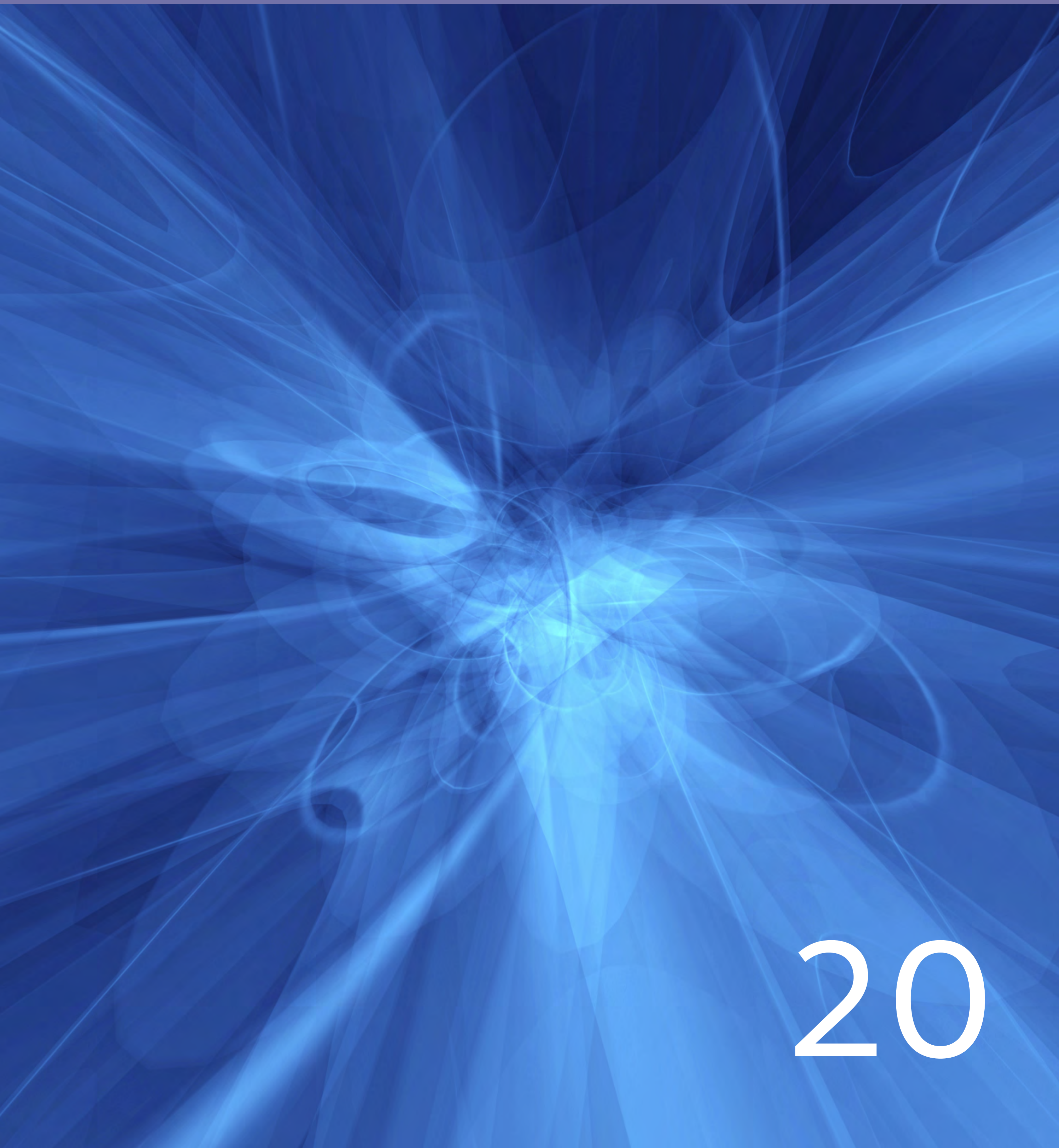
School of Mathematics and Statistics
College of Engineering

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

Postgraduate Handbook 2020



School of Mathematics and Statistics

Postgraduate Programme 2020

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 the subject.

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.

Study for all of our programmes can commence in S1 or S2. For the S2 intake it is advised to speak to the programme coordinator in advance for course planning.

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?

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 anytime for individual guidance. 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 your major 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. The pre-requisite entry requirements are given the UC Calendar. In general, each major subject requires at least 60 points from courses at 300 level within that major and 30 points from other approved courses. Normally you will have maintained at least a B+ average in these 300 level papers.

BSc (Hons) Major Subjects

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

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

These Honours programs typically 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/DATA/CAMS449 project. In the case of Data Science, the project is 45 points.

BA (Hons) Major Subjects

In Arts, Honours from our School may be completed in Mathematics or Statistics, with similar requirements to the BSc (Hons).

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 they usually have a lower GPA entry requirement. It is strongly recommended that your average grade in your majoring subject at 300 level is at least a C+. The PGDipSc can also be used as Part I of a two part research MSc.

PGDipSci and PGDipArts Major Subjects

In both Science and Arts the Postgraduate Diploma can be taken in mathematics or statistics. In addition, a Postgraduate Diploma in data science or applied data science may be taken from Science. 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 master's consists of 135 points of coursework and a 45 point project. It is designed for 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 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 Postgraduate 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. A research MSc is offered in computational and mathematical science, 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 the 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.

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 UC Course Information System (CIS) `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. Our courses are also open to students who are undertaking majors in other subjects, but we recommend you discuss the pre-requisites with the Course Coordinator listed on CIS.

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.

Some of our 400-level courses are dual-coded with the corresponding 300-level courses for which those on offer in 2020are:

- MATH433/MATH380 Mathematics in Perspective;
- MATH443/MATH343 Metric, Normed and Hilbert Spaces;
- MATH414/MATH353 Computational Methods/Computational Mathematics and Applications;
- STAT446/STAT319 Generalised Linear Models;
- STAT455/STAT312 Data Collection and Sampling Methods;
- STAT456/STAT317/ECON614/ECON323 Time Series and Stochastic Processes;
- STAT459/STAT313 Computational Statistics;
- STAT461/STAT314 Bayesian Inference;
- STAT462/STAT318 Data Mining; and
- STAT463/STAT315 Multivariate Statistical Methods.

On these dual coded courses, you will attend the same lectures and tutorials/labs as the 300 level students, but will be assigned additional coursework and assessment to achieve the NZQF Level 8 standard. Students who have completed the 300-level course cannot enrol in the corresponding 400-level course.

400-Level Projects

A broad range of possible projects are outlined below. However, this list is not exhaustive and other possibilities 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 2020. It is suggested that you seek out possible supervisors before enrolment week.

You will hand in a written report on late in term 4 of 2020, which will contribute 80% of the grade; the remaining 20% will be an oral presentation at the end of term 4.

Projects in Mathematics

Impeded random walks
Mike Plank

In a classical random walk, agents move a short distance in a randomly chosen direction at each time step. If the agents all move independently, the average agent density is governed by the heat (or diffusion) equation. But in many real situations, agents interact with one another and the environment, e.g. via physical contacts or other signals. Their movement can also be impeded by obstacles. This project will investigate random walks where agent movement is impeded in this way, in particular looking at how this affects the diffusion PDE for agent density. To take this project, some experience with computer programming is needed, e.g. Matlab or Python. Prior study of PDEs and/or random processes would be helpful but is not essential.

Maths Craft
Jeanette McLeod (Maths & Stats), Phil Wilson (Maths & Stats), David Pomeroy (Teacher Education)

Do you love mathematics and craft? Are you interested in the history, sociology, or psychology of mathematics? We are offering multiple interdisciplinary honours projects for keen students who answer yes to those questions. Maths Craft New Zealand is a non-profit public engagement initiative which makes mathematics accessible through craft. It was founded and is run by Drs Jeanette McLeod and Phil Wilson from the School of Mathematics & Statistics. Since Maths Craft's inception in 2016, we have run numerous festivals and workshops across New Zealand, and have reached over 11,000 people, making us the largest maths outreach programme in the country. Together with Dr David Pomeroy from the School of Teacher Education, we are studying the mathematical, historical, sociological, psychological, and pedagogical aspects of our craft-based approach to mathematics. If you like to think outside the box and can combine a love of mathematics and craft with a love of (or enthusiasm to learn about) social research, then please discuss project options with us.

Data driven analysis of dynamical systems
Rua Murray

Dynamical systems arise as solutions of differential equations, or in any situation where the state of a system updates iteratively with the passage of time steps (e.g., a descent algorithm for training a deep learning network). The local and global behaviour of dynamical systems is often determined by invariants of various kinds: fixed points, periodic orbits, invariant manifolds, invariant probability distributions. When the system is complex (due to very strong nonlinearities and/or high dimension), these objects are hard to find and analyse. In the last decade, a new family of tools has developed, loosely under the umbrella name of “Dynamic mode decomposition”. These methods use samples from the dynamical system to build approximate transfer operators, from which eigenvectors can be extracted. The theory behind these methods remains undeveloped, there is a plethora of possible computational strategies, and any dynamical system can be analysed in this way. The emphasis in this project can be tailored to student interest.

Optimisation and numerical linear algebra
Rachael Tappenden

Optimisation plays a crucial role in many modern, real-world applications. Below are several topics that could form the basis of a project.

- Data science - optimization algorithms play a crucial role in the solution of subproblems that arise in data science applications. This project will consider algorithms for empirical risk minimisation.
- Medical imaging - in computed tomography one must solve an ‘inverse problem’ to obtain an image. This often involves the solution of a large structured system of linear equations. This project investigates algorithms for solving such systems.
- Portfolio optimization - given some initial budget, and a basket of financial instruments (stocks, bonds, etc), how should one allocate their funds in order to maximize their expected profit? How are such problems formulated mathematically? Which algorithms can be applied to solve such problems?
- Other topics include the efficient solution of large scale linear systems, algorithms for large-scale eigenvalue calculations, and preconditioning, among others.

For these projects, it would be helpful to have some knowledge of MATLAB and of applied linear/matrix algebra.

Safe havens: Network effects for female mathematicians
Alex James

Visit almost any maths department around the world and it doesn’t take long to realise the average mathematician is male. However, the representation of women varies from department to department. Even within New Zealand we see that the proportion of women varies from none to almost 50% as we travel around the country. Is this just random chance or is there a network effect where diversity begets diversity? In this project you will use network data spanning over 400 years to look at how gender diversity is propagated through a community.

Population dynamics: Bugs, beetles, plants and animals...
Alex James

Populations, be they of bugs, plants or jellyfish, show a remarkable range of behaviours. Find out more about them in a project that uses dynamical system models to try and understand the dynamics of an example population.

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.

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 using MAPLE and would suit a student who has completed MATH302.

The combinatorics of reticulate evolution
Charles Semple

Phylogenetic networks are a certain type of directed graph that are used to represent the ancestral history of a collection of present-day taxa. Generalising evolutionary trees, networks allow for the representation of non-treelike (reticulate) events such as hybridisation and lateral gene transfer. Many combinatorial and computational questions concern the structural properties of networks. For example, how hard is it to decide if a given tree is embeddable in a given network? If we select a network uniformly at random, how many reticulations can we expect to see when the number of leaves (taxa) is sufficiently large? When is a network reconstructable from the path-length distances between its leaves? This project investigates these and other related questions. It involves discrete mathematics but there are no formal prerequisites.

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 3×3 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 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;
- 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; or
- many other possibilities…

Projects in Statistics

Historical heights of army and navy recruits

Elena Moltchanova

The population distribution of human heights reflects prevailing environmental and sociological conditions. The historical records available, however, always present a biased picture. For example, only people "tall enough" were enlisted in the army, and the definition of "tall enough" varied with demand for soldiers. For the navy, the limitations also applied to people who were too tall to comfortably live on a ship. Using the information available from the historical army and navy records to recreate the population height distribution throughout the 17th-20th century thus presents some interesting challenges. Among many attempts taken to model such data, Bayesian methods are of particular interest due to their flexibility and ability to easily include temporal autocorrelation in the model.

You will need to have taken a course in Bayesian inference and have solid knowledge of calculus (deriving conditional, marginal, etc. distributions) and good programming skills in either R, Python or C/C++.

(Other projects using Bayesian statistics are available, such as using reversible jump Markov chain Monte Carlo to model the Old Bailey's data or monitoring epidemics and manufacturing processes.)

Projects in Data Science

Ethics of data science / Data science for ethics
Giulio Valentino Dalla Riva

Using a variety of mathematical, statistical, computational, ..., approaches, we are going to analyze from an hybrid ethical-technical point of view some fundamental data scientific algorithm. As an example, think about 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: what do they all have in common? They all suggest you, based on your history and characteristics, which bit of information to consider next. They define a user-dependent priority on the available information. They filter information for you, and they shape the way you see the world (or, at least, part of it).

Recommender systems are ubiquitous machine learning algorithms for prioritizing information. Different technical decisions impact the fairness, openness, reliability, trust, and social benefit of them. We will investigate mathematical models and computational techniques to assess how state-of-the-art recommender systems perform and, eventually, propose alternative systems.

Familiarity with a scientific programming language (R, Python, Julia, ...) is recommended.

Social network and online communities analysis
Giulio Valentino Dalla Riva

This is a open ended project. If you are interested in using and developing mathematical, statistical, data scientific tools and notions to analyse the behavior of online communities in social networks, we can discuss it. We are probably going to use a variety of approaches: data wrangling, scraping, anonymization, networks modelling, natural language processing, image analysis, ... The projects can have a varying degree of theoretical - applied content.

Familiarity with a scientific programming language (R, Python, Julia, ...) is recommended. Knowledge of complex networks is welcome, but not strictly necessary (we can work around it). Original research projects in the area are encouraged.

Data Science Investigation of Historical Mathematical Tables
Giulio Valentino Dalla Riva and 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 recommended.

Image Statistical Machine Learning
Thomas Li

Statistical machine learning methods that input image data have recently been applied to self-driving cars, automated airport border security gates, facial recognition and capital asset surveying automation over the past 5-10 years. Due to the rise in computational capability in hardware and cost effectiveness of capturing data, deep neural networks have been successfully applied to many image recognition problems, and in some areas surpassed human-level performance.

This project will investigate some of the following areas of image statistical machine learning:

1. integrated multi-modal sensing (combining multiple image sensors, for our team it would be LIDAR and cameras),
2. characterize current machine learning algorithm performance,
3. 3D point clouds learning algorithms, and/or
4. 3D volumetric segmentation and machine learning.

Familiarity with a scientific programming Language (R, Python, etc.) is highly recommended.

Other Project Opportunities

Industry or Other Research Projects
Jennifer Brown

In addition, 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 a mixture of the two).

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

UC Summer Research Projects
Giulio Valentino Dalla Riva

The UC offers summer research scholarships to high performing students in a wide range of topics. These projects are often associated with industry partners or funded research programmes at UC. They last for 10 weeks (November-February) and are valued at $5,000.

These opportunities will be advertised on the UC summer scholarships website:
`http://www.canterbury.ac.nz/summer-school/summer-scholarships`

School of Mathematics and Statistics Summer Research Projects
Giulio Valentino Dalla Riva

Our School offers a range of research project opportunities over the summer period. Some projects may have scholarships available. Depending on your level of study, you are able to undertake these as MATH/STAT395 or MATH/STAT491, which can contribute to your GPA but cannot be used to fulfil your subject majoring requirements. You will write a dissertation and give a presentation on your project. These project are a great way to broaden your studies and deepen your understanding of a specialised topic and develop your research and communication skills.

These opportunities will be advertised on the School's website.

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