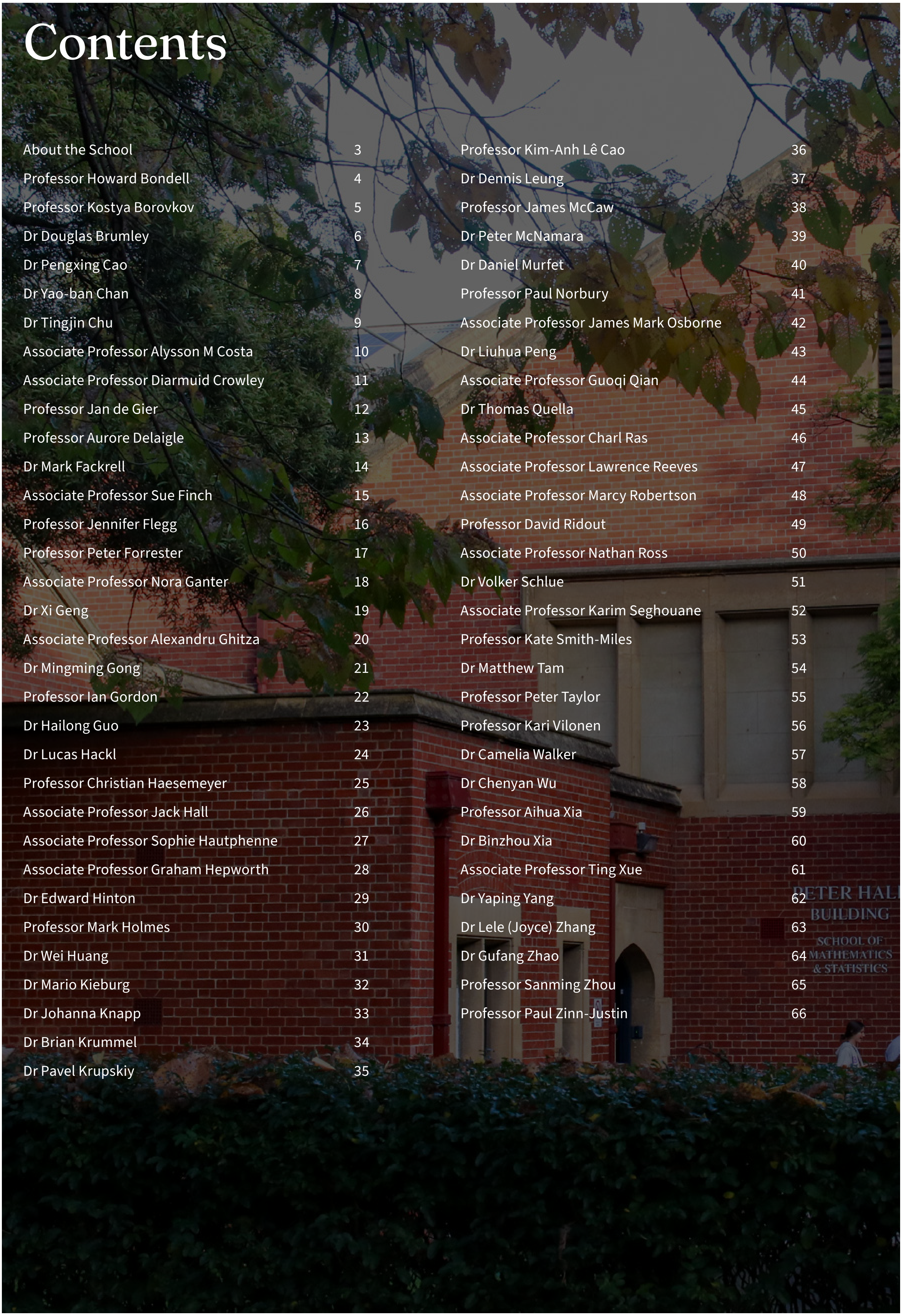
THE UNIVERSITY OF MELBOURNE

School of Mathematics and Statistics

Faculty of Science

Mathematics and Statistics Research Prospectus



Contents

About the School

Mathematics and statistics are at the core of discovery and understanding in all areas. Fundamental research and education in mathematics and statistics provides for the foundation that underlies future innovation.

The University of Melbourne's School of Mathematics and Statistics is a world-leading school of mathematics and statistics. The School has achieved this status through the high quality of its research and teaching programs, and we welcome opportunities for engagement with individuals and groups both within and outside academia.

We are a broad School with an international reputation covering all areas of pure and applied mathematics and statistics. The School is a partner in multiple Australian Research Council Centre of Excellence, an Industrial Transformation Training Centre, the collaborative research centres: Melbourne Integrative Genomics, Melbourne Centre for Data Science, and is home to the Statistical Consulting Centre that engages with industry to provide high quality statistical consulting. The School of Mathematics and Statistics has several Fellows of the Australian Academy of Science, ARC Laureates, Future and DECRA Fellows.

The University of Melbourne's Faculty of Science acknowledges the Traditional Owners of the lands on which we work: the Wurundjeri Woi-Wurrung and Bunurong peoples (Burnley, Fishermans Bend, Parkville, Southbank and Werribee campuses), the Yorta Yorta Nation (Dookie and Shepparton campuses), and the Dja Dja Wurrung people (Creswick campus). We pay respect to their Elders, past and present. We also acknowledge and respect that Aboriginal and Torres Strait Islander people are this country's first scientists, with deep and enduring knowledge of the land, waters and skies.

Professor Howard Bondell

Head of the School of Mathematics and Statistics

Professor Howard Bondell

- Data science
- Statistical modelling
- Machine learning
- Uncertainty quantification

howard.bondell@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/600991-howard-bondell

John W. Tukey reportedly told a colleague, "the best thing about being a statistician is that you get to play in everyone's back yard." Needless to say, this precise sentiment is even more applicable in the world today than when it was first uttered some 50 years ago. It is truly an exciting time to be involved in the development of statistical and machine learning methodology in today's realm of data science. I am passionate about using my mathematical and statistical expertise to develop methods for applications across diverse areas.

With the influx of data now available in both the public and private sectors, large and complex data sets have become the norm rather than the exception. Advances in data science are essential to extract meaningful information from this data for purposes of understanding and decision making.

Statistical modelling, uncertainty quantification, and decision-making with complex data

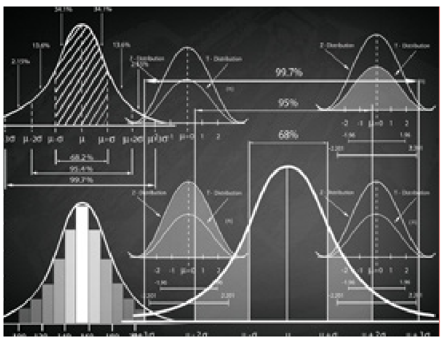
We develop innovative statistical methodology that is both interpretable and theoretically justified. By incorporating principled statistical approaches together with modern machine learning methods, our work enhances the discovery of knowledge by developing tools to analyse these complex datasets, while accounting for the uncertainty inherent in data.

Bayesian inference and optimisation of physical and mechanistic systems

Modern Bayesian inference methods provide tools to handle complex data from both a computational and modelling perspective. These approaches are also ideally suited to incorporate physical and mechanistic models to be reconciled with observable data for purposes of optimisation and decision-making. Our work develops methods to efficiently handle applications with large numbers of input variables and enables the discovery of the relevant features that separate the signal from the noise.

Application-focused statistical and machine learning methods

In many applications, the collection and format of the data does not fit nicely into an existing framework. Along with colleagues at the Melbourne Centre for Data Science, we tailor statistical and machine learning methods specifically for a targeted problem. Some examples of issues that arise include handling missing data that may not be missing at random, streaming and high frequency data, and complex sampling schemes such as repeated measures or longitudinal studies. Incorporating these complexities into flexible machine learning approaches allows for the removal of biases and produces appropriate uncertainty quantification. We have successfully worked to enable research advances for a variety of disciplines, including applications to network security, energy forecasting, climate change and public health.



Professor Kostya Borovkov

Professor Kostya Borovkov

- Limit theorems for random processes
- Large deviations
- Stochastic modelling

borovkov@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/971-konstantin-borovkova

For me, there are several motivations to do research. One is the overwhelming feeling one has when making a scientific discovery — albeit a small one. Another is that I mostly work on mathematical problems that have direct relevance to real-life systems, and solving them can bring about positive change. Yet another is that doing research makes me a better lecturer and supervisor for our students, helping me to inspire them as well.

Boundary crossing by random processes

Evaluating boundary crossing probabilities for random processes is a fundamental problem in many areas of probability theory and its applications, with some of the most eminent problems coming from collective risk theory, statistics, change–point detection and mathematical finance. Among the central topics in some other important areas in probability theory and its applications (such as extreme value theory, dam/storage problems and queueing and telecommunication theory), we often also find special cases of boundary crossing problems. Despite the large amount of work done in this area, there are many interesting open problems of which solutions can be of substantial importance for potential applications.

Dynamic point processes with preferential attachment mechanisms

A dynamic version of the Neyman contagious point process can be used for modelling the spatial dynamics of biological populations, including species invasion scenarios. The dynamics of such models have not been fully explored yet — there are open problems on more detailed descriptions of the evolution of the points population, both in distributional terms and in terms of its almost sure behaviour.

Dr Douglas Brumley

Dr Douglas Brumley

- Applied mathematics
- Fluid dynamics
- Chemotaxis
- Microfluidics
- Microbial ecology

d.brumley@unimelb.edu.au

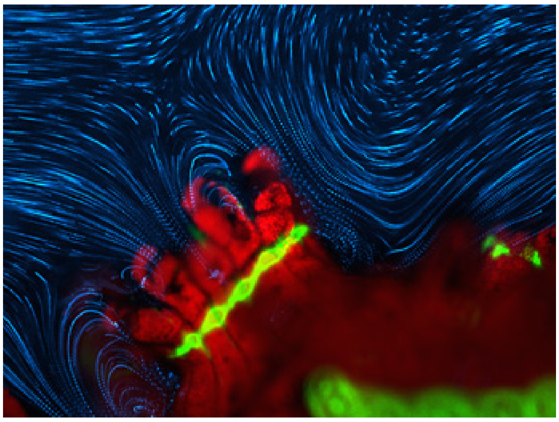
findanexpert.unimelb.edu.au/profile/250438-douglas-brumley

The Brumley lab utilises mathematics, microfluidics and microscopy to study a range of dynamic processes in biology, including bacterial motility, symbioses, and nutrient cycling and flows around coral reefs.

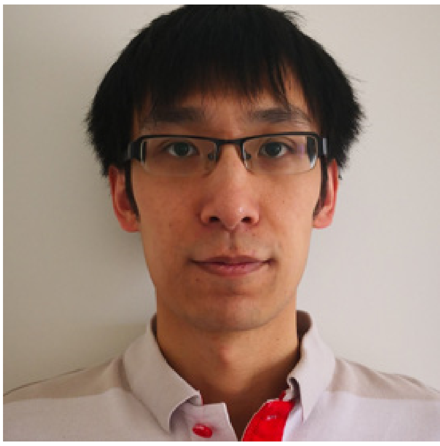
Microscale fluid flows in biology

The ways in which microorganisms interact with one another and with their surroundings underpins their collective functioning in the environment. Biogeochemical cycling in the ocean, infection of humans by pathogens, and microbial symbioses in coral reefs are all driven by the dynamics of microorganisms.

The Brumley lab has developed a range of new microfluidic tools, high-speed imaging techniques and mathematical frameworks for investigating the motion of microorganisms at the single-cell level, and is using these to predict ecosystem-level outcomes.



Dr Pengxing Cao



Dr Pengxing Cao

- Mathematical biology
- Dynamical systems
- Infectious disease modelling
- Biophysics
- Calcium dynamics

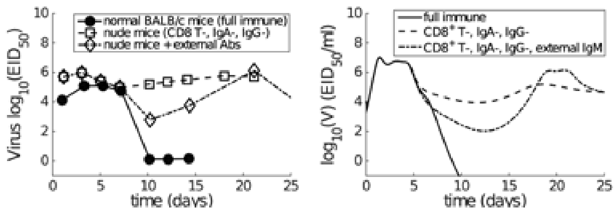
pengxing.cao@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/686725-pengxing-cao

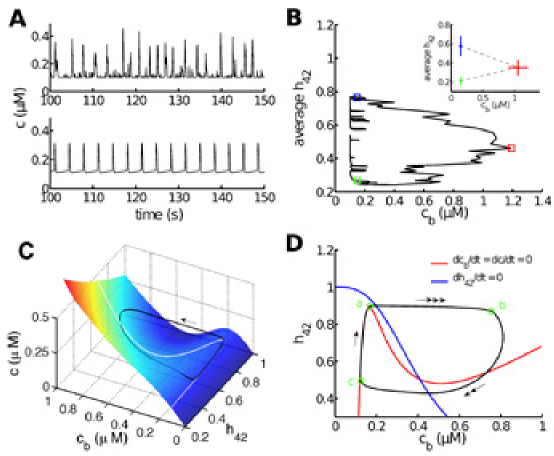
I develop mathematical models to better understand dynamic biological systems driven by nonlinear interactions and feedback between different parts of the system. When calibrated and validated against experimental data, mathematical models are a powerful tool providing novel insights into biological processes that are not directly observable in experiments

Modelling infections and intracellular signals

My research focuses on two principal areas. One is modelling dynamics of infectious diseases (e.g., influenza, malaria and tuberculosis) to better understand the growth patterns of pathogens in human hosts and the roles of various immune responses and drugs in clearing infection. The other is modelling intracellular signalling (e.g., calcium signalling) to better understand the mechanisms of signal formation and propagation and find ways of modulating those processes to mitigate associated diseases.



Comparison between experimental data (left) and the predictions of an influenza viral dynamics model (right) for various scenarios where different immune responses were knocked out (eg CD8T- means CD8 T cells were removed from the system).



Simulation of intracellular calcium concentration oscillations by calcium models (a; upper: stochastic; lower: deterministic). Phase plane analysis of the dynamics of calcium oscillation generated by stochastic model (b) and deterministic model (c & d).

Dr Yao-ban Chan

Dr Yao-ban Chan

- Statistics
- Statistical genomics
- Phylogenetics

yaoban@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/7123-yao-ban-chan

I develop and apply mathematical and statistical methods to reconstruct the evolutionary history of species and genes from genome data. This can increase understanding of ancestral species and environments, the functions of modern and ancient genes, and the biological processes that drive evolution.

Phylogenetics

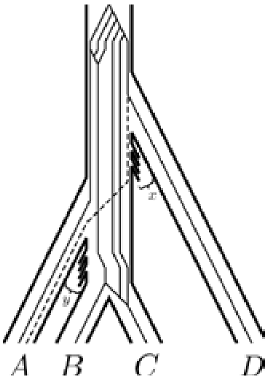
My field is phylogenetics, which utilises the massive amount of genomic data resulting from rapid developments in sequencing technology to reconstruct evolutionary history. Phylogenetic trees and networks are mathematical objects depicting the evolution of a family of species or genes through time, starting from their common ancestor.

The increasing scale of this work requires the development of sophisticated and efficient algorithms, underpinned by many mathematical and statistical tools.

Applications

This approach can be applied to study the antigen-encoding genes of the malaria parasite, which control how long it stays in the human body, the development of antibiotic resistance in bacteria, and the genealogical history of large human populations, for example.

Inferring evolutionary history from genome data.



The evolutionary history of species and genes.

Dr Tingjin Chu

Dr Tingjin Chu

- Spatial statistics
- Spatio-temporal statistics

tingjin.chu@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/795463-tingjin-chu

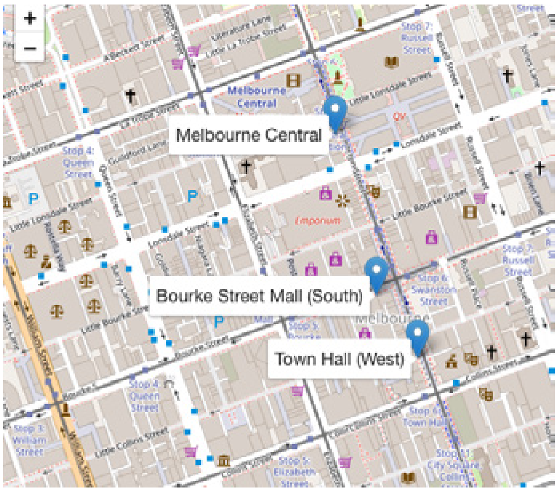
My research interests are methodologies and applications of spatio-temporal statistics.

Statistical methodologies

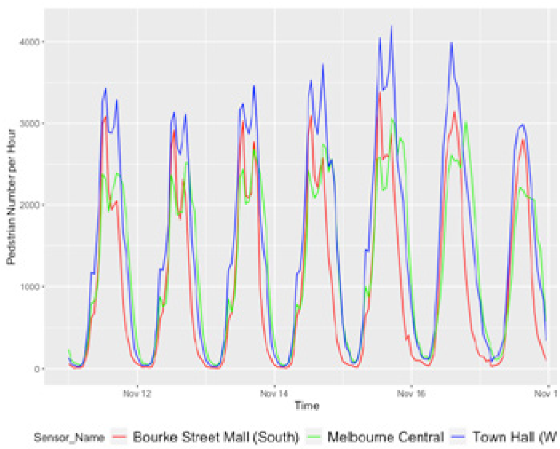
- Kriging: interpolation at the unobserved locations.
- Modelling spatio-temporal dependence and patterns.
- Combining different datasets to improve model accuracy and prediction performance.
- Forecasting for spatio-temporal data.

Applications and interdisciplinary research

- Actuarial studies: insurance policy pricing for cyber security; personalised/geo-related insurance policy pricing.
- Astronomy: covariance function estimation and kriging for metallicity variations in galaxies.
- Climatology: forecasting tropical cyclones; estimating precipitation using satellite data.
- Transportation: Melbourne CBD pedestrian flow modelling and forecasting.



Three sensors in CBD.



Pedestrian counts over a week.

Associate Professor Alysson M Costa

Associate Professor Alysson M Costa

- Operations research
- Mixed-integer programming
- Mathematical modelling

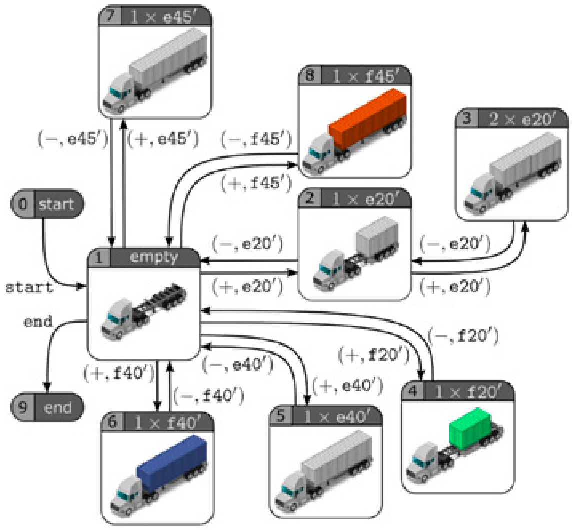
alysson.costa@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/640162-alysson-machado-costa

My mission is to identify and model decision-making problems in different areas of applications, with a focus on issues that will contribute to the well-being of the population and allow resources available to be used in an efficient and equitable way. This includes extending the limits of available solution methods to allow for the solution of even larger and more realistic models.

Decision-making problems are found in the most diverse areas of application: how can you design trams and trains schedules to better serve the public? When to release water from reservoirs in order to improve the health of endangered species in a river system? When to schedule elective surgeries to maximise the service provided? How to better route delivery trucks for faster and more efficient delivery of goods? Where to install vaccination centres to better deliver service to the population? How to schedule high school lectures to better fit the needs of students and teachers? Which crops should be planted to maximise yields while minimising impact on natural resources?

In Operations research, we tackle these (and many other) questions with an approach that relies on converting the problem to a mathematical model and then solving this model with specialised solution algorithms that can obtain the best solution for realistic models with tens of thousands of variables. Modelling and solving go hand in hand, and the research questions are often related to the obtention of the best models for the algorithms available and, conversely, on the extension of the available algorithms to better solve the models developed.



In the picture, a transition graph representing the state of a truck after serving pick-up or delivery requests in the delivery of containers. This transition graph is used within a mixed-integer programming model to obtain cheapest and more environmentally friendly routes for the operation of containers around terminals (ports, e.g.).

Associate Professor Diarmuid Crowley

Associate Professor Diarmuid Crowley

- Topology
- Manifolds
- Space

dcrowley@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/767319-diarmuid-crowley

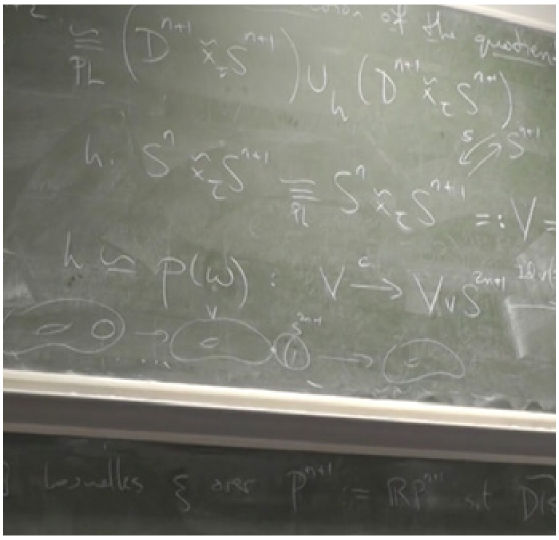
To understand the structure of high-dimensional manifolds through their classification and the mappings between them to deepen our understanding of the nature of space.

Surfaces are classified by genus: the 2-sphere (genus 0), the torus (genus 1).

Topology of manifolds

The idea of a space, a collection of locations related in a global structure, is a powerful metaphor. Abstractly conceived, spaces need not be three dimensional but can be multi-dimensional. Topology is the field of mathematics which studies space, and manifolds are a fundamental class of space which arise as solutions to complicated equations in many variables.

I study the structure of multi-dimensional manifolds and the relationships between them; in other words, the possible structures of high-dimensional spaces.



A blackboard from a talk I gave in Edinburgh in 2013.

Professor Jan de Gier

Professor Jan de Gier

- Mathematical physics
- Statistical mechanics
- Non-equilibrium processes
- Integrable models

jdgier@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/9355-jan-de-gier

I aim to unravel and understand the underlying mathematical structures and patterns that give rise to emerging macroscopic behaviour in physical and biological systems.

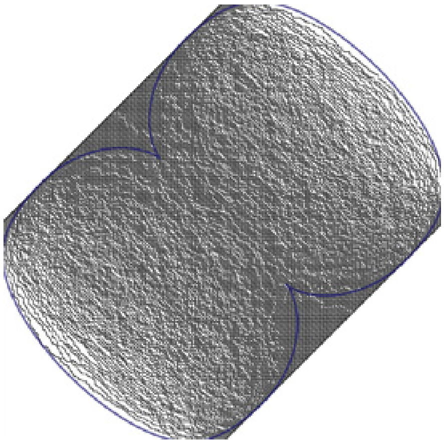
Solvable lattice models

Solvable lattice models provide useful mathematical frameworks for modeling real world phenomena. Examples of solvable lattice models are quantum spin chains as systems to implement quantum computation, models for metals, cold atoms and superconductivity. Another example is exclusion processes as general transport models in biology, physics and engineering, and more general stochastic processes to model phenomena that involve some element of randomness, such as interface or domain growth. A third calls of models are random tilings as models for quasicrystals and crystal melting.

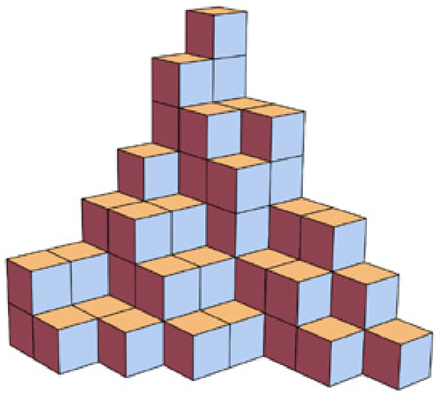
The study of solvable lattice models uses a variety of techniques in pure mathematics and mathematical physics, ranging from algebraic concepts such as the Yang-Baxter equation, Hecke algebras and quantum groups, to analytic methods such as complex analysis and elliptic curves. Due to this wide variety of methods, the study of solvable lattice models often produces unexpected links between different areas of research.

Multivariable polynomials

I study connections between enumerative combinatorics and statistical mechanics on the one hand, and (symmetric) polynomials and representation theory on the other. Schur and Macdonald polynomials are important classes of polynomials and we have developed a new framework to study and generalise such polynomials using solvable models and matrix product methods. Multi-variable polynomials may be used in problems involving many degrees of freedom, or data points. They are computationally expensive and complex to deal with in a brute force manner, but smart underlying mathematical structures and patterns can unravel these complexities.



Emerging limiting surface of random square lattice edge configurations.



Plane partition are used as models for two-dimensional interface growth as well as labels for algebraic structures in quantum toroidal algebras.

Professor Aurore Delaigle

Professor Aurore Delaigle

- Nonparametric statistics
- Errors in variables
- Functional data analysis
- Imperfectly observed data
- Grouped data

aurored@unimelb.edu.au
findanexpert.unimelb.edu.au/profile/154426-aurore-delaigle

My focus is on new frontier research challenges in statistics. I am dedicated to developing flexible method solutions that do not rely on stringent or unrealistic conditions, and ensuring their validity by developing rigorous theoretical arguments that explore their limit of application.

Nonparametric techniques for data with measurement errors

A lot of my research has been devoted to developing statistical techniques for analysing data observed with measurement errors. Often, those data make standard statistical methods fail, and the challenge is to incorporate some correction. Because of important applications to a variety of problems, measurement errors have become a popular topic of research in statistics.

A large part of my research in this area originates from the need to analyse data from nutrition. Dietary data are used to estimate the distribution of usual (average long-term) intake of various nutrients and food groups, monitor such intakes over time, and relate individual usual intakes to health outcome measures. I have developed highly effective nonparametric statistical techniques, which often involve converting abstract, theoretical concepts into completely realistic and fully applicable methodology.

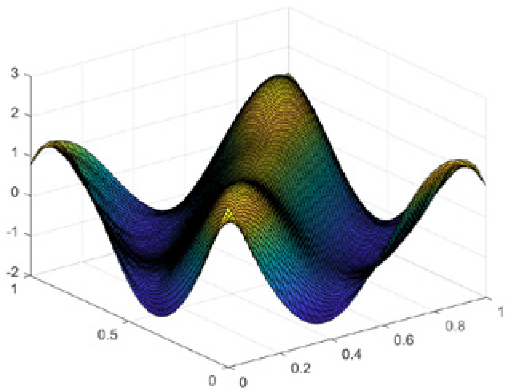
Nonparametric techniques for group testing data

I am also interested in the statistical analysis of group testing data where the primary goal is to analyse data from infectious disease studies, particularly the presence/absence of an infectious disease as detected from a blood or a urine test.

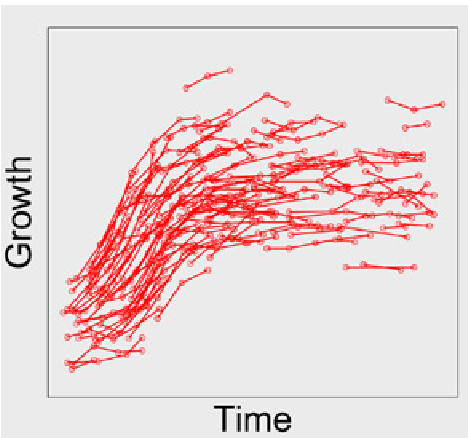
In large infectious disease studies, it is sometimes not possible to test individuals separately — only the result of tests on groups is available. This is referred to as group testing data. My research has consisted of developing nonparametric techniques for estimating the influence of various biological, environmental, or other factors on the incidence of the disease.

Functional data analysis

Another research interest is the analysis of functional data, ie data that are in the form of curves. For example, growth curves of children and yearly rainfall are functional data. One of my research directions has been to develop dimension reduction procedures that can keep as much of the information from the data as possible when the goal is to classify and cluster the individuals into groups that share similarities.



An example of the type of surfaces that need to be estimated in functional data problems.



Partially observed spine bone mineral density curves, described in Bachrach et al. (1999).

Dr Mark Fackrell

Dr Mark Fackrell

- Operations research
- Stochastic modelling
- Healthcare modelling
- Game theory
- Matrix-analytic methods

fackrell@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/8971-mark-fackrell

I enjoy the challenge of developing, analysing and applying theoretical mathematical models to solve real-world problems. I am also passionate about sharing my knowledge and research findings with fellow academics, students at all levels, industry partners, and the wider community.

Healthcare decisions under uncertainty

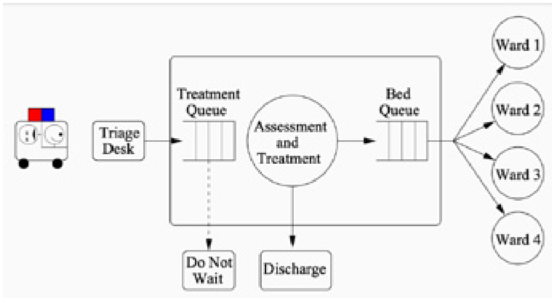
Real-world systems are complex, with degrees of uncertainty. For example, consider the operations of a hospital. A patient who has undergone surgery needs to go to the intensive care unit (ICU). But what if the ICU is full? Should the patient be kept in the recovery room until an ICU bed becomes available? Should they be moved to a less suitable ward? Or should another patient in the ICU be moved out to accommodate the incoming patient? Decision makers in hospitals face situations like this every day.

Modelling and analysing hospital and healthcare systems enables important performance measurements such as throughput and utilisation, and the results can inform better decisions.

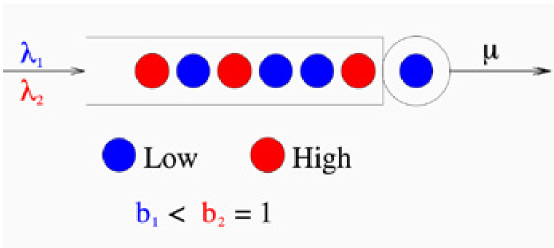
Analysing queueing systems

Queues are ubiquitous: we wait at the supermarket, at traffic lights, or to see a doctor. There are various ways to shorten wait times, for example by informing people of the length of the queue, so they can decide whether or not to join it, based on their circumstances and needs. Game Theory can be used to model and analyse queueing systems like this.

I develop and analyse mathematical models using probability theory, operations research, machine learning, and game theory to model complex real-world systems, enabling practitioners in industry to enhance their decision-making.



Schematic diagram showing patient flow in an emergency department.



An accumulating-priority single server queue. Customers are prioritised in the queue based on their priority class and time spent waiting.

Associate Professor Sue Finch

Associate Professor Sue Finch

- Applied statistics
- Statistical consulting
- Statistical literacy
- Data visualisation
- Statistical communication

sfinch@unimelb.edu.au

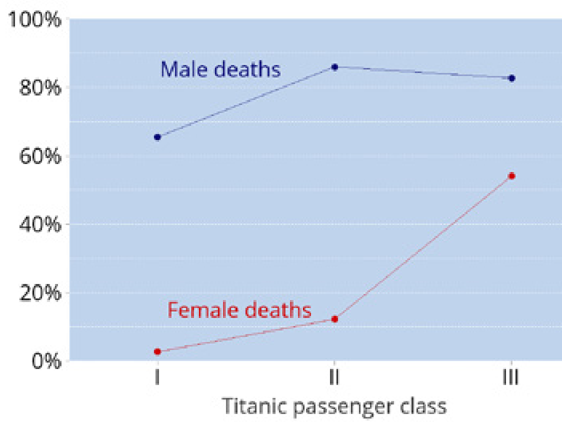
findanexpert.unimelb.edu.au/profile/25827-sue-finch

In collaborating with other researchers and providing them with statistical support, I aim to enhance the quality of the design, methodology and implementation of data-based research, provide robust data analytics and support effective, transparent communication of the findings of empirical research. My research in statistical literacy, data visualisation and statistical consulting and communication supports these goals.

Enhancing the application of data analytics in real-world practice

Reports of research findings and claims based on data pervade our everyday lives through a wide range of media channels. The societal value of such research and claims depends in part on the quality of the communication from the producers of the research, and on the capacity of potential consumers of the research to understand the findings.

My research aims to enhance the quality of data-based research outputs and communication, with a focus on data visualisation. It also aims to improve statistical literacy and statistical pedagogy in order to promote statistical literacy and critical thinking about quantitative information more broadly.



Professor Jennifer Flegg

Professor Jennifer Flegg

- Applied mathematics
- Mathematical biology
- Mathematical modelling
- Infectious disease modelling
- Tissue dynamics

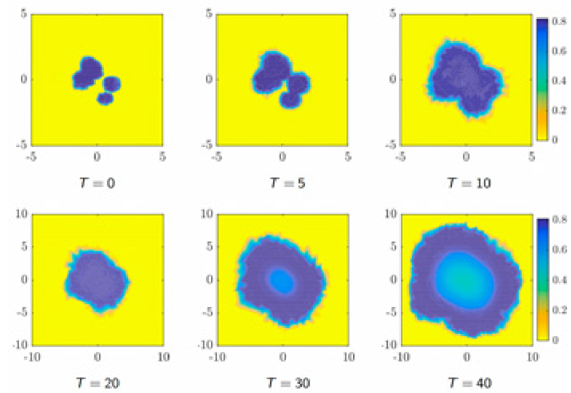
jennifer.flegg@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/762115-jennifer-flegg

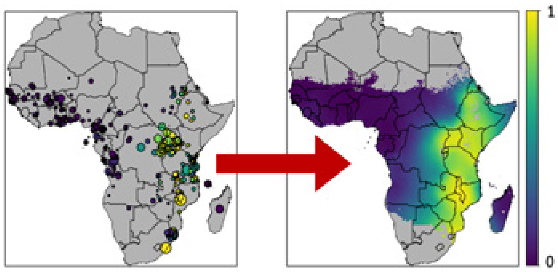
I use mathematics and statistics to help solve real-world problems. My primary research area is mathematical biology – a subfield of applied mathematics that aims to bring the organisation, structure, and rigour of mathematics to the complexity of biology.

Modelling drug resistance, wound healing, and tumour growth

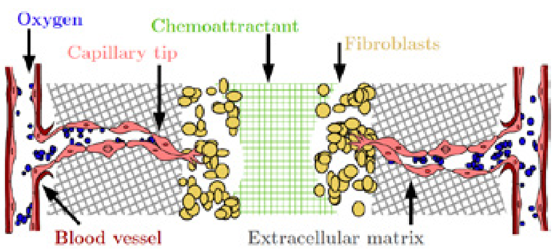
My contributions are primarily in infectious disease epidemiology and partial differential equation models of tissue dynamics in wounds and tumours. My future research plans include developing whole cell models as a member of the ARC Centre of Excellence for the Mathematical Analysis of Cellular Systems.



Tumour growth predicted by a mechanistic mathematical model.



Model-based geostatistics for predicting spatiotemporal spread of antimalarial drug resistance. These predictive maps fill in the gaps where no information is available on drug resistance and have been used by health agencies to develop new policies about where and when certain drugs are appropriate to use.



Describing the wound healing angiogesis process with mechanistic mathematical models.

Professor Peter Forrester

Professor Peter Forrester

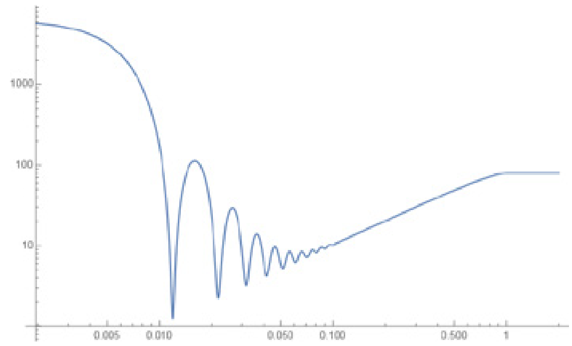
- Random matrix theory
- Statistical mechanics
- Special function theory

pjforr@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/13298-peter-forrester

My research in random matrix theory enjoys international recognition, with my research monograph 'Log-gases and random matrices' being cited over 1,400 times. This gives me the opportunity to play a leadership role in the advancement of studies in random matrix theory in the Asia Oceania region, where it is an emerging research topic.

My primary research field is random matrix theory. This is a broad research topic with links to quantum physics, number theory, disordered and complex systems, communications engineering, and neural networks, among other applications. My main tools are methods of special functions in one and several variables, which facilitate analytic computations.



Dip-ramp-plateau is a signature of many-body quantum chaos.

$$\left\langle \prod_{l=1}^{N} (x - x_l)^n \right\rangle_{\mathrm{ME}_{\beta,N}(e^{-\beta x^2/2})} = \left\langle \prod_{l=1}^{n} (x - i x_l)^N \right\rangle_{\mathrm{ME}_{4/\beta,n}(e^{-x^2})}$$

This duality formula facilitates analytic computations in random matrix theory.

Associate Professor Nora Ganter

Associate Professor Nora Ganter

- Elliptic representation theory
- Categorification

nganter@unimelb.edu.au

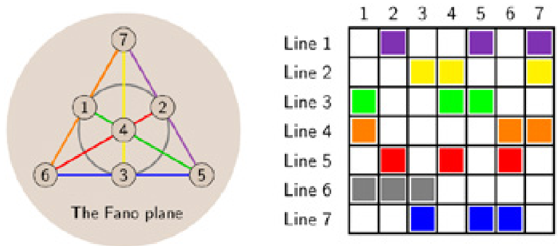
findanexpert.unimelb.edu.au/profile/197608-nora-ganter

I have a passion for involving students in research-oriented activities from day one of their education at university. Much of this is a community-building exercise, and we are very excited to have just started offering a student-organised seminar in which the students get to vote on the topics and do the presentations (currently on neural networks, previously on open key encryption). I view research and teaching as a unit and endeavour to create a research training environment that offers our students, from first year undergraduates to PhDs, the same level of opportunity that I enjoyed in my education overseas. The vision is to create a pan-Australian PhD program in mathematics with a strong cohort component, an emphasis on communication skills, and to create more high-level offerings for interested undergraduate students.

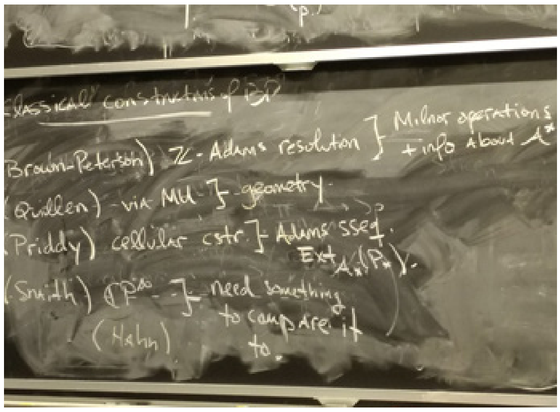
Algebraic topology studies the geometry of elastic objects. This young discipline has seen a remarkable journey over the past two decades with profound applications to machine learning, sensor fields, computational neuroscience and more. The breakthrough here is that data science is moving away from thinking of data as discrete points and moving towards understanding data as continuous (or algebraic) structures, giving a much more holistic view and demanding a completely new toolset — so new in fact that the applications have not all found their ways into the textbooks yet.

My own research is on the foundations of mathematics, but through student training and conversations with colleagues I interact indirectly with these applications rather frequently.

For instance, a former MSc student of mine is now designing efficient fiber optic networks, while another is working as an analyst in a renewable energy startup. Others are pursuing PhDs or postdocs overseas.

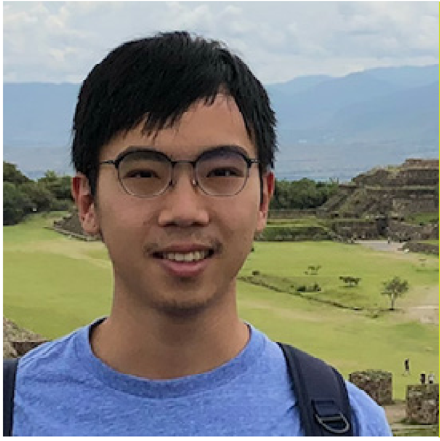


The Fano plane is at the heart of many famous phenomena, from Bott periodicity in pure mathematics to the triality symmetry in physics and the existence of error-correcting codes, used to send images from space.



Mathematical ideas are created: the power of pen and chalk.

Dr Xi Geng



Dr Xi Geng

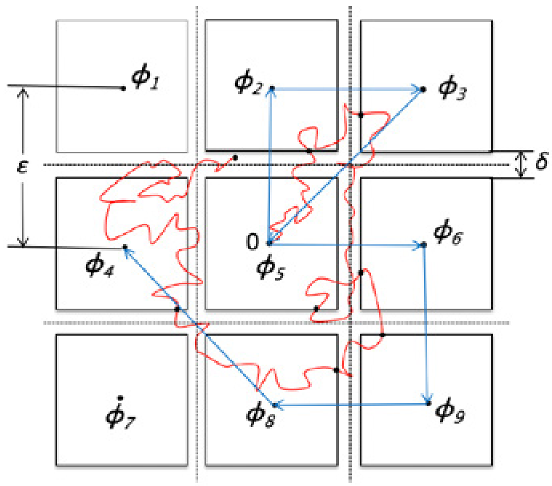
- Rough path theory
- Stochastic differential equations
- Malliavin's calculus
- Gaussian analysis
- Stochastic analysis on manifolds

xi.geng@unimelb.edu.au

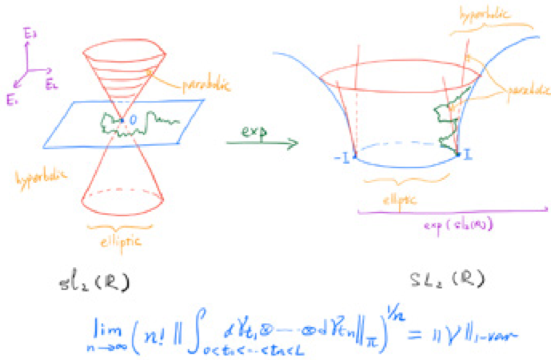
findanexpert.unimelb.edu.au/profile/818728-xi-geng

My research and academic path are driven by the intrinsic elegance of mathematics. Since I was a PhD student, I took the 'pursuit of deeper truadamental understanding about the deeper intrinsic mechanism that drives the various phenomena that we observe mathematically and physically. I choose specific areas because they fit my taste for mathematics and involve a broad range of deep mathematics, which is something I particularly appreciate.

I am a mathematician working in the interplay between analysis and probability. My core research areas are stochastic analysis and rough path theory. Broadly speaking, stochastic analysis is the differential calculus of stochastic processes and the analysis of stochastic differential equations (SDEs). One of the core problems in this area is related to the study of fine quantitative properties of SDE solutions. Rough path theory is an analytic theory of integration and differential equations with respect to highly irregular paths, providing robust analytic tools for studying problems in stochastic analysis. My research requires and emphasizes the use of a wide range of mathematical tools from analysis, geometry and algebra apart from core probabilistic methods.



Signature inversion for random processes.



Path developments and the length conjecture.

Associate Professor Alexandru Ghitza

Associate Professor Alexandru Ghitza

- Modular forms
- Elliptic curves
- Galois representations
- Number-theoretic algorithms

aghitza@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/196860-alexandru-ghitza

As number theory becomes increasingly technical and requires highly specialised knowledge from many branches of pure mathematics, we are witnessing a ghettoisation phenomenon where experts in different aspects of the same object of study are unable to communicate about their methods and results. My aim is to help reconnect these areas in order to facilitate the exchange of expertise and lower the barrier to entry for newcomers.

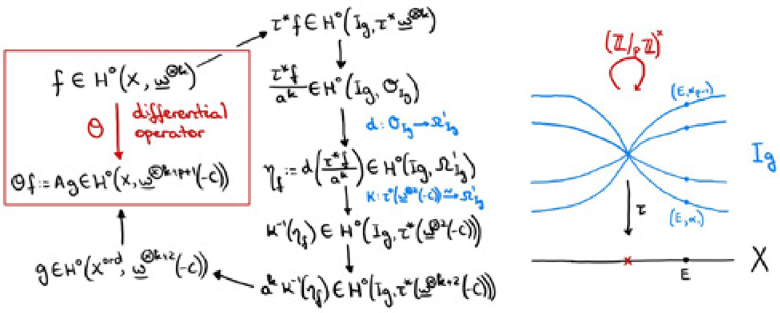
Modular forms and friends

The earliest known instance of a number-theoretic result is on a clay tablet from around 1800 BCE. A lot has happened in the intervening 4000 years, much of it motivated by the desire to resolve difficult problems such as Fermat's Last Theorem, or understand the subtleties of the distribution of prime numbers. In the process, we gradually moved from concrete questions about whole numbers to increasingly abstract constructions that model the surprisingly subtle behaviours of integers and their generalisations. One such construction is that of modular forms, a type of function that has a lot of symmetries and encodes deep arithmetic information. I study the structure of the spaces of modular forms from a variety of points of view.

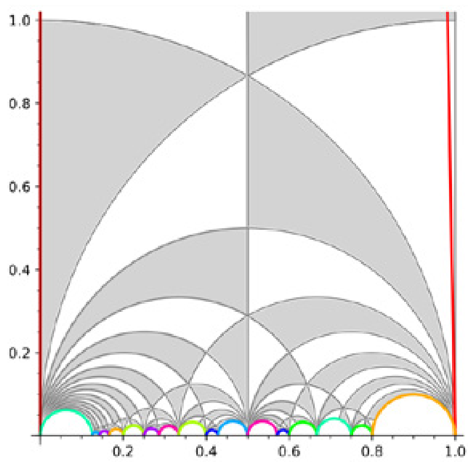
A wide web of conjectures relates them to geometric objects such as elliptic curves (well-known for their cryptographic applications) and algebraic objects such as Galois representations, and this study takes me and my students across large swaths of the contemporary pure mathematics landscape.

Computational tools for number theory

Numerical experimentation has always played a part in the discovery process in number theory. Gauss used to count prime numbers in intervals in his spare time, eventually obtaining the list of all primes up to three million. Nowadays, we have computers that can do the tedious work for us, but the subtleties of arithmetic behaviour and the abstract nature of the tools we use to study it lead to the need for efficient algorithms for experimentation in number theory. I develop, implement, and use such algorithms for computing with modular forms, elliptic curves, and their generalisations. I believe in providing equal and unrestricted access to these tools to anyone who would use them and make them available as free and open-source software (for instance within SageMath or related systems).



Construction of a differential operator.



The domain of a modular form.

Dr Mingming Gong

Dr Mingming Gong

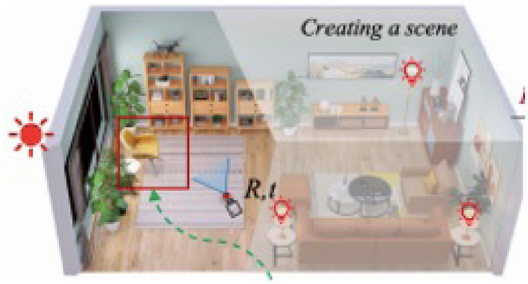
- Causal inference
- Machine learning
- Computer vision
- Bioinformatics
- Biomedical science
- Healthcare

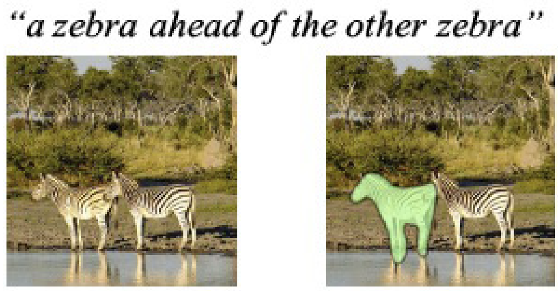
mingming.gong@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/853769-mingming-gong

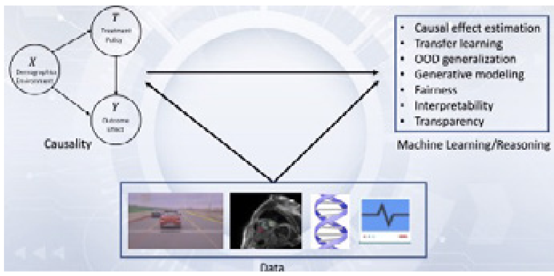
My research aims to promote data-centric intelligence and science — constructing machines that can learn and make decisions from data.

I am interested in providing theoretical foundations and computational innovations in learning the causal generative process of real-world complex data. Meanwhile, I explore the causal generative process of data to tackle challenges in machine learning, such as transferability, robustness, and interpretability. I am also interested in machine learning/reasoning problems arising from particular areas, such as computer vision, biomedical science, healthcare, and finance.





Causal learning and reasoning



Computer Vision (3D scene modeling, text-image multimodal learning)

Professor Ian Gordon

Professor Ian Gordon

- Applied statistics
- Statistical consulting
- Statistics and the law
- Statistical communication
- Data science

irg@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/16016-ian-gordon

I am an applied statistician working collaboratively to communicate statistical concepts and solve statistical problems to promote social justice, health, and well-being. I do a considerable amount of expert witness work in legal proceedings.

Justice and statistics

Court proceedings sometimes involve statistical material. This is especially important in class actions, where the law requires that a "reasonably accurate assessment" must be made of the total amount to which group members will be entitled, which often involves statistical modelling and estimation.

I have contributed to the resolution of several of the largest class actions in Australia in the past 20 years, including the East Kilmore bushfire Black Saturday settlement and the class action on behalf of women suffering adverse side effects from pelvic mesh implants. This work involved epidemiology, sample surveys, modelling, meta-analysis, and estimation.

Principled statistical practice

I aim to create and support excellence in the design and analysis of quantitative research. This requires cogent and incisive communication of statistical ideas, methods, and results. I am passionate about promoting sound statistical practice and statistical literacy in society.

East Kilmore ABC news item [Source: ABC online news, 23 December 2014].

Pelvic mesh news item [Source: ABC online news, 21 November 2019].

Dr Hailong Guo

Dr Hailong Guo

- Numerical solutions of partial differential equations
- Finite element methods
- Scientific deep learning

hailong.guo@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/817562-hailong-guo

My primary goal is to develop and analyse efficient and high-accuracy numerical methods for solving differential equations from different areas like physics, chemistry, and material science.

Numerical solution of differential equations

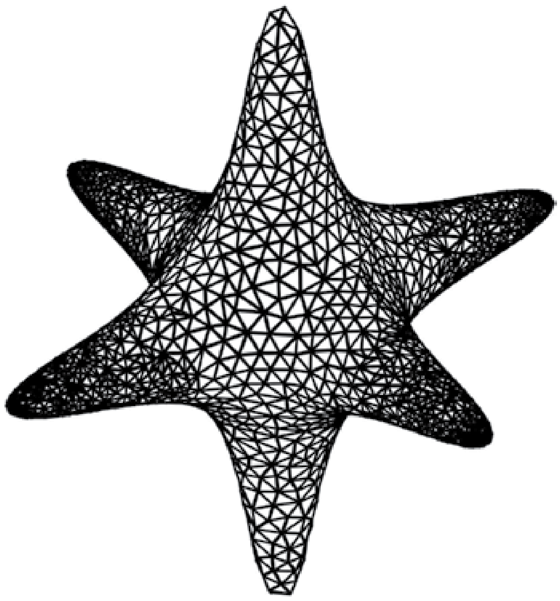
Differential equations are the mathematical language to describe the real world. We shall use mathematical knowledge and computer tools to simulate and understand the real world.

Modelling and simulation of topological materials

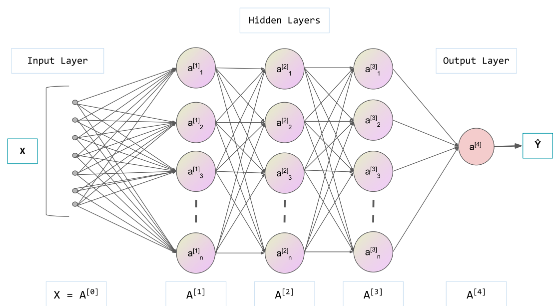
Topological materials are a class of quantum materials whose properties are preserved under topological transformations. We shall analise the topological properties of topological materials from a mathematical viewpoint. Based on mathematical analyse, our research will develop state-of-the-art numerical methods for simulating the topological materials. We also propose to use the shape optimisation approach to design topological materials.

Deep learning for partial differential equations

One of the main challenges of classical numerical methods like finite difference methods and finite element methods is the curse of dimensionality. We shall use machine learning and artificial intelligence to develop cutting-edge computational methods for solving high-dimensional problems from real applications.



Adaptive computation on a general surface.



Deep neural network.

Dr Lucas Hackl

Dr Lucas Hackl

- Quantum Information
- Fundamental theory
- Entanglement entropy
- Variational methods
- Gaussian states

Lucas.Hackl@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/877672-lucas-hackl

I develop mathematical tools to understand and model the quantum information properties of physical systems, ranging from quantum matter probed in particle accelerators to cosmological observations in spacetime. I also collaborate on applications in quantum technologies.

My research program rests on three pillars: (i) entanglement theory, (ii) variational methods and (iii) Gaussian states, which are all interconnected.

Entanglement theory

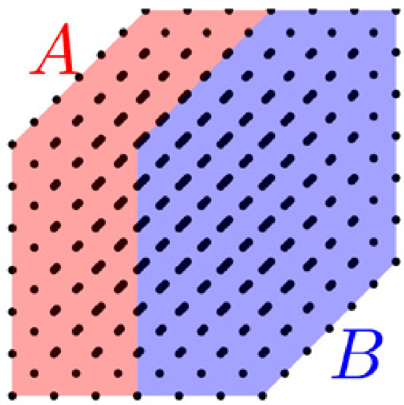
I am using quantum information quantities (such as the bipartite entanglement entropy) to explore properties of quantum systems, such as their dynamics, chaotic behaviour, and longtime averages of physical observables. Related work also explores how to extract entanglement from quantum systems to be used as a resource in quantum information processing.

Variational methods

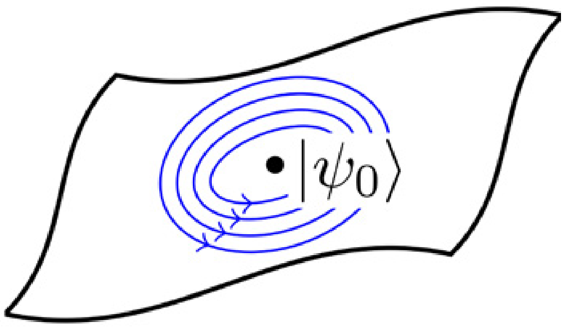
I have used tools from differential geometry to develop a systematic theory on how to approximate ground states, low excited energy eigenstates, time evolution and linear response based on the choice of a variational family.

Gaussian states

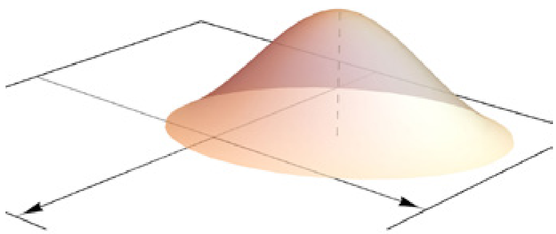
Research in this field has provided a unified mathematical framework to describe bosonic and fermionic Gaussian states based on group theory and representation theory. I apply this to the study of entanglement in Gaussian state ensembles and as a variational family for variational calculations. It also enables construction of new variational families, such as generalised Gaussian states or Gaussian state superpositions, and provides the required tools to compute expectation values of physical observables efficiently for such states.



Entanglement theory. We illustrate a lattice system divided into subsystems A and B, whose entanglement (quantum correlations) we quantify.



Variational methods. We illustrate a family of variational states with approximate ground state (black dot) and time evolution (blue).



Gaussian states. We illustrate a Gaussian state as positive distribution in the classical phase space.

Professor Christian Haesemeyer

Professor Christian Haesemeyer

- K-theory
- Algebraic geometry
- Algebraic topology

christian.haesemeyer@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/646022-christian-haesemeyer

I study the interplay of algebraic geometric structures, which are rigid, and structures in homotopy theory, which are designed to capture flexibility, to understand how algebraic and geometric information is captured and reflected in homotopical invariants.

Algebraic K-theory

My research field of algebraic K-theory lies at the intersection of algebra, geometry, and topology. K-theory is a way to organise information about matrices with entries that are functions and generalised functions. Geometrically, K-theory deals with vector bundles, which are topological constructions that allow us to examine geometric properties of a space from an algebraic perspective.

K-theory of algebraic singularities

Generally, the K-theory of even the simplest algebraic structures is incredibly complicated and poorly understood. Adding the complication of singular behaviour should only make this worse. The central feature of my work is that this is not the case – rather, making use of generalised Chern characters, it is possible to extract information about the singularity from the noise.

My newest project is studying t-structures on the derived categories of algebraic varieties and using them to constrain the geometry in play.

$$E_2^{p,q}(alg) = H_{\mathcal{M}}^{p-q}(X, A(-q)) \Longrightarrow K_{-p-q}^{alg}(X; A)$$

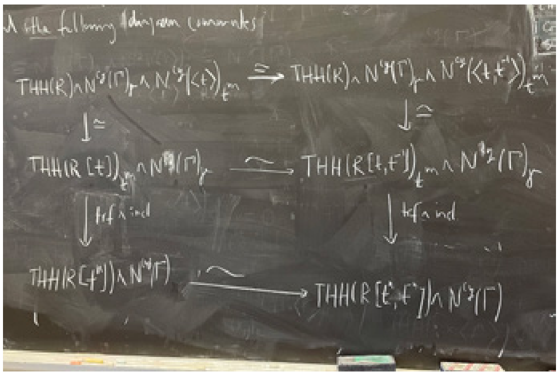
$$\downarrow$$

$$E_2^{p,q}(sst) = L^{-q}H^{p-q}(X; A) \Longrightarrow K_{-p-q}^{sst}(X; A)$$

$$\downarrow$$

$$E_2^{p,q}(top) = H^{p-q}(X^{an}; A) \Longrightarrow ku^{p+q}(X^{an}; A)$$

Going from algebra to topology, detouring through spaces of cycles.



Trace methods in action.

Associate Professor Jack Hall

Associate Professor Jack Hall

- Derived categories
- Moduli spaces
- Algebraic stacks

jack.hall@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/687336-jack-hall

An overarching goal of mine is to better understand the algebra and geometry from classification problems that arise in mathematics and its applications to physics.

Algebraic geometry has a long history. Its origins lie in the geometry of the set of solutions to systems of polynomial equations in several variables. Although simple-sounding, algebraic geometries are sufficiently rich to describe problems that arise in diverse areas, such as theoretical physics and cosmology, biology, statistics, quantum computing, cryptography, machine learning, robotics, and control theory. Being algebraic, the geometry can be computed by hand or using software packages.

Classification is fundamental to science. Well-known examples of classifications are: taxonomy in biology, the periodic table in chemistry and the elementary particles in physics. In mathematics we not only classify objects, but also study the very notion of classification itself. From this abstract point of view, the easiest type of classification is a simple list. We can also classify objects that can vary in a continuous fashion — like equations, whose coefficients we can vary. The study of this type of classification is the subject of moduli theory. Moduli theory encourages us to think about a single object of interest by analysing the geometry of a moduli space parameterising all similar objects. For example, how does the nature of an equation change if we adjust one or more of its coefficients just a bit?

$$\begin{array}{ccccc} ([N_x/G_x],0) & \longleftarrow & ([W/G_x],w) & \xrightarrow{f} & (\mathcal{X},x) \\ \downarrow & \square & \downarrow & & \\ (N_x /\!\!/ G_x, 0) & \longleftarrow & (U,u) & & \end{array}$$

Luna slices.

$$\mathrm{Hom}(\mathcal{X},\mathcal{Y}) \to \mathrm{Hom}_{r\otimes,\simeq}(\mathsf{Coh}(\mathcal{Y}),\mathsf{Coh}(\mathcal{X}))$$

Tannaka duality.

Associate Professor Sophie Hautphenne

Associate Professor Sophie Hautphenne

- Applied probability
- Stochastic models
- Branching processes
- Computational methods in probability

sophiemh@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/174876-sophie-hautphenne

My goal is to produce research in applied probability that can be used by practitioners (mainly biologists). Therefore, my research in applied probability involves the development of algorithmic and computational techniques, as well as statistical methods to fit stochastic models to various types of data. I am working in close collaboration with conservation biologists on the management of endangered species (including the Chatham Island black robins and Lord Howe currawongs) and hope to produce elements of environmental benefit to society.

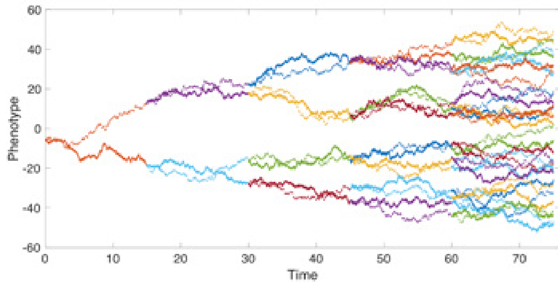
My work is motivated by real-world problems arising in population biology, ecology, and epidemiology. My research focuses primarily on branching processes, which are a flexible class of probabilistic models well suited to the study of populations that evolve randomly over time.

Analysing the probability of extinction of complex populations

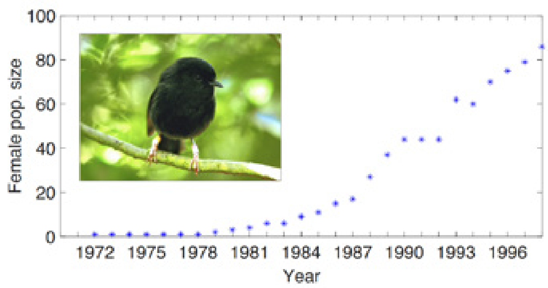
The survival or extinction of a population is subject to random events. The establishment of a population depends on several features, including the reproductive fitness of individuals and environmental factors. I am characterising the probability of extinction of various models which incorporate a number of these features. I am motivated by the practical use of these models, so my research also involves developing efficient computational methods.

Stochastic models applied to conservation biology

I am particularly interested in developing Markov models for endangered populations. One example is the Chatham island black robin, which was saved from the brink of extinction in the early 1980s. I am developing statistical methods to estimate model parameters, and I am deriving techniques that enable us to use the fitted models to analyse population viability and to design conservation strategies.



Branching model of phenotypic evolution.



Black robin population.

Associate Professor Graham Hepworth

Associate Professor Graham Hepworth

- Group testing
- Discrete inference
- Experimental design
- Statistical consulting

hepworth@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/6094-graham-hepworth

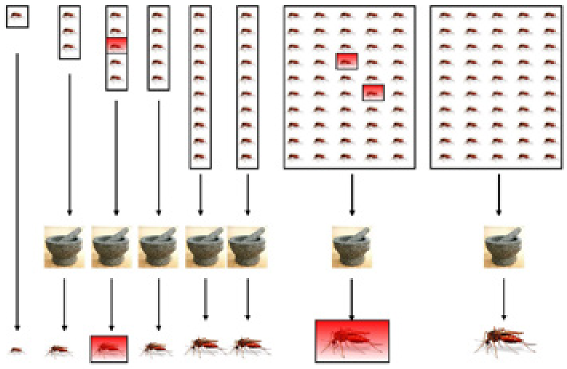
I enjoy collaborating with researchers across a range of disciplines as a statistical consultant, with particular interest in categorical data problems, especially those related to group testing.

Group (pooled) testing

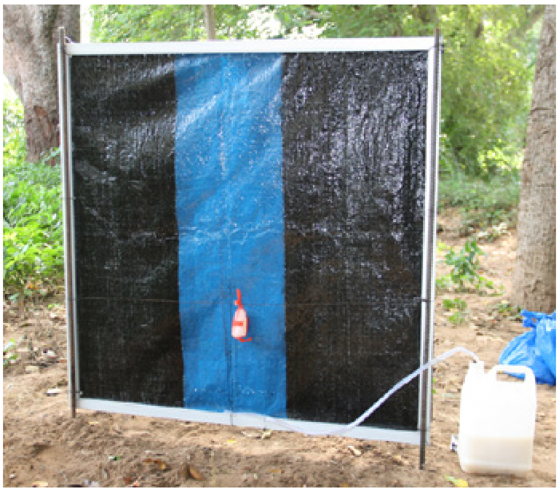
When estimating the proportion of a population with a characteristic of interest (e.g., COVID-19 infection), it is sometimes possible to pool individuals and perform a single test on the resulting group. A negative result indicates the absence of any infection in the group, while a positive outcome shows that one or more members are infected. If the level of infection in the population is small, group testing has the potential to save a lot of time and resources.

Group testing has also been applied to assess infection levels in mosquitoes carrying West Nile Virus (which can cause fever and other symptoms in humans, sometimes fatally) and in flies carrying Onchocerciasis (an eye and skin disease) . Trapping mosquitoes or flies creates groups of different size, which makes the estimation of proportions more complicated and interesting.

My work has concentrated on confidence interval methods and correction for bias. Various discrete inference problems have emerged along the way, such as the ambiguous ordering of outcomes.



Testing of mosquitoes for viruses using groups of different size.



Trapping of black flies for group testing.

Dr Edward Hinton

Dr Edward Hinton

- Applied Mathematics
- Geological Fluid Dynamics
- Flow in Porous Media
- Yield-stress fluids

ehinton@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/868039-edward-hinton

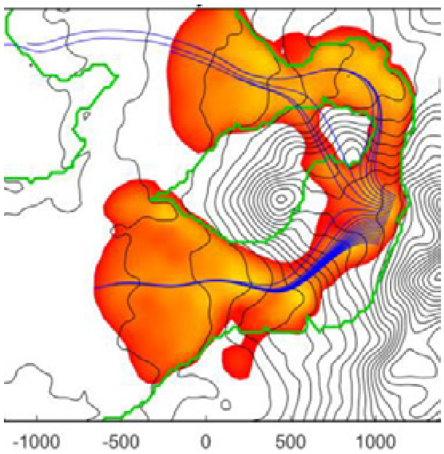
I model and interpret geological phenomena through mathematical approximations, numerical simulations, and analogue laboratory experiments. My approach is to reduce a complex physical system to a simpler configuration that retains enough key processes to provide valuable insights.

Flows in porous media

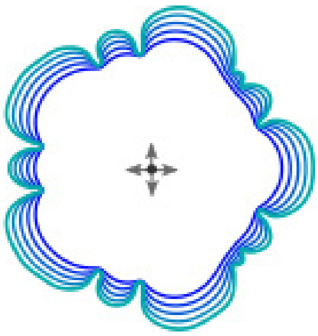
Subsurface flows are of vital importance to many industrial and environmental activities. Examples include groundwater flows, carbon dioxide sequestration, and underground hydrogen storage. A wide range of processes influence the flow from the pore scale through to the aquifer scale, and my research aims to identify the dominant phenomena and quantify their influence on the large-scale flow. Rock heterogeneity and flow instabilities associated with density and viscosity contrasts are particularly important. I investigate the onset, evolution, and shutdown of these instabilities through asymptotic analysis, numerical methods, flux-balance arguments, and complex variable techniques.

Yield-stress fluids

My work on the mobilisation of yield-stress fluids and their flow over topography and around obstructions, is applicable to hazardous geological flows such as lava, debris flows, mud slides and avalanches. Yield-stress fluids are rigid at low stresses but 'yield' and deform at higher stresses. Domestic examples include tomato sauce, mayonnaise, and toothpaste. The combination of liquid- and solid-like behaviour produces a rich array of flow features, which can be captured through mathematical and numerical approaches.



Simulating the lava field at Marcath Volcano, Nevada, USA



A numerical method for viscous fingering using complex variables.

Free-surface viscous flow around a cylinder.

Professor Mark Holmes

Professor Mark Holmes

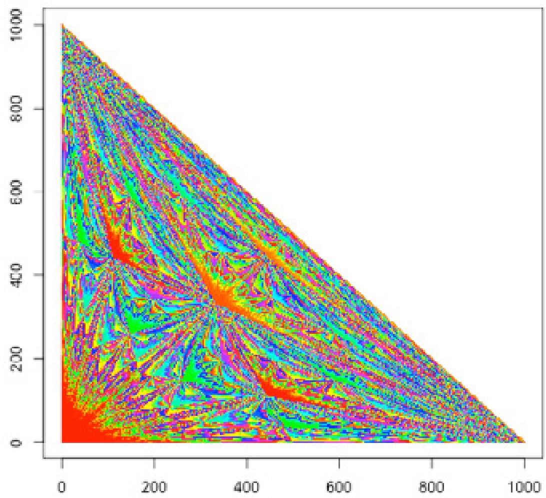
- Probability theory
- Applied probability
- Mathematical statistics

holmes.m@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/765156-mark-holmes

I initially chose to work in the area of Probability Theory because I found it fascinating, even though I didn't understand it. In my research, I continue to look for problems that are easy to state but are counterintuitive or hard to understand/solve. Probability is a fertile breeding ground for such problems.

I study various types of random processes, where one typically describes some local rules and is interested in describing the global behaviour of a system. For example, in a grid-like city at each street intersection either (with probability p) put signs pointing north and east or (with probability 1-p) put signs pointing south and west. This is an example of a random medium defined via local rules. We may now ask various global questions, for example, starting from the middle of the city, which points can you get to by following signs? More generally, I study various kinds of random processes such as reinforcement processes, random walks, random media (the above is an example of a random medium), interacting particles and queues.



This picture illustrates the probability of losing (being first eliminated) in a simple 3-player poker game when your opponents start with $x and $y respectively, and you start with $1000-x-y.

Dr Wei Huang

Dr Wei Huang

- Nonparametric regression
- Causal inference
- Functional data
- Missing data
- Measurement error

wei.huang@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/799353-wei-huang

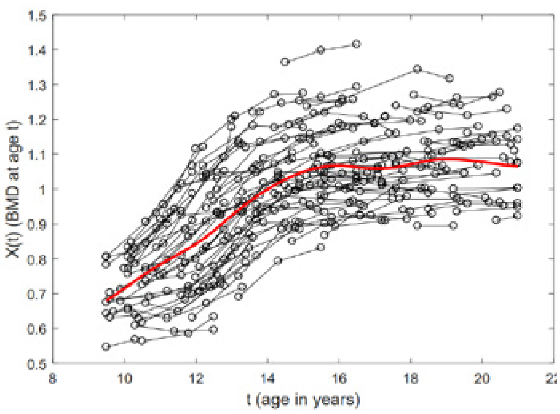
In modern society, we have so much information to deal with and so many decisions to make every day. I hope my research can help to develop more advanced data analysis techniques. By incorporating them into machine learning and AI technologies, we can one day have powerful enough AI to assist everyone in daily information gathering and decision making.

Causal inference

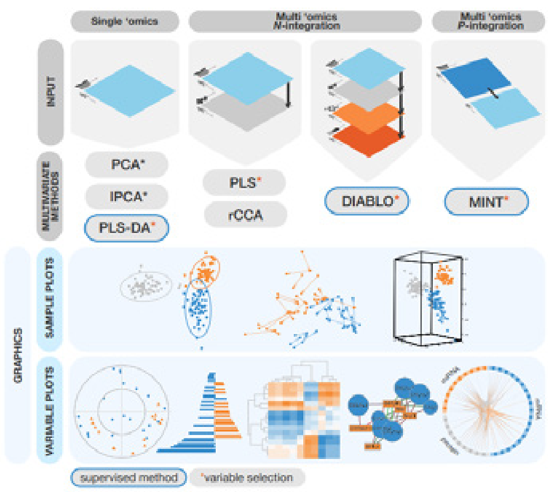
Functional data is data in the form of curves. For example, the data in the Berkley Growth Study, which consists of the heights of 93 individuals measured from their birth to eighteen years old, are functional data. The functional data analysis involves a full scale of statistical problems such as hypothesis testing, regression and classification. One challenge of the functional data analysis is that the data are usually observed partially — namely, each individual is only observable on a subset of the domain of interest. We have worked on the case where the random observable sub-domain is assumed to be independent of the data value. There, we established identifiability conditions under which the covariance function of the data can be recovered consistently and proposed a consistent estimator for it. Using this technique, we can recover the unobserved parts of the functional data.

Partially observed functional data

Most studies in the health and social sciences are motivated by causal rather than associative questions. For example, what fraction of past crimes could have been avoided by a given policy? What is the efficacy of a given drug in a given population? These questions could be answered straightforwardly if the potential outcome of any value of the cause is available while all the confounders are under control. However, in practice, such potential outcomes are usually unobservable. We aim to tackle this challenge using advanced techniques such as moment equation balancing and develop efficient methodologies to conduct causal inferences from different data types. The problem becomes even more complicated when we are given multivariate (dynamic) data, and the goal is to learn the causal structure among the variables from the data. This is called the causal discovery problem in machine learning. We aim to establish a framework to solve the problem using differential equations.

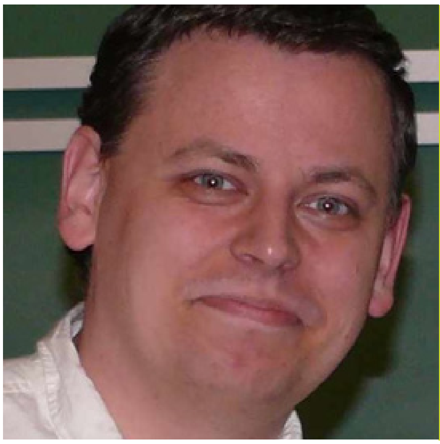


Partially observed spine bone mineral density curves for 130 females. Each fragment corresponds to one female. The red curve shows the mean.



Our recovered spine bone mineral density curves for 130 females.

Dr Mario Kieburg



Dr Mario Kieburg

- Random matrices
- Supersymmetry
- Harmonic analysis
- Orthogonal polynomials
- Probability theory
- Quantum physics

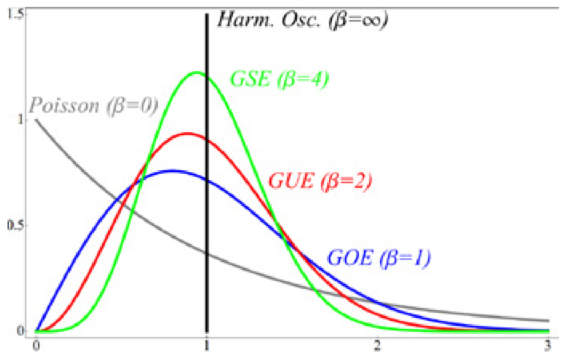
m.kieburg@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/562359-mario-kieburg

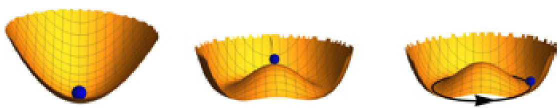
I am studying problems in Random Matrix Theory as it is exciting to see many different fields and interdisciplinary groups working on similar problems, only considering them from a different point of view. I like to work with mathematical rigour but also need to see the applications, which are a perfect motivational motor. The rich mathematical structures and the combination of tools which do not look as if they would be related are a creative challenge, which is an incentive in itself. My credo is: 'Throw everything in one pot, stir it a bit and see what the outcome is'.

Random matrices and their applications

Random Matrix Theory (RMT) is the theory where matrices are sampled randomly. It is generally a statistical and analytical mathematical tool which applications cover physical systems such as condensed matter theory, quantum chaos, quantum field theories and quantum information, as well as topics such as in engineering (telecommunications, information theory and machine learning) and statistics (time series analysis and stochastic processes). RMT is also very rich in several other mathematical tools comprising not only probability theory and linear algebra as the name suggests but is also intimately connected to differential geometry, graded algebras such as supersymmetry, harmonic analysis due to the relation to matrix groups, number theory and many more. The focus of my research lies in the mathematical and theoretical development of the tools and the understanding of RMT. Moreover, I also have several research projects on its applications such as quantum information, strongly interacting quantum field theory, time series analysis and telecommunications.



Level spacing distribution of different kind of spectra: Poisson (diagonal random matrix), GOE (real symmetric random matrix), GUE (Hermitian random matrix), GSE (Hermitian self-dual random matrix) and the Quantum Harmonic Oscillator spectrum.



The Mexican Hat Potential is a standard example of spontaneous symmetry breaking.

Dr Johanna Knapp

Dr Johanna Knapp

- String theory

johanna.knapp@unimelb.edu.au

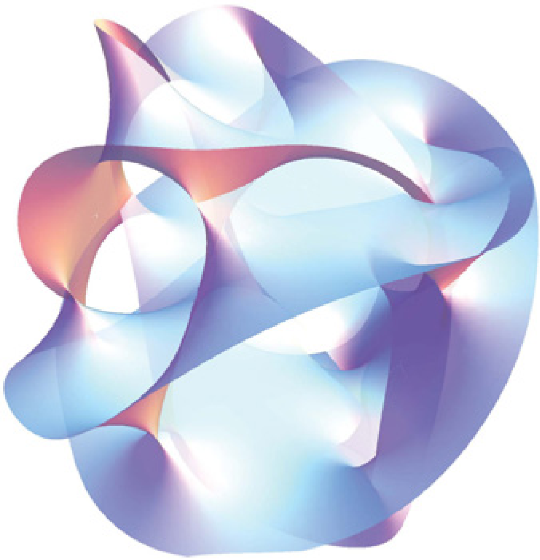
findanexpert.unimelb.edu.au/profile/860802-johanna-knapp

I am interested in understanding the fundamental laws of nature. Through my research, I hope to contribute to a better understanding of how the fundamental forces can be unified within one theoretical framework: string theory.

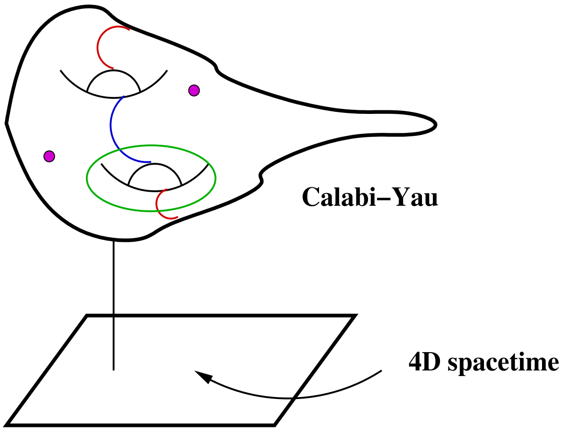
The physical mathematics of extra dimensions

My main area of research is string theory. String theory predicts the existence of extra dimensions, and the mathematical properties of the extra dimensions determine the physics that comes out of string theory. A prominent class of examples is called Calabi-Yau spaces. My research is concerned with the construction and analysis of Calabi-Yaus in the context of string theory, where I am applying standard techniques from physics to uncover mathematical properties of these spaces.

This approach is sometimes called 'physical mathematics' and has led to exciting new results both in physics and mathematics. Among those are highly non-trivial connections between different Calabi-Yaus, known as string dualities.



A Calabi-Yau space.



A cartoon of extra dimensions in string theory.

Dr Brian Krummel

Dr Brian Krummel

- Geometric analysis
- Minimal surfaces

brian.krummel@unimelb.edu.au

https://findanexpert.unimelb.edu.au/profile/905151-brian-krummel

brian.krummel@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/905151-brian-krummel

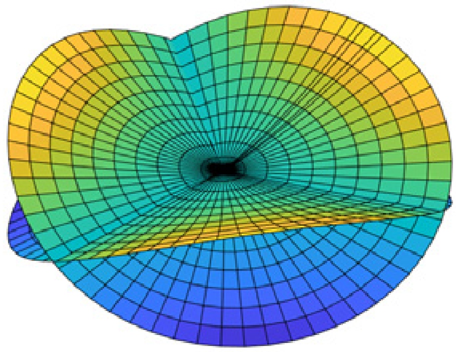
I aim to solve optimisation and time-evolution problems in geometry and physics, where surfaces frequently constrain a functional subject, such as area or energy, and often develop singularities. My goal is to understand the structure of the singular sets of such surfaces.

Singular sets of minimal surfaces

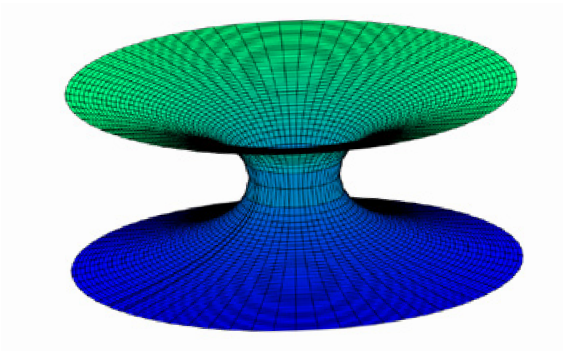
I am particularly interested in minimal surfaces, which arise from the Plateau problem of finding the surface of least area with a particular boundary. Near singular points, these surfaces are not a smoothly embedded sheet. Analysing the shape of the surface on approach to a singular point helps us to understand the size and structure of the singular set.

It is not generally known whether the singular set of a minimal surface has dimension less than that of the surface, or even whether the singular set has zero area. This is due to the presence of branch point singularities, at which the surface is tangent to a plane with integer multiplicity.

Almgren, in his ground-breaking work in the 1980s, showed that in the special case of an n-dimensional surface area-minimising surface, the entire singular set, including branch points, has Hausdorff dimension at most n-2. I am working on understanding the extent to which the singular set of a minimal surface is itself a lower-dimensional surface.



Bour's minimal surface with a branch point.



Catenoid as a minimal surface of revolution.

Dr Pavel Krupskiy

Dr Pavel Krupskiy

- Copulas
- Spatial data
- Multivariate extremes
- Measures of dependence
- Nonparametric statistics

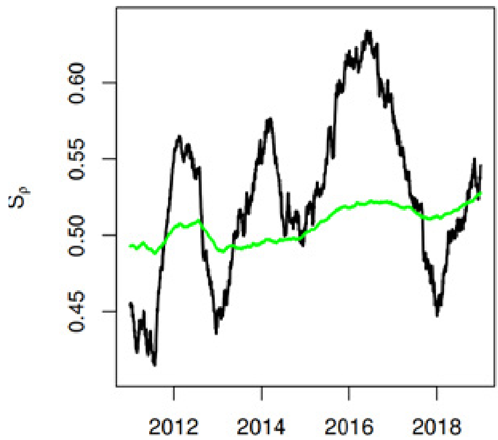
pavel.krupskiy@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/820088-pavel-krupskiy

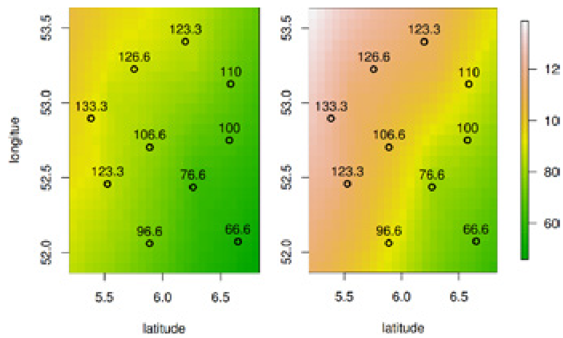
I am working on the development of very flexible models for high-dimensional data with complex dependence structures that standard models cannot capture. The proposed models can improve the fit in the tails of a multivariate distribution, and these models therefore can improve the forecasts of extreme events, such as severe floods or extreme pollution levels.

Multivariate dependence modelling

My research interests include the development of flexible models for multivariate data with complex dependence structures and fast inference methods for these models. My research is focused on modelling multivariate extremes (data that arise when very unusual or extreme events are observed, such as large negative returns on a stock market, severe flood or drought events), spatial data (data that are measured at different locations, such as pollution levels or weather data) and copula modelling. Copulas are functions used to combine univariate marginals into multivariate distributions. These functions can be used to construct flexible multivariate distributions, then used to model high-dimensional data with complex dependence structures. Potential applications include modelling financial returns, forecasting extreme weather events, and analysis of image data (such as fMRI data).



Time-varying dependence in stock returns from the consumer staples sector.



Interpolation maps for the average wind speed in Netherlands.

Professor Kim-Anh Lê Cao

Professor Kim-Anh Lê Cao

- Data integration
- Omics
- Multivariate analysis
- Feature selection
- R software

kimanh.lecao@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/791255-kim-anh-le-cao

Our research focuses on the development of computational methods, their applications in areas informed by biology, and the training of the new generation of computational biologists and data analysts. Our area of expertise is in the integration of biological 'omics data with multivariate and dimension reduction methodologies, selection of features of biomarkers in large biological data sets, and R software development. Our group provides critical collaborative expertise to biologists, bioinformaticians, statisticians, and clinicians.

Data integration methods using multivariate dimension reduction methods

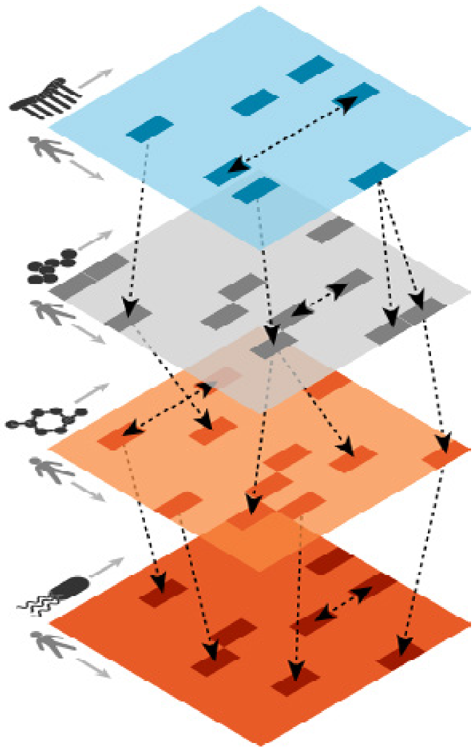
We develop dimension reduction techniques to integrate the information from cutting-edge sequencing technologies that give rise to 'omics data – transcriptomics (the study of all transcripts), proteomics (the study of all proteins), metabolomics (the study of all metabolites), metagenomics (the study of all bacteria). The challenge we are facing is the large number of features of omics molecules (hundreds of thousands) compared to the number of samples (less than 50 individuals) and the difference in scale of the data we analyse. We are currently expanding our methods for bulk experiments to single cell assays.

Statistical methods for microbiome studies

There are major statistical and computational challenges in analysing microbial communities that hinder the potential of microbiome research. We are interested in characterising and understanding microbiome-host interactions. Some of our methods' developments aim to address batch effects in microbiome experiments and analyse scarce temporal sampling in time-course studies. We analyse microbiome datasets from our collaborators for a wide range of studies, including investigating the role of gut and oral microbiome in spondyloarthropathy diseases, the development of intestinal or salivary microbiota in toddlers and infants, and investigating the gut-brain crosstalk in Huntington's disease.

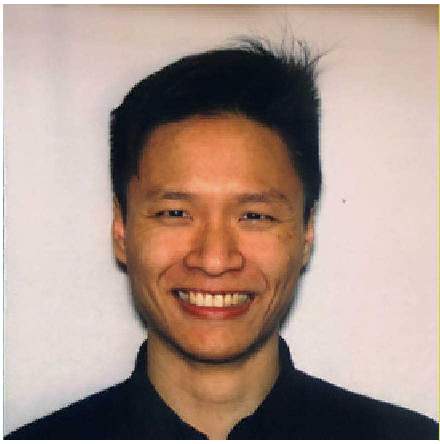
Development of the mixOmics R toolkit package

mixOmics is one of the few R packages dedicated to the integration of multiple 'omics data, and with an increasing uptake from the research community. Programming developments are ongoing for efficient programming for large-scale studies and the development of novel multivariate methods, and routinely teach multi-day workshops.



Multi-omics data integration aims to understand the relationships within each omics layers (eg from top to bottom transcriptomics, proteomics, metabolomics and metagenomics) and between omics layers for specific types of molecules identified by the methods.

Dr Dennis Leung



Dr Dennis Leung

- Multiple testing
- High dimensional inference
- Graphical models

dennis.leung@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/843419-dennis-leung

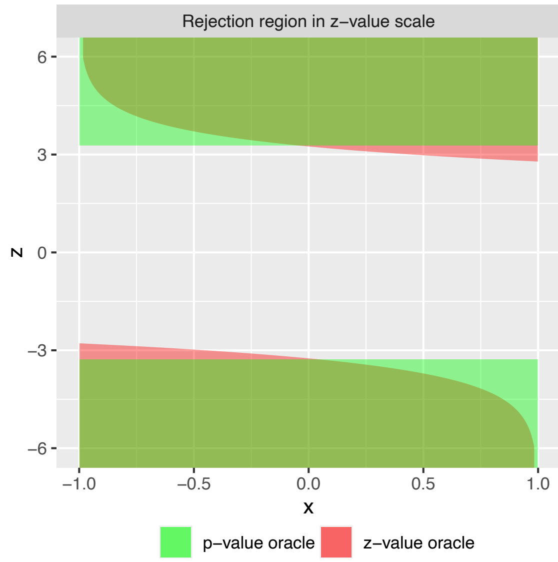
Hypothesis testing and the dual task of computing confidence intervals arguably constitute the most rigorous paradigm in statistics for uncertainty assessment, at least from the frequentist point of view. Within this paradigm, I conduct both theoretical and methodological research to develop new analytical techniques that are suitable for modern scientific applications where data can be 'big' in different senses, e.g tens of thousands of measurements for different genetic markers or millions of voxel measurements for fMRI data.

Multiple testing for false discovery control

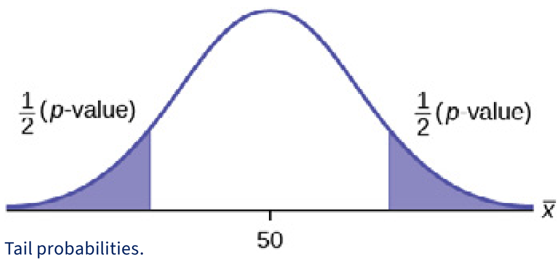
To make data-driven scientific discoveries with good reproducibility, researchers often have to routinely test a multitude of hypotheses simultaneously based on experimental data. For example, one may want to identify the potential few SNPs associated with a disease from many of them in a genetic dataset. My current research seeks to expand and refine the current methodologies on multiple comparisons in practical applications. This development is naturally propelled by the surge in demand to tease out, in a principled manner, the 'gems' from the 'haystacks' of data, such as biological data in omics scale, imaging data in millions of voxels, and many more, found in fields where large-scale datasets are generated.

High-dimensional inference

Sometimes, even a single hypothesis can be 'big'. This is true when the underlying dimension of the associated test is 'high'. For example, how would we calibrate the critical value if we were to test whether p random variables are mutually independent when the number of samples (n) we have is small compared to p? Classical asymptotic results assuming p (the underlying dimension) is fixed will give a bad approximation. Therefore, one needs to develop a new suite of high-dimensional asymptotic results to tackle problems of this kind.



Optimal rejection regions of oracle FDR procedures.



Tail probabilities.

Professor James McCaw

Professor James McCaw

- Mathematical biology
- Infectious disease epidemiology
- Virus dynamics
- Influenza
- Malaria

jamesm@unimelb.edu.au

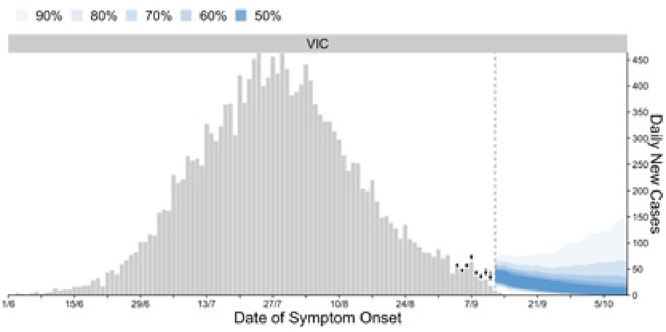
findanexpert.unimelb.edu.au/profile/4554-james-mccaw

My research goal is to advance our understanding of infectious diseases by applying mathematical and statistical theory. Through the application of rigorous analytical methods to data, my research will enable society to more effectively respond to emerging and re-emerging diseases, advancing public health.

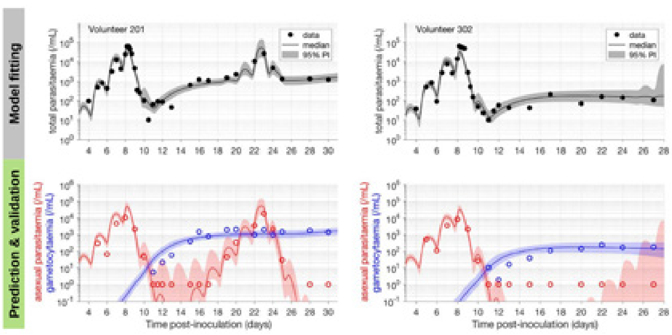
How do infectious pathogens like influenza, SARS-CoV-2 and malaria spread through the community? How do we most effectively respond to dangerous new pathogens? Can we protect ourselves and society by learning more about how the body responds to infection? All of these questions can be addressed through the development and application of mathematical models of infection and transmission. My research team uses mathematics, computational modelling and statistics to learn more about infectious diseases, how they spread and how society can most effectively respond. We develop and analyse models and apply them to data across multiple scales. We study how pathogens replicate within the body and how the immune system and drugs inhibit that replication.

We also study how pathogens spread from human to human and how public health responses — such as hygiene recommendations, physical distancing and vaccination — modify transmission.

The team develop new mathematical models for these biological processes and study their dynamics. Our research is deeply cross-disciplinary, engaging colleagues from clinical and biomedical fields through to psychology, epidemiology and public health. We contribute to fundamental knowledge in the life and mathematical sciences. Furthermore, we make direct contributions to public health policy and response measures for major infectious disease threats such as COVID-19 and malaria.

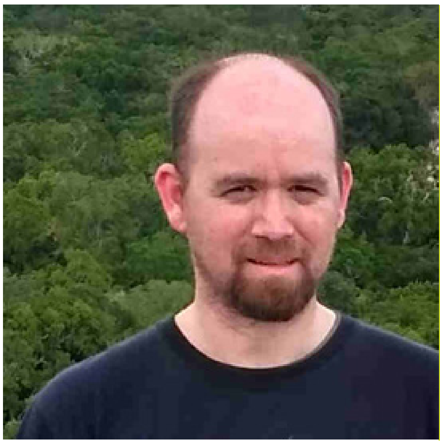


COVID-19 epidemic forecast for Victoria, September 2020 (McCaw et al, report to the Government 2020).



Model fit and validation for human volunteers infected with malaria. Our mathematical models of malaria infection capture the aspects of infection dynamics, enabling their use to predict how infectious humans are, enabling new approaches to malaria control (Cao P et al, eLife 2019).

Dr Peter McNamara



Dr Peter McNamara

- Representation Theory
- Lie Theory
- Combinatorics
- Number Theory

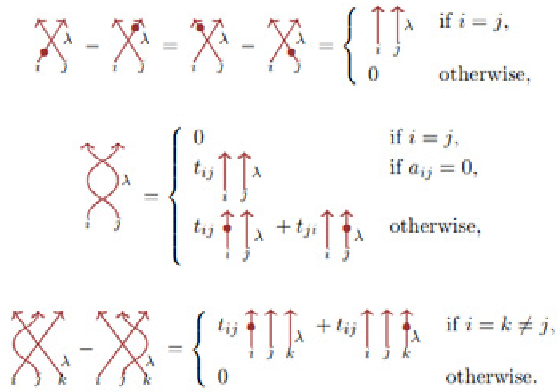
mcnamarap@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/643790-peter-mcnamara

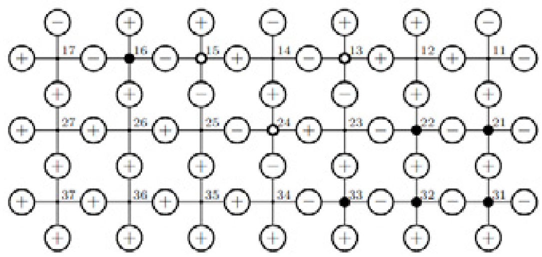
I aim to discover and understand new mathematical phenomena. I am particularly interested in categorical and geometric representation theory, understanding 'higher' symmetries and using geometric tools to study them.

Quantum groups

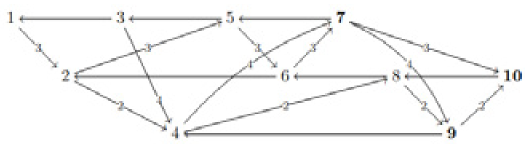
Much of my recent work involves objects related to categorical quantum groups, as part of a longstanding dream to create categorical versions of 3-manifold invariants arising from quantum groups at a root of unity, to create 4-manifold invariants. These categorified quantum groups act on many naturally occurring categories in representation theory and geometry.



Relations in the KLR algebra.

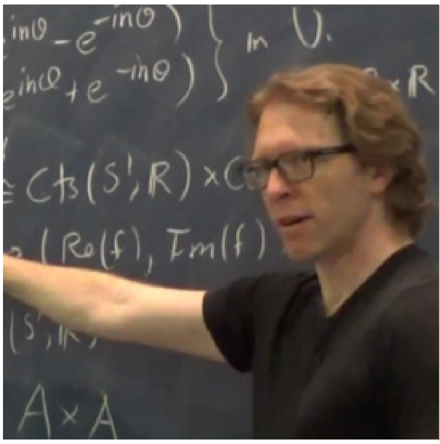


Six vertex model.



A quiver.

Dr Daniel Murfet



Dr Daniel Murfet

- Algebraic geometry
- Mathematical logic
- Theory of deep learning

d.murfet@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/390700-daniel-murfet

To understand singularities and their many manifestations in the world.

Algebraic geometry

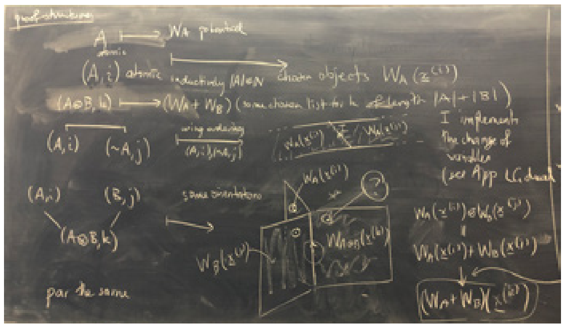
I work in singularity theory on foundational aspects of the theory of hypersurface singularities and their associated categories. My work touches on aspects of mathematical physics, and I have often collaborated with researchers in topological field theory and string theory on problems in algebraic geometry arising from those subjects.

Mathematical logic

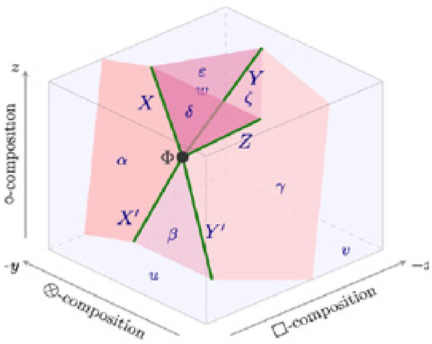
I have worked in the area of proof theory, on linear logic and its semantics, on connections between logic and algebra and between logic and the theory of computation.

Theory of deep learning

I am working with colleagues in the Melbourne Deep Learning Group on a new approach that aims to lay the foundations for a mathematical theory of deep learning based on algebraic geometry and statistical physics.



Working with one of my PhD students.



Monoidal bicategories.

Professor Paul Norbury

Professor Paul Norbury

- Geometry
- Moduli spaces
- Mathematical physics
- Gauge theory

norbury@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/13455-paul-norbury

I aim to rigorously prove heuristic ideas coming out of physics, including: {\em quantisation}, which gives various mathematical constructions of producing a quantum system from a classical one; {\em mirror symmetry}, which is a deep structure in quantum systems that uncovers surprising relations in mathematics; {\ em gauge theory}, which produces the standard model, magnetic monopoles and the Higgs field; and {\em string theory}, which seeks to develop a quantum theory of gravity.

Moduli spaces

My research involves moduli spaces that parametrise all occurrences of a geometric object. For example, the moduli space of circles is simply given by the positive reals, corresponding to the radius, or a single point if we decide similar (magnified) shapes are the same.

Riemann surfaces

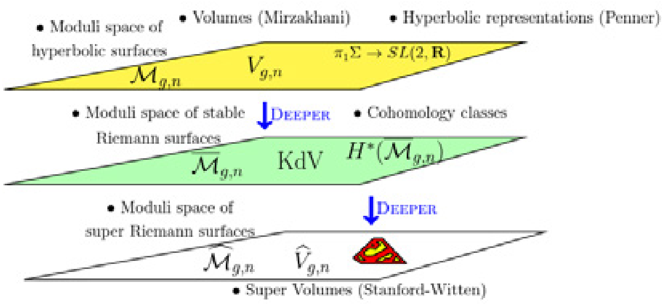
Riemann surfaces, such as spheres or spheres with holes possessing enough geometry to define angles, are rigorous objects allowing a pure mathematical analysis of world-sheets of one-dimensional strings sweeping through space-time in string theory. Integrating over all possible Riemann surfaces, using the moduli space, produces enumerative calculations useful in mathematics and physics. I study this space and a generalisation given by the moduli space of super Riemann surfaces with bosonic and fermionic coordinates, using gravity and gauge theory constructions.

Mirror symmetry

At the simplest level, mirror symmetry says that some physical systems can be described by two vastly different mathematical models, and this can be exploited to produce solutions of hard problems in one model, such as an enumerative problem, using the other model. My research uses Frobenius manifolds to give a geometric understanding of mirror symmetry.

Future Research Plans

The moduli space of super Riemann surfaces is not as well-developed as the classical module space. I am using a compactification of the moduli space of super Riemann surfaces to produce new rigorous calculations over both the super and classical moduli spaces of Riemann surfaces. Using ideas central to superstring theory, I aim to rigorously prove fundamental results in pure mathematics. Anticipated outcomes include calculations of volumes of moduli spaces of super Riemann surfaces, rigorous calculations for new super geometric problems, and, importantly, applications of these super calculations to the underlying classical problems. Expected benefits are new links between algebraic geometry and physics.



Super moduli spaces.

Associate Professor James Mark Osborne

Associate Professor James Mark Osborne

- Mathematical biology
- Multicellular systems
- Developmental biology
- Numerical methods

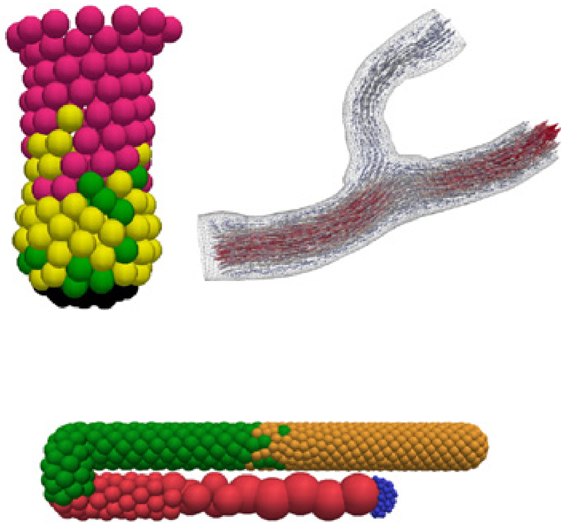
jmosborne@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/659967-james-osborne

I am trying to develop mathematical and computational methods and tools to help unravel the complex nonlinear interactions controlling organ development, homeostasis and disease.

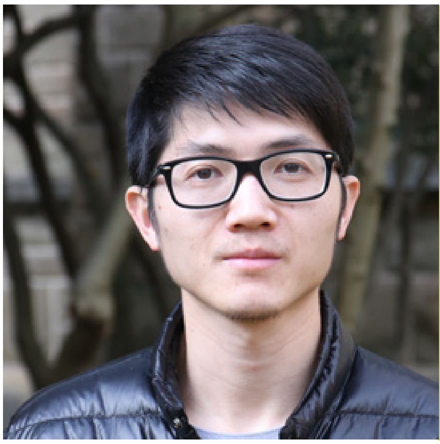
Multicellular systems biology

I combine mathematical modelling, numerical methods and computational simulation to understand multicellular processes — in particular, how cellular and subcellular interactions manifest at the tissue and organ level and how perturbations to these systems (mutations and drug interventions) influence the organs' form and function.



Example applications.
Top left: multicellular simulation of colorectal crypt.
Top right: flow in a deforming vessel bifurcation demonstrating bloodflow tissue interaction.
Bottom: multicellular simulation of C elegans germline.

Dr Liuhua Peng



Dr Liuhua Peng

- Extreme value theory
- Massive data analysis
- High-dimensional data analysis
- Bootstrap

liuhua.peng@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/795465-liuhua-peng

My research lies in many areas in statistics, especially in statistical theory. In particular, I am interested in extreme value theory with applications in economics and finance, distributed and online updating statistical inference for big data, high-dimensional data analysis, bootstrap, nonparametric inference, variable selection and model selection, random forest, and hypothesis testing in time series.

Extreme value theory with applications in economics and finance

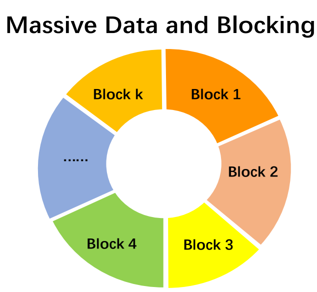
In probability and statistics, the behaviour of a distribution function in the tail region has been extensively investigated with the advancement of extreme value theory. Extreme value theory basically restricts the tail region of the distribution function to resemble a limited class of functions that can be fitted to the tail. The extreme value index plays a key role and serves as a basis for statistical applications of extreme value theory, thus statistical inference for the extreme value index and related topics are of great interest and have been broadly studied in the literature of statistics. In practice, extreme value theory combined with statistical inference offers a wide variety of applications in many scientific areas such as hydrology, environmental research and meteorology, geology, insurance, finance, and economics. In my research, we utilise extreme value theory to study extreme events and tail behaviour of datasets from many different perspectives. Our theoretical results are applied to many practical problems in economics and finance, including risk management and investment evaluation.

Distributed and online updating statistical inference for big data

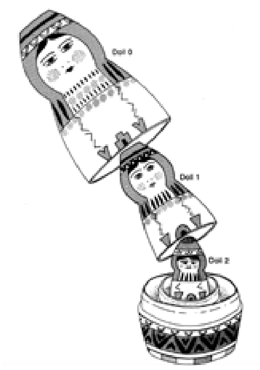
Massive data with rapidly increasing size are encountered in many scientific fields with a need for new statistical analysis. When the size of the data is huge, the implementations of statistical inference can be computationally expensive and slow. The issue is even worse when the data are stored in different locations, and we need to consider the computational cost of data communication and transformation. In my research, we aim to study the distributed inference for big data by proposing novel algorithms and investigating their theoretical properties.

Bootstrap and related areas

Bootstrap is widely used for accessing uncertainty of estimates and constructing confidence intervals since it is easy to implement and is second-order accurate under regularity conditions. Different versions of bootstrap have been implemented and studied in many areas of statistics. In my research, we study or propose different bootstrap algorithms applied to different types of datasets and different setups, and their theoretical consistency is built.



Distributed inference



A cartoon of bootstrap theory

Associate Professor Guoqi Qian

Associate Professor Guoqi Qiana

- Spatiotemporal statistics
- Machine learning
- Model selection
- Dynamic data analysis

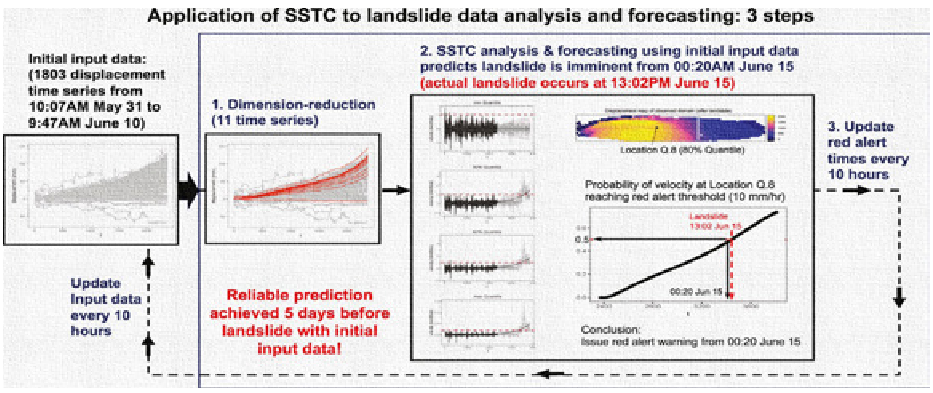
qguoqi@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/144561-guoqi-qian

I develop innovative quantitative methods and real-world applications to address statistical challenges encountered in a broad range of science, engineering, industry and business fields.

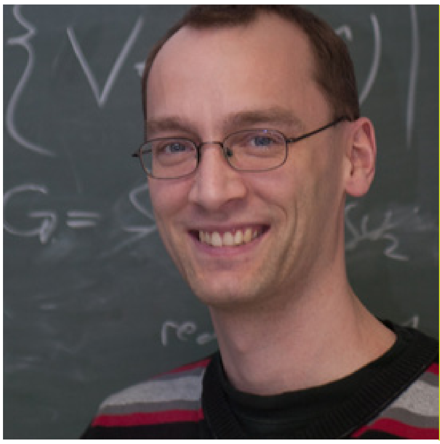
We undertake wide-ranging state-of-the-art research in statistics and data science, including spatiotemporal statistics, statistical machine learning, stochastic modelling, computational statistics, and statistical methods for climatology, epigenomics, and geo-hazard research. Examples are:

- Spatiotemporal modelling and extreme-event forecasting on big nonstationary geo-hazards data
- Spatiotemporal statistical methods for climate change research, including for seasonal tropical cyclone modelling and prediction, and for continental temperature and precipitation profiling
- Regression, clustering and classification for big and complex data/text mining and machine learning, including regression clustering,
- Support vector machines and ensemble of decision trees
- Statistical genomic and epigenomic association studies using cloud and clustered supercomputing
- Efficient computing algorithms for model selection in high-dimensional model space
- Decision and information theoretic methods for model selection
- Markov chain Monte Carlo including Gibbs sampler, EM algorithm and Bayesian computingW
- Time series analysis, including change-points and dependence structure identification
- Generalised linear models and composite likelihood for categorical, longitudinal and panel data, and
- Statistical modelling and inference for capture-recapture data in ecological studies.



A 3-step stochastic spatiotemporal cointegration (SSTC) method for landslide data analysis and forecasting.

Dr Thomas Quella



Dr Thomas Quella

- Mathematical physics
- Topological quantum matter
- Critical systems & statistical learning

thomas.quella@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/754514-thomas-quella

I'm fascinated by nature and natural phenomena and the intrinsic beauty of mathematical theories. Both passions have evolved hand in hand as I attempt to make my modest contribution to advancing the knowledge of humankind.

Topological quantum matter

On the level of individual particles, the fundamental constituents of matter and their interactions are well understood. However, in the presence of a large number of particles, the mutual interplay between interactions may lead to unexpected emergent phenomena, such as high-temperature superconductivity. Another phenomenon is associated with anyonic quasi-particles that can be manipulated to form braids and knots. These constitute a crucial ingredient of fault-tolerant topological quantum computation.

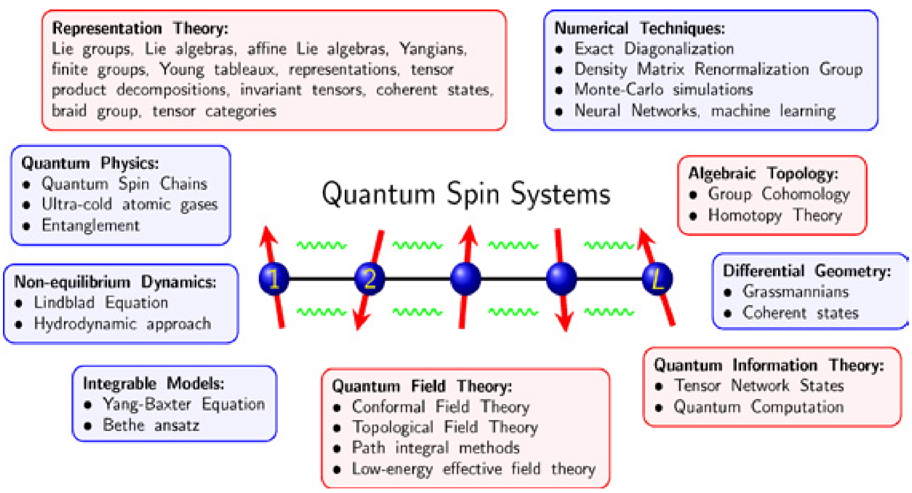
In my research, I am striving for a theoretical and mathematical description of such phenomena. This includes aspects of classification, characterisation. Besides relying on purely theoretical and mathematical reasoning usually based on symmetry and entanglement considerations, the investigations also partly involve numerical simulations using tensor networks, neural nets or quantum computers.

Critical phenomena and statistical learning

Roughly speaking, critical phenomena occur in systems that cannot decide which of two or more possibilities with fundamentally different properties they should realise. Critical phenomena are omnipresent in physics, but also play a crucial role in applied mathematics, probability theory, statistics, and even areas such as sociology and finance.

Criticality goes hand in hand with large fluctuations, and as a consequence, quantities of interest frequently diverge at a critical point. These divergencies can be described by power laws featuring so-called critical exponents. These critical exponents are usually insensitive to the microscopic details of a system, and hence permit us to make quite general and very useful statements about the behaviour of whole classes of systems.

In my research on critical phenomena, I am making use of a range of methods such as conformal field theory, symmetries, and renormalisation group ideas. Beyond the discussion of individual systems of interest, a strong focus of my research is on conceptual aspects and general structural properties of general critical phenomena.



Associate Professor Charl Ras

Associate Professor Charl Ras

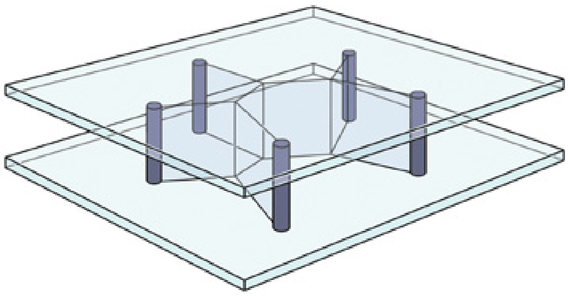
- Steiner trees
- Network design
- Algorithmics

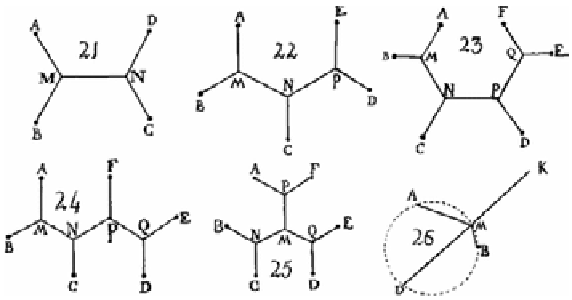
cjras@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/199833-charl-ras

Much of my research involves the development of foundational graph-theoretical tools, models and algorithms for solving optimisation problems from telecommunications, VLSI microchip design, wireless sensor networks and underground mining networks.

My primary research interest is in fundamental algorithmics for combinatorial optimisation. I have extensive experience in network optimisation, particularly in the design and analysis of exact algorithms.





Associate Professor Lawrence Reeves

Associate Professor Lawrence Reeves

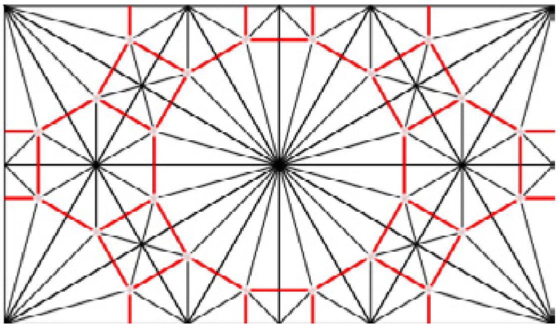
- Geometric group theory

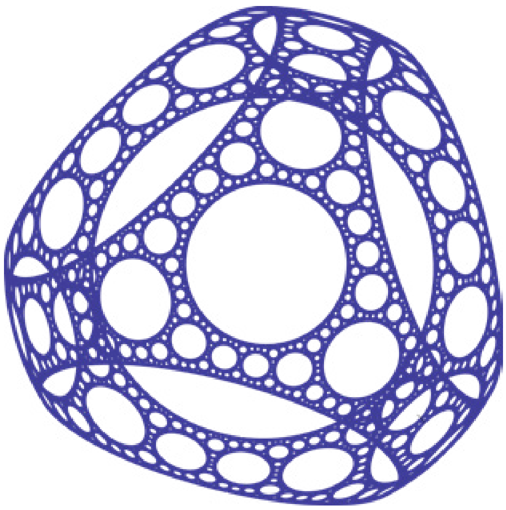
lreeves@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/27993-lawrence-reeves

The study of symmetry, as modelled by group theory, uses geometric and topological techniques. Finitely generated groups can be approached as geometric objects, and this point of view has been extremely fruitful over the past twenty-five years. To a finitely generated group, one can associate a metric space, the Cayley graph from which one then aims to deduce as much algebraic information as possible.

Symmetry is omnipresent in both our everyday lives and in the abstract world of pure mathematics. My interest in this research field is motivated by the desire to understand and analyse the mathematical abstraction of symmetry.





Associate Professor Marcy Robertson

Associate Professor Marcy Robertson

- Operads
- Homotopy theory
- Topology
- Higher category theory

marcy.robertson@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/643663-marcy-robertson

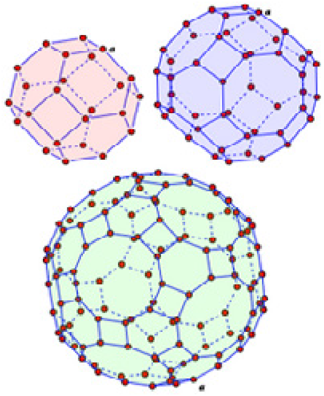
I focus on algebraic topology, particularly the development of models for infinity operads, properads, props and related structures, and applications of operads to low dimensional topology and geometry.

Depicting ambiguity

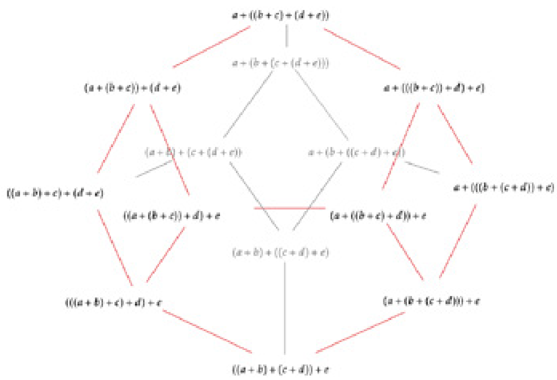
We learn early in school that (a+b)+c = a+(b+c). But if instead of clear equality we could only draw an ambiguous equivalence relation between these two algebraic sums, then adding a string of numbers would be problematic because with each number added, the final answer gains ambiguity.

Many operations used in science are only defined up to equivalence. Examples include tensor products, algebras arising in quantum mechanics with magnetic charges, field theoretical models appearing in the context of string theory, and various statistical models used in machine learning.

The resulting ambiguity can be depicted by drawing a polygon where an edge represents the relation between different sums (e.g., a pentagon depicts the ambiguity of adding 5 numbers together). To remove the ambiguity in our sums, we need to fill the polygon, making it possible to squeeze all our different sums together.

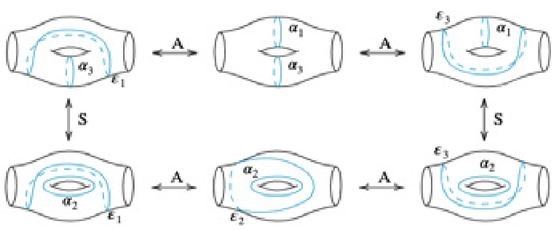


The ambiguity of a non-associative operation is represented by polytopes.



Homotopy coherent algebraic structures

I focus on the development and application of these kinds of algebraic models. Operads, props, and related structures encode algebraic structures (like addition) with any equivalences. I have constructed several first-of-their-kind models for ∞-props, properads, modular and cyclic operads. I am interested in building explicit models for modular ∞-operads and props that aid understanding of important geometric objects such as the (profinite) Grothendieck-Teichmüller group(s) and the Kashiwara-Vergne symmetry groups.



Professor David Ridout

Professor David Ridout

- Conformal field theory
- Vertex operator algebras
- Representation theory
- W-algebras
- Tensor categories

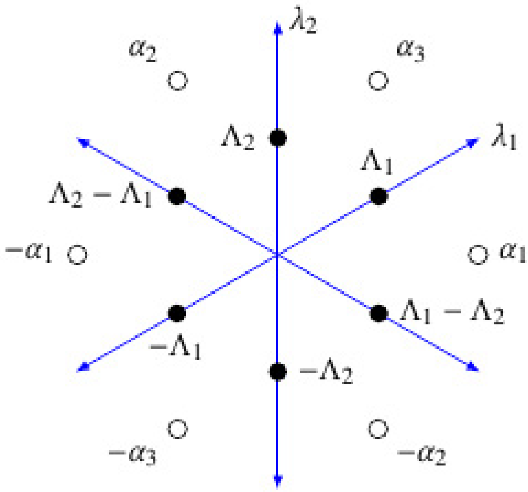
david.ridout@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/430351-david-ridout

I study the mathematical structures that underlie my favourite physical theories. These days that's mostly two-dimensional conformal field theories, especially the logarithmic ones, though I have dabbled in the past in integrability. On the mathematical side, I study the representation theory of vertex operator algebras and superalgebras. Sometimes I even prove theorems. But pretty much anything that involves cool math is fine with me.

One of my long-term interests is the class of conformal field theories known as the fractional-level Wess–Zumino–Witten models and the W-algebras obtained from them by quantum hamiltonian reduction. These are generally logarithmic, meaning that the corresponding vertex operator algebras have nonsemisimple module categories. This sounds hard (and it is), but there's a lot of cool 21st century mathematics tied up in this game, from 'relaxed' versions of highest-weight modules to generalisations of modular tensor categories and exotic new types of modular forms.

Physicists have also recently renewed their interest in this area because of newly found dualities connecting these types of conformal field theories to higher-dimensional supersymmetric gauge theories.



If you recognise this as the roots of sl(3) and the weight of its fundamental representations, then you'll know that I like to work on things related to Lie algebras.

1	$\frac{3}{8}$	0	$-\frac{1}{8}$	0	$\frac{3}{8}$	1	$\frac{15}{8}$	3	$\frac{35}{8}$	6	$\frac{63}{8}$	$\cdots$
3	$\frac{15}{8}$	1	$\frac{3}{8}$	0	$-\frac{1}{8}$	0	$\frac{3}{8}$	1	$\frac{15}{8}$	3	$\frac{35}{8}$	$\cdots$
6	$\frac{35}{8}$	3	$\frac{15}{8}$	1	$\frac{3}{8}$	0	$-\frac{1}{8}$	0	$\frac{3}{8}$	1	$\frac{15}{8}$	$\cdots$
10	$\frac{63}{8}$	6	$\frac{35}{8}$	3	$\frac{15}{8}$	1	$\frac{3}{8}$	0	$-\frac{1}{8}$	0	$\frac{3}{8}$	$\cdots$
15	$\frac{99}{8}$	10	$\frac{63}{8}$	6	$\frac{35}{8}$	3	$\frac{15}{8}$	1	$\frac{3}{8}$	0	$-\frac{1}{8}$	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

$$t = \frac{1}{2}, \qquad c = -2.$$

0	0	$\frac{1}{3}$	1	2	$\frac{10}{3}$	5	7	$\frac{28}{3}$	12	15	$\frac{55}{3}$	$\cdots$
$\frac{5}{8}$	$\frac{1}{8}$	$-\frac{1}{24}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{35}{24}$	$\frac{21}{8}$	$\frac{33}{8}$	$\frac{143}{24}$	$\frac{65}{8}$	$\frac{85}{8}$	$\frac{323}{24}$	$\cdots$
2	1	$\frac{1}{3}$	0	0	$\frac{1}{3}$	1	2	$\frac{10}{3}$	5	7	$\frac{28}{3}$	$\cdots$
$\frac{33}{8}$	$\frac{21}{8}$	$\frac{35}{24}$	$\frac{5}{8}$	$\frac{1}{8}$	$-\frac{1}{24}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{35}{24}$	$\frac{21}{8}$	$\frac{33}{8}$	$\frac{143}{24}$	$\cdots$
7	5	$\frac{10}{3}$	2	1	$\frac{1}{3}$	0	0	$\frac{1}{3}$	1	2	$\frac{10}{3}$	$\cdots$
$\frac{85}{8}$	$\frac{65}{8}$	$\frac{143}{24}$	$\frac{33}{8}$	$\frac{21}{8}$	$\frac{35}{24}$	$\frac{5}{8}$	$\frac{1}{8}$	$-\frac{1}{24}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{35}{24}$	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

If you recognise these as extended Kac tables for the logarithmic minimal models of central charge c=-2 and c=0, then you'll know that I'm a big fan of conformal field theory.

Associate Professor Nathan Ross

Associate Professor Nathan Ross

- Probability
- Stochastic processes
- Stein's method

nathan.ross@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/597202-nathan-ross

My research aims to understand probability models that frequently form the basis of likelihoods in statistical procedures. Such an understanding is necessary to quantify when a procedure 'works', meaning that its output is of an appropriate precision given the quantity and quality of the input data.

My research is at the interface of probability and statistics, and addresses problems that are fundamental to big data applications.

A main theme of my research is to understand probability models used for such data arising from real-world applications. My work has focused on understanding the structure of a number of random network and genealogical models, many times in concert with developing a powerful tool in modern probability called Stein's method. I have adapted the method to high and infinite-dimensional data settings of the kind that are now routinely encountered.

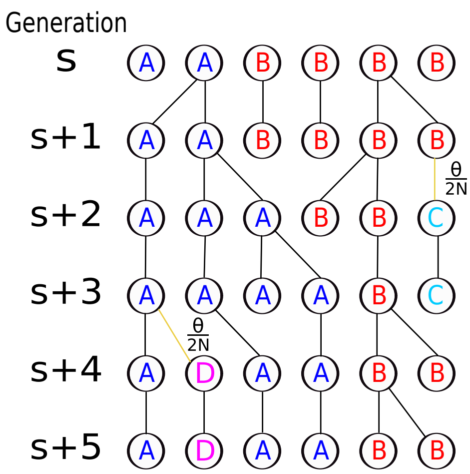
Genealogies

Consider the following problem from population genetics: A sample of size n is drawn from a population of size N, and the genes are sequenced for the purpose of inferring population parameters, for example, the past size of a viral population. For fixed sample size n, as the population size N tends to infinity the sampling distribution of types converges to the Ewen's Sampling Formula (ESF). Thus, it is standard practice to use the ESF likelihoods for inference. However, in modern genetics studies, faster and cheaper sequencing has made sample sizes large relative to population size, so it is no longer appropriate to think of n as 'fixed' and N as 'infinity'. How large can n be relative to N so that the ESF is a good approximation to the true sampling distribution? A consequence of my work is a partial answer to this question, which gives an explicit upper bound in the error between probabilities under the finite-N sampling distribution and the ESF, which is mathematically rigorous statement and meaningful in its application.

Networks

A standard approach to understanding the structure of a given network, such as a social or contact network, is to fit a parametric network model to the data. Properties of the network can be read from those of the model with the inferred parameters. For example, when modelling the spread of a disease in a community, it is important to first carefully model the structure of the underlying contact network. This will determine, for instance, if there are a few people with many contacts (super-spreaders) or if most people have close to the average number of contacts.

A popular parametric network model in sociology is the Exponential random graph model (ERGM). While ERGMs are widely used, their properties are not well understood. Some recent mathematical work suggests that in 'high temperature' parameter regimes ERGMs behave similarly to much simpler and well-understood Erdös-Rényi random networks (ERRNs). Some of my recent work derives explicit bounds on the difference between average quantities in ERGMs and ERRNs — here again the result is mathematically rigorous and can be used by practitioners to determine if their model is not appropriate.



Genealogy with mutations.

Dr Volker Schlue

Dr Volker Schlue

- Geometric hyperbolic partial differential equations
- Black holes

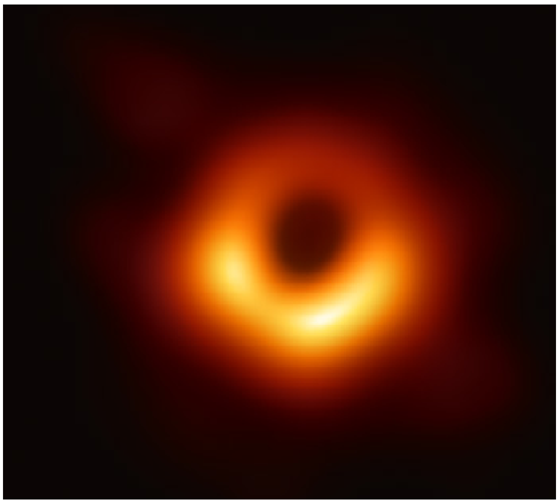
volker.schlue@unimelb.edu.au

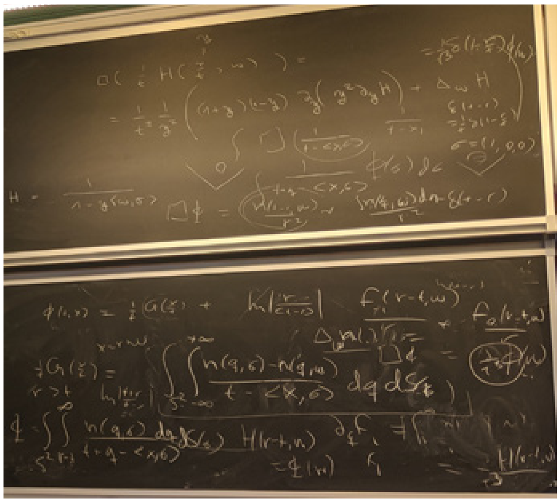
findanexpert.unimelb.edu.au/profile/839665-volker-schlue

I am driven by the explanation of many natural phenomena in mathematical terms. This is especially true in general relativity, where mathematical prediction often precedes experimental discovery. Indeed, gravitational waves were predicted 100 years before they were detected. I am aspiring to advance the mathematical theory needed to understand the many predictions of general relativity theory.

My research interests are in partial differential equations, geometry and analysis, and I am particularly interested in mathematical problems that arise in general relativity theory. These questions pertain to the study of gravitational waves, black holes and models of the expanding universe.

My primary research aims to understand the evolution of expanding black hole spacetimes and to analyse the nonlinear nature of gravitational waves in the presence of a positive cosmological constant.





Associate Professor Karim Seghouane

Associate Professor Karim Seghouane

- Statistics
- Signal processing
- Image processing
- Medical imaging
- Physiological signal analysis

abd-krim.seghouane@unimelb.edu.au

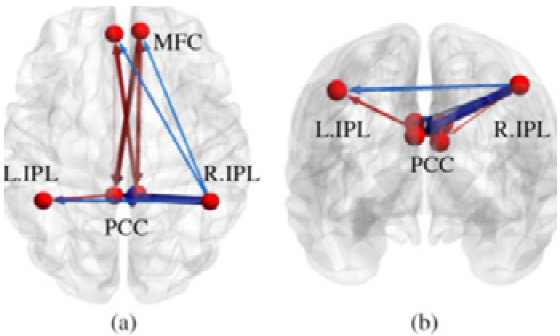
findanexpert.unimelb.edu.au/profile/470194-karim-seghouane

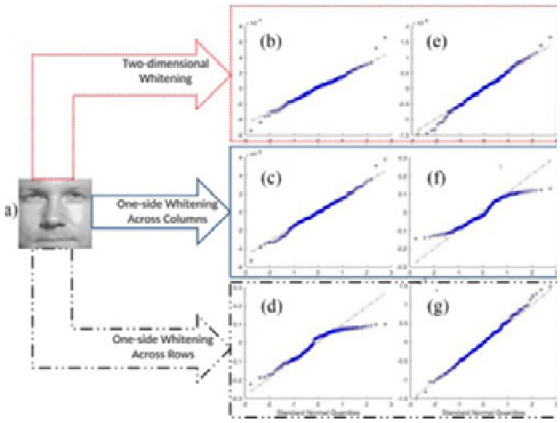
From sensors to information and decision, we develop everything in between. The type of sensors, their complexity and the nature of the phenomenon they are used to monitor are constantly evolving and changing. Extraction of valuable information for analysis and decision making from the data provided by these sensors requires the development of new and complex statistical methods and the associated algorithms. These statistical methods and algorithms differ from problem to problem and task to task. Their development is a challenge which is always different, and the result can have a direct impact in areas such as health, education, environment and defence.

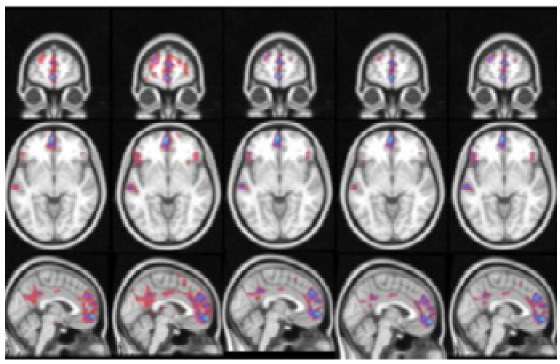
Statistical signal and image processing

Images and video can, for example, be found in the aerospace, cinema, environment and health industries. Signals, on the other hand, are found in the music, defence, communication and seismic industries. Given such information support, my research aims to develop machine learning and statistical methods and the associated algorithms to extract the carried information for analysing this type of data or decision making.

Examples of tasks can be the detection of a signal hidden in noise, recognition of a specific or unknown object, identification of a person, analysis of motion in a video, compression, anomaly detection and border security. The methods and algorithms that are developed can be used for performing tasks from a single signal or image, a batch set of signals or images, a mixture of signals and images, streaming signals and images or a set of distributed sensors, each delivering a separate piece of information.







Professor Kate Smith-Miles

Professor Kate Smith-Miles

- Optimisation
- Operations research
- Machine learning
- Data science
- Algorithm testing

smith-miles@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/811703-kate-smith-miles

I am driven to use mathematical knowledge to tackle significant problems impacting society. I enjoy interdisciplinary collaboration and have worked with colleagues in many fields, including climate science, stem cell biology, robotics, and finance.

One of the most significant societal challenges in the past decade or so has been the rise in popularity of algorithms to help make decisions. The question of whether we can and should trust algorithms has provided the impetus for my Instance Space Methodology, which provides researchers and industry with the methodologies and tools to stress-test algorithms and identify their strengths and weaknesses. Using mathematical and statistical techniques, we can reveal and understand the conditions under which an algorithm is reliable and can be trusted.

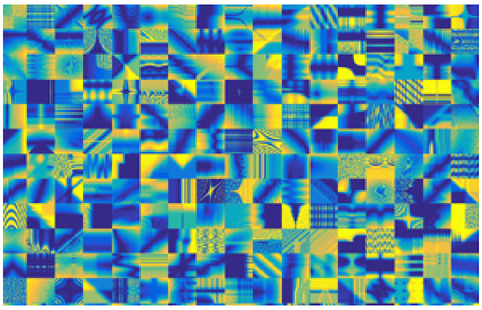
Stress-testing algorithms for establishing trust

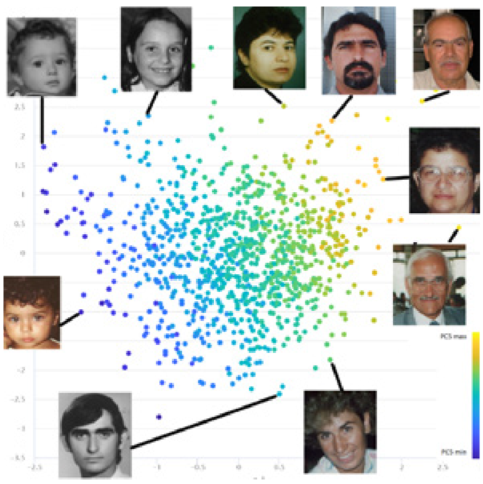
Whether we trust an algorithm depends critically on how we test it. The choice of test examples, or instances, used to test an algorithm should not be random or cherry-picked to make an algorithm look successful. Honest assessment of an algorithm's strengths and weaknesses relies on being able to prove the test instances are comprehensive and possess important properties, such as diversity, difficulty, discrimination, and lack of bias.

We have developed a powerful methodology known as Instance Space Analysis, using mathematical and statistical techniques, for visualising the whole instance space, and where an algorithm has been tested, where it should be tested with new test instances, and how the strengths and weaknesses of various algorithms can be understood in terms of instance properties. The methodology is broadly applicable, and has been applied to many problem domains in optimisation, machine learning, image processing, and other fields. Online tools are available at matilda.unimelb.edu.au to support researchers performing Instance Space Analysis for their problem domains, and stress testing their algorithms.

Industrial optimisation

Optimisation problems found in industry typically fall into two categories: model-based (where the goal is mathematically defined in terms of the decision variables) or model-free (where there is no mathematical statement of how the decisions affect the solution quality, only a limited set of past experiments that have been done to understand the cause-effect relationships between decisions and outcomes). We work with many industry partners in the ARC Training Centre for Optimisatiom Technologies, Integrated Methodologies, and Applications (OPTIMA) to tackle large-scale industrial optimisation problems of both types.





Dr Matthew Tam

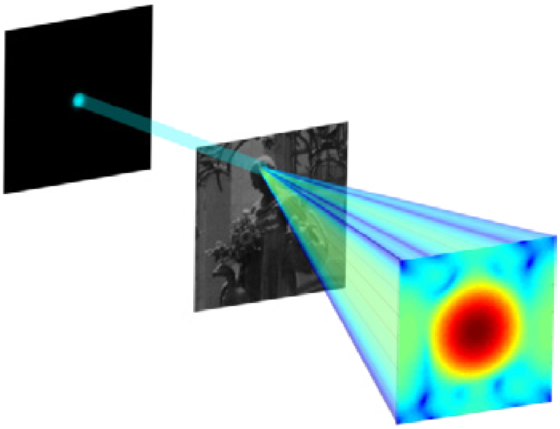
Dr Matthew Tam

- Optimisation
- Operations research

matthew.tam@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/859328-matthew-tam

Despite their ubiquitous use, many software packages routinely rely on a number of algorithms from mathematical optimisation which are not properly understood. My work aims to develop the mathematical theory required to rigorously justify the use of such algorithms and thereby ensure the integrity of the decision tools they produce.



Optimisation is the field of mathematics concerned with the problem of selecting a 'best element' from a set of permissible alternatives. Typically, these problems are expressed in terms of minimising or maximising the quantity of interest subject to constraints on the decisions that affect said quantity. My particular research interest is the development of computational methods for solving optimisation problems.

Professor Peter Taylor

Professor Peter Taylor

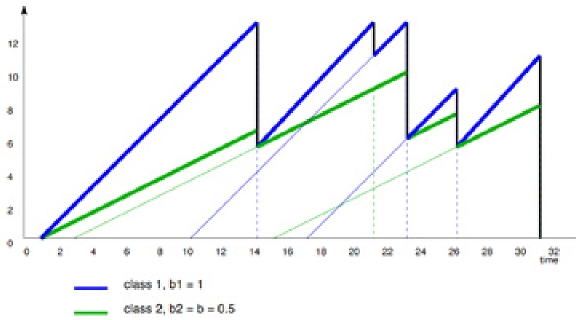
- Applied probability
- Stochastic modelling

taylorpg@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/6214-peter-taylor

My primary area of research interest is applied probability. I am interested in understanding how systems driven by random processes behave and how we can make rational decisions in respect of their management. Currently, I am working on epidemiology, blockchains, data-driven and spatial queueing problems and strategic queueing, as well as various questions in probability itself.

Systems that are driven by stochastic or random effects are ubiquitous. It is crucial for society's wellbeing, in economic and other terms, that we understand such stochastic systems and learn to control and optimise their operation. My research advances the mathematical theory of stochastic modelling at a deep level, connects with practitioners in science, economics, social science and engineering and reaches out to the public with the goal of educating people about stochastic phenomena.



The maximal priority process for a two-class accumulating priority queue.

Professor Kari Vilonen

Professor Kari Vilonen

- Langlands program
- Representation theory
- Algebraic geometry

kari.vilonen@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/554939-kari-vilonen

My goal is to understand certain basic questions regarding representation theory, most of which are motivated by the Langlands program. In its most general incarnation, the Langlands program can be regarded as a kind of grand unification scheme involving several areas of mathematics. One immediate goal is to bring certain parts of this program involving real groups to conclusion.

Representation theory, algebraic geometry and the Langlands program

My research involves the study of representation theory, often done with the aid of geometric methods. Much of my research involves real groups – algebraic objects which describe the fundamental symmetries occurring in nature. They are important both in number theory and in the physical sciences, for example, quantum mechanics and particle physics. My work aims to address deep fundamental questions about these symmetries, and my research is motivated and guided by the Langlands program. This program predicts deep connections among different areas of mathematics as well as unexpected dualities. The study of such dualities is central in my work, which involves a variety of techniques. The geometric techniques are often aided by analysis which involve understanding the structure of a system of partial differential equations. A novel feature is the suggestion that the theory of mixed Hodge modules governs the representation theory of real groups. Most recently, I have been working on theory of character sheaves in the context of graded Lie algebras. This work is connected to many other areas of representation theory, and the (at the moment still distant) goal is to apply it to representation theory of p-adic groups.

Dr Camelia Walker

Dr Camelia Walker

- Applied mathematics
- Mathematical biology
- Infectious disease modelling
- Bayesian inference

camelia.walker@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/876972-camelia-rose-walker

I use computational statistical methods and stochastic modelling to provide policy-relevant understanding of infectious diseases.

COVID-19 modelling

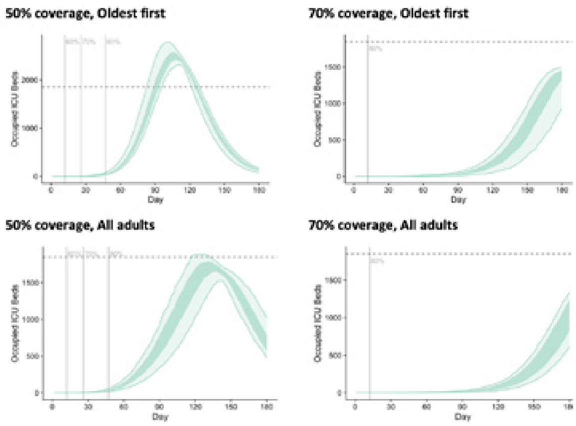
Mathematical modelling of COVID-19 transmission informed public health policies that impacted millions of people globally. In Australia, modelling provided evidence for border closures and re-openings, and for vaccination prioritisation policies. As vaccine protection waned and immune-evading variants circulated, modelling informed changes to vaccine policy. My collaborators and I have fed into these public health decisions and more.

Malaria modelling

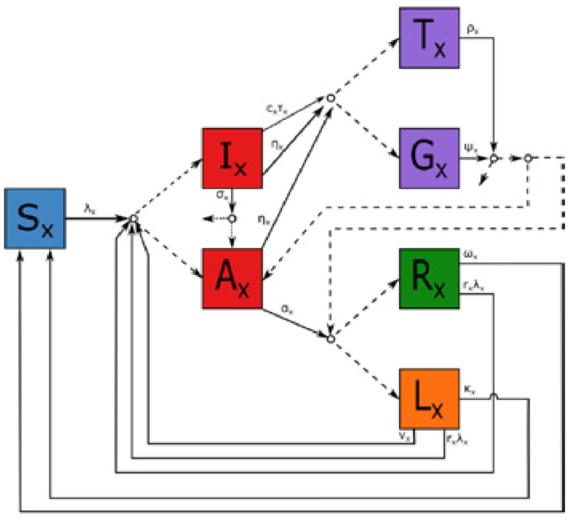
Globally, in 2020, there were 241 million malaria cases and 627,000 deaths, and USD3.3 billion was spent fighting the disease. I use mathematical modelling to understand the impact of treatment strategies in regions with multiple species of malaria. I also aim to understand how malaria spreads seasonally and spatially, so that interventions can be targeted appropriately.

Inference for epidemics

Infectious disease spread is non-linear, partially observed, and stochastic, making it computationally intractable to evaluate likelihood functions directly. I develop and apply computational statistical methods for model selection and parameter inference – such as importance sampling, data-augmented Markov chain Monte Carlo (MCMC), and particle-marginal MCMC – to characterise infectious diseases, focusing on household transmission studies and combining multiple data-sources from a single outbreak.

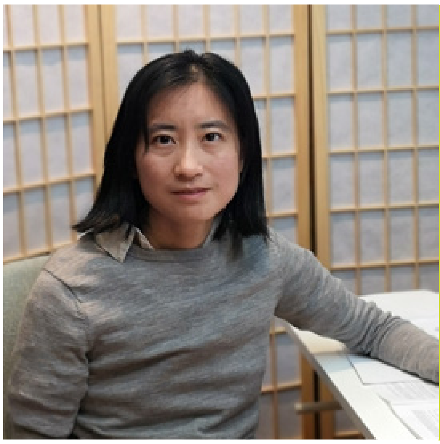


COVID-19 ICU occupancy projections by vaccine coverage and rollout strategy as presented in a report to National Cabinet.



Malaria compartmental model diagram.

Dr Chenyan Wu



Dr Chenyan Wu

- Automorphic forms
- L-functions
- Theta correspondence
- Abelian varieties
- Shimura varieties

chenyan.wu@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/816983-chenyan-wu

I love thinking about and striving to understand beautiful structures in elusive concepts. I would like to build upon them and make new discoveries. These studies may provide powerful new tools to other branches of mathematics and physics where understanding and manipulation of structures are key. The influence propagates to other disciplines, which in turn may have real-world applications that none of us that help create them can foresee.

My research area is number theory. I study automorphic forms and automorphic representations. Their invariants, such as L-functions, are mirrored in the representations of Galois groups. This is an aspect of the Langlands Program. I focus on the study of the behaviour of automorphic representations under theta correspondence and more generally under endoscopic lift/descent. We may glean important information on L-functions from this investigation. In particular, we may contribute to the resolution of conjectures such as the Riemann Hypothesis, which concerns the Riemann zeta function that the L-functions generalise. I also study Abelian varieties and their moduli spaces; my research aims to construct explicit Abelian varieties which produce L-functions with desirable vanishing properties at the critical point. The invariants attached to Abelian varieties, such as L-function and rank of groups of rational points, are the objects that appear in the Birch-Swinnerton-Dyer conjecture.

Theorem (Jiang-Wu, corollary to which gives "$\geq$")

$\mathrm{FO}^{Y}(\sigma) = \dim Y + 2r \Rightarrow$

$$\int_{[J]} \mathrm{Res}_{s=s_0} E(g, s, f_{\chi\otimes\sigma})\theta_{X_1,Y}(g,1,\phi)\,dg \neq 0$$

with $s_0 = \frac{1}{2}(\dim X - (\dim Y + 2r) + 2)$. *Here*

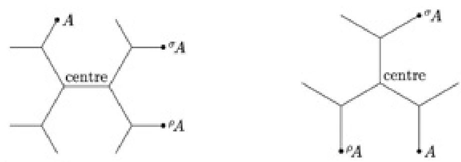
$$J = \begin{cases} \mathrm{Sp}_{2n+2-r} & \text{if } r \text{ even;} \\ \text{Jacobi group with Levi} \cong \mathrm{Sp}_{2n+2-r-1} & \text{if } r \text{ odd;} \end{cases}$$

$$J \subset \mathrm{Sp}(X_1) = \mathrm{Sp}_{2n+2}.$$

Galois Orbits in λ-tree

Definition

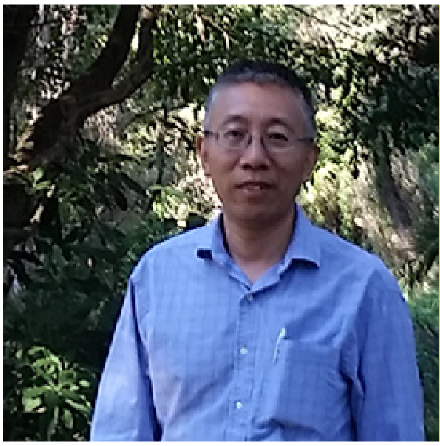
For a set of vertices define the centre to be the central edge/vertex on any longest path that connects two vertices.



Proposition

The centre associated to the set $\{[^{\sigma}A] | \sigma \in \mathrm{Gal}(\overline{F}/F)\}$ *is fixed under* $\mathrm{Gal}(\overline{F}/F)$.

Professor Aihua Xia



Professor Aihua Xia

- Point processes
- Limit theory of random processes
- Approximation theory and Stein's method
- Stochastic Modelling.

aihuaxia@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/15452-aihua-xia

I seek to understand and help solve problems that can arise from random phenomena, including bushfires, floods, traffic accidents, mining, insurance, and mortality. In the process, I enjoy working with brilliant people, deepening my understanding, developing tools, and inspiring new people in the field.

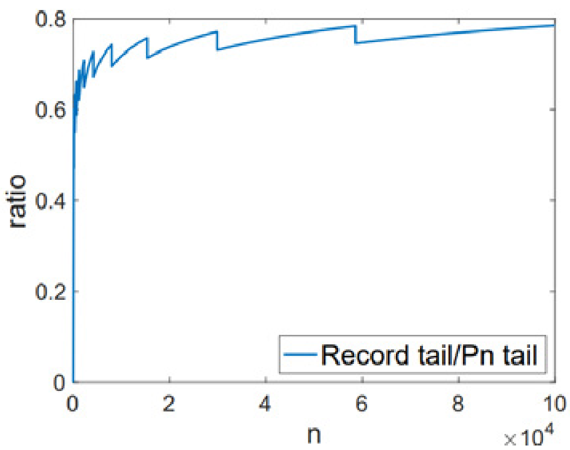
My research encompasses point processes, extreme value theory, stochastic calculus and semimartingales, limit theory in stochastic processes, Stein's method and probability approximations, Markov processes, queueing networks, image processing, and brain structure and functioning.

Point processes

Developed since the 1930s, point process theory addresses a wide range of practical problems. A random event in time and space can be recorded as a point in a suitable (high-dimensional) space, and a point process is the pattern of such recorded points. I investigate the intrinsic properties and long-run behaviour of point processes.

Extreme value theory

Extreme events such as floods, bushfires and catastrophic earthquakes are often 'unexpected', and consequently result in significant loss of life and resources. Using extreme value theory – a branch of probability theory developed through building models for historical records of phenomena – I aim to understand the asymptotic behaviour of extreme events.



Modelling the tail behaviour of a distribution.

Dr Binzhou Xia

Dr Binzhou Xia

- Permutation groups
- Graph symmetries
- Cayley graphs

xia.b@unimelb.edu.au

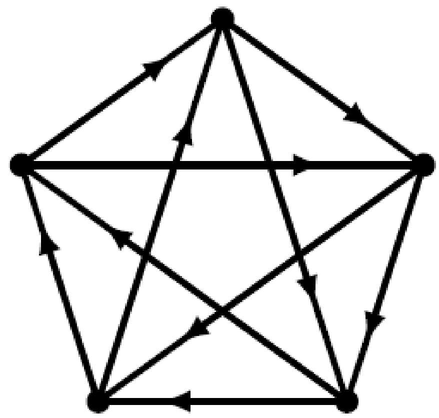
findanexpert.unimelb.edu.au/profile/666753-binzhou-xia

While there are always concrete math problems that I'm working on, the ultimate goal is always to reveal the surprising aspect of the mathematical object. This can be the pattern, analog, generalisation or link between seemingly unrelated branches. It is the intrinsic beauty of pure math that makes me appreciate it, look for it and try to touch it.

Symmetries of Cayley digraphs

Algebraic graph theory is an important branch of mathematics and Cayley digraphs are fundamental objects of study in this field. Given a group and a subset of the group one can construct a digraph, called a Cayley digraph, by regarding the elements of the group as vertices and drawing an arc between two vertices whenever their quotient lies in the subset.

Since introduced by Arthur Cayley in 1878, the study of Cayley digraphs has been at the intersection of group theory and graph theory, and is now a central topic in algebraic graph theory and geometric group theory. The aim of research in this area is to characterise and construct Cayley digraphs with different levels of symmetries, using tools from combinatorics and permutation group theory.



A digraph on five vertices.

A Cayley graph on Alt(5).

Associate Professor Ting Xue

Associate Professor Ting Xue

- Representation theory
- Algebraic groups

ting.xue@unimelb.edu.au

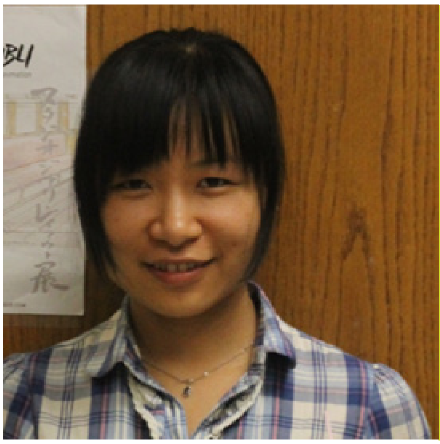
findanexpert.unimelb.edu.au/profile/658488-ting-xue

My current research aims to establish a Springer theory in the setting of graded Lie algebras. The theory provides a framework that connects many central objects in representation theory, such as Hecke algebras, affine Springer fibres and Hessenberg varieties. As such, a long-term goal is to apply our theory to gain insight into representation theory in these more complex contexts, as well as geometry of fundamental objects in algebraic geometry and number theory.

Algebraic groups and Springer theory

My research is concerned with geometric aspects of representation theory, a mathematical study of the basic symmetries that occur in nature. Representation theory is a central area of mathematics which facilitates connections among different areas and has many applications to sciences such as quantum physics and quantum chemistry. A fundamental role in representation theory of finite groups is played by the Springer theory and character sheaves. My research has focused on developing Springer theory and the theory of character sheaves in more general settings. Our theory is expected to have applications in representations of real groups and p-adic groups which encode more complicated symmetries, as well as in number theory and algebraic geometry.

Dr Yaping Yang



Dr Yaping Yang

- Lie algebras
- Geometric representation theory
- Quantum groups

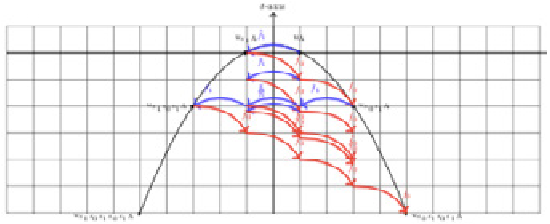
yaping.yang1@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/792490-yaping-yang

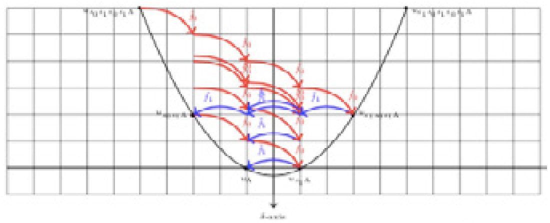
I study the relation of Morava E-theories (oriented cohomology theories in topology) and the character formulas built using Kazhdan–Lusztig polynomials in representation theory. I am interested in this project since it not only provides new insight into classical constructions, but also produces new objects. It also uncovers the profound connection between two fields of mathematics.

My primary research area is geometric representation theory. The representation theory studies the basic symmetries of mathematics and physics. The geometric representation theory is the study of the problems and objects of representation theory by discovering new geometric tools and insights and has close and deep connections to many branches of mathematics. I study the quantum groups which are deformations of the basic symmetries and their representations which can be realised as cohomology of certain moduli spaces of sheaves arising from mathematical physics.

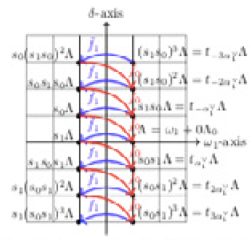
PLATE B: Pictures of $B(\omega_1+\Lambda_0)$, $B(\omega_1+0\Lambda)$ and $B(-\omega_1-\Lambda_0)$ for $\widehat{\mathfrak{sl}}_2$



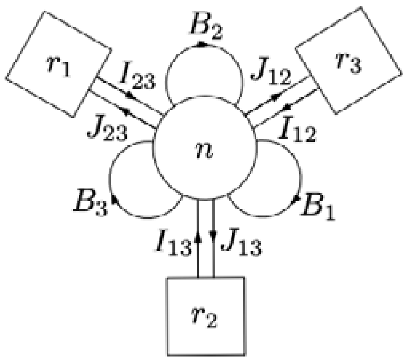
Initial portion of the crystal graph of $B(\omega_1+\Lambda_0)$ for $\widehat{\mathfrak{sl}}_2$



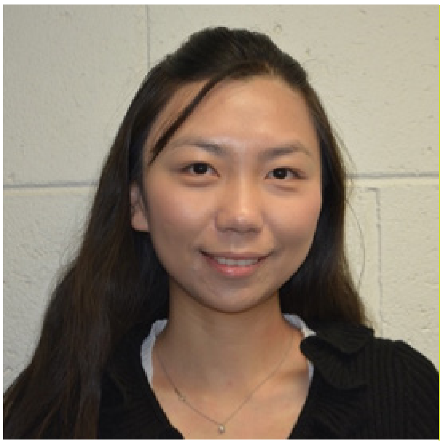
Final portion of the crystal graph of $B(-\omega_1-\Lambda_0)$ for $\widehat{\mathfrak{sl}}_2$



Middle portion of the crystal graph of $B(\omega_1+0\Lambda_0)$ for $\mathfrak{g}=\widehat{\mathfrak{sl}}_2$



Dr Lele (Joyce) Zhang



Dr Lele (Joyce) Zhang

- Operations research
- Modelling
- Optimisation
- Transportation
- Logistics

lele.zhang@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/1a2-joyce-zhang

I would like to use my knowledge and skills to solve real-life problems, such as last-mile delivery, staff rostering, public transport scheduling, traffic flow management and signal optimisation, and see the models, methods and solutions that we develop implemented in practice and benefit people.

Our research applies techniques in Operations Research to model and optimise real-life problems arising in areas such as transportation, city logistics and health care systems. Insights obtained from our research will inform stakeholders, including companies and government agencies, to make smarter decisions and achieve better performance.

City logistics

Growing freight demand from e-Commerce combined with low utilisation of freight vehicles by independent operators has considerable effects on urban traffic congestion. Our group has been working on a platform that is used for modelling an open, shared and integrated urban freight network and designing viable and effective solutions that reduce the total network costs and benefit all stakeholders. The platform can estimate the effects of the solutions on the financial performance of shippers and carriers and the impacts on traffic congestion. It helps understand the factors that motivate the stakeholders to participate in such an integrated network in practice.

Traffic flow modelling and control

Sophisticated traffic signal controllers are essential for achieving good performance of urban transportation networks. Our group develops a stochastic microsimulation model for studying the fundamental relationship between traffic flow and density and identifying the factors that determine a network's performance, which include traffic demand's spatial and temporal patterns, traffic signal settings and road lengths. The model is also used for devising traffic control strategies, including green-wave and perimeter control, and evaluating their performance in mitigating traffic congestion.

Modern warehouse/depot.
Image credit: Axisadman. License: CC BY-SA 3.0.

Traffic in Melbourne CBD.

Dr Gufang Zhao

Dr Gufang Zhao

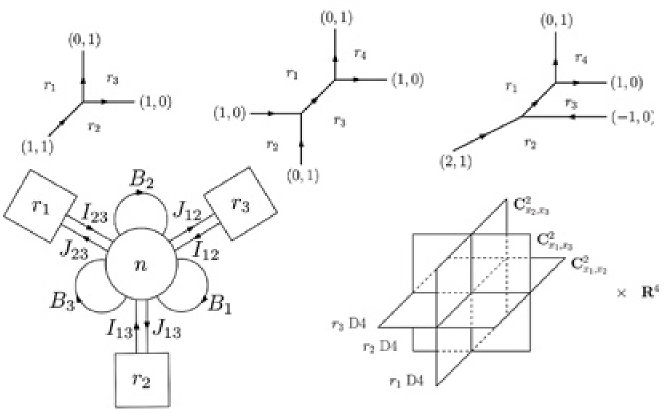
- Representation theory
- Algebraic geometry
- Topology

gufangz@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/796824-gufang-zhao

To push further knowledge in pure mathematics.

I am interested in representation theory and related algebraic geometry and topology. In particular, I am interested in various types of quantum symmetries often of mathematicophysical nature arising from geometry. The methods I use involve cohomology theories, derived category and moduli spaces.



Professor Sanming Zhou

Professor Sanming Zhou

- Graph theory
- Algebraic graph theory
- Network optimisation

sanming@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/6248-sanming-zhou

I enjoy working on various problems in graph theory, algebraic graph theory and network optimisation, using tools from different fields of mathematics.

Graph theory

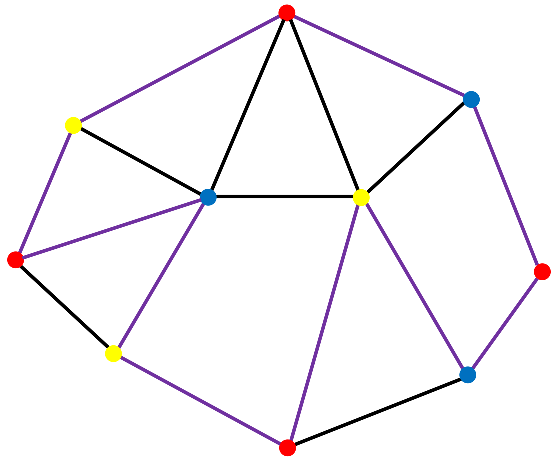
Mathematical graphs representing networks are made of vertices and edges, where each edge joins a pair of vertices. My research in graph theory focuses on classical problems such as colouring vertices of graphs with the fewest colours under some constraints, identifying cycles visiting all vertices, and finding integer flows in graphs.

Algebraic graph theory

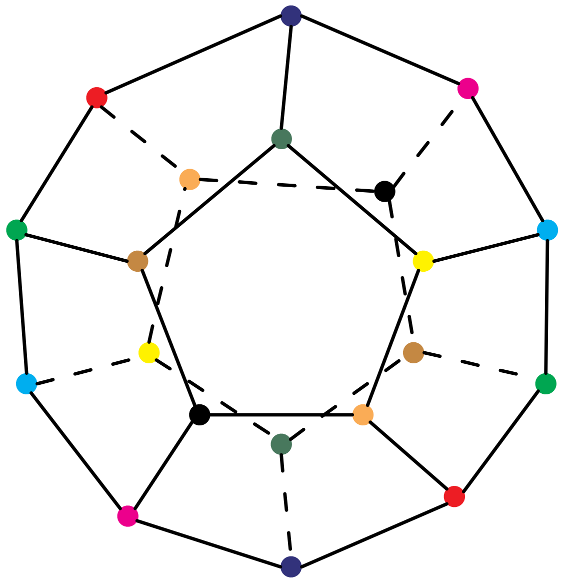
I have a passion for studying graphs with various types of symmetry using algebraic and combinatorial methods. I am also interested in applying symmetric graphs to the design of networks.

Network optimisation

In this area, my research is focused on several computationally challenging problems from theoretical computer science and communication, including the isoperimetric problem, routing and gossiping, channel assignment, colouring and optimal labelling, and network design.



The purple edges of this graph form a cycle which visits each vertex exactly once. The vertices of this graph are coloured with three colours such that any two vertices joined by an edge receive different colours.



This graph is the 1-skeleton of a dodecahedron. It is symmetric with respect to both vertices and edges. The colouring shown is not optimal – It is possible to colour this graph with three colours such that adjacent vertices receive different colours.

Professor Paul Zinn-Justin

Professor Paul Zinn-Justin

- Quantum integrable systems
- Combinatorial algebraic geometry
- Random matrices

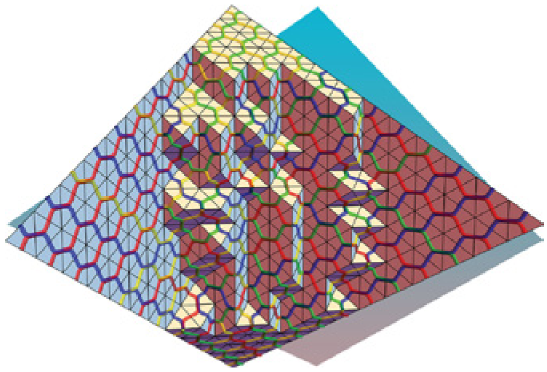
p.zinn@unimelb.edu.au

findanexpert.unimelb.edu.au/profile/454473-paul-zinn-justin

I'm interested in the mathematical aspects of fundamental theories of physics and how they can in turn shed new light on problems of a purely mathematical nature.

My main area of research is the interaction between quantum integrable systems (a topic from mathematical physics) and pure mathematics, in particular, algebraic combinatorics and enumerative geometry.

I also have an interest in computational methods in algebraic geometry and combinatorics, and in computer algebra systems.



A combinatorial model for Schubert calculus.

THE UNIVERSITY OF
MELBOURNE

UniMelb on-demand

Get to know us better in your own time

SciMelb

CRICOS Provider Code: 00116K

RFQ08492