School of Mathematics and Statistics

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MATH01: Petitions as Data

Several countries allow citizens to submit electronic petitions that are considered by the government if they receive enough public support. In the spirit of "text as data", in this project we will consider the publicly available information on these petitions to evaluate the main political topics appearing in these petitions and how they relate to the success of the petitions in gathering signatures. Different machine learning and data science techniques will be employed to collect data, perform text analysis, and characterize the fat-tailed distribution of success of the petitions.

Supervisor(s): Eduardo Altmann
Prerequisites: First year statistics or data science. Comfortable with a programing languages.
Maximum number of places available: 2
Project Location: Hybrid - Regular attendance to our Camperdown Campus is expected, but some of the meetings can take place online.
Regular attendance to our Camperdown Campus is expected, but some of the meetings can take place online (including an initial meeting in January).
Final assessment: Project presentation, 5-10 minutes
Contact: eduardo.altmann@sydney.edu.au

MATH02: What are q-circular arc polygons?

A beautiful result of 19th century mathematics says that, if you take a second order ordinary differential equation that is Fuchsian, then the ratio of two linearly independent solutions maps the real line onto a circular-arc polygon. The aim of the project is to discover an analog of this result where `differential equation' is replaced by `q-difference equation'. In particular, this could lead to the discovery of a q-analog of circular arc polygons.

Supervisor(s): Pieter Roffelsen

Prerequisites: Previous exposure to differential equations and familiarity with (complex) analysis or geometry will be helpful, e.g. through MATH2023: Analysis or MATH3061: Geometry and Topology
Maximum number of places available: 4
Project Location: On site - Carslaw Building, one or two meetings per week
We meet one or two times a week, to discuss and do research.
Final assessment: Project report, 1-2 pages
Contact: pieter.roffelsen@sydney.edu.au

MATH03: Capturing Riemann surfaces through ODEs

An almost forgotten theory by Elfving and Nevanlinna from the 1930s, relates certain linear ODEs with a single singularity to a very special class of non-compact Riemann surfaces. The aim of the project is to bring this theory to life numerically with the end goal of obtaining images of these Riemann surfaces. The pathway to achieve this goal will involve cohesive use of complex analysis, the theory of ODEs and numerics. Given the richness of these Riemann surfaces, the images are expected to be very intricate and dramatic and may lead to new insights.

Supervisor(s): Pieter Roffelsen
Prerequisites: Familiarity with complex analysis is necessary, for example through MATH2023/2923
Maximum number of places available: 2
Project Location: On site - Carslaw Building F07
We will meet about one or two times a week to discuss and do research.
Final assessment: Project report, 1-2 pages
Contact: pieter.roffelsen@sydney.edu.au

MATH04: New data science approaches for single cell spatial genomics

Recent developments in single cell RNA-sequencing and spatially resolved genomics (e.g. seqFISH, 10X Visium) have resulted in immense datasets corresponding to hundreds of thousands of observed cells and thousands of measured features. The overarching goal is to understand these data and develop new data science approaches to addressing questions in biology. There are opportunities to build capacity in terms of computational modelling, effective data visualisation and interaction, and software scalability.

Supervisor(s): Dr Shila Ghazanfar

Prerequisites: DATA2902 or DATA2002 or equivalent Please ensure you have the latest version of R installed.

Maximum number of places available: 2

Project Location: On site - Carslaw and Charles Perkins Centre

Final assessment: Project presentation, 5-10 minutes

Contact: shila.ghazanfar@sydney.edu.au

MATH05: Replacement decisions on implantable cardioverter defibrillator generator

This project aims to optimize the replacement decisions for implantable cardioverter defibrillator generator for patient health. We'll use dynamic programming and/or reinforcement learning to find the solution maximizing the expected patient lifetime.

Supervisor(s): Qiuzhuang Sun

Prerequisites: Comfortable with computers, optimization, and data analysis; familiarity with R or Python; better to know dynamic programming but not strictly required

Maximum number of places available: 3

Project Location: Hybrid - The main task is coding, either online or on-site.

Final assessment: Project report, 1-2 pages

Contact: qiuzhuang.sun@sydney.edu.au

MATH06: Mill degradation prediction with big industrial data

This project aims to use the abundant in-field data to predict degradation of a mill machine. Some covariates for prediction are sampled with extremely high frequency. We'll try both machine learning and statistics tools to analyze the data.

Supervisor(s): Qiuzhuang Sun

Prerequisites: Comfortable with computers and statistical analysis; familiarity with R or Python.

Maximum number of places available: 3

Project Location: Hybrid - The main task is coding, either on-site or online.

Final assessment: Project report, 1-2 pages

Contact: qiuzhuang.sun@sydney.edu.au

MATH07: Post-quantum cryptography

When quantum computers are operational, intruders are expected to be able to use them to easily break systems that currently protect online transactions and national secrets. This project explores mathematical ideas to protect against this looming problem.

Supervisor(s): Nalini Joshi
Prerequisites: Advanced third-year courses in mathematics. They should be comfortable using LaTeX and a symbolic algebra program.
Maximum number of places available: 2
Project Location: on site - F07 Carslaw building
I will provide preliminary reading material in December. I'd like to meet students weekly for an hour and interact online on a collaborative website (called overleaf). I expect to be away for a week in each of January and February.
Final assessment: Project report, 1-2 pages
Contact: nalini.joshi@sydney.edu.au

MATH08: Accurately predicting long-term behaviour of chaotic systems

Chaotic systems are hard to predict the future behaviour of, but they have long-term "ergodic" properties that give us a good probabilistic understanding of how they behave in the long term, such as long-term average distributions, or even the fractal dimension of their limiting sets. In this project, we will look at some in theory very simple (but practically very complex and varied) chaotic systems like the logistic map, and build new computational algorithms that allow us to estimate their ergodic properties very accurately.

Supervisor(s): Caroline Wormell
Prerequisites: Second year linear algebra, familiar with at least one scientific programming language (e.g. Julia, Python, MATLAB, C)
Maximum number of places available: 4
Project Location: hybrid - regular (e.g. weekly) meetings in person on campus.
Students will want to meet in person at least weekly, but most of the work will be coding (or figuring out what to code), which can be done anywhere.
Final assessment: Project presentation, 5-10 minutes
Contact: caroline.wormell@sydney.edu.au

MATH09: Quantum integrable systems

Quantum integrable systems can be classified in simple situations (tori and semi-toric systems). However, most quantum integrable systems are more complicated. The aim of the project is to study examples that go beyond the currently known classification theory.

Supervisor(s): Holger Dullin
Prerequisites: excellent results in MATH3977/4077, comfortable to do some numerics (computation of joint spectrum), probably using Mathematica.
Maximum number of places available: 1
Project Location: hybrid - mix of in-person meetings and the occasional Zoom meeting. Starting with some reading / preparations at the end of the semester in November would be good.
Final assessment: Project report, 1-2 pages
Contact: holger@dullins.de

MATH10: From data to diagnosis: shaping the future of medicine with data-driven approaches

Explore the cutting-edge intersection of statistics, data science and biomedical research by helping my group evaluate data-driven approaches for constructing individual reference intervals for use in personalised medicine. This project offers hands-on experience with R package development, as well as exposure to large-scale, high-dimensional biomedical datasets. Students will engage with domain experts to understand the importance and difficulties of translating complex biological data into actionable insights, all while enhancing their skills in statistical modelling and data visualisation. This opportunity is perfect for those looking to apply their statistics training in real-world medical contexts and make a tangible impact on healthcare.

Supervisor(s): Ellis Patrick
Prerequisites: Comfortable with data analysis and moderate experience with R
Maximum number of places available: 2
Project Location: Hybrid.
It is expected that students nominating this project will be committed to extending themselves and actively want to learn from those around them. They will have the opportunity to work online while also interacting with members of the Sydney Precision Data

Science Centre in the Carslaw Building, The Charles Perkins Centre and The Westmead Institute for Medical Research.
Final assessment: Project presentation, 5-10 minutes
Contact: ellis.patrick@sydney.edu.au

MATH11: Assigning significance with the three-parameter Gamma null

Summary: The three-parameter Gamma distribution (3-Gamma for short) adds a location parameter to the usual shape and scale/rate parameters that define the canonical Gamma distribution. The 3-Gamma is a flexible family of distributions that was empirically found to offer excellent fits to the null distribution of various maximization problems. We are interested in exploring some ideas on how to assign significance to an observed result assuming the underlying null distribution is the 3-Gamma.

Supervisor(s): Uri Keich
Prerequisites: STAT2911, comfortable with R
Maximum number of places available: 2
Project Location: Hybrid
We will have about two meetings per week (could be on zoom) but most of the project will be done by the students on their own.
Final assessment: Project report, 1-2 pages
Contact: uri.keich@sydney.edu.au

MATH12: FDR in mass spectrometry

In a shotgun proteomics experiment tandem mass spectrometry is used to identify the proteins in a sample. The identification begins with associating with each of the thousands of the generated peptide fragmentation spectra an optimal matching peptide among all peptides in a candidate database. Unfortunately, the resulting list of optimal peptide-spectrum matches contains many incorrect, random matches. Thus, we are faced with a formidable statistical problem of estimating the rate of false discoveries in say the top 1000 matches from that list. The problem gets even more complicated when we try to estimate the rate of false discoveries in the candidate proteins which are inferred from the matches to the peptides. We will look at some of these interesting statistical questions that are critical to correct analysis of the promising technology of shotgun proteomics.
Consider this project if you are not averse to computational analysis of large datasets.

Supervisor(s): Uri Keich

Prerequisites: STAT2911 or equivalent, comfortable with R and/or python

Maximum number of places available: 2

Project Location: hybrid (please indicate details below)

flexible

We will have about two meetings per week (could be on zoom) but most of the project will be done by the students on their own.

Final assessment: Project report, 1-2 pages

Contact: uri.keich@sydney.edu.au

MATH13: How large is this knot?

A knot is a curve in space that is closed (in other words, it stops where it began) and never passes through itself. The study of knots is a branch of topology, and a knot is best understood by thinking about the 3-dimensional space around the knot (the complement of the knot). A 3-dimensional space, however, is best understood via interesting surfaces in it. This project studies surfaces in the complements of knots (and other 3-dimensional spaces) which are closed (have no boundary) and are essential (cannot be reduced to a simpler surface). Such surfaces are at the core of most algorithms in 3-dimensional topology.

The study of surfaces in 3-dimensional spaces can be reduced to linear algebra and polytope theory via the theory of normal surfaces. Some vertices of the "normal surface polytope" correspond to essential surfaces.

Algorithms are implemented in the software package Regina that can be used to compute the polytope and check which vertices correspond to essential surfaces.

Aim: This project will undertake a systematic study of the set of all essential normal surfaces in the space of all normal surfaces, with the aim of finding answers to questions such as: Is a simplest essential surface always amongst the vertex surfaces? What is the dimension of a top-dimensional subpolytope that entirely carries essential surfaces? Does the set of essential vertex surfaces span a connected graph in the boundary of the normal surface polytope?

Methods: The participant(s) will learn some basic 3-manifold theory and linear programming, and to use Regina and Polymake to compute and analyse the normal surface polytope.

Supervisor(s): Stephan Tillmann

Prerequisites: Useful background knowledge is second year linear algebra and discrete mathematics. It would also be of benefit if at least one of the participants is comfortable with basic coding in python.

Maximum number of places available: 5

Project Location: On site - Carslaw

The first week features some hands-on introductory sessions with the supervisor. After this, students will learn and discuss background material and conduct research together, with a daily catch-up session with the supervisor.

Final assessment: Project report, 1-2 pages

Contact: stephan.tillmann@sydney.edu.au

MATH14: Topics in geometric topology

The basic objects of geometric topology are curves and surfaces. This project studies them using techniques from geometry, algebra or combinatorics. Some basic questions that may be addressed are: How do you tell two knots apart? How do you tell two surfaces apart? What geometric structures can you put on a given surface?

Supervisor(s): Stephan Tillmann

Prerequisites: Useful knowledge: Second year linear algebra, some combinatorics, a passing knowledge of geometry or topology.

Maximum number of places available: 5

Project Location: on site - Carslaw

Introductory, hands-on sessions with the supervisor give students an overview of the objects and methods of the project. Students will then learn and discuss background material and conduct research together, with a daily catch-up with the supervisor.

Final assessment: Project report, 1-2 pages

Contact: stephan.tillmann@sydney.edu.au

MATH15: Geometric Phase, Torsion, and the Magnetic Confinement of Charged Particles

The torsion of a curve in Euclidean space quantifies how much the curve twists. Geometric phase is a phenomenon that can explain how a cat falling with no angular momentum can still land on its feet. This project will investigate the relationship between the torsion of a curve and the concept of geometric phase to bring insight into how a magnetic field can be shaped to confine a charged particle in a fixed domain of Euclidean space. This has applications to the design of potential fusion reactors called stellarators.

Supervisor(s): Nathan Duignan
Prerequisites: First year core Maths, Second year core Maths. It is necessary to have a strong understanding of differential equations and vector calculus. Taking any of (and ideally all of) MATH3977, MATH3X63, or MATH3968 would greatly help, but is not required.
Maximum number of places available: 2
Project Location: hybrid (please indicate details below)
Weekly meeting on campus in Carslaw at least 2 days of a week. Online otherwise.
Students will be required to meet in person in Carslaw at least 2 days a week. Otherwise, the students will be able to conduct research from anywhere. Most of the research is unsupervised with self-guided learning. If there is more than one student, they will work together to understand and implement mathematical theory while guided by the supervisor.
Final assessment: Project report, 1-2 pages
Contact: nathan.duignan@sydney.edu.au