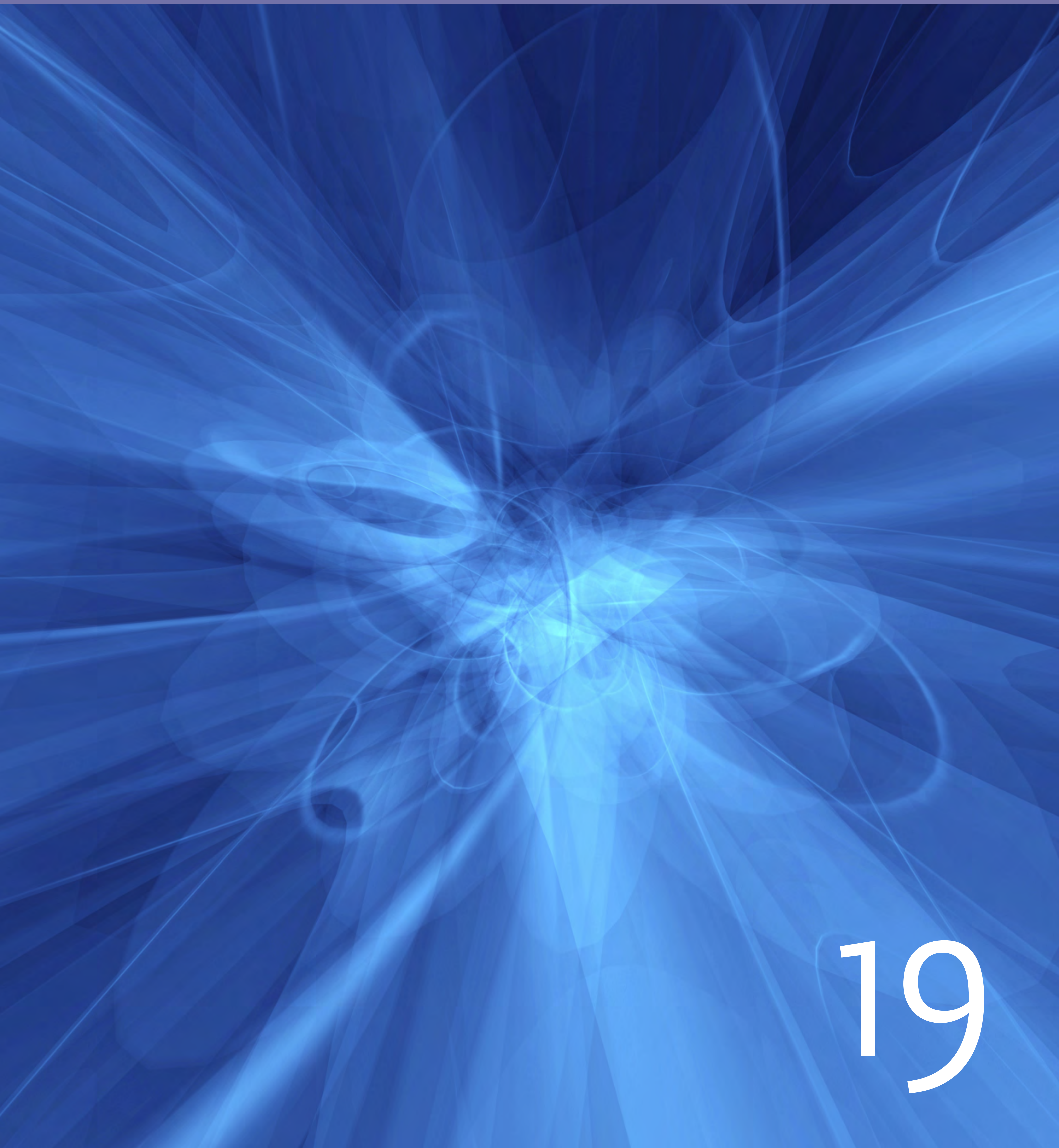
School of Mathematics and Statistics
College of Engineering

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Postgraduate Handbook 2019



School of Mathematics and Statistics

Postgraduate Programme 2019

Welcome from our School. Postgraduate study enables you to study selected mathematical and statistical topics in depth. There is a change of emphasis from the preceding undergraduate years: courses tend to be more focused on a specific problem or class of problems, rather than attempting to give a broad coverage of a branch of mathematics and statistics.

There is the possibility of taking one or more projects in which you investigate some problem with the assistance of a member of staff. Depending on the nature of the problem, this may involve literature searches, the use of various computing packages (for example MATLAB, Maple or R), resources on the internet, proving new theorems or data analysis. You will produce a written dissertation and may give an oral presentation.

Any proposed programme of study requires the approval of the 400 level coordinator. It is highly unlikely that any proposed programme that has a high workload in one semester will be approved, so you should try to construct a programme that balances your workload evenly over both semesters.

You can include some courses from other subjects (e.g. COSC480 is recommended for developing programming skills). This is a good way to ensure you have a broad program of study. Check with the School's 400 level coordinator that the courses from other subjects are suitable for inclusion within your program of study. In addition, there are a various joint programs between our School and other Departments/Schools detailed below.

At the Masters and PhD level you will undertake research, often focussed on deep study of a specialised topic. You will learn skills in undertaking systematic investigations, contextualising your work within the current state of understanding, so that your research outcomes can extend beyond the forefront of human knowledge.

Honours or PG Diploma in Mathematics/Statistics?

The School offers both Honours and Postgraduate Diploma programs of study, which can be undertaken under Science or Arts. The most appropriate program is best decided on a case-by-case basis which you should discuss with the 400 level Coordinator, Assoc. Prof. Carl Scarrott. The following guide provides some general advice about your options. You are welcome to get in touch as soon as possible, but you must do so before the formal enrolment period. If you are undertaking honours, you must have arranged a supervisor of your project in advance of enrolment. The 400 level coordinator can help you with this.

In addition, we also offer a Postgraduate Certificate in Arts for students interested in a 60 points programme of study, or a Certificate of Proficiency for undertaking a course or courses of interest.

Who should think about Honours? If you view Mathematics/Statistics as more than a means to an end, then doing Honours will be a year well spent. In addition to taught courses, the honours program has a full year 30 point project which will not only deepen your understanding of a specialised topic but will also develop many of the soft skills desired by employers or for further Postgraduate study, like self-motivation, independent learning, research, written and oral communication.

The Honours subject majors are listed below. Formal details are in the UC Calendar. To enter Honours in Mathematics, you will need at least 60 points from MATH301-394, plus at least 30 points from 300-level MATH, STAT or other approved courses. For Honours in Statistics, you need at least 60 points of 300-level STAT301-394, plus at least 30 points from 300-level STAT, MATH or other approved courses. Normally you will have maintained at least a B+ average in these papers.

BSc (Hons) Major Subjects

In the Science faculty, Honours from our School may be completed in:

- Mathematics and/or Statistics, see Assoc. Prof. Carl Scarrott;
- Data Science; see Prof. Jennifer Brown;
- Mathematical Physics, see Assoc. Prof. Jenni Adams (Physics);
- Computational and Applied Mathematical Sciences, see Prof. Rick Beatson;
- Mathematics and Philosophy, see Assoc. Prof. Clemency Montelle;
- Finance and Mathematics, see Assoc. Prof. Rua Murray;
- Finance and Statistics, see Assoc. Prof. Marco Reale; or
- Financial Engineering, see Assoc. Prof. Marco Reale.

Subject to CUAP approval (due December 2018), these Honours programs require completion of papers totalling 90 points at 400 level or above (typically six 15 point courses) in addition to the 30 point MATH/STAT/CAMS449 project. In the case of data science, the project is 45 points.

BA (Hons) Major Subjects

In the Arts faculty, Honours from our School may be completed in Mathematics or Statistics. BA (Hons) consists of a project (MATH/STAT449) and six papers (120 points in total).

Who should think about a Postgraduate Diploma? The Postgraduate Diploma can consist entirely of taught courses, as there is no requirement that any project is undertaken. The entry requirements are as for Honours, except that you are not required to have a B+ average. It is very strongly recommended that your average grade in your majoring subject at stage 3 is at least a C+. The PGDipSc can also be used as Part I of a two part research MSc.

PGDipSci and PGDipArts

In both the Science and Arts faculty the Postgraduate Diploma can be taken in mathematics or statistics. In addition a Postgraduate Diploma in data science may be taken in the Science faculty. These diplomas require completion of papers totalling 120 points at 400-level or above (typically eight 15 point courses).

Masters in Applied Data Science

Data science is a new profession emerging along with the exponential growth in size, and availability of 'big data'. A data scientist provides insight into future trends from looking at past and current data. Data science is an essential skill in a world where everything from education to commerce, communication to transport, involves large scale data collection and digitalisation. New Zealand and other countries are currently experiencing a skills shortage in this area, and the need for data savvy professionals with applied experience is growing.

This 180 point conversion master's is designed to accommodate students from a range of undergraduate backgrounds (not just those with Mathematics, Statistics and Computer Science majors), who want to enhance or build their data science capabilities and combine these with the skills and knowledge they bring from their previous studies. So long as you are data-hungry and industry-aware; this degree can add to your employability and career prospects.

Masters in Financial Engineering

Financial engineering is a cross-disciplinary field combining financial theory, mathematics, statistics and computational tools to design and develop new financial or actuarial products, portfolios and markets. It also has an important role to play in the financial industry's regulatory framework. Financial engineers manage financial risk, identify market opportunities, design and value financial or actuarial (insurance) products, and optimize investment strategies.

The year long 180 point program consists:

- 135 points from taught courses. There is a core set of required courses in finance, mathematics & statistics and computer science. Further, there are a suite of suggested courses from these topic areas, that make up the majoring subject of Financial Engineering. Depending on your prior education, it is envisaged that around half of the taught courses will be MATH400 or STAT400 papers and the other half will be FINC600 papers; and
- the 45 point paper FENG601 Application of Financial Engineering which provides the opportunity to apply

the techniques learned through the programme to real-world financial engineering problems.

There are minimum entry requirements into the program, which if not met you will be required to take FIEC601 in January-February prior to commencement of the program proper. You will be required to complete COSC480 Introduction to Programming, if you do not have equivalent programming skills (e.g. from COSC121, MATH170, EMTH171 or STAT221). Full details are provided in the UC Calendar.

Research Masters

A research Masters in Science (MSc) or Arts (MA) consists of two parts:

- Part I - a 120 points of papers (typically eight 15 point courses); and
- Part II - a 120 points research thesis.

Students can enter directly to Part II, if they have completed a Postgradute Diploma or Honours degree in the same majoring subject. For full details see the UC Calendar.

Our School offers the research MSc and MA in mathematics or statistics. An MSc is also offered in computational and mathematical sciences and data science. Enrolment in a Master's programme requires approval from the Postgraduate Coordinator, Dr Daniel Gerhard. At least one staff member must have agreed to supervise your Part II research study before approval of your programme of study.

PhD Research

The PhD programme is the highest degree offered in UC. How do you know if you are ready to purse a PhD in any of the following subjects we offer?

- mathematics;
- statistics;
- computational and applied mathematical sciences (CAMS);
- mathematical physics; and
- mathematics and philosophy.

The simplest answer is: if you are passionate about a subject and you want to get a deeper understanding of a field of study or want to use sophisticated tools from mathematical sciences to solve real world problems, then you are ready!

If you want to upscale your knowledge in the subject you love then a PhD in mathematics or statistics is the programme for you. On the other hand, if you have an interdisciplinary project in mind then a PhD in CAMS could be a good option for you.

Further details are available from the PG Office website, including scholarship information, here: `http://www.canterbury.ac.nz/postgraduate/phd-and-doctoral-study/` Excellent performance in a BSc (Hons) or BA (Hons) may provide sufficient training to undertake a PhD, thus obviating the need for a Masters degree. However, a PGDipSc or PGDipArts would not normally be sufficient.

400-600 LEVEL COURSES

The courses for 2019 are outlined on the CIS system `https://www.canterbury.ac.nz/courseinfo/GetCourseDetails.aspx`. In order to see all the offerings for, say, Mathematics, search for `MATH4`. The School reserves the right to cancel any course that does not attract four or more students, which will be determined at the beginning of each semester.

It is also possible (and often desirable) to include courses from other subjects, see the Regulations in the Calender for details with each degree. Note that any STAT courses may be included in a Mathematics degree and vice versa. For multi-disciplinary programmes like Financial Engineering and Data Science (which have courses across subjects) consult Schedule A of the BSc Hons regulation in the Calendar for a list of potential courses.

400-Level Projects

A broad range of possible projects are outlined below. However, this list is not exhaustive and other possibilities for projects are certainly possible. Project supervision is by mutual agreement of the supervisor and student. You should arrange your project by the end of the first week of term in 2019. It is suggested that you seek out possible supervisors before enrolment week.

You will hand in a written report on 19 September 2019 which will contribute 80% of the grade; the remaining 20% will be an oral presentation in Term 4.

Projects in Mathematics

Sudoku's and geometry over the integers modulo 3
Geertrui Van de Voorde

A solution to a Sudoku puzzle consist of an array of 9 rows and 9 columns such that in every row and every column, as well as in every of the nine 3x3 subsquares, we find exactly one of the symbols 1 to 9. Such a filled in puzzle is called a Sudoku square.

In this project, we look at ways of constructing Sudoku squares using geometry over the integers modulo 3; the coordinates of the points are taken in $\mathbf{Z}_3$. Depending on your interest, several further pathways are possible. Connections can be made with perfect error-correcting codes over the integers mod 3, or you can investigate the connection with MOLS (mutually orthogonal latin squares) by superimposing Sudoku squares, extend the notion of Sudoku to more general puzzles ($n \times n$ puzzles, 3D, different shapes), ...

Axiomatic planes
Geertrui Van de Voorde

In the real (Euclidean) plane, we know that there is exactly one line through two different points and that there is exactly one line through a point that is parallel to a given line. Now these two properties can be taken as axioms and a new class of planes, called axiomatic affine planes, can be constructed. In particular, it is perfectly possible to construct such planes that have only a finite number of points and lines. Probably the most important conjecture in this area is the question what the possibilities are for the number of points in an axiomatic plane.

This project can take multiple directions, according to your interests. Examples are below, but you are certainly not limited to them:

If you are interested in a more algebraic approach, you can investigate the algebraic structures that can be used to coordinatise these axiomatic planes (just as we used the real numbers for our familiar plane). If you are interested in the more combinatorial side, you can look at known constructions of planes, look at the importance of Desargues' and Pappus theorem, investigate what kind of objects are the finite counterpart of conic sections, ... Finally, if you are interested in a link coding theory, you can investigate how coding theory was used to show that there is no finite plane of order 10.

Integer Programming
Chris Price

This project looks at various applications of integer programming, and stochastic solution techniques. Applications such as set covering, packing, and partitioning will be looked at, as well as network interdiction problems. Variants of genetic algorithms will be looked at, and tested on a selection of these applications. MATH303 or similar required.

Random Walks of Building Blocks
Mike Plank

Populations of cells - sometimes called the building blocks of life - can be modelled by random walks, where cells take a sequence of steps in randomly chosen directions. If the cells all move independently, the population density follows the diffusion PDE. But in reality, cells interact with one another via physical contacts and chemical signals. Their movement can also be impeded by obstacles in the form of extracellular material. These interactions can be included in random walk models. This project will investigate the behaviour of the cells in these models and how it affects the diffusive characteristics of the population as a whole.

To take this project, some experience with computer programming is needed, e.g. Matlab or Python. Previous study of PDEs and/or random processes would be helpful but is not essential.

The Wisdom and Madness of Crowds
Mike Plank

Groups of people can often come up with better solutions to problems than any one individual on their own could. But groups can also get carried away by the spread of bad ideas, e.g. the global financial crisis, or the spread of fake news. These processes can be represented by social networks: people and the connections between them – see this interactive tutorial by Nicky Crase `https://ncase.me/crowds/`. This project is about mathematical models of the spread of an idea or behaviour through a social network. The aim is to investigate how the network structure (e.g. clustering, degree distribution, small-world) affects the speed of transmission through the network and the success or failure of the contagion to take over the network.

To take this project, some experience with computer programming is needed, e.g. Matlab or Python. Previous study of discrete maths and/or random processes would be helpful but is not essential.

How do you Kill a Stoat
Alex James

The notoriously cryptic stoat is responsible for death and destruction amongst our native bird population across a range of ecosystems. Killing a stoat is harder than you think as they are notoriously trap-shy and as inveterate carnivores they won't touch the more common poisons. A standard control technique is through another invasive predator – rats but rodent populations are strongly influenced by the seasonal and highly varying beech forest seed masting. In this project you will use population models (aka dynamical systems) to try and quantify the best way to control stoats via rats in order to save kiwi.

Exploring Links between Topology and Combinatorics
Mike Steel

Topological methods turn out to have unexpected applications in discrete mathematics. One example is the use of the "Ham sandwich theorem" to show that two thieves can always divide up a necklace with k kinds of jewels using no more than k cuts. Another example is the link between the Möbius function of a partially ordered set and the Euler characteristic of an associated topological space. This project will suit a student who has taken MATH320 and is taking MATH428.

The Combinatorics of Phylogenetic Networks
Charles Semple

Phylogenetic networks generalise phylogenetic (evolutionary) trees by allowing for non-treelike evolutionary events such as hybridisation and lateral gene transfer. The mathematical study of phylogenetic networks is, arguably, no more more that fifteen years old. From a mathematical viewpoint, phylogenetic networks are a type of directed graph. Many questions concern the structural properties of phylogenetic networks. For example, how hard is it to decide if a given tree is embeddable in a given network? If one selects a network uniformly at random, how many reticulations can one expect it to have when the number of leaves is sufficiently large? When is a network determined by the path-length distances between its leaves? In this project, we investigate these and other related questions. The project involves discrete mathematics but there are no formal prerequisites.

The Tutte Polynomial
Charles Semple

The Four Colour Problem dates back to the 1850s. It asks whether or not four colours are sufficient to colour any map of regions so that adjacent regions have different colours. A simple question, but it wasn't resolved until the 1970s. In the intervening years, Birkhoff and Lewis (1946) proposed a quantitive approach to the problem in the guise of the chromatic polynomial of a graph. This one-variable polynomial enumerates graph colourings. The Tutte polynomial is a two-variable generalisation of the chromatic polynomial. As well as enumerating the colourings of a graph, it also, for example, enumerates spanning trees and acyclic orientations of a graph. What is the Tutte polynomial? How can it simultaneously count the number of colourings and the number of spanning trees of a graph? Why is the Tutte polynomial closely connected to codes and to knot theory? This project investigates these and other related questions. There are no prerequisites for the project.

Lax Pairs

Mark Hickman

Given a non-linear differential equation, a Lax pair is a pair of linear differential operators $\mathcal{L},\ \mathcal{M}$ whose commutator vanishes only on solutions of the differential equation. A Lax pair allows one to potentially solve the differential equation by reducing the problem to an eigenvalue problem (if the operator $\mathcal{L}$ is second order, this is a Sturm-Liouville problem) and a time evolution of the eigenfunction; the so-called inverse scattering method. If $\mathcal{L}$ is first order then the Lax pair gives a conservation law of the differential equation. In this project, we will be looking at a method to compute the Lax pair of prescribed order for a differential equation (if it exists). This will involve Maple and would suit a student who has completed MATH302.

Topics in Group Theory

Gunter Steinke

Groups naturally occur as collections of symmetries of algebraic structures or geometries or algebraic structures or other objects. Knowing the structure of the group of symmetries of an object often leads to useful information about the underlying object. Groups come in very different sizes and forms and are also fascinating in their own right.

In one project we may look at abstract groups and how they can be seen as groups of symmetries. By making additional assumptions on transitivity we try to determine which groups can arise. For example, the symmetric and alternating groups are the only finite groups that are highly transitive, but there are many interesting groups that are 2-, 3- or 4-transitive.

In another project one may investigate how to describe or build up a group is by a set of generators; group elements will be products of powers in the generators. One condition one can impose is that one has finitely many generators. This still leaves a fast variety of groups, including all finite groups. By making additional assumptions one tries to determine which groups can arise. For example, one may look at finite groups generated by involutions (that is, elements of order 2), which often play a special role among all symmetries of an object.

Topics in Differential Geometry

Gunter Steinke

Manifolds are generalisations of Euclidean spaces, the standard $\mathbb{R}^n$, in that they only look locally like Euclidean spaces. They emerge in a variety of mathematical or physical contexts and comprise many well-known examples like spheres, tori, curved surfaces in 3-space or space-time in physics. Often manifolds carry an additional structure that allows to measure the speed of particles moving in it. This leads to the general concept of semi-Riemannian manifolds.

In one project one may investigate manifolds and in particular semi-Riemannian manifolds, and explores the notion of geodesics therein. Geodesics play the role of “straight lines” in semi-Riemannian manifolds. (Straight line segments in Euclidean space are shortest curves between two points.) They are locally shortest curves but can exhibit interesting global behaviour, like self-intersection. Geodesics are of significance among others in physics, since they describe, for example, the path light travels in the universe or a free-falling particle is moving along. Geodesics can described in local coordinates by certain second order partial differential equations.

One aim is to prove the so-called Hopf-Rinow Theorem, which deals with geodesical completeness of Riemannian manifolds and relates existence of geodesics between any two points to other topological properties of the manifold. One may also look at geodesics in some low-dimensional semi-Riemannian manifolds and attempt to obtain complete descriptions of their geodesics.

Projects in Statistics

Environmental Statistics
Jennifer Brown

Environmental monitoring is a fast moving, and important field of research. Data on environmental processes such as changes in water quality, endangered species distribution, weed invasion, and biodiversity are used to inform and guide how we manage our environment.

One use of environmental data is to build models to predict species distribution, and to predict the effect of environmental changes. In this project we will look at different methods used to collect field data and the effect of these differences on prediction models. We will use computer simulations to model data collection and analysis.

Extreme Value Statistical Modelling
Carl Scarrott

The statistics you meet on undergraduate course typically focus on the capturing the ”usual” characteristics of a process (e.g. properties of mean, median or variance). Extreme value statistics focus on understanding the unusual or rare events of a process. Extremes are of interests in all sort of different fields, for example:

1. financial risk (e.g. estimating Value at Risk for risk and portfolio management)
2. engineering (e.g. designing structures to withstand the stongest forces they could be exposed to, e.g. wind exposure on bridges or forces on buildings due to earthquakes!)
3. environment (e.g. are Christchurch's winter air pollution extremes reducing due to government interventions?)
4. IT (e.g. can our servers and network cope with peak demand when your assignments and projects are due in?)

I have various honours projects in extreme value modelling for financial, environmental, medical and industrial applications. So if you are thinking of becoming a statistical ”extremist” then get in touch.

Projects in Data Science

FORTSing Information Filtering System
Giulio Valentino Dalla Riva

Information filtering systems are ubiquitous machine learning algorithms to prioritize information for delivery. Think of the “Recommended” videos on YouTube, the “watch next” movies on Netflix, the “Discovery” songs on Spotify, the “related coverage” news in the New York Times. Information prioritization has strong consequences for our society. FORTS is a data ethics framework developed by DataForDemocracy, and stands for Fairness, Openness, Reliability, Trust, Social Benefit. The student will investigate mathematical models and computational techniques to assess how state-of-the-art filtering systems perform with respect to FORTS and, eventually, propose improvements to the systems. Familiarity with a Scientific Programming language (R, Python, Julia, ...) is recommended.

Data Science Investigation of Historical Mathematical Tables
Giulio Valentino Dalla Riva & Clemency Montelle

The history of computational algorithms, numerical methods, and data analysis has long been under-studied in the history of mathematics. Indeed, historians have largely been put off by the sheer volume of evidence, the majority of which is in the form of numerical tables. From trigonometric functions, to instants of syzygies in the calendar, to subtle corrections of planetary positions, these tables of numerical data, sometimes containing thousands of data points, are the direct product of an historical author-scientist carrying out an algorithm with the explicit and implicit set of mathematical assumptions that characterises their scientific culture of practise.

Classical investigation of these tables has relied on the expertise of the historians in solving complex tasks such as identifying the relationships between tables (“was this table computed starting from this other table?”). In this project the student will try to develop neural network classifiers, generative models and other data science techniques to investigate the tables. Familiarity with a Scientific Programming language (R, Python, Julia, ...) is requested.

Other Project Opportunities

Industry Research Projects
Jennifer Brown

Opportunities to work with industry partners or researchers at UC arise from time to time. These provide an excellent opportunity to work on problems of direct interest to industry or academic researchers, to learn more about working in an organisation outside of UC or as part of a research team at UC (or mixture of the two).

These opportunities will usually be advertised on the School’s website.

University of Canterbury
Te Whare Wananga o Waitaha
Private Bag 4800
Christchurch 8140
New Zealand

Telephone: +64 3 369 3999
Freephone in NZ: 0800 VARSITY (0800 827 748)
Email: info@canterbury.ac.nz
www.canterbury.ac.nz