In this issue...

Director's message
Workshop on Hamiltonian Group Actions and Quantization
Summer School in Quantum Information Processing
Distinguished Lecture Series: Peter Shor
Workshop on Novel Approaches to Hard Discrete Optimization
Workshop on Arithmetic, Geometry and Physics around Calabi-Yau Varieties and Mirror Symmetry
Banff International Research Station
A Workshop in Honour of Allan Borodin's 60th Birthday
The Fields Institute Mathematics Education Forum for 2001-02
Workshop on Mathematical Challenges in Product Development
The Fields Institute 2001 Annual General Meeting

For up-to-date information about THE FIELDS INSTITUTE
• Please visit our web site at www.fields.utoronto.ca
• Write to us at geninfo@fields.utoronto.ca to receive our monthly e-newsletter

THE DIRECTOR'S MESSAGE

It is a pleasure to write my first message as Director of the Fields Institute. To begin, let me say that Fields is not only “alive and well,” it is poised to move ahead on many exciting fronts. This past year, the Institute has been without a director in place, and Bradd Hart has been doing the jobs of two, holding the place together. He deserves tremendous credit for providing strong leadership and carrying on under a huge workload. I am very pleased to say that he is continuing on as Deputy Director.

This is again the year of NSERC’s Reallocation Process, the application procedure for whole disciplines to defend their funding every four years. So the mathematics community is again preparing to make its case. The committee is chaired by Richard Kane who masterminded the writing last time. It is a perennial challenge to bring mathematics to life for an interdisciplinary committee, which is charged with putting new funds into the most promising developments across all disciplines. This is an aspect of the proposal where the three institutes are a major asset. The institutes are the primary mechanism for fostering a wide variety of activity from running workshops and year-long programs to hosting industrial seminars and acting as an incubator for commercial

Ken Davidson

WORKSHOP ON HAMILTONIAN GROUP ACTIONS AND QUANTIZATION

The workshop on Hamiltonian group actions and quantization at the Fields Institute concluded the program on symplectic topology, geometry, and gauge theory. The program was organized jointly by the Fields Institute and the Centre de recherches mathématiques from January 2001 to June 2001.

The subject of symplectic geometry was invented by Hamilton in the early nineteenth century as a mathematical framework for both classical mechanics and geometrical optics. Physical states in both settings are described by points in an appropriate phase space (the space of coordinates and momenta). Hamilton’s equations associate to any energy

Hamiltonian Group continued on page 2
function on phase space, the “Hamiltonian”, the time evolution for the corresponding physical system. Hamilton realized that his equations are invariant under a very large group of symmetries, called canonical transformations or, in modern terminology, symplectic transformations. A symplectic manifold is a space which locally, near any point, is modeled on the phase spaces considered by Hamilton. In particular, they come with large symmetry groups of symplectic transformations. Symplectic manifolds appear in almost every area of physics, for example as solution sets of classical field theories such as electromagnetism or gauge field theories. In recent years, new and powerful techniques have transformed symplectic geometry into a deep and beautiful subject of pure mathematics.

The workshop in June 2001 at the Fields Institute focused on two special aspects of symplectic geometry. A “Hamiltonian group action” on a symplectic manifold is a group action by symmetry transformations, generated by a collection of Hamiltonians called the moment map. For instance, the action of the rotation group on the phase space of a particle in Euclidean space is a Hamiltonian group action, with moment map the angular momentum. “Quantization” of such a system means the construction of an action of the group on the quantum-mechanical phase space, the so-called Hilbert space.

The workshop was organized by Michèle Audin from Strasbourg, Jacques Hurtubise from the CRM in Montreal, and Lisa Jeffrey and Eckhard Meinrenken from the University of Toronto. One of the main goals of the workshop had been to bring together specialists working on Hamiltonian group actions with mathematicians from other disciplines who use these techniques as important tools of their subject. It was generally felt that the workshop led to a very successful interaction of the various fields, continuing a tradition set by the 1994 workshop at the Newton Institute in Cambridge.

The workshop took place over 9 days and featured almost 40 invited lectures. Here are some of the many highlights of the conference.

Victor Guillemin (M.I.T.) and Catalin Zara (Yale) delivered beautiful lectures on Morse theory on graphs. The basic idea of their approach is to study Hamiltonian group actions by graph-theoretic methods. Guillemin and Zara develop a notion of “group actions on graphs”, and prove many analogues of theorems for Hamiltonian group actions for graphs that need not be associated to any manifold at all!

Sue Tolman (Urbana-Champaign) and Jonathan Weitsman (Santa Cruz) described their work with Raoul Bott on a surjectivity theorem for Hamiltonian loop group spaces. Loop groups are the simplest examples of infinite-dimensional Lie groups. It was known that one of the basic theorems for the finite-dimensional setting, the Kirwan surjectivity theorem, fails for loop group actions. Bott-Tolman-Weitsman describe the deeper reasons for this failure, and moreover show how to ‘repair’ the surjectivity theorem.

Miguel Abreu (University of Lisbon) and Andrew Hwang (College of the Holy Cross) explained how moment maps can be used to great effect to construct special Riemannian metrics, such as extremal Kähler metrics.

Siye Wu (University of Adelaide) outlined a new geometric interpretation of the Maslov index, leading to a generalization to symmetric spaces.

Eckhard Meinrenken, University of Toronto

The first talk of the meeting was delivered by Chris Woodward (Rutgers University), who spoke on his recent joint work with Fulton on quantum Schubert calculus. The audience appreciated his very nice introduction to the world of quantum cohomology and Gromov-Witten invariants, which had also been the subject of the Coxeter Lectures by Alexander Givental earlier in the program.

THE BANFF INTERNATIONAL RESEARCH STATION

The Banff International Research Station (BIRS), an Oberwolfach-style conference center to be located at the Banff Center, is a joint Canada-US project spearheaded by PIMS and MSRI. Robert Moody from the University of Alberta is the first scientific director of the station which will begin operations in March, 2003. This innovative initiative will complement the growing infrastructure for mathematical sciences in Canada, and the Fields Institute is extremely supportive. All Canadian mathematicians are encouraged to make a proposal for an activity at BIRS. The deadline for submissions for the 2003 program year at BIRS is Oct. 1, 2001 and information on how to submit a proposal can be found at www.pims.math.ca/birs.
Summer School in Quantum Information Processing
MAY 14 - 18, 2001

The scientific organizers of this summer school were Michele Mosca (Waterloo) together with Richard Cleve (Calgary), Raymond Laflamme (Los Alamos), Daniel Lidar (Toronto) and Alain Tapp (Waterloo).

The goal of the school was to make the field of quantum computing accessible to a general audience of scientists, including computer scientists who have little familiarity with quantum mechanics, and physicists who have little familiarity with computational and complexity theory. Most (roughly 80%) of the lectures were at a tutorial level.

The Fields Institute lecture room was overflowing with 100 participants, with many more on a waiting list. Over 50% of the participants were graduate students. There were also a large number of postdoctoral researchers and faculty members, and a handful of senior undergraduate students. Close to 60% of the participants were from Canada, 20% from the USA, with the remaining from Australia, Europe, Asia, and Central America. The vast majority of participants considered themselves to be theoretical physicists or computer scientists (with a small but noticeable bias towards physics). There were a handful of other mathematicians, engineers, and experimental physicists.

Summer School continued on page 7

Distinguished Lecture Series

QUANTUM COMPUTING
CAPACITIES OF QUANTUM CHANNELS
PETER SHOR (AT&T)

Peter Shor is a mathematician at AT&T Labs. His research interests include quantum computing, algorithmic geometry, and combinatorics. He earned a B.S. in Mathematics at the California Institute of Technology (Caltech) in 1981, and a Ph.D. in Applied Mathematics at the Massachusetts Institute of Technology (MIT) in 1985. He was a postdoctoral fellow for a year at MSRI in Berkeley before starting at AT&T Bell Laboratories in 1986.

He is recognized worldwide for his work in various areas of mathematics and computation, most notably for his work in the theory of quantum computing.

Quantum computation is the study of information processing in a quantum mechanical framework. Since information is stored in a physical medium and manipulated by physical processes, it is impossible to separate any meaningful theory of computing from the laws of physics which govern computers or other information processors. For most practical purposes, the classical approximation to the laws of physics has sufficed, and will probably continue to suffice. However, early last century, scientists realized that classical physics is wrong and developed a new framework for expressing physical theory: quantum mechanics. It wasn’t until nearly the end of the last century that scientists started to understand the non-trivial impact the more precise approximation to the laws of physics, quantum physics, has on the theory of computation.

A major breakthrough in understanding the power of quantum computers came in 1994, when Shor showed how, with a quantum computer, one can factor large numbers using a number of computational steps comparable to the number of steps needed to multiply two numbers. In other words, if we allow quantum computational steps, we can factor efficiently. Many public-key encryption systems in use today are based on the fact that, with the current technology, factoring large numbers is

Distinguished Lecture continued on page 7
Workshop on Novel Approaches to Hard Discrete Optimization

This workshop was held at the University of Waterloo, April 26 – 28, 2001. The organizers were Kurt Anstreicher (University of Iowa), Panos Pardalos (University of Florida), Franz Rendl (University of Klagenfurt), Tony Vannelli and Henry Wolkowicz (University of Waterloo). It was sponsored by The Fields Institute, the National Program Committee of the Canadian Mathematical Sciences Institutes and the Faculty of Mathematics at the University of Waterloo.

Linear Programming is the now classical approach to dealing with hard combinatorial optimization problems. This approach has turned out to be a powerful method for problems like the Travelling Salesman Problem. But for other types of problems, such as Graph Partition or Quadratic Assignment problems (QAP), the linear relaxations seem either too weak or too expensive.

On the other hand, the success of interior point methods that deal with constrained nonlinear problems has led to increased interest in algorithmic nonlinear optimization in the last 15 years. Cone LP and in particular Semidefinite Programming (SDP) have turned out to be powerful tools in various branches of applied mathematics, notably for combinatorial optimization (Goemans-Williamson approximation for Max-Cut) and in System and Control theory. SDP has become a bridge between combinatorial optimization and nonlinear programming.

The breathtaking progress in algorithmic nonlinear optimization and in computer hardware has thrown new light on the analysis of NP-hard problems. Recently, a major breakthrough was achieved to solve QAP of sizes (n=30) unthinkable by conventional methods. This progress was due in part to a new nonlinear relaxation for QAP, but also to new computing facilities, allowing for massive parallel computation. Similar progress has also been made in other areas, such as clique and coloring on massive graphs.

The Fields Institute has been involved in mathematics education for five or six years, mainly at the provincial level. The Mathematics Education Forum was designed to build a relationship between academic mathematicians and school teachers of mathematics. One well-known result of this was the development of the new Ontario mathematics curriculum for the secondary schools. Now we are planning to develop a national initiative in mathematics education. I am pleased to announce that Gila Hanna has agreed to spearhead this initiative.

The third area of Fields activity is mostly new to me, but there is a lot happening. Bradd Hart and Huaxiong Huang from York University have been working on our commercial and industrial programs. This includes seminar series like our long-running and successful Financial Mathematics Seminar. The Fields Institute also acts as an incubator for commercial companies based on the application of mathematics to real business ventures. A good example of this is Karthika Technologies, founded by local businessman Hari Venkatacharya in cooperation with Kumar Murty of the University of Toronto, to develop mathematically sophisticated cryptosystems. This operation grew from a two man startup company to a 17 person operation in less than a year.

There are many events coming up this fall. Let me mention one that should be of special interest to many, the CRM–Fields prize lecture. This year’s winner is the eminent combinatorist William Tutte, who received the Order of Canada earlier this year. He will be speaking at the Fields Institute on 60 Years in the Nets on October 25th. Mark this on your calendar.

I am looking forward to working with many people across Canada and throughout the world to build the Fields Institute into an even better place for all of us to come together to discuss and do mathematics in all of its aspects.

Kenneth R. Davidson, Director
Activities at the Fields Institute
September – December 2001

Please see www.fields.utoronto.ca/programs/ for detailed information on these activities

Thematic Programs

For information, see http://www.fields.utoronto.ca/programs/scientific/01-02/numerical/ or write to us at numerical@fields.utoronto.ca

Speaker: P. Deuflhard

September 29-30, 2001 Workshop on Modeling and Scientific Computation University of New Brunswick, Fredericton, New Brunswick
Organizing Committee: V. Husain, J. Stockie, J. Watmough

October 11-26, 2001 Short Course on Matrix Valued Function Theory
Instructor: O. Nevanlinna

October 29 - November 2, 2001 Workshop on Numerical Linear Algebra in Scientific and Engineering Applications
Organizers: E. Ng and G. Golub

November 19 - 24, 2001 Workshop on Computational Biology
Organizers: J. Belair, L. Edelstein Keshet, J. Hsieh, J. Keneer, B. Langford

December 3 - 8, 2001 Workshop on Computational Challenges in Dynamical Systems
Organizers: K. Boehmer, E. Doedel, J. Guckenheimer, H. Keller, B. Langford

Coxeter Lecturers 2001-02 Gene Golub, Department of Computer Science, Stanford University
Randall J. LeVeque, Applied Mathematics Department, University of Washington
Dates to be announced: see http://www.fields.utoronto.ca/programs/scientific/01-02/numerical/

Graduate Courses- Fall 2001 Numerical Linear Algebra, Numerical Solution of ODEs, Numerical Solution of SDEs

General Scientific Activities, September – December, 2001

September 21, 2001 George Duff Memorial Conference
Organizer: R. Buchweitz
For information, see www.fields.utoronto.ca/programs/scientific/

September 24, 2001 First Annual Conference on Personal Risk Management
Organizer: M. Milevsky
For information, see www.fields.utoronto.ca/programs/cim/financial_math/ifid/personal_risk/01-02/

October 25, 2001, 4:00 p.m. 60 Years in the Nets
CRM-Fields Prize Recipient: William Tutte
For information, see www.fields.utoronto.ca/programs/scientific/01-02/crm-fields/tutte/

November 7-11, 2001 Workshop on reductions of Shimura varieties and related spaces: geometry and representation theory
For information, see www.fields.utoronto.ca/programs/scientific/01-02/shimura/

December 6-7, 2001 Workshop on Free Probability and Random Matrices
Organizers: A. Nica, R. Speicher, in association with the Winter CMS Meeting
For information, see www.cms.math.ca/Events/winter01/announce.html#symposia

December 11, 2001 Fields Day on Mathematical Modeling
Geometry and representation theory
Organizer: H. Huang For information, see www.fields.utoronto.ca/programs/cim/
Call for proposals, nominations and applications

Please see the website for detailed information on the proposal and nomination process: www.fields.utoronto.ca/proposals

THEMATIC PROGRAMS AND GENERAL SCIENTIFIC ACTIVITIES

Proposals for year long or half-year programs at The Fields Institute are currently solicited for the academic years 2002-03 and beyond. We also support programs of one day to one month of concentrated activity in a specific area of current research interest in the mathematical sciences. These activities can be in the form of workshops, seminars, conferences and/or summer schools.

POSTDOCTORAL OPPORTUNITIES AT THE INSTITUTE

Applications are invited for postdoctoral fellowship positions for the 2002-2003 academic year. These fellowships provide for a period of at least one year engaged in research and participating in the research activities of the Institute.

Among other opportunities, the Jerrold E. Marsden Postdoctoral Fellowship will be awarded. It pays a stipend of $40,000 (Cdn) and provides for a twelve-month period at the Institute for research and participation in the activities of the core program. No teaching is required. In addition to the stipend, a $2000 (Cdn) research grant will be available during the tenure of the position. Standard NSERC guidelines will apply to this grant.

Postdoctoral applications should reach the Institute by January 2, 2002.

CRM-FIELDS PRIZE

The Centre de recherches mathématiques (CRM) and the Fields Institute for Research in Mathematical Sciences solicit nominations for this joint prize in recognition of exceptional achievement in the mathematical sciences. The Fall deadline is October 15. Previous recipients are H.S.M. Coxeter, George A. Elliott, James Arthur, Robert Moody, Stephen A. Cook, Israel Michael Sigal, and William T. Tutte. Please see http://www.fields.utoronto.ca/proposals/crm-fields_prize.html for details.

NATIONAL PROGRAM COMMITTEE GRANTS

The three Canadian Institutes in the Mathematical Sciences – CRM, Fields and PIMS – support joint activities in the mathematical sciences through the National Program Committee. Program proposals of national interest lying outside the direct mandate of any of the individual institutes are welcome. Please see http://www.fields.utoronto.ca/proposals/natprogcomm.html for details.
A workshop in honour of Allan Borodin’s 60th birthday JUNE 22 - 23, 2001

T he workshop was an opportunity to celebrate Allan Borodin’s long and distinguished research career in computational complexity by featuring speakers among his former students, collaborators, and colleagues. There was a strong response when the initial invitations were sent, resulting in a full high quality program of 22 speakers, each giving a 30 minute talk.

Several talks were motivated by the World Wide Web. Jon Kleinberg showed how to model the “small world phenomenon” of the web: almost any pair of major sites is connected by a path with just a few links. Madhu Sudan showed how to model web browsing with a “backoff process”: a Markov chain with back buttons. Borodin’s current student Panayiotis Tsaparas analyzed algorithms for finding “authorities” on the web, useful for web search engines. On another subject, Les Valiant showed how a certain class of quantum computations can be simulated classically in polynomial time, but warned that physicists are attacking the traditional foundations of complexity theory like termites slowly eating away basement beams. Avi Wigderson gave an excellent survey talk showing how algebra and combinatorics have been fruitfully combined to construct expander graphs.

Steven Rudich gave a talk on the futility of formal code obfuscation, and also demonstrated his phenomenal magical skills by mysteriously sticking a playing card signed by Borodin on the ceiling of room 220. This card permanently joins the one signed by Cook during the workshop in his honour in April, 2000.

The talks were consistently well-attended, despite the intense schedule. The workshop was followed by a banquet the evening of June 23. Pictures are available from the birthday link of Borodin’s home page: www.cs.toronto.edu/~bor.

Stephen Cook, University of Toronto

Summer School  continued from page 3

The lecturers were leaders in the field of quantum computation, from Australia, Europe, USA and Canada:

Charles Bennett (IBM) Michael Nielsen (Queensland)
Gilles Brassard (Montreal) Peter Shor (AT&T)
Richard Cleve (Calgary) Aephraim Steinberg (Toronto)
Peter Høyer (Calgary) Alain Tapp (Waterloo)
Emanuel Knill (Los Alamos) Barbara Terhal (IBM)
Raymond Laflamme (Los Alamos) Umesh Vazirani (Berkeley)
Daniel Lidar (Toronto) John Watrous (Calgary)
Michele Mosca (Waterloo) Ronald de Wolf (CWI).

Topics covered during the school included the “basics” of quantum information, quantum algorithms and complexity, fault-tolerant quantum error correction, quantum communication and cryptography, and implementations of quantum information processing.

The summer school lectures included two Distinguished Lecture Series talks by Peter Shor, open to the general public. The first, held on Thursday afternoon, was a classic introductory lecture on quantum computation and his famous factoring algorithm, while the second, on Friday afternoon, was an exciting talk on the capacities of quantum channels. The non-tutorial lectures on Friday, by Bennett, Laflamme, Vazirani and Shor were also open to the general public, and were very well attended.

The school was financially supported by the Fields Institute, MITACS, the Perimeter Institute for Theoretical Physics, and the University of Waterloo.

Feedback from the participants and lecturers was very positive. The Fields Institute staff did a superb job. We are very grateful to the lecturers for agreeing to attend and to the sponsors for financing the school.

Michele Mosca, University of Waterloo

Distinguished Lecture  continued from page 3

exponentially harder than multiplying. That is, they assume that encoding information is roughly as easy as multiplying, but cracking the code is exponentially harder, and thus infeasible. Another widely used class of public-key encryption systems assumes that finding discrete logarithms in various mathematical groups is hard, but Shor also came up with an efficient algorithm for finding discrete logarithms. This algorithm can easily be generalized in order to crack any of the discrete logarithm-based cryptographic systems. Shor won the 1999 Godel prize for this work. His factoring algorithm was the topic of his first distinguished lecture on Thursday, May 17.

The discovery of these algorithms forced scientists to take more seriously the question of whether or not quantum computers could really be built or if there is some fundamental reason why large-scale quantum computations cannot be done efficiently. We can never hope to manipulate quantum systems perfectly, so we need to know if there is a reasonable way of coping with some degree of inaccuracy. Shor again provided a major breakthrough on this front, pioneering the field of fault-tolerant quantum error correction.

Some of his more recent work includes an elegant new proof (with Preskill) of the security of quantum key distribution. He has also studied the capacity of various kinds of quantum channels for transmitting both classical and quantum information; this was the topic of his second Fields lecture on May 18. His pioneering work in quantum computing also earned him the 1998 Nevalinna Award, the 1998 International Quantum Communication Award, and a 1999 MacArthur Fellowship.

Michele Mosca, University of Waterloo
The organizing and scientific committee of this workshop consisted of Victor Batyrev (University of Tübingen), Shinobu Hosono (University of Tokyo), James D. Lewis (University of Alberta), Bong H. Lian (Brandeis University), Noriko Yui (Queen’s University), and S.-T. Yau (Harvard University) (who served as a scientific advisor to the committee).

One of the most significant developments in the last decade in theoretical (high energy) physics is, arguably, string theory and mirror symmetry. String theory proposes a model for the physical world in which the fundamental constituents are 1-dimensional mathematical objects “strings” rather than 0-dimensional objects “points”. Mirror symmetry is a conjecture in string theory according to which certain “mirror pairs” of Calabi-Yau manifolds give rise to isomorphic physical theories. (A Calabi-Yau variety of dimension d is a complex manifold with trivial canonical bundle and vanishing Hodge numbers $h^{i,0}$ for $0 < i < d$. For instance, a dimension 1 Calabi-Yau variety is an elliptic curve, a dimension 2 Calabi-Yau variety is a K3 surface, and one in dimension 3 is a Calabi-Yau threefold.) Calabi-Yau manifolds appear in string theory because in passing from 10-dimensional space-time to a physically realistic description in four dimensions, string theory requires that the additional 6-dimensional space be a Calabi-Yau manifold.

Though the idea of mirror symmetry originated in physics, the field of mirror symmetry has exploded in recent years onto the mathematical scene. It has inspired many new developments in algebraic geometry, toric geometry, Riemann surfaces, and infinite dimensional Lie algebras. For instance, mirror symmetry has been used to tackle the problem of counting the number of rational curves on Calabi-Yau threefolds.

In the course of studying mirror symmetry, it has become apparent that Calabi-Yau varieties enjoy tremendously rich arithmetic properties. For instance, arithmetic objects such as modular forms, modular functions of one or more variables, algebraic cycles, L-functions, and $p$-adic L-functions, have popped up. Moreover special classes of Calabi-Yau manifolds, e.g., Fermat type hypersurfaces, or their deformations pertinent to mirror symmetry, offer promising testing grounds for physical predictions as well as rigorous mathematical analysis and computation.

The goal of the workshop was to bring together experts, recent Ph.D.s and graduate students, working in or studying Calabi-Yau varieties and mirror symmetry in physics, geometry or arithmetic, and to exchange ideas and learn the subjects firsthand while mingling with researchers with different expertise. We expected these interactions to lead to progress in solving open problems in mathematics and physics as well as to pave the way to new developments.

There were 40 registered participants—mathematicians and theoretical physicists—from ten countries. The workshop was enormously successful in fulfilling its goal. All participants were very happy with the workshop. Many expressed their satisfaction by saying that they learned a lot from this workshop. S.-T. Yau (Harvard) (one half of the workshop’s namesake “Calabi-Yau”) took part in the workshop for two days, in spite of his busy schedule (currently opening a new research institute in China). He delivered the kick-off lecture of the workshop on The Mirror Principle. His lecture served to set the tone of the entire workshop. P. Candelas (Oxford) expressed his appreciation saying that “it was a very stimulating workshop”.

The problem session on the last day of the workshop turned out to be a real hit. Many participants proposed future problems and research directions on Calabi-Yau varieties and mirror symmetry, and engaged in very lively discussions which made us almost forget the closing time of the workshop.

One of the significant outcomes of the workshop might be that we are finally beginning to understand the mirror symmetry phenomena of Calabi-Yau threefolds from the arithmetic point of view, namely in terms of the relations between the zeta and L-functions of mirror pairs of Calabi-Yau manifolds. We also formulated some future directions for research endeavours on mirror symmetry, e.g., further studies of algebraic cycles in connection with D-branes.

The proceedings of the workshop will be published in the Fields Institute Communications Series.

For further details of the workshop, see the website: www.fields.utoronto.ca/programs/scientific/01-02/cyms

Noriko Yui, Queens University
Workshop on Mathematical Challenges in Product Development

This workshop was organized by David Ferguson (Boeing), David Field (General Motors), Michael Lachance (University of Michigan-Dearborn), Ed Moylan (SIAM, Great Lakes Section), Mike Pratt (NIST) and Marshall Walker (York University) on Monday and Tuesday, June 25 – 26, 2001.

The purpose of the workshop was to identify research themes in computational and other areas of mathematics that offer the most promise over the next decade for addressing significant business and industrial problems, particularly in product development and manufacture, and to plan the organization of an international conference around those themes.

The workshop was opened by Bradd Hart, Acting Director of the Fields Institute. He welcomed the participants and described the Institute as a venue for mathematics research and a catalyst for partnership between academic institutions and industrial organizations. Thus this workshop falls exceptionally well within the purview of the Institute’s charter.

David Field, Co-President (with Mike Lachance) of the Great Lakes Section of SIAM, provided a summary of events that led to the scheduling of this workshop. A similar one at RPI in Troy NY in 1983 focused on the mathematical requirements for the then rapidly developing areas of CAD and led to the establishment of a biannual SIAM Conference on Geometry. As a result of recent conversations between David Field, David Ferguson, and Marshall Walker, it was agreed that the time was now opportune for another such workshop to determine the next generation of mathematics research opportunities, and that the Fields Institute would be an ideal setting for this workshop.

Ed Moylan, who facilitated the meeting, outlined the agenda and meeting process. A packet of twenty-nine proposed problems and research themes was distributed in order to generate discussion. These had been solicited earlier in preparation for the workshop.

Three breakout groups were then formed to discuss and analyze the proposals, to identify synergies or underlying themes, and to form opinions regarding which can have the greatest impact on business, industry, and mathematics within the next decade.

Numerous themes were reported by the groups during the subsequent open forum. These included:

- Real time interactions among a minimal set of mathematical models representing the same geometric object or process
- Large sets of data
- Mathematical model variation; reason with probabilistic geometric / processing models
- Ensuring consistent topology and geometry with multiple application instances and probabilistic error bounds
- Design Space Exploration, including the role of constraints, robustness of solutions, and visualization
- Inverse Problems, i.e., reverse engineering, geometry from continuous constraints, shape optimization, facets to surface and back
- Verification / Validation and Assessment / Accreditation, including crash simulation and analysis, physics-based models for reliability, and probabilistic analysis issues
- New capabilities directions, e.g., tools for business modeling, traffic management (auto / air / network / internet)

The mathematics required to address these themes is wide-ranging, including operations research, AI, theory of distributed computing, neural nets, graph theory, queuing theory, stochastic processes, canonical abstract representations with multiple instances, geometry, topology, numerical analysis, differential and algebraic equations, and design from variational principles.

Spirited discussion in open forum, within subgroups, and between individuals continued unabated throughout the rest of the day.

The Workshop reconvened on Tuesday at 9:00 a.m. as David Field reminded participants of its purpose. In open forum, the group considered afresh the collective input from the previous day’s deliberations. Consolidation and rationalization of the input resulted in coalescence around three overall themes:

1. Reliable Representation and Manipulation of Objects
2. Dynamics of copious data

Again three breakout groups were asked to develop specific proposals for a title for the proposed conference and to continue developing the list of themes to be included. Guideline character-
Mathematics education at all levels plays an important role at Fields, and our window on elementary and secondary education is our Mathematics Education Forum. Last year’s forum was chaired by Eric Muller from Brock university and the forum created four task forces, devoted to mathematics teacher education, the transition from high school to university and college mathematics, the mathematics of data management, and online mathematics courses. The forum holds monthly meetings which are open to everyone and are regularly attended by representatives from school boards, faculties of education, book publishers, mathematics departments and others with an interest in math education. The first meeting of this year’s Forum will be held at the end of September; if you would like to be added to the Forum’s mailing list, please send email to Alison Conway (aconway@fields.utoronto.ca).

2001-02 Mathematics Education Forum membership (not all OAME representatives have been designated):

Ed Barbeau (University of Toronto)
Steve Brown (University of Waterloo)
Stewart Craven (Toronto District School Board, OMCA)
Shirley Dalrymple (York Region District School Board, President, OAME)
Ken Davidson (Director, Fields Institute)
Sandy Dilena (Toronto District School Board, OMCA)
Gary Flewelling (Mathematics Education Consultant)
Lynda Graham (Sheridan College, OCMA)
Alison Gibbs (York University)
Gila Hanna (Fields Institute)
Bradd Hart (Deputy Director, Fields Institute)
John Kezys (Mohawk College, President, OCMA)
Andre Ladouceur (President, AEFMO)
Miroslav Lovric (McMaster University)
Trevor Luke (University of Western Ontario)
Doug McDougall (OISE, University of Toronto)
Eric Muller (Brock University)
Luis Radford (Laurentian University)
Pat Rogers (University of Windsor)
Geoff Roulet (Queens University)
Tom Steinke (Ottawa Carleton Catholic School Board, President, OMCA)
Tom Sutton (Mohawk College, OCMA)
Walter Whiteley (York University, CMS)

Product Development continued from page 9

istics of the themes were listed: succinct, energizing, reach beyond what is known to be doable, industrial appeal, enables linkages with cohesive communities, was not on the list 10 years ago, gaps to be filled, significant enhancements to what is of current interest, and provides meaningful advice to the mathematical community.

The resulting conference title proposals were
• Title I: Emerging Mathematics of Industry
• Title II: SIAM Conference on Mathematics (of / in) Industry - 20XX

Themes developed, in addition to those noted during Day 1, included
• Interoperability of mathematical models for design and manufacture including probabilistic and stochastic approaches
• Computational algebraic topology
• Fast algorithms for calculating real time geometry; on-line inspection / digitizing

• Exploration of conceptual, preliminary, and detailed design tools with associated geometry representations
• Deterministic / numerical / stochastic error bounds
• Issues of extracting information from large data sets that are not already being addressed in data mining conferences
• Data compression, translation, and transmission
• Fly / drive without testing

The overwhelming consensus of the participants was to recommend holding the planned conference in Toronto. The workshop adjourned at 2pm, after all agreed on the usefulness of the workshop and commended the Fields Institute for its excellent facilities and the impeccable cooperation of its professional support staff.

Ed Moylan, SIAM
The aim of the workshop was to bring together researchers from several communities—such as algorithmic nonlinear optimization, combinatorial optimization dealing with computational methods for NP-hard problems, and computer scientists interested in scientific parallel computing—who share a common interest in computations on (large-scale) hard combinatorial optimization problems. Attendees heard talks on topics such as: the Travelling Salesman Problem; the Quadratic Assignment Problem; Branch and Cut algorithms; and the Spectral Bundle Algorithm.

The three Bills opened up the workshop: Bill Cunningham (chair of the Department of Combinatorics and Optimization at the University of Waterloo) chaired the first morning session; this included two plenary talks by Bill Cook and Bill Hager.

**The Travelling Salesman Problem, TSP**

William Cook (Rice University) opened up the workshop with a survey of recent progress in algorithms for large-scale TSP instances. The TSP is considered to be the flagship problem in discrete optimization. It has achieved great success: from solving a problem with 49 cities in 1954; 100 cities in 1975; 666 cities in 1987; 7,397 in 1994; 13,509 in 1998. Many innovative techniques have arisen as a result of the successes on instances of TSP. For example, Bill presented a new powerful variant of the Lin-Kernighan heuristic. These new techniques, in an efficient parallel computing environment, have resulted in the largest instance of TSP ever solved: a 15,112 city optimal tour was found. The computation was carried out on a network of 110 processors located at Rice University and Princeton University. The total computer time used in the computation was 22.6 years (CPU Time used (sec) 585936700) scaled to a Compaq EV6 Alpha processor running at 500 MHz. The optimal tour has length 1,573,084 in the units used in TSPLIB; this translates to a trip of approximately 66,000 kilometers through Germany. (More details/software are available on Bill’s web page http://www.math.princeton.edu/tsp/d15sol/.)

Bill also discussed a one million city instance where an approximate solution within 2% of optimality was found (Johnson-McGeogh, 1997); and another such instance that involved a quadratic objective. Several fascinating applications of this model were presented, including the configuration of a NASA telescope.

**The Quadratic Assignment Problem, QAP**

The main topic of the workshop, as well as the motivating problem, was the QAP. As mentioned above, the TSP is considered the flagship problem in this area and has achieved great success. The QAP is well-known for the opposite reason, i.e. the lack of success.

One motivating factor for this workshop was the solution of the Nugent dimension n = 30 problem which has eluded people for many years. One major difficulty for QAP is finding good lower bounds for branch and bound methods.

William Hager was the second plenary speaker. He looked at the problem of finding lower bounds for QAP using large linear programming relaxations. For example, for n = 30, the LP had 50,000 rows, 300,000 columns, and 10⁶ nonzeros. A problem of this size would need 10 gigs of memory just for factorizations. Bill presented DASA, a dual active set method for solving these large scale LPs.

The next talk was by Kurt Anstreicher. Kurt’s recent work was the motivating factor behind the workshop.

He spoke about his recent solutions of the large Nugent QAP test problems. In particular, he used a new bounding technique which is a weakened form of a semidefinite programming relaxation of QAP. This bound is cheap to calculate and surprisingly tight. In addition, it fits into branch and bound frameworks. The combination of this new tighter bound and the CONDOR, http://www.cs.wisc.edu/condor/, high throughput computing environment resulted in the solution of several, previously unsolved, large QAPs including the Nugent n=30 test problem.

Progress on solving the large hard QAPs has depended heavily on efficient use of parallel computing. Catherine Roucairol was one of the first to employ parallel computing for QAP. This led to the first solution of problems of size n ≥ 20. Catherine discussed the reformulation procedure and LP relaxations of QAP and the use of Lagrange multipliers within a dual algorithm.

**Semidefinite Programming, SDP**

SDP has arguably been the hottest topic in optimization during the past five years. So it is not surprising that many of the talks at the workshop dealt directly or indirectly with this topic. SDP was used as a successful bound for QAP, Max-Cut, and other problems. In addition, several talks were devoted to trying to get efficient solutions to large SDPs.

Henry Wolkowicz, University of Waterloo
On June 18, 2001, the Institute began what we hope will become a tradition by having, in addition to the annual general meeting of the Members of the Corporation, several other events to mark the end of the old year and ring in the new.

The first of these was a lecture by Professor Lisa Jeffrey of the University of Toronto, one of the organizers of the thematic program on Symplectic Topology, Geometry, and Gauge Theory, which was drawing to a close. Jeffrey began by explaining the origins of the subject in classical mechanics, and then described its relationship to Riemannian geometry, algebraic geometry, and Kähler geometry.

This was followed by a discussion of the three workshops associated with the program:
- Quasiclassical and Quantum Structures (January 9 – 14),
- Symplectic and Contact Topology, Quantum Cohomology, Symplectic Field Theory and Higher Dimensional Gauge Theory (March 26 – April 7)
- Hamiltonian Group Actions and Quantization (June 4 – 13).

She described the topics in each of the workshops, explaining them and their importance, and spoke of some of the highlights of the workshops.

The transparencies used in her talk can be viewed at http://www.fields.utoronto.ca/programs/scientific/00-01/annual_general_meeting/JeffreyAGM.pdf

The new thematic program in Numerical and Computational Challenges in Science and Engineering was initiated in a second lecture by Professor Joe Flaherty of Rensselaer Polytechnic Institute. He began by listing some of the “grand challenges” of computation – weather and climate, engineering design such as the Boeing 777, nuclear stockpiling, tissue engineering, and scientific discovery in such disciplines as biology and chemistry. He also mentioned in passing some of the “petty challenges” with more commercial but still important implications for the subject.

The importance and growth of numerical analysis during the past few decades has been due in no small way to algorithmic breakthroughs, and one can expect such developments to continue unabated in the near future.

The lecture concluded with a thorough discussion of the major topics of the thematic program: linear algebra, sparse systems, multilevel strategies, ODEs and DAEs (differential algebraic systems), dynamical systems, optimization, and PDEs.

In the evening a dinner was held at the University of Toronto Faculty Club, attended by many board and corporate members and the Institute staff, as well as by many mathematicians and others involved with the Institute. The highlight was an address by the Honourable Roy MacLaren, who has served as Canada’s Minister of International Trade, and as our High Commissioner to the U.K. His speech stressed the current good fortune of Canada in spite of the pessimism of many Canadians, and the importance of trade, especially with the European Union, to our future.

Carl Riehm, The Fields Institute