Module MA469: Research Project Titles for 2008-09
(In random order)

1. **Hugo van den Berg** (Email: H.A.van-den-Berg@warwick.ac.uk Office: Hugo is based in MOAC DTC / Systems Biology in Coventry House) offers various R-projects in the area of mathematical biology. Example project descriptions can be downloaded from

   http://www.warwick.ac.uk/~maseao/projects.html

   but any particular topic can be negotiated by appointment.

2. **Thomas House** (Email: Office:) is offering topics in *Mathematical Epidemiology*. He writes:

   Infectious disease remains the leading cause of human mortality worldwide, and yet the details of infectious disease dynamics and the optimal control methods during outbreaks remain challenging questions due to the large number of interacting factors in play. Mathematical epidemiology is an interdisciplinary research area that involves the use of advanced concepts in mathematics, statistics and computer science to interact with biological and epidemiological data to answer the most pressing questions concerning the control of human pathogens.

   I would be happy to discuss any potential topic within this broad discipline, which makes use of a large number of mathematical techniques, including ODEs, PDEs, network theory, stochastic processes, algorithms, Bayesian statistics, computer algebra and more. These could be applied to the following questions:
   1. How does changing household structure and composition affect disease dynamics?
   2. How can we best approximate an infection process on a network through a simpler system of ODEs?
   3. Can we understand patterns of human movements and the relevant implications for disease control?

   This project would be particularly suitable for a student interested in the applicability of mathematics to 'real world' problems, and can easily involve interaction with more applied members of the Populations and Disease research group in Biology, as well as leading to opportunities for publication and graduate study in a variety of areas.

3. **Roger Tribe** (Email: R.P.Tribe@warwick.ac.uk   Office: C2.03) offers the theme: *Random walk models for boundary crossing*.

   A classification of all Markov models for a continuous random particle crossing a boundary point should exist. Yet there remains confusion in the applied sciences on models of molecular diffusion across membranes and on how to simulate them.

The aim of this project is to try and summarize the models and find the correct discrete approximations. Enthusiasm for Brownian motion and/or Markov chains is a useful prerequisite.

4. **Matt Keeling** (Email: M.J.Keeling@warwick.ac.uk Office: B2.36) offers a general topic in *Models in Ecology and Epidemiology*

   Ecology (the study of populations) and Epidemiology (the study of infections) pose a huge number of problems that can be treated with mathematical models. This project is very open-ended. I work on numerous problems, from Foot-and-Mouth Disease to Bubonic plague. I suggest you come and talk to me, and I'll try to match your interests and abilities to a suitable project.

5. **Vadim Lozin** (Email: V.Lozin@warwick.ac.uk Office: B2.10) can offer a project in *Graph Theory*. Topics of both algorithmic and combinatorial nature are possible. Students are advised to see him to discuss possible titles.

6. **Magnus Richardson** (Email:Magnus.Richardson@warwick.ac.uk Office: Magnus is based in Systems Biology in Coventry House) is happy to discuss a project in the general area of *Systems Biology*.

7. **Jeremy Gray** (Email: j.j.gray@open.ac.uk Office: Mainly at Open University but intermittently in B2.13) offers topics in the *History of Mathematics* (in particular in the areas of algebraic topology and differential geometry). He is already negotiating with a likely supervisee, but is willing to create a waiting list in case this falls through.

8. **Miles Reid** (Email: Miles.Reid@warwick.ac.uk Office: B1.33) is on leave in 2009 and will be away for 2 terms (Jan-May, possibly Jan-Jun). He writes "any student wanting to do something with me will have to have made a good start during Term 1 and be willing to communicate by e-mail after that". His R-Project offerings can be found on

   http://www.maths.warwick.ac.uk/%7emiles/MA469/

9. **Diane Maclagan** (Email: D.Maclagan@warwick.ac.uk Office: B 1.35) writes:
   I'm on leave in Term 2, but could reply to email while I am away if someone was interested enough to do more than half the work in the first term while I'm around.

   Title: Tropical Geometry

   Blurb: Tropical geometry is an emerging area at the intersection of (among others) algebraic geometry and polyhedral combinatorics. It aims to understand the geometry of a variety (solution set to a collection of polynomial equations) by understanding the geometry of a related polyhedral complex. For an accessible taste, see:

http://front.math.ucdavis.edu/0408.5099

Relevant background: An interested student should enjoy abstract algebra and linear algebra, and should plan to take the algebraic geometry module.

10. **Stefan Grosskinsky** (Email: S.W.Grosskinsky@warwick.ac.uk Office: B 1.34) is offering projects about

- The Tracy-Widom distribution and
- Zero-range processes (three possibilities)

The *Tracy-Widom distribution* arises as a limit law of extreme value statistics of strongly correlated random variables in a variety of contexts. It is the limiting distribution of the largest eigenvalue of a GUE random matrix and appears in surface growth models, current fluctuations in lattice gases, random tilings as well as combinatorial problems (see e.g. [1] and [2] which are recommended for background reading).

Zero-range processes (ZRP) are continuous-time Markov chains, where identical particles jump on a lattice with a rate that depends only on the local particle configuration. When the particle density is higher than a critical value \rho_c, the system phase separates into a homogeneous background with density \rho_c and a condensate site, containing all the excess particles. At various levels of description this provides a model for condensation phenomena and the effective dynamics of domain walls in phase segregation and driven diffusive systems. Applications include jamming in traffic flow, granular clustering, wealth condensation and hub formation in complex networks (see [3] and references therein). Research interest in the ZRP has been growing over recent years and there are many interesting questions to work on. Simulations, applications and projects of a theoretical nature are offered.

References

[1] K. Johansson (2005), Random matrices and determinantal processes, math-ph/0510038.

[2] H. Spohn (2005), Exact solutions for KPZ-type growth processes, random matrices, and equilibrium shapes of crystals, cond-mat/0512011.

[3] M.R. Evans, T. Hanney, Nonequilibrium Statistical Mechanics of the Zero-Range Process and Related Models. J. Phys. A: Math. Gen. 38: R195-R239 (2005)

11. **Magnus Richardson** (Email: Magnus.richardson@warwick.ac.uk Office: Warwick Systems Biology Centre, 2nd floor Coventry House) has two projects

which he would be happy to supervise in the broad field of *Mathematical Neuroscience*. Please feel free to call by if you would like to discuss their scope.

1. *Flow of electrical activity in neurones with dendrites* Neurones are extended brain cells that comprise dendrites (input structure), a cell body (integration area) and an axon (output structure). Most of the mathematical models of neurones ignore this structural aspect and treat neurones as point objects. However, there is a lot of evidence suggesting that the compartmentalisation of neurones is key to their computational power. The way electrical activity flows around neurones is described by the cable equation (a linear partial differential equation of voltage in space and time). I am interested in using this equation to understand how synaptic input is compartmentalised in these structures. Familiarity with differential equations, partial differential equations and some stochastic calculus would be a plus, but not a requirement.

2. *Analysis of oscillations in human EEG data* Brain activity can be directly measured using EEG apparatus that picks up electrical signals passing through the head. These experiments are relatively straightforward and are performed regularly at the Psychology department in Warwick. The data sets that come out of the experiment are less straightforward to analyse. This is because there are >20 simultaneous streams of noisy signals that comprise a variety of features like short-lived oscillations. Together with colleagues from Psychology, I am interested in using a number of analysis techniques to investigate the structure of these signals. This project will involve working directly with EEG data and there may also be an opportunity for involvement in an EEG experiment. Some experience with MATLAB and numerical analysis of data would be useful.

12. **Vladimir Markovic** (Email: V.Markovic@warwick.ac.uk Office: B 1.25) would like to offer a project with the title:

    Geometry and analysis on Riemann surfaces.

    Description: This is a very general area and there are many options. It combines the topics like Riemann surfaces and hyperbolic geometry with low-dimensional topology and analysis.

13. **David Preiss** (Email: V.Markovic@warwick.ac.uk Office: B 1.25) would be happy to offer a research project from many possible sub-areas of real analysis. If anyone interested in this field should contact him, by email in the first instance.

14. **Brian Bowditch** (Email: D.Preiss@warwick.ac.uk Office: B 1.26) writes:
    “In principle, I'd be happy to supervise a topic in the general area of hyperbolic geometry or geometric group theory. The specifics would depend on the student’s interests. They are welcome to contact me to discuss possibilities.”

15. **Dwight Barkley** (Email: D.Barkley@warwick.ac.uk Office: B 2.07) is offering projects in high-performance computing. These will require substantial programming experience and understanding of Unix/Linux. One particular project he has on offer is *reaction-diffusion patterns on moving domains*. More information can be found on his web pages.

    The following is more of a Maths-in-Action project, but he am willing to supervise it if anyone is interested.

    Energy Balance for the Human Body. The project involves reading up on and understanding the caloric energy balance for the human body. Basically: d(energy in)/dt - d(energy out)/dt = d (stored energy)/dt. Despite the obvious simplicity of this equation and the fact that these factors are known, there is little understanding within the general population of the implications of this to dieting, exercise, and weight loss. The goal then is to use this information to design a web page which effectively illustrates this balance to the general public. The project will involve some basic physics and possibly some modeling. Independence and creativity are required. The ability to write Java applets will be a big benefit.

16. **Colm Connaughton** (Email: C.P.Connaughton@warwick.ac.uk Office: B1.36) is offering the title is *Modeling turbulent cascades using nonlinear diffusion equations*.

    A key feature of turbulent systems is the nonlinear transport of energy across scales: energy supplied to the system at large scales is removed at much smaller scales with an energy-conserving nonlinear transport process providing the link between the two. Such a phenomenon is referred to as an energy cascade. A detailed understanding of cascade processes is often essential to obtaining better understanding of turbulent phenomena arising in real world applications. It is, however, often very difficult to obtain, owing to the intrinsic nonlinearity of the phenomenon and the large number of degrees of freedom involved.

    Generally, cascade phenomena fall into two classes, depending on the speed at which they transfer energy to smaller scales. *Infinite capacity* cascades transfer energy at most exponentially fast. Such a cascade takes infinite time to transfer energy to arbitrarily small scales. *Finite capacity* cascades, on the other hand, exhibit some form of "explosive" propagation such that they transfer energy to arbitrarily small scales in finite time. Such behaviour is often associated with some kind of finite-time singularity in the underlying nonlinear dynamics. Modelling the transition between these two types of behaviour is the main objective of this project.

17. **Bruce Westbury**
    I am offering a Research Project "On the exceptional automorphism of S(6)"

18. **Robert MacKay** (Email: R.S.MacKay@warwick.ac.uk Office: B2.05) A list of Robert's research projects can be found among the M's in this PDF file

http://mathstuff.warwick.ac.uk/files/MA4/MA469/2008/MA469_gen_3_0_08.pdf

19. **Daan Krammer** (Email: D.Krammer@warwick.ac.uk Office: B1.17) is willing to supervise an R-Project in one of the following areas: *Group Theory, Low-Dimensional Topology, Combinatorics, and Representation Theory*. You are encouraged to negotiate a project brief but should be aware that Daan is prefers research projects involving (easy) problem-solving rather than exposition.

20. **Arie Koster** (Email: Arie.Koster@wbs.ac.uk Office: In the Warwick Business School and affiliated with Maths via the Centre for Discrete Mathematics and its Applications (DIMAP)). He is offering a project on *Integer linear programming for computing the Treewidth of a Graph*. **Synopsis:** The *treewidth* of a graph is a way to measure the "tree-likeness". Many combinatorial optimization problems that are hard in general (NP-hard) can be solved in polynomial time if the underlying graph is bounded by a constant. Determining the treewidth of a graph itself is however NP-hard. Purpose of this project is to study integer linear programming formulations for computing the treewidth of a graph. Depending on the qualifications and interests of the candidate, a more theoretical or practical approach can be followed. In particular, the so-called chordalization polytope can be studied. Valid inequalities for this polytope and complete descriptions for small graphs are still unknown.

21. **Derek Holt** (Email: D.F.Holt@warwick.ac.uk Office: B1.27) is offering a project on *Computational Group Theory*, which will involve writing a computer program to implement an algorithm to carry out computations with groups. About half of the marks will be allocated for the accuracy and performance of the program, and the other half for the written part of the project, which should describe the theory behind the algorithm.

    Interested students should contact Derek to discuss further details, which will depend on their current knowledge of group theory.

22. **David Mond** (Email: D.M.Q.Mond@warwick.ac.uk Office:) is willing to supervise a 4th year project on *Discriminants in Algebraic Geometry*. Contact him directly for further details

23. **Charlie Elliott** (Email: c.m.elliott@warwick.ac.uk Office: B2.26) is willing to supervise an R-project in the general area of *Finite Element Approximation of Partial Differential Equations*. This is a topic suitable for strong students interested in either analysis or computational applied mathematics. (See http://www2.warwick.ac.uk/fac/sci/maths/people/staff/Charles_Elliott/ for more information about Charlie's research interests.)

24. **Stefan Adams** (Office: B2.18, Email: S.Adams@warwick.ac.uk and adams@mis.mpg.de) will be on leave for the first term next year, but is nevertheless willing to supervise one of the following:

Project title 1: *Large Deviations Theory and its Applications.*
Large deviations theory is a technique to derive the rate for how the probability of rare events decays, i.e., one considers unlikely events. The rate is often given by a function connected with the entropy of the particular stochastic model. There are applications of large deviations theory in queueing theory, communication networks, stochastic processes (Brownian motions, random walks), mathematical biology, financial mathematical, statistics and statistical mechanics. The student will learn the main principles and methods of large deviations theory and how to apply them to important applications.

Project title 2: *Mathematical Statistical Mechanics*
In mathematical statistical mechanics interacting particle systems (continuum or lattice) are analysed in the so-called thermodynamic limit, where the number of particle diverges as well the container in such a way that the density is finite. One of the objectives is to establish proofs for phase transitions. There are several projects in classical (Ising and Potts-Models; equivalence of ensembles; Gibbs measures; Markov chains; random walks) and quantum statistical mechanics (Bose gas; Brownian motions; path integral) as well in combinatorics (e.g. Ewens sampling in genetic; random permutation/partition structures; limit shapes of Ferres and Young diagrams). One focus is large deviations theory and its application for physical systems with high complexity. Large deviations theory is the bridge from large interacting systems with high degrees of freedom to some effective descriptions with variational formulas. The latter ones are the expressions for the rate functions and allow after a rigorous analysis an interpretation of the most probable behaviour of the system in an effective description. The principles and methods of mathematical statistical mechanics are applicable also to queueing systems, combinatorics, financial mathematics and biology.

25. **Mark Pollicott** (Email:mpollicott@googlemail.com Office: B2.27) is offering a couple of Project titles:

Project title 1: *Hausdorff Dimension of Fractal sets*
The Hausdorff dimension is a way to quantify the size of complicated sets in Euclidean space. Typically it is very difficult to compute accurately This project relates to sets which have a certain dynamical flavour to their construction (e.g. Sierpiniski gaskets and their generalizations, Julia sets, etc.) and to the techniques available in this context for more accurate estimation of the dimension; or even explicit values for typical values.

Project title 2: *Ergodic Theory and Number Theory*
The Birkhoff theorem in ergodic theory gives a powerful approach to studying

normal numbers, i.e., those for which digits occur with the same frequency in expansions to any base. However, generalizations of this theorem lead to a rich vein of results in number theory. This project explores various applications of related ideas to number theory.

26. **Florian Theil** (Email: f.theil@warwick.ac.uk Office: B2.21) is offering the title

    Backward-Error Analysis of Thermostats

    This topic involves the analysis of Ordinary Differential Equations and a little bit of Statistical Mechanics. Starting point is a recent paper *An Efficient Geometric Integrator for ThermostattedAnti-/Ferromagnetic Model*s by Leimkuhler and Arponnen. The project student should read the article and hopefully extend the approach to more general thermostats which might involve stochastic components.

27. **Neil O'Connell** (Email: n.m.o-connell@warwick.ac.uk Office: C2.19). In addition to offering the title below, Neil is happy to supervise projects in other areas of probability and stochastic analysis, e.g. Hyperbolic Brownian motion and/or its discrete analogues; random matrix theory and its connections to number theory and/or combinatorics; random analytic functions; Markov chains and discrete hypergroups.

    Project title: Intertwinings in Probability and Representation Theory
    Two linear operators S and T are intertwined if there exists another linear operator K such that SK = KT. Such intertwinings arise naturally in group representations when one considers morphisms between representations. In probability, they arise when two Markov processes can be constructed on the same probability space; in this setting, S, T and K are Markov operators. In the probability literature this is often called "duality" and plays a central role in the theory of Markov functions (functions which preserve the Markov property). There are many nice examples at the intersection of both interpretations, which include applications to card shuffling and other random walks on finite groups. The aim of this project is to understand the relationship between these topics and find interesting new examples.

28. **David Wood** (Email: David.Wood@warwick.ac.uk Office: B1.13). After this term has ended, Dave would be happy to discuss supervising projects of an applied nature based around industrial applications and/or applications of equivariant bifurcation theory (bifurcations of systems of ODEs in the presence of symmetry). Previous projects supervised include: "Modelling Dolphin populations", "Graphical representation of the Lorenz equation", "Many legged locomotion", "Airport aircraft sequencing", "Symmetry in coupled cells and neuronal networks", "Coupled cell networks, bifurcations and symmetry".

29. **John Rawnsley** (Email: J.Rawnsley@warwick.ac.uk Office: B2.30) is offering a project entitled: *Decomposing the Curvature Tensor*. To ensure that the mathematical symbols are correctly displayed, this abstract is stored as a pdf file at the following link

    http://www.warwick.ac.uk/staff/J.Rawnsley/teaching/ma469/

Not Available in 2008-09

The following members of staff are on leave and will not supervise research projects in 2008-09: Anthony Manning, Adam Epstein, Luca Sbano, Xue-Mei Hairer, Robert Kerr, Daniel Ueltschi