Project Titles

Spreading wavefronts
A range of quite different phenomena can sometimes be characterised as a wavefront spreading into new regions. Examples include tsunamis, the population density of an invasive species, the cancer cell density in a spreading solid tumour, and the temperature profile in a bushfire. This project will focus on numerical solutions of partial differential equations modelling one or more of these phenomena in order to determine how fast the front is spreading. This project has applicability in for example understanding the factors leading to a rapid spread of cancer, or in evaluating how some intended treatment may mitigate its spread. Prerequisites: a second-year differential equations course, and strong programming capability in Matlab.

Characterising chaos
This project will study the concept of chaos from a mathematical viewpoint. Qualities which characterise chaos (e.g., sensitive dependence on initial conditions, presence of periodic orbits of all periods, uncountably many aperiodic orbits, and dense orbits) will be studied. Methods for analytically proving that a system is chaotic (presence of a “horseshoe,” intersection of stable and unstable manifolds, Melnikov’s method) will be applied to different systems arising in applications. Prerequisites: a second-year differential equations course and an interest in theoretical methods of differential or difference equations.

Chaotic transport
In fluid systems which have chaotic fluid particle trajectories, the issue of quantifying the resulting chaotic transport has applications in, say, designing optimal micromixers and quantifying heat flux in the ocean. This project will review methods for quantifying chaotic transport, including Lyapunov exponents, lobe areas and a time-dependent flux, and perform numerical computations to establish connections between these methods. Prerequisites: a second-year differential equations course, and programming capability in Matlab.

Unsteady flow barriers
In unsteady (time-varying) flow fields, there are usually important invisible flow barriers which move with time. Examples include the boundary of an area (“the forbidden zone”) near the coast of Florida into which the Deepwater Horizon oilspill did not leach, and the edge of the Antarctic Circumpolar Vortex (“the ozone hole”). This project will focus on understanding and using recently developing methods for identifying such flow barriers, and (depending on student background) will choose from George Haller’s methods of curves of maximal attraction, Gary Froyland’s transfer operator methods and/or Jean-Luc Thiffeault’s topological complexity of curves method. Prerequisites: a second-year differential equations and fluid dynamics course, plus either a strong theoretical mathematics or programming background.

I am also open to topics in other areas, to be agreed upon after discussion with me.

Supervisor: Dr Sanjeeva Balasuriya

I am happy to discuss possible topics for a research project in areas such as differential geometry, topology and complex analysis.

Supervisor: Dr David Baraglia

I am happy to supervise projects in the areas of finite geometry and combinatorics. Interested students can email me to arrange a meeting and we can discuss possible project ideas.

Supervisor: Dr Susan Barwick
**Stochastic Modelling using Structured Markov Chains**

In this project we will investigate the mathematical properties of some very recent stochastic models. These models have been developed from the basic principles used in a field known as "Matrix-analytic Methods" (or MAM) where simple exponentially distributed lifetimes are replaced by lifetimes from more complex distributions. When done carefully, the analysis of the whole model becomes matrix-based, rather than scalar-based, hence the name. Of course, this brings all sorts of challenges (for example, the square root operation no longer makes any sense) and requires a much closer connection to the physical model itself. This, and an associated emphasis on computational algorithms, are the main features of this area of stochastic modelling.

**Supervisor:** Professor Nigel Bean

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**Wave propagation in random media**

Even the most simple wave problems become non-trivial and produce interesting behaviours when randomness is introduced. Students can investigate the effects of different types of randomness and in different settings, using numerical and/or analytical techniques.

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**Modelling sea ice dynamics & thermodynamics**

Climate change is weakening and fragmenting the sea ice that covers vast areas of the Arctic Ocean. An important consequence is that the ice cover is now far more dynamic, and has more potential to melt in the summer and grow in the winter. Students can undertake a project to investigate this phenomenon.

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**Mathematical and experimental modelling**

Combining mathematical and experimental models is a powerful way to accurately model real world phenomena. Students can conduct a project to develop a mathematical model of water waves and conduct simple wave tank experiments to validate the model.

**Supervisor:** Dr Luke Bennetts

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**Quantifying and modelling yeast colony spatial patterns**

Yeasts colonies can forage for food by either the process of filamentous growth, or the formation of a biofilm. Both are highly non-uniform spatial-temporal processes, often producing complex spatial patterns. The overall goal of this project is to develop models that predict the time evolution of colony morphology. However, an important part of this work is the spatial quantification of yeast growth experiments, which can be used to validate modeling predictions. Therefore, one of our aims is to develop user-friendly open source software that can process experimental images and provide metrics on the spatial patterning of colony morphology. The second aim is the modeling itself, and both continuum and discrete approaches could potentially be explored during the course of the project. The data for the statistical analysis and model validation will be obtained from laboratory experiments.

**Supervisor:** Dr Ben Binder

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**Evolution of life cycles in multicellular collectives**

Simple multicellular collectives, such as chains of bacteria, are of interest because they are the starting point for all further multicellular evolution. The emergence of life cycles and basic developmental processes are key steps in multicellular collectives becoming fully-fledged organisms. This project will involve using stochastic techniques to build models of these biological systems. These will then be studied using a combination of analytic and simulation methods.
Inference methods for epidemic models

A crucial part of epidemic modelling is to characterise a disease in the early stages of an outbreak so as to inform public health policy and implement measures to slow its spread. This project will involve learning methods for computational Bayesian analysis and applying them to household models of influenza.

**Supervisor:** Dr Andrew Black

All things considered, what is the optimal direction in which to point a solar panel?

This project could be tackled by a student who has done Maths I. The degree of difficulty is really up to the person undertaking the project, as there are many issues that could be taken into consideration—for example, the efficiency of solar panels depending on their temperature; the amount of dust in the atmosphere depending on the time of year; etc. With very basic assumptions, the problem should not be too hard.

How would we calculate the intrinsic distance between two points on a surface?

This project could be tackled by a student who has done Multivariable & Complex Calculus and Real Analysis. There are various issues to be considered, such as how we define the length of a curve; how we might find a curve that minimizes arc length (geodesics); how we might solve the differential equations for a geodesic.

The Dirichlet problem.

The classical Dirichlet problem is that of finding a function with specified boundary values whose Laplacian is some given function. Proving the existence of such a solution is technically quite difficult, but it serves as a prototype for solving many problems in analysis. This project would be appropriate for someone who has done the course Integration & Analysis III

**Supervisor:** Dr Nicholas Buchdahl

Nanoscaled oscillating systems

Nanoscaled structures such as carbon nanotubes and fullerenes undergo interactions described by van der Waals forces. At very small scales these interactions can lead to extreme accelerations, velocities and, in the case of oscillating systems, frequencies. By modelling the structures as surfaces with uniform atomic densities and the van der Waals interactions using a 6-12 Lennard-Jones potential, we can make predictions regarding these systems including deriving a formula for the frequency which is in good agreement with molecular dynamics simulations. In this project the student will look at models to calculate the force and predict the behaviour of various oscillating systems.

**Geometries and geometric issues of nanostructures**

It is clear from the various structures seen at the nanoscale that the complex interactions of these structures often lead to symmetric conformations. So in satisfying a minimum energy constraint the system often adopts a symmetric structure that shares the energetic costs of bending and stretching covalent bonds equally to all components in the structure. By assuming a symmetric conformation up front, it is possible to reduce fundamentally complex problems of molecular structure to problems with are more mathematically tractable and thereby derive results which can be confirmed by experiment and simulation and can also be used to predict ideal systems and novel structures in certain extreme cases. In this project the student will study models for nanostructures such as nanotubes, cones and spheres.
(buckyballs) with the aim to provide more precise predictions of structural parameters like length and radius.

**Supervisor:** Dr Barry Cox

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**Interactions between cells in tissues and individuals in groups**

The collective behaviour of animals in swarms, or cells in tissues, is governed by the interactions between the individuals in the group. We can use mathematical models to understand how different types of inter-individual interaction lead to different arrangements of cells in tissues, or movements of swarms. These models can be computational agent-based models, in which individual cells or organisms are represented, or systems of partial differential equations for the densities of each species, which can be investigated using a combination of analytical and numerical methods. The student is welcome to choose whichever approach best suits their interests.

**Supervisor:** Dr Edward Green

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**The Classical Groups**

The classical matrix groups are defined as invariance groups of certain multilinear maps on real, complex and quaternionic vector spaces. The aim is to study them as curved spaces within the vector space of n-by-n matrices and to establish some of the interesting relations between them that exists for small n. Further exploration can be related to topological properties of the classical groups or to the quotient spaces arising from them.

**Quaternions and Octonions**

In a similar way how the complex numbers are constructed from the reals, the quaternions are constructed from the complex numbers and the octonions from the quaternions. Thus, both can be considered as generalisations of complex numbers to higher dimensions. Many interesting algebraic and geometric phenomena are related to the quaternions and octonions. To explore these features and relations is the aim of the project.

**Other possible projects**

Apart from these two topics I am happy to discuss any topic that is related to differential geometry.

**Supervisor:** Dr Thomas Leistner

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**Studying humans ‘in the wild’ via social networks and Big Data**

With the explosion in recent times of data from large-scale social networks such as Facebook, Reddit and Twitter comes unprecedented opportunities to bring quantitative and computational methods to bear on problems in social, cultural and political science. This emerging field of computational social science blends mathematical and statistical techniques with computer science and very large data sets to study and predict the behaviours of groups of people based on their online activities — by observing them ‘in the wild’.

We will use millions of geolocated messages from Twitter to investigate peoples’ engagement with cultural events at a range of scales, from watching television to participating in national elections, and to measure population-level wellbeing. To study the dynamics of human conversations we will analyse a
new dataset comprising millions of comments from Reddit to quantify conversation length, timing and sentiment, in order to determine what makes for a successful conversation.

While rather computational in nature (we will be making use of programming languages like Python or MATLAB to make sense of these data sets; familiarity with one or both of these would be desirable), this project will provide the opportunity to engage with large, real-world data sets, and to do original research in an exciting new field.

**Predictability, information theory and culturomics**

‘Culturomics’ is an emerging form of computational lexicology that studies human behaviour and cultural trends through digital texts. Recent high-profile studies have analysed Google Books, broadcast media and digitised news articles to find large-scale cultural patterns. We will use techniques borrowed from information theory and the emerging field of sentiment analysis to study culturomical questions in a new way: Is literature becoming more predictable? Are movies becoming more generic and ‘dumbed-down’? We will apply new quantitative techniques to extremely large text-based datasets comprising tens of thousands of books from Project Gutenberg and over 1000 film scripts in order to study these questions.

We will make extensive use of programming languages such as Python and/or MATLAB in this project; familiarity with one or both of these would be desirable.

**Supervisor:** Dr Lewis Mitchell

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**Differential geometry**

**Mathematical physics**

I am happy to discuss possible topics in the areas of differential geometry and mathematical physics. Interested students should email me and arrange a meeting.

**Supervisor:** Professor Michael Murray

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**Explode or Extinct?**

Branching processes are mathematical models used to describe and analyse how populations evolve over time, with applications in many areas such as biology, epidemiology, computer science and image processing. Students can study the effects of initial starting points and growth rates on the eventual size of the population, via algorithms and/or probabilistic analysis.

**What does the Apollo spacecraft and Wall Street have in common?**

Diffusion processes played an important role in estimating the trajectories of the Apollo spacecraft on its way to the Moon and back, as well as in building the myriad of intricate models that is today’s financial world. Students can study the effects on key properties of diffusion processes when we impose boundary constraints on these models.

**How likely is that?**

Natural disasters, financial crises, large-scale accidents and system breakdowns are examples of phenomena with extreme consequences that occur with non-negligible frequencies. Heavy-tailed models are able to capture adequately the behaviour of this type of phenomena but are often intractable. Students can study a class of models associated with infinite-phase-type distributions that can replace heavy-tailed models, from numerical and/or theoretical perspectives.

**Supervisor:** Dr Giang Nguyen
Help develop a toolbox for multiscale simulation and analysis

Often a researcher/practitioner has a detailed and trustworthy computational simulation of some problem of interest. The simulation is written in terms of micro-field variable values. Typically a desired simulation over large space-times would take far, far too long. We are developing and proving techniques to enable such simulation using projective integration and patch dynamics. The project over summer is to help create a Matlab toolbox for users around the world to automatically use the techniques on problems of interest.

Establishing critically useful theory for modelling.

Recently we are understanding more and more about the fundamental relationships between mathematical models at different levels of detail. It turns out that the so-called Centre Manifold Theory provides the rigorous support needed for such understanding. However, the extant theory only deals with the mathematical ideal case of exact results for precise systems on infinite times in an unknown domain. In practice we need theory valid for uncertainly known systems over finite times in a known finite domain. The project is to continue work developing theory to generate such useful practical theorems to underpin mathematical modelling.

Supervisor: Prof Tony Roberts

Stochastic time-since-infection models

Randomness is an important component of infectious disease dynamics. So too is accounting for infectivity varying in strength with respect to the time since infection occurred. Combining these features will be the topic of this project. A number of different approaches may be considered, and the advantages and disadvantages of these approaches will be contrasted. This project would suit a student with interests in: mathematical modelling; mathematical biology/epidemiology; stochastic modelling; and, numerics.

Avoidance and detection in the global wildlife trade

Illegal wildlife trade is a multi-billion dollar business that poses large risks for the conservation of species. For illegally-traded species which appear in Australia, they are likely to have been transported from their native ranges to Australia via a path that minimises the probability of interception. This project will develop a framework in which we can calculate, assuming a fixed network with fixed detection probabilities along edges, the probability of successful transportation into Australia, hence identifying a ranking of most likely pathways of introduction. Time permitting, we will then determine an optimal allocation of resources to maximise the probability of intercepting illegal trade. This project would suit a student with interests in: mathematical modelling; mathematical biology; and, operations research / optimisation.

Supervisor: Dr Joshua Ross

Particle aggregation via multi-scale modelling

The process of particle aggregation in the presence of fluid flow, is indispensable in many important scientific and industrial applications. The atmospheric pollution, wound healing via platelet aggregation, adherence of medical gels with nano-particles for targeted drug delivery, colloidal suspensions in pulp and paper-making industries as well as wastewater treatment plants are just some examples. Research in this area involves looking at the microscopic description of surface adhesion to macroscopic modelling.
and analysis of the evolution of aggregate clusters in fluid.

**Cartilage biomechanics**

Increase in cartilage-tissue hydration and loss of proteins are the earliest signs of cartilage degeneration during Osteo-Arthritis. The goal in this project is to determine the optimal charge distribution and load bearing capabilities of different mixtures of synthetic cartilage gels (e.g. Polyethylene Glycol-Chondroitin Sulphate mixtures). Part of the project involves developing a 3-D algorithm to track concentration of each species in the moving boundary gel-solvent mixture.

**Kinetic theory for non-Newtonian (complex) fluids**

Complex fluids are fluids that exhibit non-linear stress-strain mechanical response. Polymers, bio-fluids (mucus, blood), bio-materials, material composites all come under the category of complex fluids. From an applied mathematics perspective, research in this area involves knowledge in differential equations, dynamical systems, analysis, continuum mechanics theory, kinetic theory and numerical computation.

**Supervisor:** Dr Sarthok Sicar

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**Computational survival analysis**

The analysis of time to event data is known as survival analysis and is an important area of statistics. The event could be death following a diagnosis of cancer and survival time is measured from diagnosis to death. Survival data are subject to a special form of incomplete observation called censoring which complicates the usual statistical analysis. This project will explore computer intensive methods for modelling survival data and assessing model fit, with application to predicting survival following chemotherapy for patients with large B-cell lymphoma.

**Predicting sarcopenia in seniors**

Sarcopenia is the loss of muscle mass and physical function observed with increasing age. The gold standard for diagnosis is the use of dual x-ray absorptiometry (DXA) but this is not readily available to patients in primary or aged care. The aim of this project is to develop a statistical regression model for predicting sarcopenia using easily measured patient variables such as age, sex and height. The project is in collaboration with Professor Renuka Visvanathan and Dr Solomon Yu of The Queen Elizabeth Hospital and the work will involve linear statistical modelling and prediction of cohort data from the Adelaide area.

**Missing data in omics studies**

In genomics and proteomics studies, expression values are often unobserved. The most common cause of missing values in proteomics data obtained from mass spectrometry is when the true expression level of the protein falls below the machine detection limit. This project will use training and test datasets, and K-fold cross-validation to create a model to predict whether an expression value is missing in gastric cancer protein profiles. The results of the project will inform further research into modelling missing data in omics studies.

**Supervisor:** Professor Patty Solomon

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**Algebraic topology or Category theory**

I am happy to supervise projects in algebraic topology or category theory. If you are interested, please email me to arrange a meeting to discuss possible topics.
Diffusive transport of chemical signals

An unfertilized mammalian egg is surrounded by cumulus cells. On fertilization of the egg the cumulus cells move away from the egg and this is seen in high speed video as a travelling wave. It is thought that the cells respond to one or more chemical signals from locations on the surface of the egg. This project will explore travelling wave solutions of reaction-diffusion equations with the aim of developing a model to explain the behaviour of the surrounding cells after fertilization of an egg.

Supervisor: Dr Yvonne Stokes

Quantum Chaos

Classical chaos theory tells us that there are systems whose long term behaviour is extremely sensitive to initial conditions. However quantum theory tells us that we may never completely determine initial conditions such as position and momentum. One may then ask how can we reconcile these two ideas? What is the quantum analogue of a chaotic system and how does it behave?

This overarching question gives rise to a number of potential problems in the areas of partial differential equations, harmonic analysis and the theory of random waves. I am happy to supervise projects in any of these areas (or in related areas of analysis).

Supervisor: Dr Melissa Tacy

Geometry and symmetry

I am happy to supervise summer research topics related to topology and geometry, geometry of noncommutative spaces, Fourier and harmonic analysis, groups and number theory. Interested students are encouraged to email or talk to me to figure out a detailed plan. I have successfully supervised a summer project 2014-15 supported by AMSI Vacation Research Scholarship.

Supervisor: Dr Hang Wang