UNIVERSITY OF BRISTOL

School of Mathematics

Postgraduate Study in

Pure Mathematics

Contents

November 25, 2013

1 Introduction

The Pure Mathematics group in the School of Mathematics has an international reputation for its research work. The main research themes lie in algebra (representation theory), in analysis (especially partial differential equations, potential theory and spectral theory), in set theory and mathematical logic, in number theory (analytic number theory and arithmetic combinatorics) and in ergodic theory and dynamical systems. Postgraduate students may study in any one of these areas towards the degrees of Ph.D. and M.Sc. by research.

Students whose undergraduate degree courses have not included sufficient preparatory material for postgraduate study with the group are encouraged to take a certain number of postgraduate courses and their progression will depend on this (see Section 7).

2 Research in Analysis and Probability

Stochastic interacting processes: Márton Balázs

Stochastic interacting systems consist of components (particles in many cases) which follow some simple local random dynamics. Parts of this random evolution describe how individual components interact with each other. Because of the large number of these simple units, interactions lead to very interesting and complex behaviour of the system as a whole. Often surprising phenomena occur, which require creative ideas to describe as interactions usually rule out most of the classical and well established methods.

A characteristic example in the field is the so called *simple exclusion process*, where particles would do an ordinary simple random walk by themselves on the one dimensional integer line, but they exclude each other: no particle can jump to an already occupied site. This rather simple local dynamics leads to interesting connections to the theory of nonlinear partial differential equations, combinatorics and asymptotic analysis, various matrix product algebras and, of course, exotic probabilistic scaling theorems. Systems of this type are also of great use in applied areas including biology, traffic modelling, sociology, computer science.

I have been involved in research regarding the following questions, some of which have been answered to a satisfactory level, and some are still under active investigation:

- **Construction of the processes:** What are we talking about? Is there a stochastic system with the properties we are dreaming of? Can we exclude that the desired dynamics actually leads to nonsense, like e.g. the system having infinitely many particles coming close to the origin in finite time?

- **Stationary distributions:** Is there a distribution of the system that stays invariant over time? How many? What are its properties? Is there such a distribution of the process as seen from a dynamically moving point of the system (e.g., a tagged particle)?

- **Large scale evolution:** What happens if we look at the system from a large distance so we don't see individual particles, only their density? How would this density profile evolve?

- **Fluctuations:** As the dynamics is random, we expect uncertain evolution of some quantities measured on the system. How much fluctuation is present in these? What happens to these fluctuations for large times?

In case you are interested, please take a look at my webpage at
`http://www.maths.bris.ac.uk/~mb13434/`
and feel free to contact me.

Spectral Geometry and Partial Differential Equations: Michiel van den Berg

A classical theorem of Faber and Krahn states that among all open sets Ω in Euclidean space $\mathbb{R}^m, m = 2, 3, \cdots$ with volume $|\Omega| = 1$, the open ball with volume 1 minimizes the principle eigenvalue of the Dirichlet Laplacian. The proof relies on the Schwarz or spherical decreasing rearrangement of functions in the Sobolev space $H_0^1(\Omega)$ [1]. More generally one considers the following minimization problem

$$\inf\{\lambda_k(\Omega) : \Omega \text{ open in } \mathbb{R}^m,\ |\Omega| = 1\}. \tag{1}$$

By rearranging the level sets of the two nodal domains of the second Dirichlet eigenfunction on Ω one shows that if $k = 2$ the minimizer is the union of two disjoint balls with volume $1/2$ each. The existence of a minimizer for the k'th Dirichlet eigenvalue ($k = 3, 4, \cdots$) is still an open problem. However, if the collection of open sets in (1) is enlarged to the quasi-open sets then one can show that a bounded minimizer with finite perimeter exists [3, 8]. Little is known about the shape of these minimizers. The disc is a local minimum of the functional under (1) for $m = 2, k = 3$, and it has been conjectured that it is a global minimizer. For $m = k = 3$ it has been shown that the ball is not a minimizer. If $\Omega_{m,k}$ is a minimizer of (1) and if $k \leq m + 1$ then $\Omega_{m,k}$ has at most $\min\{7, k\}$ components [2]. My current research is on variational problems of the type described above and includes other constraints such as perimeter [4, 5] and torsional rigidity [6, 7]. I am happy to discuss possible projects in this area and more generally in spectral geometry by e-mail.

References

[1] A. Henrot, *Extremum problems for eigenvalues of elliptic operators*, Frontiers in Mathematics, Birkhäuser, Basel (2006).

[2] M. van den Berg, M. Iversen, *On the minimization of Dirichlet eigenvalues of the Laplace operator*, J. Geometric Analysis **23**, 660–676 (2013).

[3] D. Bucur, *Minimization of the k-th eigenvalue of the Dirichlet Laplacian*, Arch. Ration. Mech. Anal. **206**, 1073–1083 (2012).

[4] D. Bucur, P. Freitas, *Asymptotic behaviour of optimal spectral planar domains with fixed perimeter*, J. Mathematical Physics **54**, 053504 (2013).

[5] G. De Philippis, B. Velichkov, *Existence and regularity of minimizers for some spectral functionals with perimeter constraint,* Applied Mathematics & Optimization, to appear.

[6] M.-T. Kohler-Jobin, *Démonstration de l'inégalité isopérimétrique* $P\lambda^2 \geq \pi j_0^4/2$, *conjecture par Pólya et Szegö*, C. R. Acad. Sci. Paris Sr. **A-B 281**, A119–A121 (1975).

[7] M.-T. Kohler-Jobin, *Une méthode de comparaison isopérimétrique de fonctionnelles de domaines de la physique mathématique. I. Une démonstration de la conjecture isopérimétrique* $P\lambda^2 \geq \pi j_0^4/2$ *de Pólya et Szegö*, Z. Angew.Math. Phys. **29**, 757–766 (1978).

[8] D. Mazzoleni, A. Pratelli, *Existence of minimizers for spectral problems*, J. Math. Pures Appl. **100**, 433–453 (2013).

Complex Analysis and Probability: Edward Crane

My research is in the areas of complex analysis and probability, and particularly connections between them. Some exciting connections have been discovered recently, for example in the work on Smirnov on conformal invariance of critical percolation on the infinite triangular lattice and in the work of Schramm, Lawler, Sheffield, Werner and others on some families of conformally invariant random processes in the plane called SLE and CLE, and their connections to an object from physics called the Gaussian Free Field. Discrete analogues of holomorphic functions play an important role in Smirnov's work. There are many interesting questions in this area.

My main current area of research is *circle packing*. The fundamental theorem here is the Koebe-Andreev-Thurston theorem, which says that given any finite (combinatorial) triangulation of the sphere, there is a corresponding circle packing. This is a collection of discs, one for each vertex of the triangulation, such that adjacent vertices are represented by tangent discs with disjoint interiors. In fact this packing is unique up to Möbius transformations. Moreover, it is possible to compute it! If we start instead with a triangulation of a polygon, then it is possible to find circle packings with arbitrarily specified positive radii for the boundary vertices, and again this boundary value problem can be solved numerically. Circle packings approximate conformal mappings in a precise sense, which makes circle packing an interesting tool for numerical conformal mapping. The theory has applications in combinatorics and to the construction of discrete analogues of minimal surfaces. An interesting theme is to discover which classical theorems about the geometric and topological behaviour of analytic functions in one variable have circle packing analogues.

For an idea of the theory, consult *Introduction to Circle Packing: the theory of discrete analytic functions* by Ken Stephenson (Cambridge University Press, 2005).

In joint work with Ken Stephenson and James Ashe, I have been studying branched circle packings, which are analogous to analytic functions with branch points. We have recently developed a way to move the branch points in a continuous fashion, which has good local existence and uniqueness properties and an accompanying numerical method. This is the first step in a programme aimed at solving a long-standing question about the generalization of the Koebe-Andreev-Thurston theorem to circle packings on branched covers of the sphere. These are the circle packing analogues of rational maps.

Another possible project is to study circle packings of random infinite triangulations of the plane, such as the Delaunay triangulation whose vertices are given by a unit-intensity Poisson process in the plane. It is known that the corresponding circle packing almost surely fills the plane, but it is not known how well the circle centres approximate the positions of the points in the Poisson process.

Analysis on metric spaces and geometric group theory: John Mackay

The two main themes of my research are geometric group theory and analysis on metric spaces.

Geometric group theory involves the study of infinite, finitely generated groups by considering how they act on appropriate spaces. My main focus is on Gromovs hyperbolic groups and how they can be studied using their "boundary at infinity". (For example, three dimensional hyperbolic space, in the Poincaré ball model, has a natural sphere at infinity.) These boundaries are metric spaces, usually fractal, and may carry a rich analytic structure. The key question is to relate the algebraic properties of such groups with the analytic properties of their boundaries. Interesting examples of hyperbolic groups include Gromov's "random groups" and many examples from low dimensional topology.

I am particularly interested in the *conformal dimension* of the boundary. This is a variation on Hausdorff dimension due to Pansu. There are many spaces of interest where this dimension is not known, or even well estimated.

Conformal dimension links to my other main interest, analysis on metric spaces. This involves the study of (non-smooth) functions on metric spaces that have no given smooth structure, but satisfy some weaker conditions. This is motivated first by applications where the spaces that arise have only weak regularity. A second motivation arises from the desire to understand classical results better by finding out exactly what hypotheses they require. A potential question here is to find necessary conditions for a metric space to admit a Poincaré inequality.

If you are interested in discussing potential projects in these areas, please do contact me. For more information, see:

`http://www.maths.bris.ac.uk/~jm13806/`

References

1. P. de la Harpe, *Topics in geometric group theory*, Chicago Lectures in Mathematics, University of Chicago Press, Chicago, IL, 2000.

2. J. Heinonen, *Lectures on analysis on metric spaces,* Universitext, Springer-Verlag, New York, 2001.

Function Spaces, Spectral Theory and Exceptional Sets: Yuri Netrusov

My main area of research is the study of spaces of weakly differentiable functions defined on open subsets of Euclidean space $\mathbb{R}^n$. Let Ω be a domain in $\mathbb{R}^n$, and let $1 \leq p \leq \infty$. Denote by $L^{l,p}(\Omega)$ the Sobolev space equipped with the following semi-norm $(\int_\Omega |\nabla^l f(x)|^p dx)^{1/p}$. One of the most interesting problems connected with these spaces is the description of their traces on subsets of Ω (the case $l = 1$, $p = 2$ is very important for applications to partial differential equations and harmonic analysis). This problem was investigated by many analysts but the general situation is still unclear.

Many problems of spectral theory can be reformulated in terms of Sobolev spaces. For instance one can see that eigenvalues of Neumann Laplacian coincide with s-numbers of imbedding

$$L^{1,2}(\Omega) \subset L^2(\Omega).$$

Suppose that X is some space of functions defined on $\mathbb{R}^n$. Let K be a compact subset of $\mathbb{R}^d$. Denote by $Cap_X(K) = inf||g||_X$ capacity associated with this space. Here the infimum is taken over all functions g such that $g = 1$ on the set K, $g \in C_0^\infty(\mathbb{R}^n)$. One can see that in the case when X is coincides with the Sobolev space $L^{l,1}$, $l < d$ or $L^{1,2}$ the quantity Cap_X is equivalent to the Hausdorff content or harmonic capacity respectively. There are many interesting questions connected with these quantities for different functional spaces. Most attention is paid to the class of all compacts K such that $Cap_X(K) = 0$. These classes appear in many problems of analysis.

Microlocal Analysis: Roman Schubert

My research is mainly centred on time dependent problems in quantum mechanics and on hyperbolic wave equations. It ranges from questions in pure mathematics to applications in physics and chemistry and a PhD project can be concentrated on one of these aspects or it can bridge several areas. I use mainly methods from microlocal (or semiclassical) analysis, a beautiful area which combines analysis, symplectic geometry and ideas from dynamical systems to construct asymptotic solutions to partial differential equations. Two excellent very recent references are the books *Semiclassical Analysis* by Maciej Zworski and *Hyperbolic Partial Differential Equations and Geometric Optics* by Jeffrey Rauch. The topics for PhD theses will be related to current research in the field and evolve therefore in time. But pure topics in the following areas can be investigated:

- Spectral geometry and spectral asymptotic: The study of eigenfunctions and eigenvalues of the Laplace Beltrami operator on a Riemannian manifold and how their properties depend on the geometry of the manifold. The main tool for this is actually the study of related wave equations on the manifold.

- Non-linear Schrödinger equations: geometric optics constructions for non-linear Schrödinger equations on manifolds and relations to the underlying geometry.
- The Lindblad equation and Quantum Dynamical Semigroups: The Lindblad equation models coupling to an environment, the aim is to extend methods from microlocal analysis developed for the Schrödinger and wave equations to the Lindblad equation.

Probability with a physics flavour
Bálint Tóth

The main areas of my research are problems of probability and stochastic processes motivated by physical phenomena. I am particularly interested in phenomena where short range interactions between constituent components of a large system give rise to long range correlations and thus conventional methods of probability theory are not applicable. A few examples follow:

Random walks and diffusions with path-wise self-interaction and/or in inhomogeneous random environment: The long-time asymptotic behaviour of ordinary (e.g. simple symmetric) random walk is fully characterized by the central limit theorem and its functional counterpart, the invariance principle. If the random walk mechanism also includes some path-wise self-interaction in terms of past occupation times e.g. the random walker prefers to visit new, unseen domains rather than returning to sites many times visited in the past the long-time asymptotics becomes much more complicated and interesting. Depending on the nature of self-interaction a very rich asymptotic picture arises. Likewise, if the jump probabilities of a random walker vary in space the long-time asymptotic behaviour could be very different from that of ordinary (simple symmetric) random walk. Yet again, new methods and ideas are needed in order to understand it.

Brownian motion and "Brownian motion": The physical phenomenon called Brownian motion is the apparently random displacement of a particle suspended in a fluid, driven by collisions and interactions with the molecules of the fluid which are in permanent thermal agitation. One of the idealised mathematical models of this random drifting is the stochastic process commonly called "Brownian motion", or the Wiener process. This is a random process characterised by (1) independence of increments in non-overlapping time intervals, (2) time-stationarity of increments, and (3) continuity of its sample paths. A dynamical theory of Brownian motion should link these two: derive in a mathematically satisfactory way — as a kind of macroscopic scaling limit — the idealised mathematical description from microscopic principles. The mathematical problem is very intimately related to the random walk problems of the previous paragraph.

Stochastic representations of quantum spin systems and their use: Since the mid-nineties various efficient stochastic representations of quantum spin and particle systems were introduced, based on Feynman-Kac and/or Trotter formulae. These representations helped to understand the behaviour of quantum systems in the thermodynamic limit: providing various rigorous bounds on the long range order parameters for interacting boson gas and spin systems, but there is much more potential in these representations. I plan to further investigate the still open questions related to mathematically rigorous proof of existence of long range order at low positive temperature in various quantum spin systems.

All these problems are mathematically hard and physically relevant. The methods involved are a rich mixture of probabilistic, analytic and combinatorial ideas and techniques. For more information don't hesitate to contact me (mabat@bristol.ac.uk) and consult my webpage
`http://www.maths.bris.ac.uk/~mabat/`

3 Research in Combinatorics

Combinatorics at Bristol is currently of a largely analytic flavour but likely to expand significantly in the coming years. We run an active seminar series and have a significant throughput of people interested in discrete mathematics, not least due to the department's association with the Heilbronn Institute.

Geometric and arithmetic combinatorics and geometric measure theory: Misha Rudnev

The term *combinatorics* rarely appears in modern mathematical literature without an additional appellation. *Geometric* combinatorics deals with counting properties of arrangements of a large number of geometric objects in space. *Arithmetic* combinatorics pursues combinatorial estimates associated with the arithmetic operations (addition, multiplication and their inverses) in groups, rings and fields. *Additive* combinatorics focuses on Abelian groups. I am interested in all three areas.

Arithmetic and geometric combinatorics interact with one another by way of formulating the former's questions as *incidence* problems, which constitute my core research interests. Generally speaking, one has a set of geometric objects X of some type and a set of points P in some space, and asks for the bound on the cardinality of the set of incidences $I = \{(p, x) : p \in x\}$, in terms of the cardinalities $|X|, |P|$. In a notable case the space is a projective plane and the sets are straight lines. If the plane is Euclidean, the sharp incidence bound is given by the famous Szemerédi-Trotter theorem (1981). In $\mathbb{R}^3$ it is the Guth-Katz theorem (2010). There are some generalisations of these results to higher dimensions, leaving many open questions. Another source of open questions is how the incidence theorems are influenced by the metric, e.g. when $\mathbb{R}^2$ gets replaced by the sphere or the hyperbolic plane, and the straight lines by geodesics. The latter set-ups are more than just curiosity: they are closely liked to the so-called *sum-product type* questions.

The paradigmatic question of the latter type is the so-called *Erdős-Szemerédi conjecture*, a major challenge in arithmetic combinatorics. The original conjecture is that for any finite set A of integers, the cardinality of the set of all sums or products (denoted respectively by $A+A$ and $A \cdot A$) of pairs of elements of A is almost as great as the cardinality of A, squared. That is: $|A + A| + |A \cdot A| \gg |A|^{2-o(1)}$.

Today, the question is primarily asked in the context of reals $A \subset \mathbb{R}$ (as well as the complex field $\mathbb{C}$) or the prime residue field $A \subset \mathbb{F}_p$, with p large and $|A|$ sufficiently small relative to p. The current "world records", some of which are mine, are far from what is believed to be true. Similar questions can be asked with more variables in A. For instance, the following two sharp estimates have recently been established: $|\{(a_1 - a_2)^2 + (a_3 - a_4)^2 : a_{1,\ldots,4} \in A\}|$, $|(A + A) \cdot (A + A)| \gg |A|^{2-o(1)}$, as a result of resolving the famous Erdős distance problem (first estimate, Guth-Katz) and its Minkowski metric version (second estimate, Roche-Newton and myself).

Even though the methods used to resolve these questions combine classical combinatorics, graph, group theory, analysis, algebraic geometry and topology, they apply efficiently only to a rather narrow class of questions. As of today, there are more open than solved questions of this type, in particular, over finite fields, and new ideas are eagerly awaited.

Finally, over the past 30 years or more, similar questions have been asked in the "continuous" setting, where finite set cardinalities get replaced by Hausdorff dimensions. The corresponding problems acquire a distinct harmonic-analysis flavour and appear to be linked to the famous Kakyeya, Restriction, etc. conjectures. For example, the continuous version of the Erdős distance problem, known as the Falconer conjecture, stating that any bounded Borel set in $\mathbb{R}^2$ whose Hausdorff dimension is > 1 generates a positive Lebesgue measure set of distances, is wide open.

More specific description of concrete projects is presented on `http://www.maths.bris.ac.uk/~maxmr/phd.pdf`.

Arithmetic combinatorics: Julia Wolf

My research focuses on combinatorial problems arising from arithmetic operations on sets of integers. These tend to be easy to state, such as the famous theorem of Szemerédi, which asserts that for any integer k, any sufficiently dense subset of the integers 1 up to N contains an arithmetic progression of length k. Another prominent example is known as Freiman's theorem: what can you say about the structure of a subset A of the integers if you know that the set of its pairwise sums is not much larger than A itself?

These and similar problems have been tackled successfully using a combination of purely combinatorial, probabilistic and Fourier-analytic techniques. Important advances in this area in recent years have led to more than one breakthrough result in number theory, for example the Green-Tao theorem on long arithmetic progressions in the primes. This area of research also has close connections with graph theory, parts of ergodic theory and theoretical computer science, all of which I am actively interested in.

Prospective students will wish to consult my website at `www.juliawolf.org` and email me for further details on specific projects.

Analytic number theory and arithmetic combinatorics: Trevor Wooley

My research centres on the use of Fourier analysis in problems of a number-theoretic flavour, and in recent times, a significant part of my research and that of my research students has focused on combinatorial aspects of these methods. Given a subset of the rational integers, or of a polynomial ring, or some other interesting algebraic set, can one infer the existence of arithmetically interesting structures merely from information concerning the number of elements in the set of a given height? The archetypal result of this flavour is due to Klaus Roth in 1953, and asserts that whenever a set of integers not exceeding N possesses no 3-term arithmetic progressions, then the set contains no more than $N/\log\log N$ integers, and hence has relative density zero. Rather than linear equations, as in this example, in my work and that of my students we typically consider equations of higher degree. One arena of interest right now is the relationship between the sensational work of Gowers, as pursued by Green and Tao, over the integers, or vector spaces over finite fields, and analogous function field problems. Another is the pursuit of higher-degree analogues of Freiman's theorem suggestive of alternatives to Gowers norms.

I am happy to discuss potential directions for research in this area with interested students.

4 Research in Number Theory

Number Theory:
Tim Browning

I am interested in problems that lie at the interface of analytic number theory and Diophantine geometry. Often this involves studying aspects of the locus of rational or integral solutions to a system of Diophantine equations. Such a system defines an algebraic variety, and one might then ask to what extent the behaviour of this locus is dictated by the geometry of the variety. At other times one wants to study problems coming from analytic number theory. Many such problems refer to (or can be reduced to) questions involving rational or integral solutions to Diophantine equations. This area of research combines tools from analytic number theory with concepts from algebraic geometry, and would suit anyone who has an interest in both of these two fields.

I am happy to discuss further details of possible projects in this area by email, some indication of which can also be found on my web page:
`http://www.maths.bris.ac.uk/~matdb/`.

Algebraic Number Theory and Elliptic Curves:
Tim Dokchitser

I mostly work in algebraic number theory and elliptic curves, and especially with things related to Birch-Swinnerton-Dyer Conjecture and arithmetic of L-functions. I am also interested in all kinds of connections between number theory and Galois theory, finite groups and representation theory. Most of the things that I do rely heavily on computers and computational algebra systems. I use computer experiments a lot to formulate and to test conjectures, and to get inspiration about their proofs as well.

I have many possible projects that concern elliptic or hyperelliptic curves, abelian varieties and their L-functions; feel free to drop by to discuss them if you are interested. You can also have a look on my webpage, `www.maths.bris.ac.uk/~matyd/` for my publications, summer school lecture notes and the like.

Number Theory and Automorphic Forms:
Abhishek Saha

My research lies at the interface of number theory and representation theory. More precisely, I work with various kinds of 'modular forms' and their L functions; these are nicely behaved objects that encode deep number theoretic information. I use techniques from analysis as well as from algebra and representation theory (of Lie and p-adic groups) in my work.

I am particularly interested in Siegel modular forms; these are generalizations of the classical modular forms and their Fourier coefficients are much more mysterious than the classical case. I am also interested in understanding local and global representations of algebraic groups, particularly in relation to the Langlands program. Some of my work deals with the phenomenon of equidistribution of various parameters connected with modular forms or suitable families of modular forms. I am happy to discuss possible projects in these areas.

Number Theory:
Lynne Walling

I work with quadratic forms and various types of automorphic forms, which are nicely behaved functions whose Fourier coefficients encode number theoretic information. One type of automorphic form, called theta series, encodes the number of times a quadratic form represents each integer, or more generally, each quadratic form of smaller dimension. So understanding these automorphic forms helps us understand these representation numbers. On the other hand, the arithmetic theory of quadratic forms helps us understand automorphic forms, particularly those called Siegel modular forms. While most researchers study automorphic forms using analytic or representation theoretic tools, I mainly use algebraic tools.

I am happy to discuss further details of possible projects in this area
by email: l.walling@bristol.ac.uk.

Analytic Number Theory:
Trevor Wooley

My research is centred on the Hardy-Littlewood (circle) method, a method based on the use of Fourier series that delivers asymptotic formulae for counting functions associated with arithmetic problems. In the 21st Century, this method has become immersed in a turbulent mix of ideas on the interface of Diophantine equations and inequalities, arithmetic geometry, harmonic analysis and ergodic theory, and arithmetic combinatorics. Perhaps the most appropriate brief summary is therefore "arithmetic harmonic analysis".

Much of my work hitherto has focused on Waring's problem (representing positive integers as sums of powers of positive integers), and on the proof of local-to-global principles for systems of diagonal Diophantine equations and beyond. More recently, I have explored the consequences for the circle method of Gowers' higher uniformity norms, the use of arithmetic descent, and function field variants. The ideas underlying each of these new frontiers seem to offer viable approaches to tackling Diophantine problems known to violate the Hasse principle.

I am happy to discuss possible research projects by email — anything connected with the topics above (arithmetic harmonic analysis). See my web page for some surveys and other details of work with which I am currently involved.
`http://www.maths.bris.ac.uk/~matdw/`

5 Research in Ergodic Theory and Dynamical Systems

Dynamical Systems and Number Theory: Alex Gorodnik

My research interests are in ergodic theory, theory of transformation groups, and number theory. While most nontrivial dynamical systems exhibit complicated chaotic behaviour, it is possible to develop techniques to analyse asymptotic properties of the orbits. This is not only of fundamental importance in the theory of dynamical systems, but also has many far-reaching applications to number theory. For instance, these techniques can be used to study solutions of Diophantine equations and inequalities. Another important scheme in my research is various rigidity phenomena in dynamical systems. Given a dynamical system, one may ask to describe, for instance, maps that commute with the action, closed invariant sets, invariant measures, etc. It turns out that in several important cases these objects have algebraic origin and can be completely classified, which leads to many surprising applications.

I will be happy to supervise a PhD project in one of the following directions:

- statistical properties of orbits for actions of large groups,
- dynamical systems appearing in Diophantine geometry,
- rigidity properties of dynamical systems.

Prospective students should consult a gentle introduction to my research:

`http://www.maths.bris.ac.uk/~mazag/res.html`

and contact me in person or by email to discuss details of potential projects.

Dimension Theory in Dynamical Systems: Thomas Jordan

Properties of self-similar sets

A self-similar set is given by the attractor of an iterated function system consisting of a finite number of contracting similarities. It is well know that if the system satisfies the open set condition then the Hausdorff dimension is given by the solution to $\sum r_i^s = 1$ (where r_i are the contraction ratios). However in some cases this still gives the dimension even when the open set condition is not satisfied. A potential problem is to find a condition about the similarities which is equivalent to the Hausdorff dimension dropping below s. A further area of study could be when is it possible for self-similar sets with positive Lebesgue measure to have empty interior. In, [1] it is shown that such sets can exist in R^d for $d \geq 2$. However whether such sets exist in 1-dimension is still unknown. A more tractable problem may be to look at the same problem for random self-similar sets in 1 dimension.

References

[1] M. Csörnyei, T. Jordan; M. Pollicott; D. Preiss; B. Solomyak. Positive-measure self-similar sets without interior. Ergodic Theory Dynam. Systems 26 (2006), no. 3, 755–758

Dimension theory of non-conformal systems

The properties of self-similar sets satisfying suitable separation condition is now very well understood. Similarly if we take a non-linear family where the maps are conformal (at every point the derivative is a similarity) then the same is generally true. However if we consider the case of self-affine system or non-conformal nonlinear systems then much less is known. There are several possible projects in this area. For example there is a formula for the dimension of self-affine systems which holds almost surely. However there are very few cases where it can be shown to hold for a specific example particularly if the dimension is greater than one. It would be of great interest to find more cases where this can be shown. For non-linear systems an interesting project would be to see if it is possible to find the dimension under suitable random perturbations (this can be done for self-affine sets).

If you are interested in either of the above projects or in any project in the dimension theory of dynamical systems or fractal geometry then you are welcome to contact me by email (thomas.jordan@bris.ac.uk).

Number theory. Quantum Chaos; Dynamical Systems: Jens Marklof

Kinetic transport equations capture the time evolution of coarse, macroscopic features of highly complex systems. A fundamental example is the linear Boltzmann equation, or Boltzmann-Lorentz equation, which models the dynamics of a dilute particle gas in matter. The linear Boltzmann equation has wide-ranging applications, including nuclear physics (neutron transport in a moderator), semiconductors, radiative transfer and ocean wave scattering. The equation was derived by Lorentz in 1905, following Boltzmann's groundbreaking work on the kinetic theory of gases. Lorentz assumed, crucially, that the gas is sufficiently dilute so that the moving particles only interact with the fixed scatterers but not with each other. The dynamics of the Lorentz gas then reduces to an effective one-particle motion, and the corresponding transport equation is linear. This significantly simplifies the technical challenges present in Boltzmann's original setting of an *interacting* particle gas—yet a completely rigorous derivation of the linear Boltzmann equation from first principles had to wait a further six decades since Lorentz' original studies.

A central hypothesis in the seminal work by Gallavotti (Phys Rev 1969), Spohn (Comm Math Phys 1978), and Boldrighini, Bunimovich and Sinai (J Stat Phys 1983), is that the configuration of the fixed scatterers should be sufficiently irregular. Without this assumption, the linear Boltzmann equation may indeed fail: In the case of a periodic scatterer configuration, Golse (Ann Sci Fac Toulouse 2008) showed that the estimates on the free path lengths of Bourgain, Golse and Wennberg (Comm Math Phys 1998) imply that the linear Boltzmann equation must fail. The question what the correct transport equation should be, or even whether the kinetic limit exists at all in this case, remained open. In a series of papers with A. Strömbersson (Uppsala), we have solved this long-standing problem by proving that the kinetic limit is governed by a completely new transport equation which is distinctly different from the linear Boltzmann equation. One of the main features of our limiting process is that (contrary to Lorentz' assumption) consecutive collisions are no longer independent: The collision kernel of our transport equation does not only depend on the particle velocity before and after each collision, but also on the flight time until the next collision and the velocity thereafter. Our key idea was to employ a renormalization technique based on flows on homogeneous spaces, and use the ergodic properties of this flow to prove the existence of a limiting Markov process.

I am currently working on several projects extending the above findings to more general settings, including certain non-periodic (quasicrystal) scatterer configurations, other dynamical systems, and the quantum setting. If you are interested in a PhD in this area, I would be more than happy to discuss potential projects.

Ergodic Theory and Teichmüller Dynamics: Corinna Ulcigrai

My main research interests are in ergodic theory and Teichmueller dynamics, an area of research in dynamical systems which has developed and bloomed in the last decades and that often involves arithmetical, geometrical and combinatorial tools.

Examples of systems studied in Teichmueller dynamics are:

- Polygonal billiards, in which a point-particle moves in a planar polygon bouncing elastically at sides.
- Geodesics on translation surfaces, which are locally Euclidean surfaces but at some conical singularities.

- Maps of the interval which are piecewise isometries, called interval exchange transformations (IETs).

One is interested in investigating ergodic properties that describe how chaotic these systems are.

The properties of these elementary systems are beautifully and deeply connected with the dynamics on an abstract space of deformations, more precisely with the Teichmueller geodesic flow and the SL(2,R) action on moduli spaces. At the level of interval exchange transformations, this connections can be exploited at a more combinatorial level, using a continued fraction algorithm called Rauzy-Veech induction.

Some areas of research for possible Phd projects:

- Area preserving flows on surfaces: in a natural class of flows locally given by a Hamiltonian, I recently studied properties like mixing and weak mixing; many interesting questions about spectral properties are open;

- Cutting sequences: in a joint work with Smillie, we gave a characterization of the symbolic sequences which code linear trajectories in regular polygons. Similar questions could be addressed in other translation surfaces with the lattice property.

- Interval exchange transformations: questions about distributions of orbit points, as spacings and discrepancy, in the spirit of limit theorems or for special classes of IETs (like bounded type).

If you are interested in knowing more about this research area and potential projects, feel free to contact me. My email address is corinna.ulcigrai@bristol.ac.uk

6 Research in Algebra

Group Theory:
Tim Burness

My main area of research is in group theory. I am interested in simple groups, both finite and algebraic, with a particular focus on subgroup structure, conjugacy classes and representation theory. I am also interested in permutation groups and related combinatorics, and in the application of probabilistic and computational methods.

Bases for permutation groups

If G is a permutation group on a set S then a subset B of S is a base for G if the pointwise stabiliser of B in G is trivial. The base size of G, denoted $b(G)$, is the smallest size of a base for G. Bases have been widely studied since the early days of group theory in the nineteenth century, and they are used extensively in computational group theory. There are many possible projects in this area:

- Investigate $b(G)$ when G is a finite almost simple primitive group. For example, it is known that $b(G) \leqslant 7$ if G is "non-standard", and the proof uses probabilistic methods. It would be interesting to develop these methods to determine the exact base size for all non-standard groups. This will involve a detailed study of the subgroup structure and conjugacy classes in the almost simple groups of Lie type.

- Study the finite primitive groups G with the extremal property $b(G) = 2$. For example, if $G = V \rtimes G_0 \leqslant \mathrm{AGL}(V)$ is an affine group, then $b(G) = 2$ if and only if the irreducible subgroup $G_0 \leqslant \mathrm{GL}(V)$ has a regular orbit on V, and determining the possibilities for G_0 and V is a well-studied problem in representation theory.

- Investigate bases and related base-measures for interesting families of infinite permutation groups.

Fixed point spaces and applications

In the study of group actions, there are many interesting problems concerning the fixed point sets of elements or subgroups. For example, if G is an algebraic group acting on an algebraic variety X then the fixed point set $C_X(g) = \{x \in X \mid xg = x\}$ is a subvariety and we can study its dimension as we vary X and the element $g \in G$. Further, we can use bounds on the dimension of these fixed point sets to estimate the proportion of fixed points of elements in a corresponding action of the finite group G_σ, which is the set of fixed points of a Frobenius morphism σ of G. This interplay between algebraic and finite groups is a common theme in my research.

The case where G is a simple algebraic group is particularly interesting. Indeed, fixed point ratios for finite simple groups have been applied in a wide range of problems in recent years, e.g. base sizes, generation problems for finite groups, and the study of monodromy groups of compact connected Riemann surfaces.

An overview of my recent research activities (with references) can be found here:
`http://seis.bristol.ac.uk/~tb13602/research.html`.
If you are interested in any of the above projects, or if you would like to know more about my research, then please feel free to contact me by email (t.burness@bristol.ac.uk).

Representation Theory:
Jeremy Rickard and Aidan Schofield

Representation theory is a field that covers many of the currently most exciting areas of algebra, and at present, there are two permanent members of the Bristol School of mathematics, Professors Aidan Schofield and Jeremy Rickard, active in research on various aspects of this field.

The two main areas they work in are representations of quivers (for a definition, see below) and representations of finite groups. Both of these can be thought of as special cases of the study of modules for a ring: in the case of quivers, the ring in question is the so-called 'path algebra' of the quiver and in the case of groups it is the group algebra.

Aidan Schofield works on the representation of quivers and related questions. A quiver is a set of vertices together with a set of arrows between these vertices, and a representation of a quiver is just a way of assigning a vector space to each vertex of the quiver, and a linear map to each arrow. To give a simple example: the quiver might have a single vertex and a single arrow going from that vertex to itself; in this case a representation is just a vector space together with a linear endomorphism. The study of this rather simple idea of a quiver turns out to be fundamental to representation theory and to other areas of mathematics because many classification problems in mathematics can be reduced to studying representations of a quiver. To return to the very simple example given earlier, the classification of representations of the quiver with one vertex and one arrow is equivalent to that of square matrices up to conjugacy, which is given by the Jordan normal form.

The techniques used in the study of representations of quivers involve geometric ideas. The basic idea is that if you fix the vector spaces involved in a representation of some quiver and fix a basis for each one, then the choice of linear maps just involves choosing the entries in a collection of matrices, and hence is equivalent to choosing a point in a (usually rather large) vector space V whose dimension is the total number of entries that need to be chosen. However, many choices will lead to isomorphic representations, as a different choice of basis might have been made for the vector spaces. A little thought shows that there is a group acting on V in such a way that elements of V give isomorphic representations precisely when they are in the same orbit. Thus we are led to the study of orbits of groups acting on vector spaces, which is the subject of geometric invariant theory. If you come to Bristol to do a Ph.D. in this subject, then, you should expect to learn a certain amount of algebraic geometry.

Jeremy Rickard works on the modular representation theory of finite groups. A representation of a finite group G is just an action of G by linear maps on a vector space V, or in other words a group homomorphism from G to the group $GL(V)$ of invertible linear endomorphisms of V. You may have come across representations over the complex numbers in an undergraduate course. In this case, the problem of classifying representations reduces to finding the (finitely many) irreducible representations, as a general representation is a sum of these. Moreover, one can calculate which irreducibles occur as constituents of a given representation from its character, so the character table of a group contains virtually all the information about its representation theory.

The word 'modular' refers to the study of representations over fields of non-zero characteristic p, where p divides the order of the group G. Here matters are much more complicated, as it is no longer true that every representation is a sum of irreducibles, and it is only in the simplest cases that a complete classification can be found (for example, there is not even a classification of representations of $C_3 \times C_3$ over a field of characteristic 3). However, this added complexity has the compensating advantage that more powerful techniques can be brought to bear.

This field is a very exciting one to be working in at present, as many deep and intriguing conjectures have arisen over the last decade or so, completely transforming the subject. If you come to Bristol to study modular representation theory, you will be working on questions intimately related to these exciting recent developments: although it might be over-ambitious to expect to settle the main problems that are currently motivating research in the area, there are many more tractable problems that they have given rise to.

Much of the most important current work on modular representation theory involves ideas related to homological algebra and algebraic topology. Topological ideas come into group representation theory in many different ways: one of the more obvious is that many important representations have geometric constructions – if a group acts on a topological space then it acts on the homology groups of the space, which therefore become representations of the group.

If you come to Bristol to do a Ph.D. in this subject, you will learn a great deal about the more algebraic side of algebraic topology.

7 Research in Logic and Set Theory

Set theory and its applications: Andrew Brooke-Taylor

I am very interested in how strong axioms and other tools and techniques from set theory may be applied in other areas of mathematics, with particular emphasis on applications to category theory and algebraic topology.

As a first example, *large cardinal axioms* from set theory were recently responsible for the partial resolution of an important, 30 year old problem in algebraic topology: Casacuberta, Scevenels and Smith showed that, if you assume the large cardinal axiom schema known as *Vopěnka's Principle*, then every generalised cohomology theory admits a localisation functor. The strength of axiom required for the known proof has since been reduced to the existence of a proper class of supercompact cardinals, but the exact large cardinal strength that is truly necessary for this result remains unknown. Underlying the work of Casacuberta, Scevenels and Smith is the theory of *accessible categories*, in which large cardinals have had a significant role to play for many years. However, there remain many interesting open questions in the area, and most of the work that has been done has been from a very category-theoretic perspective, so there is great potential for breaking new ground using a set-theoretic perspective.

Another exciting recent application of set theory has been the use of Borel reducibility analysis in areas such as C^* algebras and ergodic theory. Here one considers the reducibility of different equivalence relations to each other by means of simple maps, where "simple" is taken to mean Borel. Showing that there are no such reductions can lead to concrete theorems telling us that it is impossible to classify certain objects by simple invariants. There is great scope for using the same techniques in algebraic topology, in particular considering countable simplicial sets, which are often used as a convenient combinatorial stand-in for topological spaces.

Set Theory: Philip Welch

Modern set theory evolved from attempts by logicians to put the foundations of mathematical analysis on a sure axiomatic footing, and avoid the paradoxes of Russell and others. The Zermelo-Fraenkel ("ZF") axioms are commonly regarded as achieving this – but various questions remained unanswered about, for example, the *sizes* of subsets of the real line, the most notable being the Continuum Hypothesis. Since the 60's, and from the work of Gödel, we know such questions are unanswerable on the basis of ZF, even in theory. (Moreover whatever axiomatic theory we choose, there will be such unanswerable questions.) Set theorists study various "axioms of strong infinity" relating to ZF-models (structures that satisfy the ZF-axioms, much as a group satisfies the group axioms). A whole hierarchy of theories have been discovered, the study of which has evolved into a branch of pure mathematics in its own right. This study of "inner models" has used metamathematical methods to provide results in other areas of mathematics. It appears, somewhat paradoxically, that the presence of extremely large sets in the universe of all sets can affect how the analyst must view the real line for example.

(i) Some current exciting developments relate *axioms of determinacy* (stated in terms of infinite 2-person perfect information games on integers: "do such games have winning strategies for either player?"), statements about the real line ("Is every uncountable set in (1-1) correspondence with the whole line?") and with large sets (such as so-called "measurable cardinals") which are startlingly remote from the sets of reals, but which involve such large cardinal numbers, and their inner models, generalising the work of Gödel. A program of research here at Bristol would typically involve a detailed investigation into the structural properties of such a model and how this model's existence effects those games' outcomes.

(ii) Combinatorics. Certain infinite cardinal properties lend themselves to characterisation in terms of *infinitary combinatorics*, generalising, for example the Ramsey Theorem on natural numbers. There are some difficult questions here, but there are numerous others that are suitable for tackling at the Ph.D. level.

(iii) In very weak systems of set theory (or even just the straightforward theory of analysis) only very simple games of the type mentioned in (i) can be determined. One can ask which kinds of axiom system are needed to prove the existence of winning strategies. It has recently been noticed that certain techniques used by philosophers when building *theories of truth* or *theories of definitions* use very similar systems. Certain kinds of abstract infinitary algorithm derived from computer science are also coincidentally of this kind. What are the exact relationships here?

8 Academic Staff in Pure Mathematics

Professor Michiel van den Berg:
Partial differential equations, in particular spectral geometry.
e-mail: m.vandenberg@bris.ac.uk

Dr Andrew Booker:
Analytic and algorithmic number theory.
email: andrew.booker@bris.ac.uk

Dr Andrew Brooke-Taylor:
Set theory and its applications.
email: a.brooke-taylor@bris.ac.uk

Professor Tim Browning:
Analytic number theory; Diophantine geometry.
email: t.d.browning@bris.ac.uk

Dr. Tim Burness:
Group theory, representation theory and combinatorics.
email: t.burness@bris.ac.uk

Professor Brian Conrey:
Analytic number theory, especially the analytic theory of L-functions.
email: b.conrey@bris.ac.uk

Dr. Edward Crane:
Complex analysis and probability, especially circle packings and SLE processes.
email: Edward.Crane@bristol.ac.uk

Professor Tim Dokchitser:
Elliptic curves, algebraic number theory, group theory and representation theory.
email: tim.dokchitser@bris.ac.uk

Professor Alex Gorodnik:
Dynamical systems and number theory
email: a.gorodnik@bris.ac.uk

Dr Thomas Jordan :
Dimension theory in dynamical systems
e-mail: thomas.jordan@bris.ac.uk

Dr John Mackay :
Analysis on metric spaces and geometric group theory
e-mail: john.mackay@bris.ac.uk

Professor Jens Marklof:
Number theory; Quantum chaos; Dynamical systems.
email: j.marklof@bris.ac.uk

Dr. Yuri Netrusov:
Functional Spaces, Partial differential equations, Spectral theory.
email: y.netrusov@bris.ac.uk

Professor Jeremy Rickard:
Representation theory of finite-dimensional algebras. Modular representation theory of finite groups. Homological algebra.
email: j.rickard@bris.ac.uk

Dr Abhishek Saha:
Nmmber theory and automorphic forms.
email: abhishek.saha@bris.ac.uk

Professor Aidan Schofield:
Representation theory of finite dimensional algebras, Kac-Moody Lie algebras. Also invariant theory and the study of rings with polynomial identities.
email: aidan.schofield@bris.ac.uk

Dr Roman Schubert:
Mahtematical physics.
email: roman.schubert@bris.ac.uk

Dr Corinna Ulcigrai:
Ergodic theory and Teichmüller dynamics.
email: corinna.ulcigrai@bris.ac.uk

Dr Lynne Walling:
Number theory, working with quadratic forms and various types of automorphic forms.
email: l.walling@bris.ac.uk

Professor Philip Welch:
Set theory, fine structure and core models. Problems concerning determinacy, large cardinals and strong axioms of infinity.
email: p.welch@bris.ac.uk

Dr. Julia Wolf:
Arithmetic combinatorics
email:julia.wolf@bris.ac.uk

Professor Trevor Wooley:
Analytic Number Theory, Diophantine Equations and Diophantine Problems, Harmonic Analysis. The Hardy-Littlewood Circle method, and the theory and applications of exponential sums.
email:trevor.wooley@bris.ac.uk

9 Ph. D and M.Sc. by Research

The normal entry requirement for a PhD in Bristol is a good honours degree (1st class or upper second class) in Mathematics or a related subject from a British University; equivalent qualifications from overseas institutions are accepted. Funded positions are awarded on a competitive basis. The funded period of study is three and a half years. The UK Research

Councils currently award research studentships for maximum three and a half years for British and EU students who have been residents in UK for 3 years prior to application.

Each student has an adviser with whom he or she works. In many cases the adviser is chosen before the student arrives. This is necessary for certain studentships. In other cases, the adviser is chosen in the first few weeks of study. Many students are also supervised jointly by two advisers.

Research degrees are awarded on the recommendation of the examiners of the student's final dissertation; this includes an oral examination.

New starting students are expected to attend postgraduate lecture courses, and sometimes undergraduate lecture courses, in order to ensure a solid background knowledge of their subject. In fact PhD students are required to have 100 hours of assessed courses over the course of their degree, with at least 60 hours in their first year. Seminars keep the School abreast of current developments and all students are expected to attend. 'Formal' seminars are given by distinguished visitors from elsewhere in Britain and abroad. 'Informal' seminars are usually given by people already in Bristol, including postgraduates themselves.

Students are encouraged and supported financially to attend meetings and conferences relevant to their work. Normally students will be funded to attend at least one international conference during the tenure of their award, provided that they are presenting a talk about their work.

Masters programme

The School also has a **M.Sc. programme in Mathematical Sciences**. During this 1-year course students will focus on an area at the forefront of research in Mathematics where they will be able to attend specialised lectures and perform their own research under the supervision of a member of staff. This course runs for a full year from October to September. Students choose under the guidance of a mentor a combination of taught units that are usually examined in April and early June. Students will focus on their projects during the summer.

10 Studentships and Funding

British and EU Students

The main single source of funding for UK and EU students, who have been residents in the UK for 3 years prior to application, is the School's **EPSRC**-based Doctoral Training Account (DTA), which awards studentships on a competitive basis. Application must be made through the School, preferably by **1 April** for students wishing to start the following October. An EPSRC studentship meets all the tuition fees and pays a maintenance allowance to the student. The precise figures for each session are announced in mid-summer, but from October 2013 the value of this allowance is £13,726 plus fees per annum. No tax is payable on this income, nor is there any abatement of the allowance on account of income from other sources. Supplements are available for disabled students, mature students, students with dependents and for students with suitable postgraduate work experience.

Other students from European Union countries may be eligible for fees-only grants from the EPSRC and awards from the EU.

(There are no EPSRC awards available for students undertaking the M.Sc. by research). The awards, available for a maximum period of three and a half years, are made on a competitive basis and are generally only awarded to students with First or Upper Second Class Honors degrees or equivalent. Full details of the terms of EPSRC studentships may be obtained from:

Engineering and Physical Sciences Research Council
Polaris House
North Star Avenue
Swindon SN2 1ET
United Kingdom

or from the EPSRC website `http://www.epsrc.ac.uk`.

These studentships are awarded competitively, that is to say to the best qualified students. Preference may be given to candidates who are taking up projects in certain 'earmarked areas' or changing university. In the recent past, candidates with first-class degrees and some good upper seconds have been awarded studentships.

The school should also have some studentships available for students from **UK** and particularly **EU** countries. These awards will typically cover fees and a maintanence allowance at the same level as the EPSRC (DTA)-studentships mentioned above. Information and deadlines about such studentships will appear at
`http://www.maths.bris.ac.uk/admin/jobs/`
and
`http://www.bris.ac.uk/studentfunding/eu.html`.

Further information is available from:

Student Funding Office
University of Bristol
Senate House (Ground floor)
Tyndall Ave
Bristol BS8 1TH
United Kingdom

Project Students

Sometimes a member of staff will have a PhD studentship for a specific project. These studentships will be available for UK and EU students. Any such studentships will be advertised at `http://www.maths.bris.ac.uk/admin/jobs/`.

CASE studentships

These are co-operative awards with an industrial partner, and so are more common in applied mathematics. They are awarded for specific topics proposed and applied for by the advisers.

Overseas Students

Overseas students should check
`http://www.bris.ac.uk/studentfunding/overseas_pg/cent_overseas_schols.html`
for news about sources of funding. Also each year the school may have some funded studentships that overseas students can apply for. Details of such studentships will appear on
`http://www.maths.bris.ac.uk/admin/jobs/`
A leaflet listing possible sources of funding for overseas students is available from:

Student Funding Office
University of Bristol
Senate House (Ground floor)
Tyndall Ave
Bristol BS8 1TH
United Kingdom

Tutorial, problem classes & marking work

Postgraduates usually have an opportunity to supplement their income by giving tutorials and marking undergraduate work. This supplement can often be quite significant. The hourly rate for this work is usually £13.79 and for tutorials this will include preparation time. Students are **not normally permitted** to give more than 6 hours of tutorials per week. Typically students have been earning in the range of £1600 to £1700 per year tax-free (these amounts are not guaranteed, but are typical of what students have been earning in the year 2008).

11 Enquiries and Application Procedures

Application Procedure

If you are interested in pursuing your postgraduate study in the school you should complete an online application, see
`http://www.bristol.ac.uk/prospectus/postgraduate/2014/apply/`.
Please include in the application the full list of courses and marks from your university, English language certificates for overseas students, two references and the areas of research you are interested in. These documents can be uploaded on the website. Letters of reference can also be sent directly by the reference writers. PhD applicants should already have, or expect to be awarded, a first or upper second class degree in a relevant subject. Submitting an application is in no way a commitment to accepting a place.

When the application has been received, UK applicants will be invited to visit Bristol to meet relevant staff. Reasonable travel expenses will be reimbursed. For overseas applicants we will often conduct interviews by phone or skype. Most decisions about funding are made between February and April, but for UK applicants there is also a possibility to make early offers to outstanding applicants who apply earlier.

Once a student accepts an offer, admission is handled by the Faculty of Science. Evidence must be provided of financial support for fees and subsistence. For most UK students this is satisfied by the award of a studentship

For all other inquiries, please contact:

Dr. Thomas Jordan
School of Mathematics
University Walk
University of Bristol
Bristol BS8 1TW
UK

Telephone: 0117 331 5246
email: thomas.jordan@bris.ac.uk

The fees for full-time postgraduate PhD students can be found at
`http://www.bristol.ac.uk/academicregistry/fees`.

Overseas students whose native language is not English are required to give evidence of their fluency in English. There are various ways in which this may be done, e.g. in many countries there are offices of the British Council where a test such as the IELTS may be taken leading to a report for the University. The University's normal requirements are outlined at
`http://www.bristol.ac.uk/study/postgraduate/language-requirements/`

12 Closing Dates

There is no fixed closing date for application for M.Sc. or Ph.D. study. However, we strongly urge prospective candidates to apply as early as possible (preferably before **April**) to facilitate the admissions procedure and tenable decisions to be made speedily.

Overseas students should check the webpage
`http://www.bris.ac.uk/studentfunding/overseas_pg/`
for news about sources of funding and deadlines. EU students wishing to apply for funding should check
`http://www.bristol.ac.uk/studentfunding/eu.html`