Short Course on Mathematical Aspects of Fluid Dynamics

Many aspects of the theory of fluid dynamics have influenced mathematicians and the direction of mathematical research. In the last few decades, it has been a source for numerous problems in nonlinear partial differential equations (PDE), spectral theory, and dynamical systems. As well, it has been a motivating influence on infinite dimensional Lie theory and in classical algebraic geometry over infinite genus objects. In our short course (October 22–30), we presented a sequence of accessible lectures on these topics. The speakers were Walter Craig (McMaster), Constantine Dafermos (Brown), Boris Khesin (Toronto) and Micha Vishik (Texas–Austin). The lectures were very successful and well attended.

Dafermos spoke on recent advances in hyperbolic conservations laws, which are nonlinear hyperbolic PDE which arise in physical settings from (generally nonlinear) density/flux pairs. Starting from a very basic hypothesis on the form that a density and flux could have, he concluded with a structural theorem on the form that all conservation laws must take. Dafermos’s second lecture addressed more analytic aspects of conservation laws posed in one space dimension, including their existence, uniqueness and long time asymptotic behaviour. The core problems are still open, but recent developments have led to progress that may well revolutionize the field.

Khesin spoke on the geometry and topology of Euler hydrodynamics and the KdV equation. He addressed the Euler equations of hydrodynamics as a geodesic flow on the infinite dimensional manifold of smooth volume preserving diffeomorphisms. This manifold is a Lie group, and Khesin went on to describe the analogous construction in other settings. These include the Euler top, Burger’s equation, and the KdV equations, as well as Euler’s equations of incompressible inviscid fluid dynamics. He finished with a discussion of the possible topological classification of the steady states for Euler flow. Khesin’s second lecture discussed the way in which the Virasoro algebra appears as the Lie algebra of the group underlying a number of the examples from the first lecture, and how this is related to the fact that the resulting systems are completely integrable. The KdV and Camassa-Holm equations are principal examples of this phenomenon.

Vishik spoke on mathematical questions of linear and nonlinear stability for the Euler equations posed in two dimensions, and the analogous and much more difficult problem in three or more dimensions. One of the issues of this hydrodynamical spectral problem is the lack of self-adjointness in the linearized problem. In two dimensions Vishik gave a complete proof that the Lyapunov index of the underlying fluid flow and the essential spectral radius coincide. Vishik’s
second lecture addressed the construction of approximate
eigenfunctions and their smoothness, and gave details of his
theorem of nonlinear instability in two-dimensional flows under
certain hypotheses. Principal examples of such flows are the
doubly-periodic Beltrami flows and Kolmogorov flows.

Craig’s first lecture gave a presentation of a recent paper
by D. Cordoba, C. Fefferman, and R. de la Llave on squirt
singularities for incompressible flows. These situations include
a number of scenarios for singularity formation that have been
proposed in the physics literature. One main result is that this
scenario implies an integral estimate of the sup norm of the
velocity up to the time of the singularity. The second main
result is that this estimate is violated in many reasonable settings,
including the Navier-Stokes equations for fluid dynamics.
The conclusion is that such flows cannot therefore exhibit squirt
singularities. Craig’s second two lectures addressed his own
work on surface water waves.

The topics were: (i) the \textit{a priori} regularity of steady
travelling water waves, and, in fact, of solutions of a general class
of free boundary problems with Neumann boundary conditions;
(ii) an existence theorem for travelling free surface water waves
in dimension 3 (and higher) when surface tension is present.
In the absence of surface tension, this is still an open problem.

\textbf{Walter Craig (McMaster and Fields)}

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**Workshop on Resonances in Linear and Nonlinear Schrödinger Equations**

A SATELLITE OF THE THEMATIC
PROGRAM on nonlinear PDEs, the
August 22 one-day workshop focused on
asymptotic stability, parametric resonance,
and decay of bound states in linear and
nonlinear Schrödinger equations. In
an informal setting, some of the leading
experts in these areas talked about their
recent developments and results.

Michael Weinstein (Bell Labs) gave
an overview of resonance problems
for dispersive wave equations, focusing
on parametric decay of excited states
in nonlinear Schrödinger equations.
Eduard Kirr (Chicago) talked on parametric
resonances in linear systems with periodic,
 quasi-periodic, and random forces. Alex
Tovbis (Central Florida) covered embedded
solitons occurring due to nonlinear
resonances in singularly perturbed nonlinear
equations. Peter Miller (Michigan) presented
a review of multi-component bound states
in integrable nonlinear equations. Dmitry
Pelinovsky (McMaster) discussed analysis
and modelling of dispersion-managed
solitons and their resonance-induced
nonlinear decay. Scipio Cuccagna (Virginia)
and Vitali Vougalter (McMaster) spoke on
spectral theory for linearized operators
associated with the nonlinear Schrödinger
equation in three dimensions, in particular,
on resonances, embedded eigenvalues, and
eigenvalues of the negative energy.

The workshop accompanied the
two-week research-in-team program
titled Rigorous Analysis of Parametric
Resonance in Dispersion-periodic NLS
Equations. The collaborations of the
researchers aimed to develop rigorous
estimates on the bound terms in analysis
of nonlinear parametric resonance of
dispersion-managed solitons.

Dispersion-managed solitons are
special solutions of the dispersion-periodic
nonlinear Schrödinger equation, which
model optical pulses in dispersion-managed
fiber communications. Such special
solutions do not actually exist, as the
parametric resonance couples the bound
states and the radiative waves and results
in energy transfer from the bound states to
the continuous spectrum and subsequently
to radiative damping of the bound states.
The research team followed recent papers
of Kirr and Weinstein and of Soffer and
Weinstein and applied similar ideas to
analysis of parametric resonance in the
dispersion-periodic nonlinear Schrödinger
equation. The Fields Institute provided
an excellent venue for presentations,
discussions, and collaborative activities,
which enabled the group to successfully
complete the project and to start working
on preparation of a new manuscript.

The workshop was supported by the
Fields Institute and the McMaster University
Program in Mathematical Sciences.

\textbf{Dmitry Pelinovsky (McMaster)}

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The Fields Institute for Research in Mathematical
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a year (September, January, and May).

\begin{itemize}
  \item **Director:** Kenneth R. Davidson
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In his lectures, Evans defined three variational problems which had a common structure but different interpretations in their limits. Their solutions all consisted in finding a minimizer of a functional depending on a parameter $k$, and then asking the question of what happens to this minimizer as $k \to \infty$. In all cases, the limiting function solved a transport equation (which was the limit of the Euler-Lagrange equation associated with each problem), coupled to a Hamilton-Jacobi equation imposing some constraint on the gradient of the solution. The lectures illustrated how to take advantage of this universality in order to obtain estimates on the limiting functions by means of standard methods in the analysis of partial differential equations. Evans also pointed out interesting open questions related to each of the three variational problems.

The first lecture, Introduction, Optimal Mass Transfer, presented the main issues and then focused on the first singular problem, whose interpretation in the limit as $k \to \infty$ was that of Monge-Kantorovich optimal mass transfer. It is a generalization of the initial problem of Gaspard Monge (1746–1818), described in Mémoire sur la théorie des déblais et des remblais, Hist. Acad. R. Sci. Paris 666–704 (1781), which consists in finding the best way to move a pile of soil from one location to another, so as to minimize the amount of work or equivalently the total distance by which “particles” of soil are moved. Another application concerned the dynamics of sand pile models. The second lecture, Weak KAM Theory for Dynamics, related a singular variational problem to Mather’s minimization problem, which consists in finding a measure that minimizes a generalized action, subject to some constraints. Indeed, the Hamilton-Jacobi equation obtained in the limit was the generalized eikonal equation defining the effective Hamiltonian of Fathi’s weak KAM theory, and a measure solving Mather’s problem could be obtained as the limit of a sequence of probability measures $\mu_k$, defined from the minimizers at each $k$. One of Evans’s current research interests is to push this unifying point of view further in order to obtain a quantum analog of the weak KAM theory.

The final lecture was entitled Calculus of Variations in the max Norm and showed that the limiting minimizer defined in the third variational problem was an absolutely minimizing Lipschitz extension, as defined by Aronson’s variational principle, and was also the unique viscosity solution for the infinity-Laplace equation with Dirichlet boundary conditions. The rest of the lecture focused on discussing this last partial differential equation.

Craig Evans’s lectures were part of the 2003–2004 thematic program on Partial Differential Equations. The topics of his lectures combined nicely with the other activities of the thematic program, which in the fall of 2003 focused on elliptic and parabolic differential equations. Audio and slides of Craig Evans’s lectures are available online at www.fields.utoronto.ca/audio/#coxeter_lectures. Selected papers by Evans may be downloaded from his web site at math.berkeley.edu/~evans.

Joceline Lega (Fields and University of Arizona)
Workshop in the Calculus of Variations: Geometric Problems, Superconductivity, and Material Microstructures

THE CALCULUS OF VARIATIONS is the traditional meeting point of geometry and physics. Several exciting avenues of research today continue this tradition: geometrical ideas are used to understand basic physical phenomena; physical insights motivate fundamental advances in differential equations; nonlinear partial differential equations pervade both fields.

The workshop (August 25–29), co-organized by L. Bronsard (McMaster), R. Jerrard (Toronto), and R. McCann (Toronto), celebrated the subject by bringing together many of its leading experts, who presented their latest results on a variety of topics. One of the central themes of the workshop was the Ginzburg-Landau model for superconductivity. Landau’s theory of second order phase transitions laid the foundation for what is commonly called the Ginzburg-Landau functional, the minimization of which leads to a well-established macroscopic theory for type-II superconductivity. Its Euler-Lagrange equations or related gradient flow equations are commonly referred to as the Ginzburg-Landau equations, and their solutions typically possess many of the fascinating vortex structures observed in type-II superconductors.

A second major theme of the workshop was multiscale analysis of material microstructures. In today’s focus on the “nano” world, the morphology of these microstructures is a subject with important and timely applications. An interesting aspect of some of the talks was the unexpected use of tools from hyperbolic PDE in studying stationary problems. An important problem in material microstructures stems from the study of grain boundaries and their evolution. D. Kinderlehrer (Carnegie-Mellon) presented a lively and illuminating talk on a mesoscale view of grain growth and discussed recent simulations at the mesoscale level, the answers they provide, and the rich collection of problems that they unveil. Another central theme within this subject—Kinderlehrer was one of its pioneers—is devoted to the study of microstructures in certain solid-solid phase transitions, and the relation to variational integrals which fail to be weakly lower semicontinuous.

There were many fascinating talks on other areas of analysis related to the calculus of variations, for example, nonlinear Maxwell equations in relativity, dynamic scaling in Smoluchowski’s coagulation equation, and variational models for dissipative evolution equations or for quantum chemistry.

There were also several shorter talks by young researchers covering the entire spectrum of topics in the calculus of variations and PDE.

The workshop on the calculus of variations was part of the ongoing 2003–2004 thematic year in Partial Differential Equations at the Fields Institute. The organizers were delighted by the terrific turn-out of bright and inquisitive mathematicians at all stages of their careers, and for the outstanding support they received from the Fields Institute staff. We are particularly grateful to Alexa Brand and Alison Conway for all their work.

Stan Alama (McMaster) and Rustum Choksi (Simon Fraser and Fields)
Workshop on Patterns in Physics

IN MID-NOVEMBER THE FIELDS INSTITUTE HELD a five-day workshop entitled “Patterns in Physics.” This was one of the signature workshops that are part of the current year-long thematic program on Partial Differential Equations. Pattern formation in physical systems played a central role in the development of Nonlinear Dynamics in the last century. Modern developments in the analysis of PDEs have been strongly influenced by the theoretical needs that accompanied scientific advances in the experimental investigation of pattern forming systems. This continues to be true in the present era of remarkable technological discoveries which enable one to observe spatial pattern structures on many scales as well as across diverse disciplines.

The November workshop focused on five areas where there are emerging PDE models of pattern formation that appear ripe for mathematical analysis: Rayleigh-Bénard convection; wave patterns; reaction-diffusion systems; biological pattern formation including neural models; and models of coarsening, defect formation, and interface evolution in materials and thin films. The workshop included a number of experimental demonstrations in the lectures as well as in the lab of Steven Morris of the Physics Department at the University of Toronto.

There were approximately forty speakers at this meeting, representing a wide range of interests from analysis, applied mathematics, theoretical and experimental physics, and biology. Thanks to NSF support from a co-operative grant with the University of Arizona (Principle Investigator, Joceline Lega) more than half of these were junior mathematicians (graduate students, postdocs or pre-tenure faculty). There was a high level of attendance throughout the workshop, confirming the new level of mathematical interest in pattern formation. The organizers were very pleased that the next generation of researchers in this fascinating area was so well represented among the participants.

Nicholas Ercolani (University of Arizona)

Canadian researchers were in the forefront of research in queueing theory in the late 1960s and 1970s. To recognize their achievements, there was also a feature presentation by M. Mandelbaum on the history of queueing in Canada. A survey article is being written on this topic by M. Hlynka and M. Mandelbaum.

Raj Srinivasan (Saskatchewan)
Statistical and Modelling Challenges in Genomics

THE FIELDS OF GENETICS AND MOLECULAR BIOLOGY are undergoing an unprecedented revolution triggered by the mapping of genomes of various organisms—including human—which has put emphasis on high-throughput, automated genetic experiments. The high-throughput techniques were developed to gain faster understanding of the roles of various pieces of molecular machinery and thus were born DNA chips (or micro arrays), SNP (single nucleotide polymorphism) arrays, and proteome chips. If sequencing the genome is aimed at answering the questions “What?” and “Where?” a large part of modern genomics—functional genomics—addresses the important questions of “Why?” and “How?”

Modern functional genomics utilizes biochips and other high-throughput modalities in ever larger experiments generating huge quantities of data. This data can be enormously varied depending on the modality and technology used or on the nature of the experiment carried out. Such data present a unique set of mathematical and statistical challenges that are common across high-throughput genomic modalities. Sometimes these strike at the heart of classical statistical thinking and force us to re-examine our long-held beliefs.

Thus, the field of statistical genomics has emerged, a field in which molecular biologists, geneticists, and bioinformaticians can address challenges such as the following: very large problem dimensionality compared to the number of observations available, small signal to noise ratios, many uncontrollable sources of variability, multistage approach to data generation and preparation, unique experimental design issues, vast quantities of raw data, including auxiliary data available in a multitude of publicly held databases. Problem solvers in statistical genomics require a wide array of skills: solid mathematics, theoretical and applied statistics, computational algorithms design, optimization theory. What they need most, however, are an open mind and the ability to carry out research in a highly diverse and multidisciplinary setting.

In early September, the Fields Institute hosted a three-day event: the First Canadian Workshop on Statistical Genomics, organized and chaired by Rafal Kustra, a biostatistician in the Public Health Sciences Department at the University of Toronto. This was the first conference at Fields of the new National Program on Complex Data Systems (NPCDS). One of the goals of the workshop was to expose relevant and important challenges that remain unsolved in the modelling of high-throughput genomic experiments and data, such as those obtained from DNA microarray, protein mass-spectrometry, or SNP-chip experiments. In hindsight, it seems that this goal was not hard to achieve: the problems and challenges, both applied and theoretical, facing statisticians working with modern genomic data, are numerous and complex and, at the same time, highly relevant and exciting.

The workshop was designed to encourage the maximum amount of interaction, participation, and spontaneous discussion—and there was no shortage of these. Although Kustra and the four session leaders are all statisticians, the participants also included mathematicians, computer scientists, molecular biologists, biochemists, and researchers involved in clinical settings. And while many presentations required a moderately high mathematical maturity, speakers were asked to provide enough non-mathematical clues to make the talks accessible and useful to less mathematically-inclined people in the audience. Judging by the questions after the talks and numerous “hallway discussions,” this seemed to have worked well.

The workshop spanned the spectrum of statistical genomics—from sessions on dimension reduction techniques, experimental design, phylogenetics, and clinical applications to one on computational and visualization challenges. Each morning featured a keynote speaker, beginning with a presentation from Rob Tibshirani (Stanford), one of the best-known applied statisticians today. He was involved in statistical genomics long before it became
Computational Neuroscientists of Upper Canada (CNUC):
Computational Approaches to Vision

THE FIRST CNUC MEETING OF 2003–04 was held on Tuesday, October 28, in the James Stewart Library of the Fields Institute on the topic Computational Approaches to Vision. James Elder (York) started the meeting by discussing complex algorithms for processing edges and contours in images using approaches including multi-scale edge detectors and Markov chains. He showed that these approaches, which are closely related to early cortical processing in human vision, could effectively segment images into regions of interest such as outlined faces and hands of subjects.

Niko Troje, who recently moved to Queen's University from Germany and holds a CRC chair, next focused on the perception of biological motion. By extracting only the motion of key joints (elbows, shoulders, hips, knees, etc.) from videos of walkers, he was able to analyse the perceptual information intrinsic to walking style. Perceptual studies based on a principal component analysis of walking show that observers can reliably determine the sex of walkers from their gaits and can also estimate the relative weight and even the mood of the walker. Troje's demonstration of these effects proved fascinating to the overflow audience.

After a break for a pizza lunch and discussion, the afternoon session was begun by David Fleet (Computer Science, Toronto). His talk combined aspects of the morning's topics, as he focused on computer algorithms to track heads as people walked through an environment. The model incorporated a probabilistic learning routine that estimated key features of the particular head that were relatively invariant to the motion. Competition among three underlying probabilistic models allowed the algorithm to tolerate partial occlusion, rotation of the head, and other sophisticated transformations.

Finally, the meeting organizer Hugh Wilson (York) shifted gears to talk about cortically induced hallucinations in migraine auras. These auras typically consist of flashing lines that move slowly from central into peripheral vision over the course of about twenty minutes. To model auras, Wilson introduced nonlinear differential equations that provide a simplified but accurate description of electrical activity in cortical nerve cells. Networks of these neurons were shown to capture the major features of auras...

Rafal Kustra (Public Health Sciences, Toronto)

known as such. In his talk, he described a new modelling approach to the mass-spectrometry of proteins—an emerging technology that seems to work better than proteome chips at measuring activities of tens of thousands of proteins simultaneously. Day two opened with a keynote address by Brent Zanke, Vice-President, Ontario Cancer Research Network and a director of Tumour Bank. The latter is an initiative of the Ontario government to collect tens of thousands of tumour samples together with clinical information, which eventually will be systematically investigated by high-throughput genomics to advance our understanding of cancer, and ultimately result in more effective and tailored treatment regimens. Zanke’s message was simple: the success of the revolution spawned by modern genomics rests in the hands of data scientists.

If one of the scientific goals was to expose statistical and modelling challenges in high-throughput genomics, the overall objective was to spur collaboration among researchers involved with modelling and analysing experimental data and scientists who utilize modern genomic techniques in their endeavours. There is a crucial need in Canada for co-ordinated research efforts to develop and evaluate statistical and mathematical models in order to deal with such data, and this challenge can only be achieved when enthusiastic researchers on both sides—experimental and modelling—make efforts to work together and understand each other. There is also a crucial need in this country to train highly qualified researchers to be able to work on the interface of biology and statistical or mathematical modelling. It is yet too early to judge the success of the workshop on this front, but there currently are some promising initiatives under way that aim to address the need for productive and collaborative effort.

Hugh Wilson (York)
Workshop on Adaptive Designs

THE SEPTEMBER WEEKEND WORKSHOP ON ADAPTIVE Designs was kicked off with an overview of the field given by Nancy Flournoy (Missouri), who described its diversity. She distinguished adaptive designs from conventional experimental design, focusing on the key distinction that with adaptive designs the chance that a subject (group) will get a particular treatment changes as information accrues in the study. This radically changes the underlying mathematical formulation of these designs from combinatorics to stochastic processes. She also reported that sequential analysis research involving early stopping rules was now also being called adaptive designs, creating a lot of confusion.

Research interest in adaptive designs is exploding now owing to theoretical advances in stochastic processes and to computational advances such as in capabilities for multiple integration. Interest in applications is growing fast too, particularly in toxicology and pharmaceuticals.

Talks fell into five categories: 1) adapting to balance subject allocation between treatment groups; 2) two-stage designs; 3) Bayesian designs; 4) optimal designs and approximations to them; 5) ad hoc designs (up and down designs for toxicity assessment and phase 1 clinical trials, up and down designs for phase 1–2 trials, and urn designs). In categories 1 and 2, adaptation is based on treatment allocation information only. Categories 3 and 4 involve “response-driven adaptive designs,” in which adaptation is based on outcome data as well as treatment allocation information. In category 5, the big issues of estimation and inference were the focus of two talks, while the big issues of efficiency and power were the subjects of four talks.

The field of adaptive designs was well represented by the spectrum of presentations. Major future thrusts were identified. Possibly the most significant outcome of the workshop lies in the future and derives from bringing together promising young researchers interested in adaptive designs. On behalf of the other organizers, N. Balakrishnan (McMaster) and Sri Gopal Mohanty (McMaster), I would like to express our thanks to the Fields Institute for making the workshop possible.

Nancy Flournoy (Missouri)

Midwest Model Theory Meeting

FOR OVER TWENTY YEARS NOW, MODEL THEORISTS in the centre of North America have met once a year for a weekend to discuss the latest results, talk informally, and meet the new crop of postdoctoral fellows and graduate students. Traditionally this meeting has attracted participants from the major centres in the Midwestern U.S.—Urbana, Chicago, Notre Dame, Madison, Columbus, Ann Arbor—as well as further afield, including, increasingly, Canada. For the first time, the meeting moved north of the border: the model theory group at McMaster hosted the Midwest Model Theory Meeting at the Fields Institute, Nov. 8–9, 2003.

An exciting pair of talks given by Rahim Moosa (MIT) and Kobi Peterzil (Haifa) opened and closed the meeting. Moosa spoke on the ongoing efforts to introduce the analogue of jet spaces from algebraic geometry and complex analytic geometry into the category of differential varieties. This was done successfully by Pillay and Ziegler for one derivation, and Moosa discussed extensions to several derivations. This work sits at one end of the spectrum of modern model theory. In his closing talk, Peterzil spoke about the development of K-analytic geometry and K-manifolds where K is the algebraic closure of a real closed field. Much of complex analytic geometry goes through in this context using the machinery of o-minimality, a subject which is usually thought of as the other pole in modern model theory. Both talks provided methods of attack on questions about compact complex manifolds, and questions arising from them spilled over into lunch, tea-time, and one hopes, beyond.

The Lefshetz principle deals with the transfer of information from of characteristic p to characteristic 0. Matthias Aschenbrenner (Illinois–Chicago) discussed an interesting sufficient condition for a local ring to embed well into an ultraproduct of rings of non-zero characteristic—the latter being one of the ways that model theorists think of the Lefshetz principle. Yoav Yaffe (McMaster) gave a whirlwind tour of the model theory and geometry underlying Lie differential fields including a version of Hensel’s lemma that takes into consideration both the valuation and the derivation. Matt Valeriote (McMaster) discussed the current state of the art in understanding the number of finitely generated algebras in an equational class. Extremely strong structural results can be obtained if the number of n-generated algebras is bounded by a polynomial in n. James Tyne (Ohio State) discussed an effort to formulate a version of the important Wilkie inequality in o-minimal theories which are not polynomially bounded.

One indication of the times we live in was that the number of graduate students present at this meeting was low by historical standards. The Fields Institute had generously offered money for graduate students to attend, but the formalities foreign graduate students face in obtaining visas for entry into Canada and for re-entry to the U.S. were an obstacle to an excellent opportunity for graduate students and postdocs to show their stuff.

Bradd Hart (McMaster)
Ian F. Blake (Toronto) spoke about the use of one-way functions in cryptography, for example, in the RSA encryption scheme. Particular emphasis was placed on the discrete logarithm problem (DLOG), which for given integers $y$, $a$, and $p$ amounts to finding an integer $x$ such that the $x$th power of $a$ is congruent to $y$ mod $p$. The best-known complexity bound for this problem is sub-exponential, though not polynomial, which is the basis for the use of DLOG in key exchange.

Blake gave generalizations of DLOG to elliptic curves, rather than in the cyclic group as above. In that context, one is interested in counting the number of points in the group of integers. He described some of his work in the area, as well as the strong contribution of other Canadian groups. More generally, one can look at hyperelliptic curves, in which the arithmetic and counting of points is much harder, and at applications to smart cards and to secure multiparty communication. One concrete application of the elliptic curve methods was mentioned—the recent sale of a product based on these algorithms to NSA for $25$ million.

Keith J. Worsley (McGill) described some of the statistical techniques his group has been working on, and their application to the identification of clusters of galaxies, and to signal detection in functional MRI brain imaging. The basic problem is that one observes a multidimensional image (or random field). One wants to know whether its geometric features are significant, or are simply artifacts of random noise.

Imagine that one observes a random function of several variables as a signal. The approach taken by Worsley and his co-authors is to look at the level set of the signal being observed, that is, the set where this signal coincides with a given threshold. For what values of the threshold will this level set indicate the location of a significant effect? They perform a statistical test based on the Euler characteristic of the level set. For example, the mean Euler characteristic can actually be computed for certain models, which establishes a basis for comparison. One can then go on to examine other geometric properties. For example, in a certain chi-square random field, the zero set appears to be a collection of loops, and one can ask whether these are knotted or not.

J. Ian Munro (Waterloo) addressed the question how can you encode a very large tree or other combinatorial object in a small space and still perform queries quickly? Computer science is “arbophilic,” that is, it loves trees. Just witness directory hierarchies, B-trees, graphs, etc. that occur in computer code structures. A typical application searches for a text string in a large text file that may, for example, represent a DNA molecule.

Various well-known methods for representing a tree include balanced strings of parentheses and the heap notation. Munro explored various strategies for searching a tree. Often this involved blocking the tree into segments first. The so-called “big step–little step” algorithm, for example, basically moves one along in large steps until one has passed the desired location, and backtracks with small steps.

Munro explored in more detail the way in which one can compute efficiently with permutations. Then he discussed how to extend these ideas to functions which are not bijections. The conclusion was that it is possible to encode combinatorial objects along with certain key information computed ahead of time so that queries can be done efficiently.

Henri Darmon (McGill) began his talk with an overview of certain approaches to Pell’s equation, which is now understood as the group of units of a quadratic number ring. Yet some solutions were known in tenth-century India. Fermat described the group precisely, and provided an algorithm based on continued fractions to construct a generator. The corresponding complex variety can be parametrized by an exponential map defined in terms of hyperbolic trig functions. Curiously counting solutions modulo $p$ leads to an interesting power series; and Dirichlet discovered the rather surprising fact that if you plug a rational value into this series, and then apply the exponential map, the result is always algebraic.

Then he considered rational solutions on an elliptic curve. This set of solutions is also an abelian group, but the structure is not completely understood. Finding an algorithm for the rank and a basis of fundamental solutions is equivalent to the million dollar conjecture of Birch and Swinerton-Dyer. The set of complex solutions is parametrized using the Weierstrass $P$ function and its derivative. Again one counts solutions modulo $p$ and constructs a power series. It again turns out that applying this to certain algebraic numbers and mapping it onto the curve always yields algebraic values. The proof relies on the famous work of Wiles on the Shimura-Taniyama conjecture and Fermat’s last theorem.
Is Mathematics Made in Heaven?
Or Is It Just a Language Game?

THE ROYAL CANADIAN INSTITUTE, an organization in Toronto that has been around for over a century, offers a series of public lectures on science Sunday afternoons in the fall and winter. Since last year, Fields has provided a mathematics talk for each session. This fall there was a two-person talk. Leading off was Chandler Davis, a well-known mathematician and editor-in-chief of the Mathematical Intelligencer. He was followed by philosopher Ian Hacking, a University Professor at Toronto and simultaneously a professor at the Collège de France.

Davis led off the discussion by arguing that mathematicians have great certainty about many things even though these cannot be related to physical objects. He gave several examples, of increasing complexity, of mathematical facts that he considered to be evidently correct to any discerning intelligence. For him, this meant that mathematical truths are inherent to our universe, and not a product of our biological or cultural backgrounds.

Hacking, on the other hand, suggested that the truth of mathematics is universal, but our notion of proof is likely a product of human biology or local culture. Certain aspects of our understanding of proof could be hard-wired, based on evolution going back one hundred thousand years. He pointed to two historical modes of proof, the geometric approach of the Greeks and the algebraic tradition of the Arabic world. While both are used today, he argued that the type of argument we accept may not be universal but may depend on the accident of which version of proof emerges in which culture. Hence, he dismissed the idea that mathematics is just a language game because mathematics is not purely linguistic.

In the discussion during question period, Davis argued that mathematics is definitely linguistic. Mathematical ideas are communicated through language. Hacking, while acknowledging that communicating ideas through language is important, felt that mathematical insights can come without expression in language.

If we are typical, the audience would have liked to see more debate at the end, and indeed would have been happy to join in. Unfortunately, time constraints brought the discussion to a close.

Kenneth Davidson (Director, Fields) and Philip Siller (Deputy Chair, Fields)

CRM–
Fields Prize
Lecture

Ed Perkins

THE WINNERS OF THE 2003 CRM–Fields prize were John McKay (Concordia) and Ed Perkins (UBC). Both were scheduled to present lectures on November 5, 2003, but unforeseen circumstances forced McKay to postpone his talk. It will be rescheduled later in the year.

Ed Perkins first spoke about Brownian motion and its universality properties as a scaling limit of random walks. The microscopic properties of the random walks in question disappear in the limit, to be captured by a single parameter of the Brownian motion, namely its covariance matrix.

He then passed to his main topic, namely super Brownian motion (SBM) —a measure valued (and hence infinite dimensional) analogue of Brownian motion. Again, SBM has universality properties as a limit of discrete models. Again, the microscopic details of the discrete models disappear in the limit, being absorbed into a small number of parameters for the SBM, such as its branching, growth, and diffusion rates. He described the history of the model, from its invention by Watanabe, through the many contributions of researchers such as Dawson, LeGall, Perkins, and Dynkin, to recent work by Mselati applied to nonlinear PDEs.

Much of the talk discussed apparently unrelated models that actually belong to the same universality class, and thus have SBM as a limiting object. These include the voter model, in the theory of interacting particle systems. Here, one can realize the voter model in terms of random births and deaths, and the issue is to show that the birth and death rates are asymptotically deterministic. This approach recently led to a shape theorem for the voter model. Likewise, he showed the connection to SBM from the contact process, from models of lattice trees, from the Fleming Viot model (the connection to SBM being through conditioning on the population size staying constant), to stochastic partial differential equations.

An apparently simple situation should be the case where the state space for SBM is finite, so that SBM becomes a finite-dimensional diffusion. Even in that case there are difficult problems that arise, due to the boundary conditions for the resulting degenerate stochastic differential equations. In fact, he was able to close his fascinating talk with a natural open problem in this area.

Tom Salisbury (Fields)
Lectures on Mathematics in Biotechnology: Exploding Data and Design Challenges

SIAM HELD A REGIONAL MEETING in Toronto October 13–15 on Mathematics for Industry: Challenges and Frontiers. Originally scheduled for last June, the meeting was postponed because of SARS. As a satellite event, Fields sponsored an evening talk October 14 on Mathematics in Biotechnology.

There were two speakers: Elisabeth Tillier is a computational biologist working for the Ontario Cancer Institute, which is a part of the University of Toronto Health Network; and Daniel Kobler is a mathematician, trained as a graph theorist, who works at TM Bioscience, a biotech company which manufactures micro arrays.

Elisabeth started off with a graph showing rapid exponential growth of data stored in GenBank, the world depository of genome sequence data. Most of her talk was a primer on genome analysis. Even a small organism such as the SARS virus has about thirty thousand base pairs in the DNA. A bacteria has four million.

The data on the DNA sequence of a dog takes 2.4 gigabytes. So comparing DNA from two organisms can be tricky, especially considering that 1 to 2 per cent of these pairs are recorded incorrectly. Nevertheless, biologists are able to detect homologous groups (long sequences almost matched) to correlate between species and to identify key changes within populations.

She concluded her talk by pointing to the future in systems biology and the goal to combine all the diverse data on the DNA of an organism to determine protein-protein interactions between all gene pairs, describe gene functions, and in total arrive at a complete description of the cell from a genetic standpoint.

Dan started his talk by passing around two commercially available micro arrays, which are microscopic ordered arrays of nucleic acids, proteins, and small molecules that enable the parallel analysis of complex biochemicals. Usually they consist of DNA fragments. This technology had its roots in 1975 when it was shown how to detect a DNA fragment in a sample because it was then possible to synthesize a high density sample of specific DNA pieces. The applications to disease diagnosis, gene detection, and drug development are now well known.

Dan went through the various stages of a typical micro array experiment, from planning to data analysis, and pointed out a half-dozen places where mathematicians, statisticians, and computer scientists are important and even crucial. He concluded by noting that micro arrays are essential tools in today’s biotechnology. Many mathematical challenges remain—experimental design, data analysis, and optimization techniques lead the list. There is a great need for cross-disciplinary work between biologists, engineers, computer scientists, and mathematicians.

Kenneth Davidson (Fields)
A THREE-DAY WORKSHOP WAS HELD IN OCTOBER at the University of Ottawa on Concentration Phenomenon, Transformation Groups, and Ramsey Theory, an area that lies at the crossroads of geometric functional analysis, infinite combinatorics, and topological dynamical systems. This theory offers a new insight into the geometry and dynamical properties of those dynamical systems where either the acting group or the phase space (or both) are infinite-dimensional. Here, one obtains strong nonlinear fixed-point theorems which, in turn, can often be reformulated as Ramsey-type results for structures found in a great many parts of mathematics. The scope of possibilities is remarkable: from operator algebras, ergodic theory, and topological dynamics to combinatorics and model theory.

A remarkable and most mysterious thing is that the dynamical property of groups (the so-called fixed point on compacta property, or extreme amenability) turns out to be closely linked, on one hand, with high-dimensional geometry (phenomenon of concentration of measure) and on the other hand, to structural Ramsey theory.

On the first day, Slawomir Solecki (Illinois–Urbana Champaign) gave an overview of Polish groups and their actions, and connection to Borel complexity. Stanislaw Szarek (Case Western Reserve and Paris VI) discussed the concentration of measure on high-dimensional structures, with applications to ensembles of random matrices. Vladimir Pestov (Ottawa) spoke of uniform structures on topological groups, introducing the fixed point on compacta property and the distortion property in the language of infinite-dimensional groups.

Day two opened with Vitali Milman (Tel Aviv), who spoke on asymptotic geometric analysis (phenomena arising in high dimensions). Vladimir Uspenskij (Ohio) described the universal Urysohn metric space, its group of isometries, and other closely related infinite dimensional groups such as the group of homeomorphisms of the Hilbert cube. Eli Glasner (Tel Aviv) spoke about universal minimal flows, especially those of infinite-dimensional groups, where they can sometimes be computed explicitly, unlike the “classical” case of locally compact groups. Thierry Giordano (Ottawa) surveyed measure-preserving transformation groups and unitary groups of von Neumann algebras, and described the way in which the concentration phenomenon can be used to establish the fixed point on compacta property.

On the third day, Benji Weiss (Hebrew University, Jerusalem) spoke of genericity in groups of measure-preserving transformations and homeomorphisms of various spaces, especially spheres. Anatoly Vershik (Steklov Institute) gave an account of randomness versus universality in the category of separable metric spaces, particularly his treatment of Gromov’s metric triples. Stevo Todorcevic (Toronto and Paris VII) introduced structural Ramsey theory and its links with the fixed point on compacta property developed in a recent joint work with Kechris and Pestov.

Overall, the workshop was a remarkably coherent event of high synergy and lots of discussion. Participants report a number of newly established research interactions, and we expect the workshop will have considerable impact on the direction of research pursued by younger attendees.

Vladimir Pestov (Ottawa)

Fall Mathematics Education Forum Meetings

THE OCTOBER MEETING FOCUSED on students at risk, with presentations by Barry Onslow (UWO) and John Mighton (Fields). Onslow spoke on the Esso Family Math Project, which focuses on economically disadvantaged primary school students and their parents. This project is based on the community rather than on the school, and involves parents and children coming together for a meal followed by an evening of mathematics activities. The goal of the project is to initiate community-based family math evenings that continue beyond the initial involvement by the Esso Family Math team.

John Mighton spoke about the JUMP program. This program, like the Esso Family Math program, is situated in schools in economically disadvantaged areas. The heart of the JUMP program lies in the belief by JUMP volunteers that all students can and should do complex mathematics. A JUMP volunteer becomes a second math teacher in the classroom and provides students with challenging math activities as well as positive reinforcement. The program has experienced a lot of success and has spread quickly among schools.

Both programs incorporate ideas that shake the foundation of existing mathematics education practices.

The November meeting focused on mathematics learning objects. A learning object may be seen as a web-based interactive activity/investigation/simulation with a narrow content focus. In school districts, the recent focus on developing full courses online appears to be on the wane, owing to cost and difficulties in reusability. Learning objects offer the potential to create a set of mathematics teaching and learning “building blocks” that may be used and reused in a variety of ways and for a variety of purposes. There were four presentations by Fields Math Forum members who are currently developing and researching mathematics learning objects, namely, Eric Muller (Brock), Geoffret Roulet (Queen’s), Margaret Sinclair (York), and George Gadadonis (Western).

George Gadadonis (Western)
Grad School Information Day at the Fields Institute

THE FIELDS INSTITUTE FOR ME was an unreachable place in the clouds. When I saw a poster on Dr. Hans Boden’s door announcing a Fields grad school information day, I was excited about going and finding out about other schools in Ontario. As I entered the building, I immediately felt warm and comfortable in this little haven for mathematicians. The people were nice; they made me feel welcome; and they let me go to the library upstairs. This is where I found the schedule of talks at the BIRS Institute and immediately included BIRS in my summer wish list. The library is my favourite place in the Fields building because it is a perfect place for studying math!

During the poster time, I had an opportunity to talk to professors from different schools and I very much appreciated the fact that most universities had representatives from both pure and applied math. It would be a very good idea if professors from other schools in Canada came too. I gained a general picture about research in different schools and about life as a grad student. It would have been nice if more graduate students had been there, as their opinions and personal experiences are valuable. I got many of my questions answered, however—on admission procedures, TA-ing, what universities expect from grad students, scholarships, etc.

There were two talks that emphasized the importance of math in our lives and gave a comprehensive introduction to two different areas of research—computer science and applied math. Both talks were very interactive and informative. For this reason, more talks would have been better, even if at the price of making them shorter. Both talks, however, were extremely motivating. The first was given by Sam Roweiss, from the Computer Science Department, University of Toronto. It was called The Mathematics of Computer Science, and described how some computer science problems really come down to mathematics, for example, the way in which Google uses linear algebra. The second speaker was Victor LeBlanc from the Department of Mathematics and Statistics of the University of Ottawa. His title was Euclidean Symmetry and the Dynamics of Spiral Waves, and he spoke about some examples of how spiral wavefronts arise in both mathematics and in applications. It made me want to rollerblade home as soon as possible and study some PDEs.

In conclusion, I would like to say that I had a great day, very informative and inspiring. Thank you so much, Fields Institute, for organizing grad school information day.

Barbara Ulitsky (Barbara is a third-year student in theoretical physics at McMaster.)

OTHER EVENTS

SINCE THE START of the academic year in July, Fields has hosted or sponsored more events than can be reported on in detail in the available space. Among these is the successful MOPTA series (McMaster Optimization conference), organized by Tamás Terlaky and his colleagues. The latest was held July 30–August 1, 2003, and the next instalment is now being planned. Also at McMaster was a workshop on Magnetic Resonance Image Reconstruction, held July 17, 2003, and organized by Christopher Anand, Noriko Yui (Queens) and James Lewis (Alberta) arranged a number of weekend workshops titled Arithmetic and Geometry of Algebraic Varieties, with special emphasis on Calabi-Yau varieties. These took place at Fields October 4–5 and November 8–9, 2003. Fields helped sponsor a number of activities at the University of Waterloo, including the seventh workshop on Elliptic Curve Cryptography (August 11–13, 2003) and the fourth annual privacy and security workshop (November 6–7, 2003). The PDE thematic program generated frequent seminars, including a workshop on Inverse Problems (October 1–4, 2003) organized by Adrian Nachman, in addition to the activites reported elsewhere in this issue. Fields also hosts a number of ongoing seminar series. This year, a weekly probability seminar and a seminar on geometry and model theory joined the existing series in string theory, and in quantum information. The Quantitative Finance Seminar met on two evenings in the fall term, with the October seminar being sponsored by PhiMac.

Tom Salisbury (Fields)
Call for Proposals, Nominations, and Applications

For detailed information on making proposals or nominations, please see the website: www.fields.utoronto.ca/proposals

General Scientific Activities
Proposals for short scientific events in the mathematical sciences are welcome any time, with a lead time of at least one year recommended. Activities supported include workshops, conferences, seminars, and summer schools. If you are considering a proposal, we recommend that you contact the Director, Ken Davidson (davidson@fields.utoronto.ca) or Deputy Director, Tom Salisbury (salt@fields.utoronto.ca).

Thematic Programs
Deadlines for letters of intent and proposals for semester or year-long programs at the Fields Institute are March 15 and August 31 each year. Organizers are advised that a lead time of several years is required, and are encouraged to submit a letter of intent prior to preparing a complete proposal. They may consult the directorate about their projects in advance to help structure their proposal.

Postdoctoral Opportunities
Applications are invited for postdoctoral fellowship positions for the 2004–2005 academic year. The thematic program on the Geometry of String Theory will take place at the Institute from August 2004 to June 2005. Qualified candidates who have recently completed a PhD in a related area of the mathematical sciences are encouraged to apply. The fellowships provide for a period of at least one year of engagement in research and participation in the activities of the Institute. They may be offered in conjunction with partner universities, through which a second year of support may be possible. One recipient will be awarded the Institute's prestigious Jerrold E. Marsden Postdoctoral Fellowship. Applicants seeking postdoctoral fellowships funded by other agencies (such as NSERC or international fellowships) are encouraged to request the Fields Institute as their proposed location of tenure, and should apply to the address below for a letter of invitation.

The deadline for postdoctoral applications for the Geometry of String Theory was January 6, 2004, although late applications may be considered.

CRM-Fields Prize
The Centre de recherches mathématiques (CRM) and the Fields Institute invite nominations for this joint prize in recognition of exceptional achievement in the mathematical sciences. The candidate’s research should have been conducted primarily in Canada or in affiliation with a Canadian university. Previous recipients are H.S.M. Coxeter, George A. Elliott, James Arthur, Robert Moody, Stephen A. Cook, Israel Michael Sigal, William T. Tutte, John Friedlander, John McKay, and Edwin Perkins. Please see www.fields.utoronto.ca/proposals/crm-fields_prize.html for details.

Nominations for the CRM-Fields Prize should reach the Institute by October 1, 2004.

Please send applications, nominations, and proposals to: The Director, Fields Institute
222 College Street, Toronto, Ontario, M5T 3J1 Canada
Thematic Programs

PARTIAL DIFFERENTIAL EQUATIONS, 2003–2004
Organizers: W. Craig, N. Ercolani, C. Sulem

MAR. 15–19, 2004
Workshop on Nonlinear Wave Equations

MAR. 24–26, 2004
Short Course on Kinetic Theory

MAR. 29–APRIL 2, 2004
Workshop on Kinetic Theory

MAY 3–7, 2004
Coxeter Lecture Series, Sergei Kuksin (Heriot-Watt)

MAY 10–15, 2004
Distinguished Lecture Series, Jean Bourgain (IAS, Princeton; and Illinois, Urbana-Champaign)

MAY 10–15, 2004
Short Course on Hamiltonian Partial Differential Equations

MAY 17–21, 2004
Workshop on Integrable and Near-integrable Hamiltonian PDE (joint with CRM)

MAY 24–28, 2004
Workshop on Hamiltonian Dynamical Systems (joint with CRM), at CRM

MAY 10–15, 2004
Short Course on Hamiltonian Partial Differential Equations

MAY 17–21, 2004
Workshop on Semi-classical Analysis (joint with CRM) June 1–5, at CRM; June 7–11, at Fields

MAY 14–18, 2004
Conference on Free Surface Water Wave

GRADUATE COURSES

SEPT. 2003–APRIL 2004
Partial Differential Equations

JAN. 12–APRIL 23, 2004
Applied Nonlinear Equations

JAN. 13–APRIL 20, 2004
Inverse Problems

JAN. 16–APRIL 30, 2004
Asymptotic Methods for PDE

General Scientific Activities

JAN. 15–19, 2004
QIP 2004: Seventh Workshop on Quantum Information Processing, at Perimeter Institute and Institute for Quantum Computing, Waterloo

FEB. 23–25, 2004
The Point of Point Processes, at University of Ottawa

APRIL 2004
Distinguished Lecture in Statistical Science, Sir David Cox

APRIL 2–4, 2004
Midwest Several Complex Variables Meeting, at University of Western Ontario

APRIL 28, 2004
Third Annual IFID Conference on Asset Allocation and Mortality

MAY 5–7, 2004
Mathematics of Learning Objects Symposium, at University of Western Ontario

MAY 5–9, 2004
Workshop on Representation Theory of p-adic Groups, at University of Ottawa

MAY 12–14, 2004
Workshop on Shape Optimization and Applications, at University of Ottawa

MAY 12–16, 2004
The Coxeter Legacy: Reflections and Projections, at University of Toronto

MAY 12–15, 2004
Large-Scale Nonlinear and Semi-definite Programming, at University of Waterloo

MAY 14–18, 2004
Gauge Theory and Low-dimensional Topology Conference, at McMaster University

MAY 19–23, 2004
2004 Canadian Operator Theory and Operator Algebra Symposium, at University of Waterloo

JUNE 7–26, 2004
Summer School on Statistical Methods for Ranking Data, at University of Ottawa

JUNE 17–19, 2004
Conference in Honour of D. Brownawell, at University of Waterloo

JUNE 20–25, 2004
CNTA8 Canadian Number Theory Association VIII Meeting, at University of Toronto
From the Director: Mathematics and Its Representation

Readers will immediately notice a new Fields logo, as well as a change in the name and format of our newsletter. Our old logos (the picture of John Charles Fields and the green bar) have served us well. But into our second decade, we felt it was time to have a logo that makes a more immediate connection to mathematics and to the Institute.

Visitors to the Fields are always struck by our numerous blackboards, constantly in use. Despite its technological sophistication, mathematics has a strong connection to its past, symbolized by the continued working out of mathematical ideas in chalk. We think that this image, which was designed by the firm Scott Thornley + Company, will strengthen our visibility within the mathematical community and will also resonate with a much wider audience. And yes, the pieces of chalk used in the logo actually came from a Fields blackboard tray. In addition, the new logo capitalizes on the reality that colloquially we are known as “Fields.” We will introduce these and related changes incrementally over the coming year.

We are changing our call for proposals in a significant way. To encourage many groups to explore the possibility of running a theme semester or year at Fields, we are now asking interested groups to submit a one-page letter of intent briefly outlining the ideas for a program. This will allow us to enter into discussions with these groups, and get the feedback of the Scientific Advisory Panel long before proposers invest a large commitment of time. Selected groups would be asked to develop full proposals, with our help. See p. 14 and www.fields.utoronto.ca/proposals/thematic.html.

This year’s theme program is in Partial Differential Equations. Organizers Walter Craig, Catherine Sulem, and Nick Ercolani have done a tremendous job of bringing in people for this program, and the Institute has been a very lively place this fall. Through a variety of ingenious funding mechanisms, we have sixteen PDFs around for the program. They have established a regular colloquium series for senior speakers and a weekly seminar series where younger members are encouraged to talk at length about their work. There have already been four workshops and a mini-course.

Plus there was a great Coxeter lecture series by Craig Evans, in addition to the Britten lectures at McMaster by Haim Brezis. The spring ahead looks to be an even more intense period, having a number of workshops, including a pair of two-week meetings split between Fields and the CRM in Montreal. We are also looking forward to Coxeter Lectures by Sergei Kuksin and the Distinguished Lecture Series by Fields medallist Jean Bourgain, both in May.

This year’s Distinguished Lecture Series in the Statistical Sciences will feature Sir David Cox of Oxford. Cox has been a major figure in statistics for more than half a century. He has written many influential books in addition to hundreds of papers. He has many students, grand-students, and great-grand-students. Indeed, there is a conference next summer in honour of his eightieth birthday—yet if you look at his list of publications, you will see that he has not slowed down. His talks are scheduled for April, the dates to be announced on our website.

Another exciting upcoming event is a conference on Bifurcation Theory and Spatio-Temporal Pattern Formation in PDE. Though this sounds related to PDE program, it is actually planned as a celebration of Bill Langford’s sixtieth birthday. Bill was the Deputy Director here from 1996 to 1998. He tells me he is thrilled that such a stellar lineup has agreed to participate.

Next year’s program is a year-long program in String Theory, an area of mathematical physics which requires sophisticated tools from geometry. The organizers include both mathematicians (Jeffrey and Khesin from Toronto, and Kapranov from Yale) and physicists (Myers from Perimeter, Peet and Hori from Toronto). It is jointly funded by Fields and the Perimeter Institute. We are working on the non-trivial (but not insurmountable) difficulties of having a program at two locations which are commuting distance apart.

Those of you who follow Fields activities will note that there has been a significant increase in the number and scope of activities that we are now running at our sponsoring universities. This is due in part to increased financial support from these universities. It has also resulted in renewed vigour within the community in terms of organizing activities. I encourage everyone to get involved in this way. Fields is here to help make things happen.

Kenneth Davidson, Director, Fields Institute