computational modelling exploration, all these tumour relapse scenarios are investigated assuming the presence of clinically relevant chemo-radio therapy. Numerical results suggest that a higher concentration of GBM cells near the surgical cavity edge led to limited spread and slower progression of tumour relapse. Finally, we explore mathematical and computational avenues for reconstructing relevant shapes for the initial distributions of GBM cells within the oedema from available MRI scans. The results obtained show good overlap between our simulation and the patient's MRI scan taken 850 days into the treatment. While still under analytical investigation, this milestone paves the way for robust reconstruction of tumour relapses from available clinical data.

Andrew Fraser

Talk Title: *Computational Analysis of Continuous Glucose Monitoring*

Abstract:
Type 1 diabetes is an autoimmune disease characterised by abnormally elevated blood glucose levels and issues in the manufacturing of the hormone insulin. Continuous Glucose Monitoring (CGM) is a recently introduced technology utilised by type 1 diabetes patients for the measurement of glucose levels. CGM devices produce continuous 24/7 glucose signals.

We analysed CGM signals in the context of (i) comparison of a clinical outcome biomarker HbA1c and its CGM-derived surrogate metric GMI; (ii) Prediction of low glucose events (hypoglycaemia) on a medium timescale (weeks); (iii) Generation of a glucose "circadian ranking" of patients and its' clinical relevance.

Observed disparity between HbA1c and GMI cannot be improved by use of kernel weighting glucose signals but can by employing a patient-specific modelling approach. Much of the benefit of personalised modelling comes from the historical clinical HbA1c record. Prediction of Hypoglycaemia can be performed on a timescale of weeks, with a patient-specific model improving on baseline average models. Patients can be ranked robustly according to how strong a "circadian score" their glucose signals display, but this ranking has limited clinical relevance.

Patient-Specific approaches to CGM signal analysis show better performance compared to population average or baseline approaches. Continued study of CGM glucose signals and their metrics is required to better understand these results. CGM technology is an exciting advance in the diabetes field that motivates more study of personalised medicine and aids the management and research of the disease.