2022 Honours Projects in Applied Mathematics

This booklet contains descriptions of thesis projects offered for Honours year students in Applied Mathematics. Honours candidates are strongly encouraged to contact their preferred supervisor as early as possible to discuss potential projects and to make sure they have any requisite background knowledge. More information about the Honours year is available by emailing the Applied Mathematics honours coordinator or at
https://www.maths.unsw.edu.au/currentstudents/honours-mathematics-and-statistics.

Mathematical Modelling

Christopher Angstmann

Adelle Coster

- **The insulin signalling pathway in adipocytes: a mathematical investigation.**

The insulin signalling pathway in adipocytes (fat cells) is the main controller of the uptake of glucose in the cells. Understanding of this system is vital in the investigation of diabetes, which is a deficiency in this control system. Projects in this area include the development a mathematical description of the movement of the vesicles (small membrane spheres) containing glucose transporter proteins, and also the diffusion of the proteins if the vesicle fuses with the cell surface, and also the analysis of the biochemical signalling pathway from the insulin receptor. These will involve analysis of differential equations and possibly some computational simulations of the system. Experimental data for comparison with the models will be available

- **Do glucose transporters queue to get to the cell surface?**

Cells transport glucose into their interior via protein channels. In adipocytes (fat cells) glucose uptake is regulated by insulin, as a dynamic balance between exocytosis (outward transport) and endocytosis (inward transport) of the proteins. The proteins are, however, packeted into small vesicles (spheres of membrane) when transported. One characterisation of the observed transport behaviour utilises queueing theory. This idea stems from the presence of the microtubules that cross the cytoplasm of the cells. Microtubules are implicated in the sorting of different endocytic vesicular contents and have well characterised molecular motors which control the movement of vesicles down their lengths. Vesicles carrying the proteins have been observed to be transported along microtubules. Could these act as a scaffold for the vesicles, which would then form queues waiting for exocytosis? This project will model the recycling system as a closed Markovian queueing network and explore what characteristics of the network may be responsible for the transitory behaviour when insulin is applied, initiating protein transport. Experimental data for comparison will be available and the investigation will have both theoretical and computational aspects.

- **Modelling of drug epidemics**

In recent years, use of methamphetamine has grown rapidly. It’s a dangerous drug for the user and those with whom they interact. At present we have no working model of the methamphetamine epidemic that could be used to explore various policy options to deal with the epidemic or simply project its likely course. This project will explore different models developed for drug use and develop a credible model of the methamphetamine epidemic in Australia. This work would be jointly supervised by Prof Don Weatherburn at the National Drug and Alcohol Research Centre.

- **Recidivism in the Criminal Justice System**

Researchers are often called upon to evaluate programs designed to reduce the rate of re-offending. Typically, however, there are not observations of every offence a person commits, but rather only for those that result in an arrest or a conviction. How big a change would you need in actual re-offending rates to see a measurable difference in re-arrest or re-conviction rates? What interventions could be made, and what would be their effects? The investigation will look at different mathematical approaches to model this problem and intervention strategies.
This work would be jointly supervised by Prof Don Weatherburn at the National Drug and Alcohol Research Centre.

- **Modelling Myelinated Nerve Function.**

Pacemaking in cardiac and neuronal cells is primarily controlled by the interaction between different voltage gated ion channels. An existing mathematical model of the human motor axon utilises coupled differential equations to describe the electrical activity within the nerve. This model will be explored to interpret the measured responses to extended hyperpolarisation and the contribution of different ion currents to the transmission of signals. It will also investigate the responses of sensory neurons to strong longlasting hyperpolarisation and contrast with motor neurons. Extensions to the model will then be made to incorporate additional inhomegeneities within the neuron structure. This project will include analysis and development of coupled differential equations, numerical simulations and the optimisation of the model using data from the experimental literature.

Gary Froyland

- **Lagrangian coherent structures in haemodynamics**

Haemodynamics (the dynamics of blood flow) is believed to be a crucial factor in aneurysm formation, evolution, and eventual rupture. Turbulent motion near the artery wall can weaken already damaged arteries, as can oscillations between turbulent and laminar flow. Simulations of 3D blood flow is either derived by (i) computational fluid dynamics (CFD) from patient-specific mathematical models obtained from angiographic images or (ii) laser scanning of real flow through a patient- specific physical plastic/gel cast. In this project, joint with Prof. Tracie Barber (UNSW Mech. and Manufact. Engineering), you will apply the latest mathematical techniques for flow analysis, based on dynamical systems and elliptic PDEs to separate and track regions of turbulent and regular blood flow. Prof. Barber will provide the realistic flow data from her laboratory, from both CFD simulations and physical casts. There is also the opportunity to further develop mathematical theory to solve problems specific to haemodynamics.

Michael Watson

- **Modelling Phagocytic Capacity in Atherosclerotic Plaque Macrophages**

Atherosclerosis, the primary cause of heart attacks and strokes, is characterised by the growth of plaques in the walls of arteries. Plaques are initiated by so-called “bad cholesterol", which accumulates in the artery wall and triggers an immune response. Macrophages (specialised immune cells) are subsequently recruited to consume (phagocytose) and remove this cholesterol. However, when cholesterol-loaded macrophages die in the artery wall, the problem remains unresolved. This stimulates further macrophage recruitment, and, if the non-resolving state persists, a plaque full of fat and cellular debris develops. Plaque formation can be studied mathematically by modelling how fat is accumulated and recycled within a macrophage population. This involves the use of structured population models, in which macrophages are classified by their internalised fat content. Recent models of this type assume that there is no upper limit to how much fat a macrophage can internalise. While this assumption is mathematically convenient, it is clearly physically unrealistic (not least because internalised cholesterol has well-known cytotoxic effects). This project will develop new models that include an upper limit on macrophage phagocytic capacity. Based on both biological and mathematical considerations, a range of ways to impose this limit will be considered. The project will analyse and computationally solve differential equation models and will aim to understand the implications of macrophage phagocytic capacity for real life atherosclerotic plaques. Note that other projects related to atherosclerotic plaque modelling may also be available.

Amandine Schaeffer

- **Gene thieves: how a nudibranch incorporates the stinging cells of the Bluebottle jellyfish (co-supervision Fabio Zanini, Fabilab).** More info here.

Computational Mathematics

Josef Dick

- **Well distributed points in high dimension with applications to numerical integration**
- **Generation of non-uniform quasi random numbers**
- **Approximation properties of neural networks**

Gary Froyland

- **Operator-theoretic and differential-geometric kernel methods for machine learning**

This project will develop new mathematical and computational approaches to analyse high-dimensional data. Operator-theoretic methods will be explored, including the use of transfer operators, dynamic Laplace operators, and Laplace-Beltrami operators, which extract dominant dynamic and geometric modes from the data. In the theoretical direction, this project will tackle the mathematisation of aspects of machine learning. In a combined theoretical and numerical direction, this project will investigate the construction of these operators from high-dimensional data using dynamic and geometric kernel methods. A possible application is to analysing global scalar fields obtained from satellite imagery such as sea-surface temperature to extract climate oscillations such as the El Nino Southern Oscillation and the Madden-Julian Oscillation. This project will use ideas from dynamical systems, functional analysis, and Riemannian geometry.

Frances Kuo

- **The theoretical development and/or practical application of Quasi-Monte Carlo methods**

Quasi-Monte Carlo methods, or QMC methods in short, are numerical methods for high dimensional integration and related problems. The prefix “quasi” indicates that these methods rely on cleverly designed pointsets or sequences in high dimensions, as opposed to the regular Monte Carlo method which is based on sequences of pseudorandom numbers. We now know how to construct good QMC methods efficiently in thousands of dimensions, with fast error convergence independently of dimension! A potential honours project would be on the theoretical development and/or practical application of QMC methods.

Quoc Thong Le Gia

- **Approximate cloaking simulation**
- **Analysis of changing data and applications**
- **Long Short-Term Memory network and its applications**

In machine learning, artificial neural networks are popular and effective algorithms that have many applications ranging from image recognition to simulations of financial markets. There are a few types of popular neural networks based on their structures, namely fully connected neural network (FCN), convolutional neural network (CNN) and long short-term memory network (LSTM).

In this project, we will investigate the structure of long short-term memory network and its use in the problem of portfolio optimization.

Bill McLean

- **Hierarchical Matrices**
- **Approximating the fractional powers of an elliptical differential operator**
- **Adaptive error control using discontinuous Galerkin time stepping**

Thanh Tran

- **The role of the Landau-Lifschitz equation in micromagnetism**

One of the hallmarks of modern society is the increasing demand for the large data storage which can be rapidly and efficiently accessed. The most important devices for information storage are magnetic memories which are used in, for example, mobile phones, credit cards, televisions, and computer hard drives.

Submicron-sized ferromagnetic elements are the main building blocks of data storage devices. They preserve magnetic orientation for a long time, allowing bits of information to be encoded as directions of the magnetisation vector. The stored information can be modified by an external magnetic field.

A well-known model for magnetisation is the Landau-Lifshitz-Gilbert equation. The equation possesses complex mathematical properties such as nonconvex side-constraints, strongly nonlinear terms and the appearance of singularities. These properties demand sophisticated numerical approximations.

In this project you will learn different numerical methods to solve the equation. Depending on your needs and interests, there are open problems to cut your teeth on.

- **Stochastic differential equations**

In this project, you will learn how different basic numerical methods are developed for stochastic differential equations. You will then learn how to apply them to solve practical problems and compare the performance of the methods.

- **Problems in random domains**

In many industries (e.g., in aerospace engineering) random discrepancies between the ideal geometries conceived in the design phase and their actual realisation may lead to considerable variations in expected outcomes.

The effect of randomness in domains is even more dramatic in manufacturing of nano-devices (e.g. data storage devices governed by the Landau-Lifshitz-Gilbert equation). Indeed, under certain resolution, surfaces of these devices become rough, and a minor discrepancy results in relatively large adverse effects. In this project you will learn how shape calculus can be used to deal with problems on random domains.

- **Boundary element methods**

Boundary element methods have long been used in engineering to solve boundary value problems. These problems are formulated from many physical phenomena, ranging from mechanical engineering (e.g. in car design) to petroleum engineering (e.g. for simulation of fractured reservoirs).

In this project, you will first learn basic concepts of boundary element methods, how to implement and analyse efficiency and accuracy of the methods. Then, depending on your needs and interests, you will use the methods to solve practical problems in engineering or geodesy. Problems in geodesy will involve programming with data collected by a NASA satellite, which may contain up to almost 30 million points.

Jan Zika

- **Truncating climate errors: Developing new methods to improve how numerical climate models describe fluid flow and improve their projections of global warming.**

Fluid Dynamics, Oceanography and Meteorology

Gary Froyland

- **Lagrangian Coherent Structures in Ocean and Atmosphere Models**

The ocean and atmosphere display complex nonlinear behaviour, whose underlying evolution rules change over time due to external and internal influences. Mixing processes of in the atmosphere and the ocean are also complex, but carry important geometric transport information. Using the latest models or observational data, and methods from dynamical systems, and elliptic PDEs, this project will identify and track over time those geometric structures that mix least. Known examples of such structures are eddies and gyres in the ocean, and vortices in the atmosphere, however, there are likely many undiscovered coherent pathways in these geophysical flows. There is also the possibility for the project to further develop mathematical theory and/or algorithms to treat one or more specific challenges arising in these application areas. This could a joint project with Mark Holzer or Shane Keating.

Mark Holzer

- **Modelling and analysis of ocean biogeochemistry**

- **Construction of matrix models for geophysical flows**
- **Modelling of turbulent transport**

Shane Keating

- **Simulating fractal curves in turbulent fluids**

Material immersed in a turbulent fluid, such as oil, chlorophyll or dye, will be stirred and deformed into strikingly beautiful fractal-like filaments and curves. The geometry of these curves has a strong influence on how quickly the material is mixed and diffused throughout fluid. However, numerical models of turbulence often lack the computational power to fully resolve the dynamics of these curves and must represent or "parameterize" the average effect of the flow on the material using simplified models,

In this project you will explore a novel approach to parameterizing mixing in a turbulent fluid using a stochastic method to simulate fractal curves directly. The geometry of these curves will the be used to estimate the diffusion of material by the turbulent fluid. Strong coding ability with Matlab or Python is required.

- **Ocean current velocimetry from ultra-high resolution satellite imagery**

Particle image velocimetry (PIV) is a widely used technique for measuring flow velocities by tracking features in sequential images.

In this project, we will test the feasibility of using PIV to estimate ocean currents at the surface of the ocean from satellite images of sea-surface temperature. Knowledge of satellite remote sensing and ocean dynamics is not required, but strong computational ability in Matlab or Python is a must.

- **Fluid transport by vortex ring entrainment**

Vortices are rotating bodies of fluid that remain coherent for long periods, and are frequently observed in the atmosphere, ocean, and in laboratory experiments. Observations and simulations of vortices indicate that they are important for transporting properties such as heat, biological material, or pollutants over large distances.

While some fluid is transported by the core of the vortex, there is also transport due to ambient fluid that is captured or "entrained" within the outer ring and then travels with the vortex as it propagates. In this project, we will examine transport by entrainment of fluid in the vortex ring, or of multiple vortex rings. Experience with Python is required.

- **Fluid dynamics of cycling peloton formation**

In competitive cycling, a "peloton" is a group of riders that travels together in formation in order to reduce drag and save energy. The shape of the peloton will change depending on headwind and sidewind and the strategy of individual riders or teams of riders.

In this project, we will study the fluid dynamics of cycling pelotons and investigate how collective behaviour of cyclists can lead to peloton formation under different scenarios. No fluid dynamics knowledge is required, but Python programming experience is essential.

Trevor McDougall

Moninya Roughan

- **Characterising marine extremes along the coast of southern NSW**

The oceans along southern NSW are warming at some of the fastest rates on earth. Using long time series of in situ (measured) ocean temperature data we will explore the statistical characteristics, structure and drivers of marine extremes on the southern NSW shelf. Some knowledge of Python or Matlab and some basic statistics is as well as a keen interest in the ocean is required.

- **Watermass characteristics of eddies in the Tasman Sea**

The Tasman Sea is an ocean warming hotspot, and eddies are transporting more heat poleward, yet recent results showed that eddies (large rotating bodies of water) were freshening but not warming. We will use sub surface temperature and salinity data from autonomous profiling floats to explore the characteristics of extreme (warm and cold) Tasman Sea eddies and understand the nuances derived from the spatial structure and distribution of the eddies. Some knowledge of Python or Matlab and some basic statistics is as well as a keen interest in the ocean is required

Chris Tisdell

- **Exploring the theory of Navier-Stokes equations and their applications to fluid flow**

Navier-Stokes equations are of immense theoretical and physical interest. These partial differential equations have been used to better understand the weather, ocean currents, water flow in a pipe and air flow around a wing. However, the theory of the equations has not yet been fully formed. For example, it has not yet been proven whether solutions always exist in three dimensions and, if they do exist, whether they are smooth - i.e. they are infinitely differentiable all points in the domain. The Clay Mathematics Institute has identified this as one of the seven most important open problems in mathematics and has offered a US$1 million prize for a solution or a counterexample.

In this project we will examine existence and smoothness of solutions to problems derived from the Navier-Stokes equations that arise in laminar fluid flow in porous tubes and channels. Channel flows - liquid flows confined within a closed conduit with no free surfaces - are everywhere. In plants and animals, they serve as the basic ingredient of vascular systems, distributing energy to where it is needed and allowing distal parts of the organism to communicate. In engineering, one of the major functions of channels is to transport liquids or gases from sites of production to the consumer or industry. Such a project will involve the nonlinear analysis of boundary value problems and some numerical approximations.

Amandine Schaeffer

Jan Zika

- **Novel machine learning and optimisation techniques to characterise the ocean and provide a blueprint for quantifying the ocean's role in a changing climate.**
- **How does heat get into the ocean? An investigation of the physical mechanisms that control the ocean's uptake of heat and its effect on climate.**
- **Making climate models work better: Developing new methods to validate and improve the inner workings of numerical climate models and improve their projections of global warming and its impacts.**
- **Will it mix? New perspectives on turbulence in rotating fluid flows and how we estimate mixing from observations.**

Mathematics Education

Chris Tisdell

- **Improving the ways we teach and learn mathematics**

Research into learning and teaching mathematics at universities is a relatively new and sub-optimally theorized field. It has largely remained sheltered from critical debate due to dominant views of mathematics and its teaching as a universal, absolute and unchanging state within tertiary institutions. As such, inherited long-standing ways of teaching and learning therein have gained a lustre of naturalized value, forming what appears to be a state of global pedagogical agreement.

Responding to this over-stabilization, this project explores the following research questions:

1. What are the limitations and hidden consequences of traditionally dominant pedagogy within university mathematics education?
2. How might we constructively reframe and renew these situations by offering alternative pedagogical perspectives?

Dynamical Systems

Christopher Angstmann

Gary Froyland

- **Topics in dynamical systems, ergodic theory, and differential geometry**

Ergodic theory is the study of the dynamics of ensembles of points, in contrast to topological dynamics, which focusses on the dynamics of single points. A number of theoretical Honours projects are available in dynamical systems, ergodic theory, and/or differential geometry, aiming at developing new mathematics to analyse the complex behaviour of nonlinear dynamical systems. Depending on your background, these projects may involve mathematics from Ergodic Theory, Functional Analysis, Measure Theory, Riemannian Geometry, Stochastic Processes, and Nonlinear and Random Dynamical Systems.

- **Differential and spectral geometry with applications to fluid mixing.**

Techniques from differential geometry and spectral geometry (via Laplace-type operators) have recently been shown to be particularly effective for analysing complex dynamics in a variety of theoretical and physical systems. This project will focus on developing and extending powerful techniques to extract important geometric and probabilistic dynamical structures from fluid-like models. If desired, application areas include the ocean (an incompressible fluid) and the atmosphere (a compressible fluid). This project will involve dynamical systems, differential geometry, and PDEs.

- **Stability of linear operator cocycles.**

Classical perturbation theory yields continuity of the spectrum and eigenprojections of compact and quasi-compact linear operators. The situation is dramatically different when one creates a cocycle of different operators, driven by some ergodic process. This dramatic difference even occurs in finite-dimensions (cocycles of matrices). This project will discover theory for which one can expect continuity of the corresponding spectral objects, namely Lyapunov exponents and Oseledets spaces. The project will use mathematics from probability and statistics, functional analysis, and connects to dynamical systems and ergodic theory.

- **Extreme value statistics for chaotic systems.**

Accurately estimating the probability of rare events is particularly challenging in models with long memory, such as systems with a high level of determinism and a low level of randomness. This project will develop mathematical theory and accurate, rigorous numerical schemes to handle such systems. The project will also apply these new methods to estimate the likelihood of rare events from real data. The project will use mathematics from probability and statistics, functional analysis, and connects to dynamical systems and ergodic theory.

- **Transfer operator computations in high dimensions.**

Many real-world dynamical systems operate in phase spaces that are very high dimensional and/or unknown. For example, the dynamics of ocean-atmosphere circulation at various spatial and temporal scales (e.g. from local weather to global climate) is invariable extremely high dimensional. On the other hand, there is increasing availability of spatial datasets from e.g. satellite imagery, which provide high resolution spatial images as ``movies'' in time. One can hope to construct dynamics of a projected system from the dynamics of these images, which are themselves operating in a high-dimensional space (dimension >= number of pixels in the image). This project will investigate recent ideas in constructing transfer operator for high-dimensional systems, and use ideas from dynamical systems, stochastic processes, functional analysis, and Riemannian geometry.

John Roberts

- **Algebraic dynamics**
- **Discrete integrable systems**

Wolfgang Schief

- **Topics in Soliton Theory**

Solitons constitute essentially localised nonlinear waves with remarkable novel interaction properties. The soliton represents one of the most intriguing of phenomena in modern physics and occurs in such diverse areas as nonlinear optics and relativity theory, plasma and solid state physics, as well as hydrodynamics. It has proven to have important technological applications in optical fibre communication systems and Josephson junction superconducting devices.

Nonlinear equations which describe solitonic phenomena (`soliton equations' or `integrable system') are ubiquitous and of great mathematical interest. They are privileged in that they are amenable to a variety of solution generation techniques. Thus, in particular, they generically admit invariance under symmetry transformations known as *Bäcklund transformations* and have associated nonlinear superposition principles (*permutability theorems*) whereby analytic expressions descriptive of multi-soliton interaction may be constructed. Integrable systems appear in a variety of guises such as ordinary and partial differential equations, difference and differential-difference equations, cellular automata and convergence acceleration algorithms.

It is by now well established that there exist deep and far-reaching connections between integrable systems and classical differential geometry. For instance, the interaction properties of solitons observed in 1953 by Seeger, Donth and Kochendörfer in the context of Frenkel and Kontorova's dislocation theory and later rediscovered by Zabusky and Kruskal

(1965) in connection with the numerical treatment of the important Fermi-Pasta-Ulam problem are encoded in the geometry of particular classes of surfaces governed by the sine-Gordon equation and Korteweg-de Vries (KdV) equation respectively. The geometric study of integrable systems has proven to be very profitable to both soliton theory and differential geometry.

Integrable systems play an important role in *discrete differential geometry*. The term `discrete differential geometry' reflects the interaction of differential geometry (of curves, surfaces or, in general, manifolds) and discrete geometry (of, for instance, polytopes and simplicial complexes). This relatively new and active research area is located between pure and applied mathematics and is concerned with a variety of problems in such disciplines as mathematics, physics, computer science and even architectural modelling. Specifically, theoretical and applied areas such as differential, discrete and algebraic geometry, variational calculus, approximation theory, computational geometry, computer graphics, geometric processing and the theory of elasticity should be mentioned.

Soliton theory constitutes a rich source of Honours topics which range from applied to pure. Specific topics will be tailored towards the preferences, skills and knowledge of any individual student.

Chris Tisdell

- **Advanced Studies in differential equations**

Many problems in nonlinear differential equations can reduced to the study of the set of solutions of an equation of the form f(x) = p in an appropriate space. This project will give the student an introduction to the applications of analysis to nonlinear differential equations. We will answer such questions as:

1. When do these equations have solutions?
2. What are the properties of the solution(s)?
3. How can we approximate the solution(s)?

A student who completes this project will be well-prepared to make the transition to research studies in related fields.

- **A Deeper Understanding of Discrete and Continuous Systems Through Analysis on Time Scales**

Historically, two of the most important types of mathematical equations that have been used to mathematically describe various dynamic processes are: differential and integral equations; and difference and summation equations, which model phenomena, respectively: in continuous time; or in discrete time. Traditionally, researchers have used either differential and integral equations or difference and summation equations | but not a combination of the two areas to describe dynamic models. However, it is now becoming apparent that certain phenomena do not involve solely continuous aspects or solely discrete aspects. Rather, they feature elements of both the continuous and the discrete. These types of hybrid processes are seen, for example, in population dynamics where non-overlapping generations occur. Furthermore, neither difference equations nor differential equations give a good description of most population growth. To effectively treat hybrid dynamical systems, a more modern and flexible mathematical framework is needed to accurately model continuous, discrete processes in a mutually consistent manner.

An emerging area that has the potential to effectively manage the above situations is the field of dynamic equations on time scales. Created by Hilger in 1990, this new and compelling area of mathematics is more general and versatile than the traditional theories of differential and difference equations, and appears to be the way forward in the quest for accurate and flexible mathematical models. In fact, the field of dynamic equations on time scales contains and extends the classical theory of differential, difference, integral and summation equations as special cases. This project will perform an analysis of dynamic equations on time scales. It will uncover important qualitative and quantitative information about solutions; and the modelling possibilities. Students who undertake this project will be very well equipped to make contributions to this area of research.

- **Advanced Studies in Nonlinear Difference Equations**

Difference equations are of huge importance in modelling discrete phenomena and their solutions can possess a richer structure than those of analogous differential equations. This project will involve an investigation of nonlinear difference equations and the properties of their solutions (existence, multiplicity, boundedness, etc). Students who complete this project will be very well-equipped to contribute to the research field.

Optimisation

Gary Froyland

- **Efficient optimisation methods for optimal transport.**

Optimal transport concerns the transformation of one probability distribution into another with least cost. The theory of optimal transportation involves connections between optimisation, Riemannian geometry, and measures/probabilities. A key practical aspect is determining the optimal transport transformation, or at least the cost of this optimal transformation. This project will explore highly efficient techniques to determine optimal costs for transportation on large or high-dimensional domains.

- **Optimising fluid mixing.**

Combining techniques from dynamical systems and optimisation, this project aims to develop new mathematical algorithms and practical strategies for enhancing or controlling mixing in fluids, with applications in environmental (e.g. biology or pollution) and industrial settings. The project will use mathematics from optimisation, dynamical systems, functional analysis, and probability.

- **Topics in integer programming and combinatorial optimisation.**

Integer programming is a mathematical framework for solving large decision problems. Usually there is some underlying discrete structure for the problem such as a network or graph. You will learn new mathematical techniques in discrete mathematics, algebra, and geometry. If desired, application areas may include public or private transport modes in urban environments, medical imaging, scheduling airlines, rail, or mining processes.

- **Stochastic integer programming.**

Almost all real-world models have significant uncertainty in their measured data. A naive approach is to replace probability distributions of data with their mean value and create a single deterministic model. However, optimising this deterministic model typically results in decisions that are far from optimal. In order to make better decisions, the underlying probability distributions must be properly incorporated into the optimisation process. This is the aim of stochastic programming. The aim of this project is to develop rigorous optimization methods that include uncertainties in the forecast data and evaluate all possible options in light of the latest information. Familiarity with probability theory is essential. If desired, application areas may include scheduling airlines, rail, traffic, or mining processes.

Jeya Jeyakumar

- **Robust Optimization Approaches to Feature Selection in Machine Learning**

This project will examine Difference of Convex (DC) optimization approach to optimally choose representative features in data while constructing a support vector machine classifier simultaneously.

Guoyin Li

Vera Roshchina

Jan Zika

- **Novel optimisation techniques to quantify the ocean's role in climate.**

Joint projects

Elise Payzan (elise@unsw.edu.au)
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- **Using biofeedback to improve financial trading? A neurofinance study.**

It is well known that financial trading is like modern war fighting or police shooting in high-risk contexts: its success hinges on high-speed adaptability to cope with sudden unexpected changes (the so-called "jumps" or "regime shifts" in finance), which in turn hinges on managing emotion. It is however not known what "managing emotion" means, despite the immense interest of the question to both behavioural finance scholars and investors in the field. The sole focus so far has been on "down-regulating" (i.e., minimizing) emotion, following the old cartesianist viewpoint of emotion as unnecessary and disruptive, despite growing evidence from decision neuroscience that this view is faulty and emotion is actually needed for optimal decision-making, even if it is ambivalent (like with everything in life, too much hurts). This suggests that instead of minimising emotion, traders ought to optimise emotion, which leaves us with the challenge of determining the optimal level of emotional arousal for a given trader in a given time and context. This project sets out to do this, by building a full-blown live financial decision support device to help traders regulate their emotional arousal in real-time through biofeedback (henceforth, "BioFS"), and testing it in a laboratory experiment. The latter will involve modelling optimal behaviour in a computerised financial trading task recently designed to capture the foregoing key aspect of trader decision-making, namely, high-speed adaptability. Optimal behaviour in the task will be studied in simulations and then compared to the behaviour of task participants who will perform one run of the task at UNSW Business School Experimental Laboratory (BizLab).
This project is in the domain of computational neuroeconomics and has a highly interdisciplinary nature, bridging finance and cognitive sciences to the computer sciences and applied mathematics. The successful candidate will work in close collaboration with academic members whose core expertise is in "neurofinance" (neurology and psychology applied to financial decision-making) and computer science.

Pre-requisites: Programming knowledge in Matlab or Python Knowledge of mathematical modelling and statistics.
Topic area:
Finance, Applied Mathematics / Computer Science, Psychology

Prof Jamie Vandenberg at the Victor Chang Cardiac Research Institute.

- **Modelling electrical communication and synchronisation in cardiac networks**

The rhythmic contraction and relaxation of the heart is controlled by a high-fidelity electrical communication system. Abnormalities of electrical signalling are a major cause of morbidity (atrial fibrillation) and mortality (sudden cardiac death). This project will model the effects of network connectivity on the speed and efficacy of communication and synchronisation between coupled cardiac cells. This will involve dynamical systems modelling, development of simulations and analysis of the effects of the network complexity. This work would be jointly supervised by Prof Jamie Vandenberg at the Victor Chang Cardiac Research Institute. Please contact Adelle Coster: A.Coster@unsw.edu.au.