Pacific Institute for the Mathematical Sciences

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Magazine

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BIRS Opens its Doors to the World


The scenic backdrop that greeted visitors to the BIRS inaugural event at the Banff Centre in Banff, Alberta

Towering mountains, falling snow, crisp winter air... a splendid setting for the inaugural meetings of the Banff International Research Station for Mathematical Innovation and Discovery (BIRS) that took place February 28–March 1, 2003 in Banff, Alberta.

Nassif Ghoussoub (PIMS Director and Chair of the BIRS Executive Committee), **David Eisenbud** (MSRI Director and AMS President), and **Robert Moody** (BIRS Scientific Director) welcomed mathematicians, scientists and supporters of the mathematical sciences from across North America and around the world.

BIRS was honoured by the presence of **Tom Brzustowski** (President, Natural Sciences and Engineering Research Council of Canada), **Isabelle Blain** (Vice President, NSERC), **Arthur Carty** (President, National Research Council of Canada), **Bob Church** (Chair, Alberta Science and Research Authority), **Hon. Victor Doerksen** (Minister of Innovation and Science, Government of Alberta), **Jean-Claude Gavrel** (Director, NCE program), and **William Rundell** (Director, Division Mathematical and Physical Sciences, U.S. National Science Foundation), among 200 other distinguished guests. Local dignitaries included **Mary Hofstetter** (President and CEO, The Banff Centre), **Philip Ponting** (Chair, Board of Governors, The Banff Centre) and **Dennis Shuler** (Mayor, Town of Banff).

Senior administrators from universities across Canada, including **Luc Vinet** (Provost and Vice-Principal Academic, McGill U), **Michael Stevenson** (President, SFU), **Harvey Weingarten** (President, U. Calgary), and **Barry McBride** (Vice President Academic and Provost, UBC), showed strong support with their presence.

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PIMS Initiates its
Collaborative Research Groups

In April of this year, PIMS initiated its Collaborative Research Group programme, which will be a pivotal component of the future development of PIMS. A Collaborative Research Group (CRG) consists of researchers with a common research interest and with a desire to collaboratively develop various aspects of their research programme.

Every year, the PIMS Scientific Review Panel selects up to five Periods of Concentration from those proposed by existing or developing CRGs. The Periods of Concentration consist of one or two year multi-event, multi-site coordinated activities by the members of the CRG, in tandem with their national and international collaborators.

Starting this April are the first five Periods of Concentration: String Theory, Number Theory, Topological Dynamics and Related Areas, Scientific Computing, and Mathematical Ecology. Although each CRG tailors its activities to its own needs, typically a Period of Concentration consists of summer schools, workshops, BIRS events, Pacific Northwest Seminars, distinguished chairs, and postdoctoral fellows.

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Interview with PIMS Founding Director Nassif Ghoussoub

Interview by Heather Jenkins, PIMS Communication Officer

Dr. Ghoussoub, you have recently announced your resignation from the directorship of PIMS after 7 years at the helm. You have also been a leading activist within the mathematical community for the last 10 years. How did you get interested in large scale organized research activity?

Not long before PIMS, my first attempt at coordinating a larger scale research activity was in 1994. I submitted a proposal to NSERC for the support of an international collaborative research group in Partial Differential Equations, consisting of Fields medallists J. Bourgain, P. L. Lions, as well as world mathematical leaders like L. Nirenberg, H. Hofer, I. Ekeland, J. Feldman and others. The decision was negative! One of the many failures to follow!

Nassif Ghoussoub

At about the same time, NSERC's first allocations exercise had ranked mathematics at the bottom of its list of disciplines, taking 10% out of an already underfunded research grant envelope. That's when I started questioning the status quo, wondering how things can be changed, how to get this country's math community to shake off that negative assessment, and how to move forward. In retrospect, that setback was a blessing in disguise and a great stimulus for our community.

How did the mathematical community react to that setback?

I remember calling Steve Halperin who was then Head of Math at Toronto. I didn't know Steve then, but we quickly realized that we needed a coordinated national effort to get the Canadian mathematical community revitalized. It was the beginning of a great partnership, and a dear friendship. A crucial line of communication and collaboration between Western and Central Canada had been established.

We arranged to meet NSERC's management in Ottawa. Nigel Lloyd, who was then NSERC's Director General for research grants and scholarships, had the wisdom to suggest the establishment of a Math/NSERC Liaison committee. This was a momentous decision. For us, it was the beginning of a long educational process on how the "system" worked. For NSERC, it was—I believe—a step toward making the Council more in tune with the concerns and aspirations of the scientific communities, an attitude adopted fully—and with great success—by Tom Brzustowski who became NSERC's President shortly thereafter.

How did the idea of PIMS emerge and how did you get started?

The CRM and the Fields Institute had been great assets to Quebec and Ontario's mathematics. The Western community—which was growing strong at a fast rate—was, however mostly out of the loop, in spite of occasional valiant efforts by the institute Directors. It was also becoming clear that an institution to support all aspects of the math sciences in Western Canada was overdue. The interactions with NSERC also required involvement and leadership from the West, so it was urgent to create an appropriate vehicle to fill this institutional void.

A small group from UBC, UVic and SFU started meeting regularly. Myself, Ed Perkins, Robert Miura, Jonathan Borwein, Arvind Gupta, Brian Alspach, Reinhard Illner to name a few. Barry McBride, then Dean of Science at UBC, and his counterpart at SFU, Colin Jones, were intrigued by our amateurish efforts. Their support was strong and crucial and we took off. In 1995, an executive committee was formed to start the groundwork. I was appointed first PIMS director in September 1996.

It is common knowledge that the early days of PIMS were difficult and controversial. How did things develop?

Our first attempt to secure federal funding was through NSERC's research network programme. So, I coordinated an initiative to develop the "National Network for Collaboration in the Mathematical Sciences" (NNCMS) consisting of the—then already NSERC funded—CRM and Fields, with a proposal to fund the nascent PIMS, but also two regional associations: AARMS in Atlantic Canada and CAARMS in the prairies. After a long year of hard work and sustained efforts by many selfless colleagues like Don Dawson, Ed Perkins and Francois Lalonde, NSERC's decision was negative. We had failed again!

NSERC however provided us with an interim grant of $200K per year for 1997 and 1998 to keep the effort of building PIMS alive. Tom Brzustowski, Nigel Lloyd and others at NSERC management were able to see what the notoriously conservative peer review process couldn't: that the innovative potential of this intellectual mass movement deserved a chance. They believed in the vision and deserve lots of credit for keeping it alive. Encouraged also by an extremely positive international review of Canadian mathematics, they allowed PIMS access to the institutes envelope at the next competition. This came in 1998, where the review was positive but the accompanying funding decision was again met by widespread disappointment from an exhausted PIMS community. NSERC's management came again to the rescue and their investment paid off. Three short years later, PIMS was the big winner of the 2002 re-allocations exercise with a 60% increase in its NSERC budget.

There were also other challenges to be faced in order to get the provincial governments of BC and Alberta, the private sector and the universities to believe in our mission. They are now the institute's greatest supporters.

How did the MITACS network emerge?

The 3 institutes wanted to develop industrial outreach but their budgets were ridiculously inadequate for covering all the aspects of their proclaimed mandates: Research, Training, HQP, Education, Industrial outreach, Communication and Awareness!!! Now that's a tall order for any institution. The NSERC budgets for Fields and CRM were about $800K each, while PIMS' was $200K! So, right after our failure to fund the NNCMS as an NSERC's research network, I approached Don Dawson—who was then the Director of the Fields Institute—with the idea of developing an NCE (Network of Centres of Excellence). This was the "big league” for a scientific community whose average individual research grant is $14,000, and many colleagues were skeptical. The hard work of PIMS towards developing industrial outreach, and the investment of the math community in the NNCMS project came in handy. MITACS was funded at $14.4M for 4 years (1999–2003).

You just returned from the BIRS inaugural ceremony. How did this project come into existence?

After a visit to Luminy near Marseilles, France in November 1999, I realized that the time for a North American Oberwolfach had come. The PIMS' Board of Directors gave the go-ahead in the Spring of 2000 and we were on our way. By that time, PIMS had a track record and had earned the trust of many governments and granting councils. The support of Lorne Taylor, Alberta minister for Science and Innovation and Bob Church, Chair of ASRA, came early. Tom Brzustowski—who knew of Oberwolfach—was also a believer and Nigel Lloyd facilitated our first contacts with the NSF management. A phone call to MSRI’s Director David Eisenbud sealed a great partnership between the two institutes. We were fortunate to have Rita Colwell at the helm of NSF, and Philipe Tondeur as the division director, both great believers in the important role of mathematics within the sciences. I am particularly proud of the recruitment of Robert Moody as BIRS’ first scientific director. Besides his obvious scientific credentials, his personal commitment to the project was a huge bonus.

You have been an active member of the scientific community. What would you characterise as your main contribution?

More important than PIMS, MITACS, BIRS or any other development in this explosive period of growth, is—in my mind—the dramatic change in attitude and the new state of mind of the Canadian math community. We learned that we can and should think big, think globally, change outdated and often flawed perceptions about mathematical research and education, be an integral part of the country's global R&D effort, and play a leading role on the international level. It was a period where the community learned to confidently look outward, to put forward bold visions and to lead.

Tell us about people who have had a defining impact on you and your work.

This is tricky as there are literally dozens of people to whom I owe in friendship, support, mentorship and help. I will however venture a few names.

No accomplishment is possible without the support of the home institution and Barry McBride’s support was crucial. He was also a mentor and a friend. Our community’s message and its reactions to certain NSERC decisions were not always polished, but Tom Brzustowski and Nigel Lloyd saw the potential and found a way to empower the movement and to let it explode in innovation and creativity. With that they earned our respect and admiration. You cannot lose by having Dick Peter as a believing partner: a giant heart in a man of steel. No crisis could be dissipated without the calm and methodical approach of Ed Perkins, a trusted friend of more than 25 years. Nothing has been more comforting than the brotherly affection and counsel of Arvind Gupta. Steve Halperin's friendship coupled with his experience and wisdom made the building process fun and formative. The dignified ways of Don Dawson, the thoroughness and dedication of Bob Moody, the pleasant yet determined personality of Luc Vinet, the gentle demeanor yet steely resolve of Dave Eisenbud, the calm leadership of Richard Kane... were all quite an inspiration.

What is your next project?
Building Human Capital for Canada’s R&D effort.

How would you characterize your style of leadership and management?

Develop resources and opportunities faster than people can ask for them. Identify the people with ideas, energy and commitment and give them all the support you can muster. Never say No to anybody with a good, innovative and “non self-centric” initiative. Do not believe in zero-sum games. Only make offers that university administrators, granting councils, government officials, policy makers, and industrial partners cannot refuse.

What is your next project?

Building Human Capital for Canada’s R&D effort. We now have adequate infrastructure and resources to support a whole array of scientific programs. However, Canada is in need of a major infusion of mathematical and computational expertise. The math sciences are evolving rapidly and their applications to new areas of technology are multiplying at a dizzying rate. In that direction, we are presently working on an exciting initiative focussed on those aspects of mathematics that are playing an increasingly central role in emerging areas of science and technology.

Our initial goal is to lay out the intellectual framework and an implementation plan for a distributed National Laboratory in Canada, consisting of about 100 researchers, half of whom would be on the staff of Canada’s National Research Council (NRC), while the other half will be faculty members at some of the Canadian universities. They would be supported by the CRM, Fields and PIMS, which will provide some of the required scientific infrastructure. The lab would have groups in areas such as computational biology, modelling of materials and fluids, environment and climate, high performance computing, stochastic modelling and finance.

This is being done in close collaboration with NSERC and the NRC. At the present time, a steering commitee consisting of myself, Ken Davidson (Director,Fields), Jacques Hurtubise (Director, CRM), Isabelle Blain (Vice-President, NSERC), Peter Hackett (Vice-President, NRC). We are being helped by an impressive international advisory panel consisting of: Rick Durrett (Cornell), Pierre-Louis Lions (College de France), Alain Bensoussan (Paris-Dauphine), David McLaughlan (NYU), Avner Friedman (Ohio State), Doug Arnold (Minnesota), Jose Scheinkman (Princeton), Michael Waterman (UCLA), and Bill Pulleyblank (IBM). This exciting enterprise is destined to shape Canada's efforts in building mathematical and computational expertise, for the next twenty years.

Why have you decided to step down now?

PIMS is now well anchored and its funding is as secure as can be. Most of the institute’s grants have been renewed for a 2 or 4 year period starting in April, 2003. The BIRS grants from the NSF, ASRA and NSERC have also been secured for 3 years starting in April. MITACS is in good hands and has also been renewed. The Canadian mathematical community has never been stronger, more confident and in the thick of the Canadian research enterprise. It is a good time to step back and enjoy.

BIRS Inaugural Celebration

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Also present were members of the PIMS Executive and Board of Directors, the MSRI Academic Sponsors and Board of Trustees, and the MITACS Board of Directors and Research Management Committee.

Bob Church, Chair of the Alberta Science and Research Authority (ASRA)

Many leaders of the Canadian and U.S. mathematical sciences community attended, including **Doug Arnold** (Director, IMA), **Ken Davidson** (Director, Fields Institute), **Jacques Hurtubise** (Director, CRM), **James Ramsay** (President, SSC), **Christiane Rousseau** (President, CMS), **Sam Shen** (President, CAIMS), **Michael Singer** (Acting Director, MSRI) and **Philippe Tondeur** (former Director, Mathematical and Physical Sciences, NSF).

The Scientific Programme, chaired by BIRS Scientific Director **Robert V. Moody** of the University of Alberta, took place in a packed Margaret Greenham Theatre to open the celebrations on Friday afternoon.

Nobel laureate, mathematician and economist **James Heckman** of the University of Chicago spoke on *The Economics & the Mathematics of the Pricing of Quality*. Dr. Heckman was introduced by his long-time collaborator and new Canada Research Chair at U.B.C., **Ivar Ekeland**.

Robert Moody, BIRS Scientific Director

Next, the audience was treated to a witty lecture entitled *The Chaotic Evolution of Newton's Universe* given by **Donald Saari**, Distinguished Professor of Mathematics and Economics and Director of the Center for Decision Analysis at the University of California, Irvine. Dr. Saari had recently visited the University of Victoria as a PIMS Distinguished Chair. He was introduced by **David Eisenbud**, Director of the Mathematical Sciences Research Institute in Berkeley, CA.

The Scientific Programme concluded with a presentation by **Jay Ingram**, host of the television science daily @Discovery.ca. His presentation, *A Talk by Someone Who got 68 in Calculus*, ranged from the hilarious to the sombre as he mused on the hopes and expectations of communicating science, especially mathematics, to the general public. Mr. Ingram was introduced by Robert Moody.

Videos of the scientific programme are available on the PIMS website at **www.pims.math.ca/birs/opening/Agenda_BIRS.html**.

Several local high school students and a few members of the media also observed the scientific programme. *MacLean's* magazine printed a feature on BIRS in its March 17, 2003 issue. BIRS was also featured in radio broadcasts and newspaper articles in Ottawa, Edmonton, Banff, and Calgary.

The highlight of the Inaugural Meetings was a banquet on Friday evening. The guests' enjoyment of the delicious meal was augmented by a performance by the Edmonton chamber ensemble **Vivace**. The PIMS Research and Education Prizes for 2002 were presented at the conclusion of the evening. Videos of speeches during the banquet and the PIMS prizes presentations are available on the PIMS website (see **www.pims.math.ca/birs/opening/Agenda_BIRS.html**).

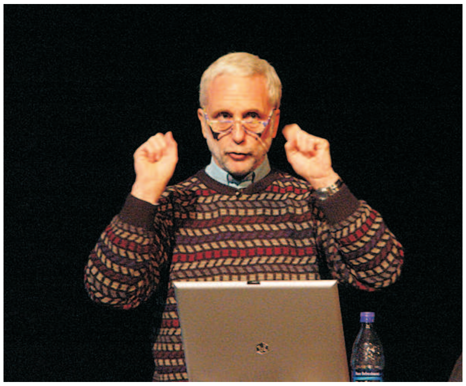
PIMS, MSRI and MITACS took advantage of the gathering to hold Board, Executive and Management Committee meetings, including the first-ever joint meeting of the three Boards. The PIMS Board of Directors meeting was interrupted by a group of deer grazing outside the window…another indication of the marvellous natural setting for BIRS.

The creation of the Banff International Research Station is a collaborative effort between the Pacific Institute for the Mathematical Sciences (PIMS) and the Mathematical Sciences Research Institute (MSRI). Funding comes from the Canadian government through NSERC (grant to PIMS), the Alberta government through ASRiP (grant to PIMS), the U.S. government through NSF (grant to MSRI), and from MITACS. The administration of BIRS is performed by PIMS.

Jean-Claude Gavrel (Director NCE Program) and Tom Brzustowski (President, NSERC)

BIRS is located in Corbett Hall and the Max Bell Building of The Banff Centre in Banff, Alberta. In its first 3 weeks of operations, BIRS has already hosted three full 5-day international workshops and a 2-day workshop of western Canadian analysts. Everyone seems thrilled with the fabulous mountain setting, the rich artistic life of the Banff Centre, and the excellent facilities that BIRS offers for accommodation and meetings. We expect to welcome more than 1700 researchers at 5-day workshops, 2-day workshops, research in teams, focused research groups and summer schools over 40 weeks of operation in 2003. A list of upcoming workshops for 2003 and for 2004, as well as more information on BIRS and how to apply for BIRS programming time, is available on the BIRS website: **www.pims.math.ca/birs/** .

The Scientific Programme of the BIRS Inaugural Meetings



Jay Ingram speaks during the Scientific Programme of the BIRS Inaugural Meetings

The opening of the Banff International Research Station was ushered in by three distinguished speakers of varying backgrounds in this momentous example of international cooperation in scientific research. Economist Dr. James J. Heckman, mathematician Dr. Donald Saari, and television producer and host Jay Ingram joined us for the opening on February 28, 2003 and spoke about the new collaboration between the Mathematical Sciences Research Institute (MSRI) in Berkeley, California, and the Pacific Institute for the Mathematical Sciences.

James Heckman is the Henry Schultz Distinguished Service Professor of Economics at the University of Chicago where he has served since 1973. He holds a parallel appointment as Director of Social Program Evaluation at the Harris School of Public Policy at the University of Chicago, and is also a Senior Research Fellow at the American Bar Foundation.

Heckman's research combines both methodological and empirical interests in evaluating the impact of a variety of social programs on the economy and on the society at large. He has also contributed substantially to the literature both in applied and theoretical econometrics. His methodological work on selection bias and on the evaluation of social programs is widely used, as is his research on the analysis of heterogeneity in consumer preferences and in the analysis of longitudinal data. He also has a series of influential papers on the identifiability of broad classes of econometric models.

David Eisenbud, Director of MSRI and AMS President

Heckman has received numerous honors for his research. He is a fellow of the Econometric Society, a member of the American Academy of Arts and Sciences and of the National Academy of Sciences. He received the John Bates Clark Award of the American Economic Association in 1983 and was awarded the Nobel Prize in Economics in 2000.

Don Saari received his PhD in mathematics from Purdue University and held a post doctoral position in the Yale University Astronomy Department. Until moving to UC at Irvine in July, 2000, Professor Saari was in the mathematics, economics, and applied mathematics departments at Northwestern University where he was the Pancoe Professor of Mathematics and chair of the mathematics department.

His two most recent books (both in 2001) are *Chaotic Elections! A Mathematician Looks At Voting*, American Mathematical Society (AMS), and *Decisions and Elections; Explaining the Unexpected*, Cambridge University Press. Among his editorial positions, he is the Chief Editor of the *Bulletin of the AMS*.

His current research interests centre around applying mathematical notions (primarily from dynamical systems) to decision analysis, voting, mathematical economics, and game theory. And of course, Dr. Saari also has a continued interest in the evolution of the universe, such as the Newtonian N-body problem.

Renowned science broadcaster and writer **Jay Ingram** is a co-host and producer of Discovery Channel's award-winning @discovery.ca, the television world's first and only daily science and nature news magazine. He joined Discovery in November, 1994 and was instrumental in helping shape the program format.

Donald Saari and Nobel Laureate James J. Heckman

Prior to joining Discovery, Ingram hosted CBC Radio's science program *Quirks And Quarks*, from September 1979 to January 1992. During that time, he earned two ACTRA Awards, including one for Best Host. The program also garnered a variety of Canadian Science Writers' Awards. In 1993, Ingram hosted The Talk Show, a CBC Radio series about language which also won a Science in Society Journalism Award. Following that, Ingram presented items on the brain for the CBC television show The Health Show and contributed regular weekly science features for CBC Newsworld's Canada Live (1993-94). Ingram is also the author of three children's science books, a contributing editor for Owl magazine, and weekly science column contributor for the Toronto Star.

Ingram has been awarded The McNeill Medal and the Sandford Fleming Medal (both for the popularization of science), the Michael Smith Award, and honorary doctor of science degrees from McGill University and Carleton University. He is also a Distinguished Alumnus of the University of Alberta, and was—for the spring semester of 2002—a Distinguished Visiting Journalist at the University of Western Ontario.

PIMS Distinguished Chairs in Fall 2002

Donald Saari

In September 2002, **Donald Saari** delivered a series of five lectures at the University of Victoria as a PIMS Distinguished Chair. Saari is a Distinguished Professor of Mathematics and Economics and Director of the Center for Decision Analysis at the University of California, Irvine, and the former Arthur and Gladys Pancoe Professor of Mathematics and Professor of Economics at Northwestern University. He is recognized for his important contributions to the theory of dynamical systems and to the social sciences.

In his research Saari uses mathematical models to analyze a wide variety of social phenomena: politics, markets, and intra-organizational behaviour. He made significant advances in celestial mechanics, in which Saari's conjecture—proposed in 1970 and now a landmark in the field—is still unsolved. Saari is a member of the National Academy of Sciences.

His lectures at the University of Victoria were presented to a broad general audience and showed how interesting mathematics can be generated by questions coming from the social sciences.

Mathematical Social Sciences, an Oxymoron? presented how basic questions from the social sciences lead to new mathematics or new uses of mathematics. The talk emphasized how hidden symmetries influence everyday decision making.

Singularity Theory and Departmental Discussions dealt with simple models of basic decision theory, connecting it with singularity theory and with some unresolved questions from the n-body problem of celestial mechanics.

Evolutionary Game Theory; Examples and Dynamics explained why dynamical systems are becoming an important tool for handling the new area of evolutionary game theory. The conclusions for game theory can be surprising. The impact for dynamical systems is that new structures are found.

Chaotic Dynamics of Economics refuted Adam Smith's invisible hand theory through a careful mathematical examination, which showed that chaos is more likely than stability in economics models.

Dynamics, Symmetry, and the Social Sciences concluded the lecture series by showing other uses of dynamics and symmetry in understanding basic concerns coming from the social sciences. One of the issues discussed was Arrow's theorem and a new way of interpreting it.

The lectures were widely attended by faculty, PDFs, graduate and undergraduate students from the mathematics and the economics departments, visitors from other universities, and several members of the general public. Long and interesting discussion followed after every talk. This has been a highly rewarding experience for all those who attended. A video recording of the lectures and a written version of the notes are available on the PIMS website.

During November 2002 **Klaus Schmidt**, who is a Professor at the Mathematics Institute of the University of Vienna, and the Director of the Erwin Schrödinger Institute for Mathematical Physics, gave a series of five talks at the University of Victoria.

The talks were about Algebraic Z^d-actions and covered the following topics: Z^d-actions by automorphisms of compact abelian groups, general theory, higher order mixing, homoclinic points and the symbolic representations of algebraic Z^d-actions, and rigidity properties.

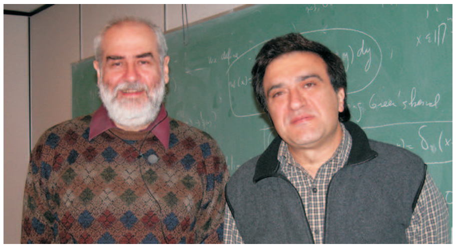
Klaus Schmidt was the winner of the 1993 Ferran Sunyer i Balaguer Prize. He was a founding editor of the journal *Ergodic Theory and Dynamical Systems* and is a member of the Austrian Academy of Sciences.

At the start of November 2002 **Gunther Uhlmann** (University of Washington) gave three two-hour talks at UBC. The topics were *inverse boundary and inverse scattering problems*. Inverse boundary problems are a class of problems in which one seeks to determine the internal properties of a medium by performing measurements along the boundary of the medium. These inverse problems arise in many important physical situations, ranging from geophysics to medical imaging to the non-destructive evaluation of materials. The appropriate mathematical model of the physical situation is usually given by a PDE (or a system of such PDEs) inside the medium. The boundary measurements are then encoded in a certain boundary map, usually called the Dirichlet-to-Neumann (DN) map. The inverse boundary problem is to determine the coefficients of the PDE inside the medium from knowledge of the boundary map. In inverse scattering problems, in which the observations are made far from the medium, the information is encoded in the scattering amplitude. The inverse scattering problem is to determine the medium properties from this information.

The first two lectures discussed the prototypical example of an inverse boundary problem, the inverse conductivity problem, also called electrical impedance tomography, whose mathematical formulation is due to A. P. Calderón. In this case the DN map is the voltage to current map; that is, the map assigns to a voltage potential on the boundary of a medium the corresponding induced current flux at the boundary of the medium. The inverse problem is to recover the electrical conductivity of the medium from the DN map. Gunther Uhlmann discussed the role of complex geometrical optics solutions in solving this inverse problem.

The first part of the last lecture described a solution of the inverse scattering problem at a fixed energy in dimension three or larger by reducing the problem to the study of the set of Cauchy data for the Schrödinger equation for a large ball. In the second half recent progress was discussed on an inverse boundary problem arising in geophysics and rigidity questions in Riemannian geometry. The problem is to determine a Riemannian metric on a compact Riemannian manifold with boundary by measuring the lengths of geodesics (travel times) joining points of the boundary.

These lectures series may be watched in real video format at **www.pims.math.ca/video/mini/**.



Gunther Uhlmann and Nassif Ghoussoub

Activities of the Periods of Concentration in 2003

Period of Concentration on String Theory

The first activity of this Period of Concentration was a BIRS workshop on *Recent Developments in String Theory*, held March 15–20, 2003. This workshop, which was the first held at BIRS, was a forum for discussion and development of new ideas in the interface between superstring theory, mathematics and modern theoretical physics. A key aim was to promote interdisciplinary work, by bringing together active researchers working at research frontiers from both the mathematics and physics communities. The workshop was organized by Jim Bryan (UBC), Steve Giddings (UC, Santa Barbara), Mikhail Kapranov (U. Toronto), Andreas Karch (U. Washington), Amanda Peet (U. Toronto), Moshe Rozali (UBC), Gordon Semenoff (UBC), Mark Van Raamsdonk (UBC), and K. Viswanathan (SFU).

Frontiers of Mathematical Physics Summer School on Strings, Gravity & Cosmology

PIMS-UBC, July 14–25, 2003

The major event of 2003 will be the *Frontiers in Mathematical Physics Summer School on Strings, Gravity & Cosmology*. While this will be the seventh year that PIMS has co-sponsored the Frontiers in Mathematical Physics Workshop, the format has been expanded and converted into a Summer School for the String Theory Period of Concentration.

This Summer School will focus on the most recent developments in string theory. It is aimed at graduate students and postdoctoral fellows who study string theory and its interrelations with other subjects in theoretical physics, from early universe cosmology to algebraic geometry.

In continuation of last year's collaboration the school is cosponsored by PIMS, the Asia Pacific Institute for Theoretical Physics (APCTP), and the Perimeter Institute for Theoretical Physics. Additional support is provided by TRIUMF.

Invited Speakers:
V. Balasubramanian (U. Pennsyvania)
M. Berkooz (Weizmann Institute)
R. Brandenberger (Brown University)
M. Dine (UC, Santa Cruz)
D. Kutasov (University of Chicago)
Y. Makeenko (ITEP, Moscow)
A. Marshakov (Lebedev Inst., Moscow)
R. Myers (Perimeter Institute)
V. Schomerus (Saclay)
A. Sen (Harish-Chandra Institute)
***S. Sethi** (University of Chicago)
***L. Susskind** (Stanford University)
***H. Tye** (Cornell University)
M. Van Raamsdonk (Standford/UBC)
P. Yi (KIAS)
* to be confirmed.

Organizing Committee:
Taejin Lee (APCTP)
John Ng (TRIUMF, UBC)
Moshe Rozali (UBC)
Alexander Rutherford (PIMS)
Gordon W. Semenoff (UBC)

For registration and further information please see **www.pims.math.ca/science/2003/fmp/.**

In the Fall of 2003, another Pacific Northwest Seminar in String Theory will be held at PIMS-UBC. This will be the third in this highly successful series of 2–3 day meetings. As the programme of this meeting is being developed, it will be posted at **www.pims.math.ca/science/pnw/pnwstring.html**. Links to previous PNWST seminars may also be found there.

During this summer, **Ashoke Sen** (Harish-Chandra Research Institute) will hold a PIMS Distinguished Chair as part of this Period of Concentration. While at PIMS-UBC, he will give a series of lectures, which will be linked to some of the mini-courses in the FMP Summer School.

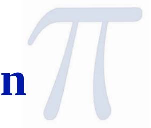
Professor Sen's significant contributions to string theory include his early work on string field theory, duality symmetries, and black hole solutions. This led him to the study of strong-weak coupling duality of supersymmetric gauge theories. His proof of the existence of the conjectured bound states required by those dualities is now one of the classic works in the field. This work has had enormous influence and is usually credited as the start of the "second superstring revolution"—a shift of perspective which the field is still undergoing. In 1998, Professor Sen initiated the study of non-supersymmetric states in string theory. Once again, this has proven to be a very fruitful study. Most recently, he has returned to the study of string field theory in the context of tachyon condensation on D-branes. This has led to his current work on the cosmological consequences of tachyon condensation.

Two PIMS Postdoctoral Fellowships have been awarded as part of the String Theory Period of Concentration. During 2003–04, Ehud Schreiber and Kengo Maeda will hold fellowships at PIMS-UBC.

Faculty of the CRG:
Group Leaders: Gordon Semenoff (UBC), Eric Woolgar (U. Alberta)
U. Alberta: B. Campbell, V. Frolov, D. Page (Physics), T. Gannon (Math)
UBC: M. Rozali, M. Van Raamsdonk, K. Schleich, D. Witt, M. Choptuik, W. Unruh (Physics and Astronomy), J. Bryan, K. Behrend (Math).
U. Lethbridge: M. Walton (Physics)
Perimeter Institute: R. Myers, L. Smolin
SFU: K. Viswanathan (Physics)
U. Toronto: A. Peet (Physics)
U. Washington: A. Karch (Physics)

The String Theory CRG webpage is at **www.pims.math.ca/CRG/string/**. Further information and a preliminary list of activities for 2004–05 may be found there.

Period of Concentration on Number Theory



Number theory is one of the oldest, deepest and most vibrant branches of modern mathematics. It centrally incorporates some of the most sophisticated and profound mathematical ideas that have been been developed and yet remains broadly useful in many areas of pure and applied mathematics. A notable recent example is the field of cryptography and internet security, whose protocols are based on number theoretic problems.

The first workshop of a busy programme will be the *Many Aspects of Mahler's Measure Workshop*, held at BIRS on April 25–May 1. This workshop will explore the many apparently different ways in which Mahler's measure appears in different areas of mathematics. It will bring together experts specializing in many different fields: dynamical systems, K-theory, number theory and topology, with the hope that common threads will emerge from the interaction between the participants.

The organizers of this workshop are David Boyd (UBC), Doug Lind (U. Washington), Fernando Rodriguez Villegas (U. Texas, Austin), and Christopher Deninger (U. Meunster).

PIMS at Simon Fraser University will host a summer school on Mahler's Measure, which will be a follow up to the BIRS workshop.

Mahler's Measure of Polynomials

PIMS-SFU, June 2–29, 2003

Mahler's measure for polynomials in many variables was introduced by him as a device to provide a simple proof of Gelfond's inequality for the product of polynomials in many variables. It has turned out to have a much more fundamental signifigance. The starting point was the proof in the late 1970's that the Mahler measure of a several variable polynomial is the limit of the Mahler measure of one variable polynomials. The limit theorem was used by Lind, Schmidt and Ward in their proof that the logarithmic Mahler measure is the entropy of a Z^d action. Recently Deninger has shown that the Mahler measure of a many variable polynomial is related to Beilinson's higher regulators. Since then Boyd, Rodriguez-Villegas and others have explored this connection with K-theory. Some of these results can be regarded as verifications of conjectures of Kontsevich and Zagier in their general theory of periods. In another direction, connections have been found between the Mahler measure of certain two variable polynomials called A-polynomials and invariants of hyperbolic 3-manifolds such as the volume and Borel regulator. There is an intriguing conjecture of Chinburg about realizing special values of Dirichlet L-functions as logarithmic Mahler measures that seems to have a close connection to the study of the A-polynomials of arithmetic hyperbolic manifolds.

The first week of this summer school will consist of an intensive graduate course taught by **Stephen Choi** (SFU). This course will prepare the students for the series of lectures to be given by **Jeffrey D. Vaaler**, the holder of the PIMS Distinguished Chair in Number Theory.

A focused workshop will be held in the third and fourth weeks of the programme.

Organizing Committee:
Stephen Choi (Chair, SFU)
Peter Borwein (SFU)
Imin Chen (SFU)
Ron Ferguson (PIMS and MITACS)

For further information, please see **www.pims.math.ca/science/2003/mahler/.**

In late summer, a second BIRS workshop on number theory will be held. The Workshop *Current trends in Arithmetic Geometry and Number Theory*, August 16–21, 2003, will focus on the many recent developments in number theory that have relied crucially on the use of p-adic methods.

The organizers of this workshop are Imin Chen (SFU), Brian Conrad (U. Michigan Ann Arbor), Eyal Goren (McGill), Adrian Iovita (U. Washington), Chris Skinner (U. Michigan, Ann Arbor) and Nike Vatsal (UBC).

The summer 2003 holder of the PIMS Distinguished Chair in Number Theory is **Jeffrey D. Vaaler** of the University of Texas at Austin. He is a prominent analytic number theorist and one of the world experts on Mahler's measure problems. He will deliver a series of 4 lectures on Mahler's measure at PIMS-SFU:

June 12: *Equivalence of Lehmer's conjecture and a conjecture of Schinzel on the number of irreducible factors of a polynomial*.
June 17: *A new form of the ABC inequality for heights*.
June 18: *Estimates for the number of polynomials with small Mahler measure*.
June 19: *An extension of the classical Schanuel estimates for the number of algebraic numbers of fixed degree over a number field and bounded Weil height*.

These lectures will be taped and made available at **www.pims.math.ca/video**.

The second Distinguished Chair in Number Theory will be held by **Sergei Konyagin** of Moscow State University, who will visit UBC from March 1–May 1, 2004. Winner of the Salem Prize in 1990, Prof. Konyagin has made numerous significant contributions in number theory, approximation theory and harmonic analysis.

Postdoctoral fellows in the Number Theory CRG are Ron Ferguson (MITACS/PIMS PDF at SFU, 2002–03), William Galway (PIMS PDF, 2002–03 at SFU), Alexa van der Waall (MITACS PDF, 2002–03 at SFU), Ben Green (PIMS PDF, 2003–04 at UBC), Friedrich Littman (PIMS PDF, 2003–05 at UBC) and Christopher Rowe (PIMS PDF, 2003–05).

Faculty of the CRG:
Group Leaders: Peter Borwein (SFU), David Boyd (UBC)
UBC: Michael Bennett, David Boyd, Bill Casselman, Rajiv Gupta, Izabella Laba, Greg Martin, Nike Vatsal
SFU: Peter Borwein, Imin Chen, Stephen Choi, Petr Lisonek
U. Calgary: Richard Guy, James P. Jones, Richard Mollin, Renate Scheidler,Hugh Williams
U. Alberta: James D. Lewis
U. Washington: Ralph Greenberg, Adrian Iovita, Neal Koblitz, Boris Solomyak
Other institutions: Amir Akbary (U. Lethbridge), Edward Dobrowolski (College of New Caledonia), Matt Klassen (DigiPen Inst. of Tech.), Kristin Lauter (Microsoft)

The Number Theory CRG webpage is at **www.pims.math.ca/CRG/number**. Further information and a preliminary list of activities for 2004–05 may be found there.

Period of Concentration on Scientific Computing

Scientific computing has become essential to solving many real-world problems.

It is used in:

- modelling of physical, chemical and biomedical phenomena
- designing engineered parts, structures, and systems to optimize performance
- planning and managing financial and marketing strategies
- understanding and optimizing manufacturing processes.

Problems in these areas arise in the manufacture of a host of industrial and consumer products such as aircraft, automobiles, engines, textiles, computers, communications systems, chemicals and drugs as well as in various service and consulting organizations. They also arise in many national and international initiatives such as global change, biotechnology, and advanced materials.

In February, the Scientific Computing CRG hosted senior undergraduate students from across Canada for the Fourth IAM-CSC-PIMS Senior Undergraduate Math Modelling Workshop. At UBC, **Chen Greif** (Computer Science, UBC) introduced the students to *Image restoration using PDE-based methods* and **Rachel Kuske** (Math, UBC) introduced the students to *Optimal scheduling policies in networks with multi-task servers*. At SFU, **Ljiljana Trajkovic** (Computer Science, SFU) presented problems in the *Characterization of Internet traffic and its impact on network performance* and **Peter Berg** (MITACS, SFU) taught the students about *Pedestrian flow and cellular automata*.

The Scientific Computing Period of Concentration will feature two workshops at BIRS during 2003. The first will be the *Workshop on Computational Fuel Cell Dynamics*, held April 19–24. This workshop is particularly timely, because the world's major automotive manufactures are currently engaged in an historic race to develop Proton Exchange Membrane (PEM) fuel cells as clean, high-efficiency alternatives to internal combustion engines for automotive power. PEM fuel cell technology not only holds out the promise of a more environmentally friendly automobile, but also of an extremely versatile power generation system with a broad spectrum of applications. This workshop is a continuation of the first Computational Fuel Cell Dynamics Workshop, hosted by PIMS and Ballard Power Systems at Simon Fraser University in June 2001. The organizers of this workshop are John Kenna (Ballard Power Systems), Trung Van Nguyen (U. Kansas), Keith Promislow (SFU), and Brian Wetton (UBC).

The BIRS Workshop on C*omputational Techniques for Moving Interfaces* will be held August 23–28. Currently some of the most difficult problems in computational science involve moving interfaces between flowing or deforming media. Exciting research is currently underway in the development of better algorithms to address these problems.

This workshop will address the accuracy of these algorithms and their application to specific scientific and engineering problems. It is being organized by Randy LeVeque (U. Washington), Robert D. Russell (SFU), and Steven Ruuth (SFU)

In addition to the activities at BIRS, PIMS-UBC will host the following workshop, which will be more in the style of a summer school.

Numerical Linear Algebra and Applications
PIMS-UBC, August 4–8, 2003

This workshop will focus primarily on topics in numerical linear algebra. Topics that will be covered include Krylov subspace solvers, solutions of indefinite linear systems, preconditioning techniques, and techniques for solving ill-posed problems. In addition, it will cover areas of research and applications of scientific computing that are closely related but are not exclusively within the category of numerical linear algebra. These include numerical solution of elliptic partial differential equations, and numerical optimization. The main focus will be on survey talks and tutorials. A couple of short courses will be offered as well. The talks will be accessible to graduate students and postdoctoral fellows who are not necessarily experts in the field, but do have a solid background in scientific computing.

Invited Speakers:
Anne Greenbaum (U. Washington)
Peyman Milanfar (UC, Santa Cruz)
Iain Duff (CERFACS, France)
Gene Golub (Stanford University)
Alison Ramage (Strathclyde University, Scotland)
Edmond Chow (Lawrence Livermore National Laboratory)
Michael Overton (New York University)
Uri Ascher (UBC)
Eldad Haber (Emory University)
Xiao-Wen Chang (McGill University)

This workshop is being organized by Chen Greif (UBC). For registration and further information, please see **www.pims.math.ca/science/2003/numerical**.

An ongoing activity of the Scientific Computing CRG is the PNW Numerical Analysis Seminar Series. Information about these seminars may be found at **www.pims.math.ca/science/pnw/pnwnas.html**.

To date **Jian-Jun Xu** has been awarded a PIMS Postdoctoral Fellowship in Scientific Computing at Simon Fraser University. A second fellowship will be awarded in the near future.

Faculty of the CRG:
Group Leaders: Steve Ruuth (SFU), Manfred Trummer (SFU), Chen Grief (UBC), Randy Leveque (U. Washington), Yanping Lin (U. Alberta), Elana Braverman (U. Calgary)
SFU: R. Choksi, M.C. Kropinski, T. Möller, D. Muraki, K. Promislow, B. Russell, L. Trajkovic, J. Verner, R. Zahar.
UBC: U. Ascher, O. Dorn, S. Dunbar, I. Frigaard, A. Peirce, B. Seymour, B. Shizgal, J. Varah, M. Ward, B. Wetton, M. Yedlin
U. Alberta: J. Macki, P. Minev, Y.S. Wong
U. Calgary: T. Ware, R. Westbrook
U. Victoria: D. Olesky, P. van den Driessche
U. Washington: L. Adams, D. Durran, A. Greenbaum, G. Hakim, N. Kutz, R. O'Malley, P. Schmid, J. Burke, C. Bretherton
Ballard Corporation: R. Bradean, J. Kenna
Boeing Corporation: J. Lewis, S. Filipowski, M. Epton
Quadrus Financial Technologies: S. Reddy

The Scientific Computing CRG webpage is at **www.pims.math.ca/CRG/scientific/**. Further information and a preliminary list of activities for 2004–05 may be found there.

Period of Concentration on Dynamics and Related Areas

The study of dynamical systems has had a long and distinguished history in mathematics. This study has ranged from applications involving differential equations and information theory, to more theoretical work focusing on systems with topological or algebraic structure. During the last century, deep and fruitful connections were developed between dynamics and operator algebras. In recent years, interactions between topological dynamics and C*-algebras has grown with the development of tools in Connes's program for non-commutative geometry. This has been particularly evident in the theory of aperiodic order, largely through Bellissard's work connecting tilings, C*-algebras, K-theory, and solid state physics and the recent solution of the so-called gap-labeling problem. This field continues to grow dramatically, and completely new directions are being opened up.

During 2003, this Period of Concentration features two meetings at BIRS. The first was the two-day BIRS *Northwest Functional Analysis Symposium*, held on March 27–29, 2003. This symposium was organized by Michael Lamoureux (U. Calgary), Tony Lau (U. Alberta), Ian Putnam (U. Victoria), and Nicole Tomczak-Jaegermann (U. Alberta).

Ian Putnam (U. Victoria) the co-leader of the CRG on Dynamics and Related Areas

The second BIRS event on dynamics will be the five-day workshop, C*oordinate Methods in Nonselfadjoint Operator Algebras*, held on December 13–18, 2003. This workshop will investigate a family of related techniques that have been developed by researchers studying diverse nonselfadjoint algebras. These techniques, which exploit the existence of a diagonal *-subalgebra sitting inside the larger non-*algebra under consideration, fall under the general term of "coordinate methods", because this diagonal algebra can be used to provide a coordinatization, or decomposition, of the full algebra, from which properties and characterizations of the larger algebra may be fully described. The objective of this workshop is to unify and broaden the technical machinery of coordinate methods to a wide class of nonselfadjoint operator algebras. The organizers of this workshop are Allan Donsig (U. Nebraska) and Michael Lamoureux (U. Calgary).

Recently, **Klaus Schmidt** of the University of Vienna held the PIMS Distinguished Chair in Dynamical Systems at the University of Victoria, where he gave five lectures on algebraic Z^d-actions. He has contributed a summary article on his lectures to this issue of the PIMS Magazine. His lectures may be viewed online at **www.pims.math.ca/science/2002/distchair/schmidt/**.

The 2003 holder of the PIMS Distinguished Chair in Dynamics at the University of Alberta is **Alexander Helemskii** of Moscow State University. Prof. Helemskii will give a series of four lectures at the University of Alberta.

July 25: *Projective modules in Banach and quantized homology*.
July 26: *Projective Hilbert modules over operator algebras*.
August 9: *Projective homological classification of C*-algebras*.
August 11: *Biprojective algebras and homological dimensions*.

While visiting the University of Alberta, he will also chair one of the workshops in the PIMS Conference on Banach Algebras and their Applications. More information on this conference is available at **www.pims.math.ca/science/2003/banach/**.

The first PIMS Postdoctoral Fellowship in Dynamics has been awarded to **Mario Roy**, who will work at the University of Victoria. A second fellowship will be awarded in the near future.

Faculty of the CRG:
Group Leaders: Ian Putnam (U. Victoria), Doug Lind (U. Washington)
U. Alberta: Robert Moody, Anthony Lau, Volker Runde, Al Weiss
UBC: Brian Marcus
U. Calgary: Michael Lamoureux, Berndt Brenken, Igor Nikolaev
U. Washington: Christopher Hoffman, Douglas Lind, Steffen Rohde, Boris Solomyak, Selim Tuncel, Manfred Einsiedler.
U. Victoria: John Phillips, Marcelo Laca, Chris Bose, Rod Edwards
Visitors and Other Contributors: Klaus Schmidt (Vienna), Mike Boyle (Maryland), Christopher Denninger (Muenster), William Parry (Warwick), Daniel Rudolph (Maryland).

The Dynamics and Related Areas CRG webpage is at **www.pims.math.ca/CRG/dynamics/**. Further information and a preliminary list of activities for 2004–05 may be found there.

Douglas Lind (U. Washington) the co-leader of the CRG on Dynamics and Related Areas

Period of Concentration on Mathematical Ecology

As the current revolution in biological information progresses, there is a well recognized need for new quantitive approaches and methods to solve problems in ecology. One mathematical challenge is to model complex ecological systems, which depend upon a myriad of inputs. However, often there are only incomplete details available regarding these inputs. Such systems range from spatial disease dynamics (eg. influenza, tuberculosis, SARS) to the response of biota to global environmental change (eg. vegetation shifts and the impact of fragmentation on species survival).

Historically, mathematical modelling in biology has provided fundamental scientific advances. As early as the 1950's, major quantitative breakthroughs allowed scientists to find new ways to understand biological systems. For example, Alan Hodgkin and Andrew Huxley's mathematical modelling of the giant axon of squids using partial differential equations allowed them to deduce and calculate ion-based currents as the basis for electrical impulse transmission in nervous tissue.[1]
They received the 1963 Nobel Prize in Medicine for their ground-breaking research. Other work, ranging from Skellam's models of biological invasions with partial differential equations to Turing's descriptions of morphogenesis using spatially coupled dynamical systems have produced results which form the very foundation of our modern-day understanding of these biological processes.

Summer School in Mathematical Ecology and Biology PIMS-UA, April 30–May 9, 2003.

As part of the Period of Concentration, a summer school in Mathematical Ecology and Biology will be held at the University of Alberta.

This summer school will consist of a 10-day intensive mathematical biology course offered to 25 undergraduate students from mathematics or other quantitative sciences from across North America. Typically, students should have completed 2–3 years of undergraduate study (or equivalent) in mathematics or a similar quantitative science. Undergraduates in their third year are especially encouraged to apply. The summer school will have three major components: lectures, computer labs and projects. The instructors at the school are **Mark Lewis**, **Thomas Hillen**, **Gerda de Vries** and **Frithjof Lutscher** from the Department of Mathematical and Statistical Sciences at the University of Alberta. For further information on the Summer School, please see **www.math.ualberta.ca/~mathbio/summerschool/**.

Later in the summer, there will be a BIRS Workshop on *Mathematical Biology: From molecules to ecosystems—The legacy of Lee Segel*. The unifying theme of this workshop is the work and contributions of **Prof. Lee Segel.** The participants will include a number of colleagues, peers, former students, and luminaries who have either worked with Prof. Segel, or who share his wide and diverse interests in mathematical biology. Another interesting aspect of this workshop is that it will be uniquely poised to showcase the spectacular evolution of mathematical biology over the past three or more decades, from marginalized esoteric areas to centre stage. The organizers of this workshop are Leah Keshet (UBC), Simon A. Levin (Princeton) and Mark Lewis (U. Alberta).

Bryan Grenfell of the University of Cambridge will hold the PIMS Distinguished Chair in Mathematical Ecology during September, 2003 at the University of Alberta. Prof. Grenfell is a preeminent mathematical epidemiologist whose specialty is analysis of patterns in epidemiological data and understanding the spatio-temporal dynamics of diseases and populations using mathematical and statistical models. He was recently awarded the Order of the British Empire for services to epidemiology and the control of infectious diseases. Recent research includes mathematical analysis of foot-and-mouth disease, measles modeling, and analysis of nonlinear population dynamics. Prof. Grenfell's lectures will be taped and made available on **www.pims.math.ca/video.**

Mark Lewis (U. Alberta), one of the Mathematical Ecology CRG Group Leaders. The other leaders are Michael Doebeli (UBC) and Edward McCauley (U. Calgary)

Faculty of the CRG:

Group Leaders: Michael Doebeli (UBC), Mark Lewis (U. Alberta), Edward McCauley (U. Calgary)

U. Alberta: Mark Boyce, Herb Freedman, Thomas Hillen, Subhash Lele, Michael Li, Jens Roland, Joseph So

U. Calgary: Shane Richards

UBC: Fred Brauer, Leah Keshet, Dolph Schluter

SFU: Eirikur Palsson, Bernard Roitberg

U. Victoria: Pauline van den Driessche

U. Washington: James Anderson, Carl Bergstrom, Daniel Grunbaum, Ray Hilborne, Mark Kot

The Mathematical Ecology CRG webpage is at **www.pims.math.ca/CRG/ecology/**. Further information and a preliminary list of activities for 2004–05 may be found there.

Nobel Laureate Sir Andrew Huxley at the PIMS Thematic Programme on Mathematical Biology

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[1] *Prof. Huxley gave a lecture on his work with Hodgkin at PIMS in 1999. This lecture is available online at* ***www.pims.math.ca/science/1999/bio99/huxley/****.*

Algebraic Z^d-Actions

by Klaus Schmidt, University of Vienna and Erwin Schrödinger Institute for Mathematical Physics

This article is based on the notes from the series of lectures Klaus Schmidt gave as a PIMS Distinguished Chair in November 2002 at the University of Victoria.

This series of lectures was devoted to the ergodic theory of $\mathbb{Z}^d$-actions, i.e. of several commuting automorphisms of a probability space. Although such actions have played an important role in physics (for example, in the lattice models of statistical mechanics), the mathematical theory of these actions was hampered by the lack of classes of examples which one could actually analyze systematically.

About 15 years ago a class of $\mathbb{Z}^d$-actions emerged which was rich enough to exhibit a variety of new and unexpected phenomena and yet simple enough to allow detailed investigation: the $\mathbb{Z}^d$-actions by commuting automorphisms of compact abelian groups.

After a few introductory remarks on more general $\mathbb{Z}^d$-actions these lectures focused exclusively on such 'algebraic' $\mathbb{Z}^d$-actions, their sometimes surprising properties, and their connections with algebra and arithmetic.

1 Algebraic $\mathbb{Z}^d$-actions

An *algebraic* $\mathbb{Z}^d$*-action* is an action $\alpha\colon \mathbf{n} \mapsto \alpha^{\mathbf{n}}$ of $\mathbb{Z}^d$, $d \geq 1$, by continuous automorphisms of a compact abelian group X. Pontryagin duality yields a one-to-one correspondence between algebraic $\mathbb{Z}^d$-actions and modules over the ring of Laurent polynomials $R_d = \mathbb{Z}[u_1^{\pm 1}, \dots, u_d^{\pm 1}]$ with integral coefficients in the commuting variables $u_1, \dots, u_d$. In order to see this we write every $f \in R_d$ as $f = \sum_{\mathbf{m} \in \mathbb{Z}^d} f_{\mathbf{m}} u^{\mathbf{m}}$ with $u^{\mathbf{m}} = u_1^{m_1} \cdots u_d^{m_d}$, $f_{\mathbf{m}} \in \mathbb{Z}$ for every $\mathbf{m} = (m_1, \dots, m_d) \in \mathbb{Z}^d$, and $f_{\mathbf{m}} = 0$ for all but finitely many $\mathbf{m}$. If α is an algebraic $\mathbb{Z}^d$-action on a compact abelian group X, then the additively-written dual group $M = \widehat{X}$ is a module over the ring R_d with operation

$$f \cdot a = \sum_{\mathbf{m} \in \mathbb{Z}^d} c_f(\mathbf{m}) \widehat{\alpha^{\mathbf{m}}}(a)$$

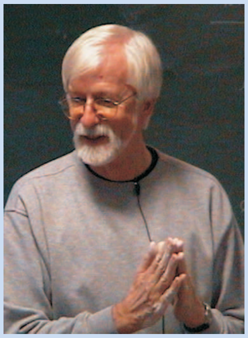
for $f \in R_d$ and $a \in M$, where $\widehat{\alpha^{\mathbf{m}}}$ is the automorphism of $M = \widehat{X}$ dual to $\alpha^{\mathbf{m}}$. In particular, $u^{\mathbf{m}} \cdot a = \widehat{\alpha^{\mathbf{m}}}(a)$ for $\mathbf{m} \in \mathbb{Z}^d$ and $a \in M$. Conversely, any R_d-module M determines an algebraic $\mathbb{Z}^d$-action α_M on the compact abelian group $X_M = \widehat{M}$ with $\alpha_M^{\mathbf{m}}$ dual to multiplication by $u^{\mathbf{m}}$ on M for every $\mathbf{m} \in \mathbb{Z}^d$.

This correspondence between algebraic $\mathbb{Z}^d$-actions $\alpha = \alpha_M$ and R_d-modules M allows one to build a 'dictionary' between dynamical properties of α_M and algebraic properties of the module M. It turns out that

Klaus Schmidt is a Professor at the Mathematics Institute of the University of Vienna and the Director of the Erwin Schrödinger Institute for Mathematical Physics.

He gave series of five talks at the University of Victoria as a PIMS Distinguished Chair in November 2002.

This lectures series may be watched in real video format at **www.pims.math.ca/video/mini/**.



Klaus Schmidt

	Property of α	$\alpha = \alpha_{R_d/\mathfrak{p}}$	$\alpha = \alpha_M$
(1)	α is expansive	$V_{\mathbb{C}}(\mathfrak{p}) \cap \mathbb{S}^d = \varnothing$	M is Noetherian and $\alpha_{R_d/\mathfrak{p}}$ is expansive for every $\mathfrak{p} \in \operatorname{asc}(M)$
(2)	$\alpha^{\mathbf{n}}$ is ergodic for some $\mathbf{n} \in \mathbb{Z}^d$	$u^{k\mathbf{n}} - 1 \notin\subset \mathfrak{p}$ for every $k \geq 1$	$\alpha^{\mathbf{n}}_{R_d/\mathfrak{p}}$ is ergodic for every $\mathfrak{p} \in \operatorname{asc}(M)$
(3)	α is ergodic	$\{u^{k\mathbf{n}} - 1 : \mathbf{n} \in \mathbb{Z}^d\} \not\subset \mathfrak{p}$ for every $k \geq 1$	$\alpha_{R_d/\mathfrak{p}}$ is ergodic for every $\mathfrak{p} \in \operatorname{asc}(M)$
(4)	α is mixing	$u^{\mathbf{n}} - 1 \notin \mathfrak{p}$ for every non-zero $\mathbf{n} \in \mathbb{Z}^d$	$\alpha_{R_d/\mathfrak{p}}$ is mixing for every $\mathfrak{p} \in \operatorname{asc}(M)$
(5)	α is mixing of order $r \geq 2$		For every $\mathfrak{p} \in \operatorname{asc}(M)$, $\alpha_{R_d/\mathfrak{p}}$ is mixing of order r
(6)	α is mixing of every order	Either $\mathfrak{p}$ is equal to pR_d for some rational prime p, or $\mathfrak{p} \cap \mathbb{Z} = \{0\}$ and $\alpha_{R_d/\mathfrak{p}}$ is mixing	For every $\mathfrak{p} \in \operatorname{asc}(M)$, $\alpha_{R_d/\mathfrak{p}}$ is mixing of every order
(7)	A nonempty finite set $S \subset \mathbb{Z}^d$ is α-mixing		For every $\mathfrak{p} \in \operatorname{asc}(M)$, S is $\alpha_{R_d/\mathfrak{p}}$-mixing
(8)	$h(\alpha) > 0$	$\mathfrak{p}$ is principal and $\alpha_{R_d/\mathfrak{p}}$ is mixing	$h(\alpha_{R_d/\mathfrak{p}}) > 0$ for at least one $\mathfrak{p} \in \operatorname{asc}(M)$
(9)	$h(\alpha) < \infty$	$\mathfrak{p} \neq \{0\}$	If M is Noetherian: $\mathfrak{p} \neq \{0\}$ for every $\mathfrak{p} \in \operatorname{asc}(M)$
(10)	α has completely positive entropy (or is Bernoulli)	$h(\alpha^{R_d/\mathfrak{p}}) > 0$	$h(\alpha_{R_d/\mathfrak{p}}) > 0$ for every $\mathfrak{p} \in \operatorname{asc}(M)$

Figure 1: A pocket dictionary

some of the principal dynamical properties of α_M can be expressed entirely in terms of the prime ideals associated with the module M.[1] Figure 1 provides a small illustration of this correspondence; all the relevant results can be found in [18]. In the third column we assume that the R_d-module $M = \widehat{X}$ defining α is of the form $R_d/\mathfrak{p}$, where $\mathfrak{p} \subset R_d$ is a prime ideal, and describe the algebraic condition on $\mathfrak{p}$ equivalent to the dynamical condition on $\alpha = \alpha_{R_d/\mathfrak{p}}$ appearing in the second column. In the fourth column we consider a countable R_d-module M and state the algebraic property of M corresponding to the dynamical property of $\alpha = \alpha_M$ in the second column.

The notation in Figure 1 is as follows. In (1), α is *expansive* if there exists an open neighbourhood $\mathcal{O}$ of the identity $0 \in X$ with $\bigcap_{\mathbf{n}\in\mathbb{Z}^d} \alpha^{-\mathbf{n}}\mathcal{O} = \{0\}$, and

$$V_{\mathbb{C}}(\mathfrak{p}) = \{c \in (\mathbb{C} \smallsetminus \{0\})^d : f(c) = 0 \text{ for every } f \in \mathfrak{p}\}$$

is the *variety* of $\mathfrak{p}$, and $\mathbb{S} = \{c \in \mathbb{C} : |c| = 1\}$. From (2)–(4) it is clear that α is ergodic if and only if $\alpha^{\mathbf{n}}$ is ergodic for *some* $\mathbf{n} \in \mathbb{Z}^d$, and that α is mixing if and only if $\alpha^{\mathbf{n}}$ is ergodic for *every nonzero* $\mathbf{n} \in \mathbb{Z}^d$. In (5), α is *mixing of order* $r \geq 2$ if

$$\lim_{\substack{\mathbf{n}_1,\dots,\mathbf{n}_r\in\mathbb{Z}^d \\ \|\mathbf{n}_i-\mathbf{n}_j\|\to\infty \text{ for } 1\leq i<j\leq d}} \lambda_X\left(\bigcap_{i=1}^{r} \alpha^{-\mathbf{n}_i}B_i\right) = \prod_{i=1}^{r}\lambda_X(B_i)$$

for all Borel sets $B_i \subset X$, $i = 1,\dots,r$. In (7), a nonempty finite set $S \subset \mathbb{Z}^d$ is α-*mixing* if

$$\lim_{k\to\infty}\lambda_X\left(\bigcap_{\mathbf{n}\in S}\alpha^{-k\mathbf{n}}B_{\mathbf{n}}\right) = \prod_{\mathbf{n}\in S}\lambda_X(B_{\mathbf{n}})$$

for every choice of Borel sets $B_{\mathbf{n}} \subset X$, $\mathbf{n} \in S$, and *nonmixing* otherwise. In (8)–(10), $h(\alpha) = h_{\text{top}}(\alpha)$ stands for the topological entropy of α (which coincides with the metric entropy $h_{\lambda_X}(\alpha)$). In fact, there is an explicit entropy formula for algebraic $\mathbb{Z}^d$-actions in [10]: in the special case where $\alpha = \alpha_{R_d/\mathfrak{p}}$ for some prime ideal $\mathfrak{p} \subset R_d$ this formula reduces to

$$h(\alpha) = \begin{cases} |\log \mathsf{M}(f)| & \text{if } \mathfrak{p} = (f) = fR_d \text{ is principal,} \\ 0 & \text{otherwise,} \end{cases}$$

where

$$\mathsf{M}(f) = \begin{cases} \exp\left(\int_{\mathbb{S}^d} \log|f(\mathbf{s})|\,d\mathbf{s}\right) & \text{if } f \neq 0, \\ 0 & \text{if } f = 0, \end{cases}$$

is the *Mahler measure* of the polynomial f. Here $d\mathbf{s}$ denotes integration with respect to the normalized Haar measure on the multiplicative subgroup $\mathbb{S}^d \subset \mathbb{C}^d$.

The remaining lectures were devoted to two problems which have seen interesting developments recently: the order of mixing and isomorphism rigidity.

2 Higher order mixing properties of algebraic $\mathbb{Z}^d$-actions

The higher order mixing properties appearing in Figure 1 (5)–(7) turn out to be intimately connected with certain diophantine results on additive relations in fields due to Mahler ([11]), Masser ([7], [12], [13]) and Schlickewei, W. Schmidt and van der Poorten ([5], [19]).

Let α be an algebraic $\mathbb{Z}^d$-action on a compact abelian group X with dual module $M = \widehat{X}$. Then X is connected if and only if *no* prime ideal $\mathfrak{p} \in \operatorname{asc}(M)$ contains a nonzero constant, and X is zero-dimensional if and only if *every* $\mathfrak{p} \in \operatorname{asc}(M)$ contains a nonzero constant. In view of Figure 1 we can restrict our study of nonmixing sets and the order to mixing to the case where $\alpha = \alpha_{R_d/\mathfrak{p}}$ and $M = R_d/\mathfrak{p}$ for some prime ideal $\mathfrak{p} \subset R_d$. If α is not mixing, then there exist Borel sets $B_1, B_2 \subset X$ and a sequence $(\mathbf{n}_k,\ k \geq 1)$ in $\mathbb{Z}^d$ with $\lim_{k\to\infty}\mathbf{n}_k = \infty$ and

$$\lim_{k\to\infty}\lambda_X(B_1 \cap \alpha^{-\mathbf{n}_k}B_2) = c$$

for some $c \neq \lambda_X(B_1)\lambda_X(B_2)$. Fourier expansion implies that the latter condition is equivalent to the existence of nonzero elements $a_1, a_2 \in M$ such that $a_1 + u^{\mathbf{n}_k} \cdot a_2 = 0$ for infinitely many $k \geq 1$. In particular,

$$(u^{\mathbf{m}} - 1) \cdot a_2 = 0$$

for some nonzero $\mathbf{m} \in \mathbb{Z}^d$ (cf. Figure 1 (4)). A very similar argument shows that α is not mixing of order $r \geq 2$ if and only if there exist elements $a_1, \dots, a_r$ in M, not all equal to zero, and a sequence $((\mathbf{n}_k^{(1)}, \dots, \mathbf{n}_k^{(r)}),\ k \geq 1)$ in $(\mathbb{Z}^d)^r$ such that $\lim_{k\to\infty}\|\mathbf{n}_k^{(i)} - \mathbf{n}_k^{(j)}\| = \infty$ for all i, j with $1 \leq i < j \leq r$ and

$$u^{\mathbf{n}_k^{(1)}} \cdot a_1 + \dots + u^{\mathbf{n}_k^{(r)}} \cdot a_r = 0 \tag{2.1}$$

for every $k \geq 1$.

Similarly one sees that a nonempty finite set $S \subset \mathbb{Z}^d$ is nonmixing if and only if there exist elements $a_{\mathbf{n}} \in M$, $\mathbf{n} \in S$, not all equal to zero, such that

$$\sum_{\mathbf{n}\in S} u^{k\mathbf{n}} \cdot a_{\mathbf{n}} = 0 \tag{2.2}$$

for infinitely many $k \geq 1$.

We embed the integral domain $R_d/\mathfrak{p}$ in its field of fractions K and obtain from (2.2) an integer $r \geq 2$ and elements $x_1, \dots, x_r, c_1, \dots, c_r$ in $K^\times$ with

$$\sum_{i=1}^{r} c_i x_i^k = 0 \tag{2.3}$$

for infinitely many $k \geq 0$.

If the field K has characteristic zero (which means that $\mathfrak{p}$ contains no nonzero constants and that $X_{R_d/\mathfrak{p}}$ is connected), then a theorem of Mahler in [11] states that there exist integers $s \geq 1$ and i, j with $1 \leq i < j \leq r$ such that $x_i^s = x_j^s$. After translating this back to our algebraic $\mathbb{Z}^d$-action α we obtain the following result.

Theorem 2.1 ([16]). *Let α be a mixing algebraic $\mathbb{Z}^d$-action on a compact connected abelian group X. Then every nonempty finite subset $S \subset \mathbb{Z}^d$ is mixing.*

If K has positive characteristic, the situation is considerably more complicated due to the possible presence of nonmixing sets.

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[1] A prime ideal $\mathfrak{p} \subset R_d$ is *associated with* M if $\mathfrak{p} = \{f \in R_d : f \cdot a = 0_M\}$ for some $a \in M$. The set of all prime ideals associated with M is denoted by $\operatorname{asc}(M)$; if M is Noetherian, then $\operatorname{asc}(M)$ is finite.

Example 2.2 ([9]). Let $\mathfrak{p} = (2, 1+u_1+u_2) = 2R_2 + (1+u_1+u_2)R_2$, $M = R_2/\mathfrak{p}$, and let $\alpha = \alpha_M$ be the algebraic $\mathbb{Z}^2$-action on $X = X_M = \widehat{M}$. The group X can be represented as the closed, shift-invariant subgroup

$$\begin{aligned} X = \{x = (x_{\mathbf{m}}) \in (\mathbb{Z}/2\mathbb{Z})^{\mathbb{Z}^2} &: x_{(m_1,m_2)} + x_{(m_1+1,m_2)} + x_{(m_1,m_2+1)} \\ &= 0 \pmod 2 \ \text{ for every } \ \mathbf{m} = (m_1,m_2) \in \mathbb{Z}^2\}, \end{aligned}$$

where α is the shift-action defined by

$$(\alpha^{\mathbf{m}} x)_{\mathbf{n}} = x_{\mathbf{m}+\mathbf{n}}$$

for every $x = (x_{\mathbf{m}}) \in X$ and $\mathbf{n} \in \mathbb{Z}^2$. The action α is mixing by Figure 1 (4), but not three-mixing, and the set $S = \{(0,0), (1,0), (0,1)\} \subset \mathbb{Z}^2$ is nonmixing.

Indeed, a little calculation shows that $x_{(0,0)} + x_{(2^n,0)} + x_{(0,2^n)} = 0 \pmod 2$ for every $x \in X$ and $n \geq 0$. For $B = \{x \in X : x_{(0,0)} = 0\}$ it follows that

$$B \cap \alpha^{-(2^n,0)}(B) \cap \alpha^{-(0,2^n)}(B) = B \cap \alpha^{-(2^n,0)}(B),$$

and hence that

$$\lambda_X(B \cap \alpha^{-(2^n,0)}(B) \cap \alpha^{-(0,2^n)}(B)) = \lambda_X(B \cap \alpha^{-(2^n,0)}(B)) = 1/4$$

for every $n \geq 0$. If α were three-mixing, we would have that

$$\lim_{n\to\infty} \lambda_X(B \cap \alpha^{-(2^n,0)}(B) \cap \alpha^{-(0,2^n)}(B)) = \lambda_X(B)^3 = 1/8.$$

This shows that the set $S = \{(0,0), (1,0), (0,1)\} \subset \mathbb{Z}^2$ is indeed nonmixing.

A mixing algebraic $\mathbb{Z}^d$-action α on a disconnected compact abelian group X has nonmixing sets if and only if it is not Bernoulli (cf. Figure 1 (10)). In particular, if α is an ergodic algebraic $\mathbb{Z}^d$-action on a compact zero-dimensional abelian group X with zero entropy, then α has nonmixing sets. The description of the nonmixing sets of such an action α is facilitated —but not made obvious —by a theorem of Masser ([7], [12]), which is an analogue of Mahler's result in positive characteristic.

Theorem 2.3. *Let K be an algebraically closed field of characteristic $p > 0$, $r \geq 2$, and let $(x_1, \dots, x_r) \in (K^\times)^r$. The following conditions are equivalent:*

(1) *There exists an element $(c_1, \dots, c_r) \in (K^\times)^r$ such that*

$$\sum_{i=1}^{r} c_i x_i^k = 0$$

for infinitely many $k \geq 0$;

(2) *There exists a rational number $s > 0$ such that the set $\{x_1^s, \dots, x_r^s\}$ is linearly dependent over the algebraic closure $\bar{F}_p \subset K$ of the prime field $F_p = \mathbb{Z}/p\mathbb{Z}$.*

For a detailed discussion of how to calculate nonmixing sets with the help of Theorem 2.3 I refer to [7].

After embedding $R_d/\mathfrak{p}$ in its field of fractions K, equation (2.1) leads to the following problem: given a finitely generated multiplicative subgroup $G \subset K^\times$, an integer $r \geq 2$ and $(c_1, \dots, c_r) \in (K^\times)^r$, describe the set of solutions $(x_1, \dots, x_r) \in G^r$ of the equation

$$\sum_{i=1}^{r} c_i x_i = 0. \tag{2.4}$$

The following Theorems 2.4 and 2.5 turn out to be equivalent.

Theorem 2.4 ([5], [19]). *Let K be a field of characteristic 0 and G a finitely generated multiplicative subgroup of $K^\times = K \smallsetminus \{0\}$. If $r \geq 2$ and $(c_1, \dots, c_r) \in (K^\times)^r$, then the equation (2.4) has only finitely many solutions $(x_1, \dots, x_r) \in G^r$ such that no sub-sum of (2.4) vanishes.*

Theorem 2.5 ([17]). *Let α be a mixing algebraic $\mathbb{Z}^d$-action on a compact connected abelian group X. Then α is mixing of every order.*

The 'absolute' version of the S-unit theorem in [5] contains a bound on the number of solutions of (2.4) without vanishing subsums which is expressed purely in terms of the integer r and the rank of the group G (in our setting: the order of mixing and the rank of the group $\mathbb{Z}^d$). This bound could be used, for example, to obtain quite remarkable uniform statements on the speed of multiple mixing for all irreducible and mixing algebraic $\mathbb{Z}^d$-actions (cf. Definition 3.1).

For algebraic $\mathbb{Z}^d$-actions on disconnected groups one has to study equation (2.4) over a field K of positive characteristic. Without going into details, let me mention the following remarkable consequence of a very recent result by Masser in [13] which reduces the order of mixing problem to the problem of determining the minimal size of nonmixing sets.

Theorem 2.6. *Let α be an algebraic $\mathbb{Z}^d$-action on a compact abelian group X, and let $r \geq 2$. If every subset $S \subset \mathbb{Z}^d$ of cardinality r is mixing, then α is r-mixing.*

3 Conjugacy of algebraic $\mathbb{Z}^d$-actions

Two algebraic $\mathbb{Z}^d$-actions α and β on compact abelian groups X and Y are *measurably conjugate* if there exists a bijective Borel map $\phi \colon X \longrightarrow Y$ such that $\lambda_X \phi^{-1} = \lambda_Y$ and

$$\beta^{\mathbf{n}} \circ \phi = \phi \circ \alpha^{\mathbf{n}} \quad \lambda_X\text{-a.e.} \tag{3.1}$$

for every $\mathbf{n} \in \mathbb{Z}^d$. If the map ϕ in (3.1) can be chosen to be continuous, then α and β are *topologically conjugate*, and any continuous choice of ϕ in (3.1) is a *topological conjugacy*. If ϕ in (3.1) can be chosen to be a group isomorphism then α and β are *algebraically conjugate*. Finally, a bijection $\phi \colon X \longrightarrow Y$ is *affine* if it is of the form

$$\phi(x) = \psi(x) + y$$

for some continuous group isomorphism $\psi \colon X \longrightarrow Y$ and some $y \in Y$.

Every algebraic $\mathbb{Z}^d$-action α with completely positive entropy is measurably conjugate to a Bernoulli shift (cf. Figure 1 (10)). Since entropy is a complete invariant for measurable conjugacy of Bernoulli shifts by [14], α is, for example, measurably conjugate to the $\mathbb{Z}^d$-action

$$\alpha^A : \mathbf{n} \mapsto \alpha^{A\mathbf{n}}$$

for every $A \in \mathrm{GL}(d, \mathbb{Z})$, since the entropies of these actions coincide. In general, however, α and α^A are not topologically conjugate.

Every algebraic $\mathbb{Z}^d$-action α with positive entropy has Bernoulli factors by [10] and [15], and two such actions may again be measurably conjugate without being algebraically or topologically conjugate. For zero entropy actions, however, there is some evidence for a very strong form of isomorphism rigidity. Let us begin with a special case.

Definition 3.1. An algebraic $\mathbb{Z}^d$-action α on a compact abelian group X is *irreducible* if every closed, α-invariant subgroup $Y \subsetneq X$ is finite.

Irreducibility is an extremely restrictive hypothesis: if α is mixing it implies that $\alpha^{\mathbf{n}}$ is Bernoulli with finite entropy for every nonzero $\mathbf{n} \in \mathbb{Z}^d$. If β is a second irreducible and mixing algebraic $\mathbb{Z}^d$-action on a compact abelian group Y such that $h(\alpha^{\mathbf{n}}) = h(\beta^{\mathbf{n}})$ for every $\mathbf{n} \in \mathbb{Z}^d$, then $\alpha^{\mathbf{n}}$ is measurably conjugate to $\beta^{\mathbf{n}}$ for every $\mathbf{n} \in \mathbb{Z}^d$. However, if $d > 1$, then the actions α and β are generally nonconjugate.

Theorem 3.2 ([6], [8]). *Let $d > 1$, and let α and β be irreducible and mixing algebraic $\mathbb{Z}^d$-actions on compact abelian groups X and Y, respectively. If $\phi\colon X \longrightarrow Y$ is a measurable conjugacy of α and β, then ϕ is λ_X-a.e. equal to an affine map. In particular, measurable conjugacy implies algebraic conjugacy.*

If the irreducible actions α and β in Theorem 3.2 are of the form $\alpha = \alpha_{R_d/\mathfrak{p}}$ and $\beta = \alpha_{R_d/\mathfrak{q}}$ for some prime ideals $\mathfrak{p}, \mathfrak{q} \subset R_d$, then measurable conjugacy implies that $\mathfrak{p} = \mathfrak{q}$. By exploiting this fact one can construct algebraic $\mathbb{Z}^d$-actions with very similar properties which are nevertheless measurably nonconjugate (cf, [6], [8]).

Without the hypothesis of irreducibility the picture is much less clear. Bhattacharya proved recently in [1]–[2] that every measurable conjugacy between zero-entropy mixing algebraic $\mathbb{Z}^d$-actions on zero-dimensional compact abelian groups has to coincide *a.e.* with a topological conjugacy, but does not have to be affine. On the positive side, the following result was proved in [3] and, with a completely different method, in [4].

Theorem 3.3. *Let α and β be measurably conjugate mixing algebraic $\mathbb{Z}^d$-actions on zero-dimensional compact abelian groups X and Y, respectively. Suppose furthermore that there exists a subgroup $\Gamma \subset \mathbb{Z}^d$ of infinite index such that the restriction of α to Γ has completely positive entropy as a Γ-action. Then every measurable conjugacy between α and β is affine.*

For algebraic $\mathbb{Z}^d$-actions on compact connected abelian groups there is currently no analogue of Theorem 3.3 which goes significantly beyond the irreducible case. According to the current state of knowledge it remains conceivable that any measurable conjugacy between zero-entropy mixing algebraic $\mathbb{Z}^d$-actions on compact connected abelian groups is affine.

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Numerical Construction of Spacetimes

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Einstein's theory of relativity is described by one of the most complex systems of equations found in physical theories. Some solutions to these equations have been found only in the presence of simplifying assumptions. These solutions have given rise to significant results and enabled us to gain valuable knowledge of the theory in different regimes. However, our understanding of it is rather limited as these solutions only give us a very limited view of the allowed ones. The use of numerical simulations is finally enabling researchers to start probing deeper into the theory. In this article we review some of the salient features and open problems of the numerical simulation of Einstein equations.

1 Introduction

About a century ago Einstein's theory introduced a radically new way to understand gravitation and its effects. This theory teaches us that gravity manifests through the *curvature* of the spacetime (where physical processes take place) and this curvature governs the dynamics. The curvature is described through (derivatives of) a Lorentzian metric tensor, which does not "live on top" of the spacetime but rather it defines it. Moreover, no preferred time notion exists. In this setting, it does not come as a surprise that the equations representing the theory are intrinsically difficult to deal with. These equations form an overdetermined, highly coupled, quasilinear PDE system relating the Ricci curvature of the spacetime with the matter/energy content of it.

Naturally, obtaining a handle on the solutions of such system is a complicated task. Indeed, for about six decades, only in very specialized situations were researchers able to obtain particular solutions (see for instance [1, 2]). These assumed the existence of symmetries and/or concentrated on asymptotic regimes that allowed considerable simplifications of the equations reducing them to a manageable (and 'analytically' solvable) system. Although considerable 'new' physics has been learned from these these solutions, the full implications of the theory remain elusive.

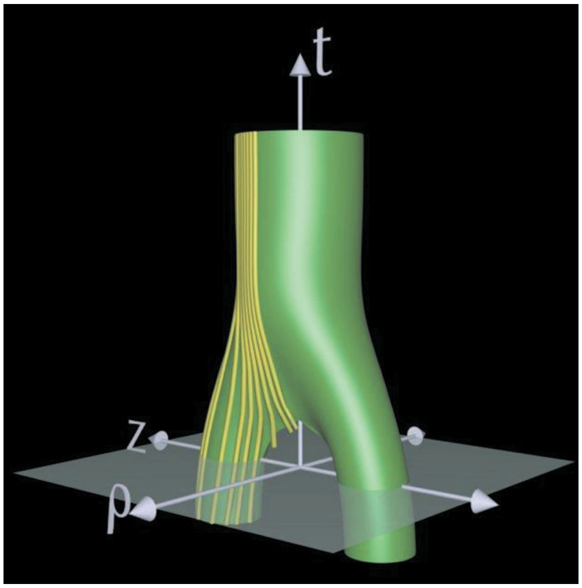
The 'computer revolution' of the past decades has provided us with a new tool to attempt an unraveling of what the theory has so far kept hidden, by solving the equations via numerical means. This allows to study systems which would be otherwise impossible through analytical means. Furthermore, these simulations serve as theoretical laboratories for General Relativity, where the past impossibility of constructing a gravitational laboratory prevented data-driven research from aiding in our explorations of the theory [3].

Another exciting possibility is to use numerical simulations of strongly gravitating/highly dynamical systems in a new form of astronomy. A new generation of highly sophisticated detectors is being set which will be capable of measuring the gravitational waves (which are extremely weak when they reach us) produced by these systems. Deciphering the informations carried out by these waves will open up a new window through which to scrutinize our universe.

Thus, the numerical construction of spacetimes holds the promise to probe deep in the theory and use it in gravitational wave astronomy. Unfortunately, simulations of the most interesting systems are still plagued by a number of unresolved issues (both of analytical and numerical origin) and consequently the promise is still unfulfilled. Nevertheless, the possibility is a certain one, and understanding some of these issues might hold the clue to finally opening up a large number of explorations of the theory.

2 Arena

Einstein's equations provide the spacetime defined as the pair $(\mathcal{M}, g_{ab})$; where $\mathcal{M}$ is an orientable, n-dimensional manifold of all physical events and g_{ab} is a Lorentzian metric tensor describing the geometry of $\mathcal{M}$. This manifold (or at least the region of interest) is assumed to be simply connected and globally hyperbolic; thus, *in principle* given appropriate data on an initial hypersurface, its future development can be obtained by means of solving Einstein's equations. To this end, one needs to express them in convenient form, i.e. to define the initial value problem in a suitable way. This entails introducing a foliation of the spacetime which provides a notion of "time" (related to the labeling of the leafs of the foliation). Each leaf describes an $(n-1)$-dimensional hypersurface which can be spacelike, null or of more generic types. In this article, for the sake of simplicity, we will restrict to the first case which is the one followed in the Cauchy approach to Einstein's equations and concentrate mostly on vacuum spacetimes.



Event horizon structure in the axysimmetric collision of two black holes (in a head-on orbit). This simulation, performed at NCSA in the mid 90's, was done in two dimensions (exploiting the symmetry of the problem).

3 Putting the pieces together

3.1 Equations

Suppose we have parametrized $\mathcal{M}$ with the a parameter t. Now, given a hypersurface Σ_t we assign labels x^i ($i = 1..n$) to each point in it. Spacetime points therefore have coordinates $x^a \equiv (t, x^i)$ (where $a = 0, 1..n$). Note that this labeling and foliation are arbitrary; thus we have four related free functions which are collectively referred to as *coordinate freedom*.

The spacetime geometry is represented by the line element

$$ds^2 = g_{ab} dx^a dx^b = -\alpha^2 dt^2 + \gamma_{ij}(dx^i + \beta^i dt)(dx^j + \beta^j dt) \qquad (1)$$

where α, β^i are functions manifesting the coordinate freedom referred above and γ_{ij} is the metric tensor describing the intrinsic geometry of the hypersurfaces. Now, if n^a is the orthogonal vector to Σ_t, the projection of Einstein's equations, $R_{ab} = 0$ (where R_{ab} is the Ricci tensor defined by g_{ab}), onto Σ_t provides a set of six second order quasilinear *essentially* hyperbolic equations for γ_{ij}, while the projections $n^a R_{ab} = 0$ (to the orthogonal direction) provide four *essentially* elliptic equations involving, at most, first time derivatives of γ_{ij}. (These are known as the Gauss-Codacci equations, basically relating the embedding of an $(n-1)$-dimensional manifold on an n-dimensional one).

Already at this basic level we encounter one of the issues referred to earlier, as we have an overdetermined system of equations between the evolution and constraint equations. It can be seen, however, at the analytical level, that if the constraint equations are satisfied initially, they will remain so in the future of determinacy of the initial data when the γ_{ij} have been obtained at later times with the evolution equations. It is then customary to define the initial value problem by providing data satisfying the constraint equations and employing solely the evolution equations to determine the solution at later times. This strategy is known as *free evolution* and the constraint equations are employed simply as monitors of the obtained solution. (Note however that one could have traded some of the evolution equations for constraint ones; this strategy is referred to as *constrained evolution*, we will return to this point later).

Another important issue relates to the wording *essentially* above. For instance, only under a very specific choice of coordinates does one see that the evolution equations (from the straightforward projection of $R_{ab} = 0$ onto Σ_t) are symmetric hyperbolic. Dealing with symmetric hyperbolic systems is a necessary path in the road to define a well posed problem. However, one does not want to restrict to these coordinates, as they may not be well adapted to the particular problem at hand. The situation can be overcome by observing that the evolution equations are hardly unique. Indeed, one can arbitrarily add the constraints to them and obtain explicitly symmetric hyperbolic systems not dependent on particular or too restrictive coordinates. There has been considerable activity in this area in recent years and a large number of "reformulations" of Einstein's equations having this property have been presented (for a review on the topic see [4]).

3.2 Initial boundary value problem: Setting up the problem in a consistent way

Even after having settled the equations to use, in order to tackle a specific problem one must provide initial and boundary data. As mentioned, consistent initial data, consisting of the pair $\{\gamma_{ij}, \partial_t \gamma_{ij}\}$, satisfy the four constraint equations which can be written in an explicit elliptic form via the Lichnerowicz-York approach (see [5] for a recent review on this topic). Here the metric γ_{ij} and its 'time derivative' are decomposed in a particular way to yield an elliptic system. These elliptic equations can be solved via standard techniques providing *consistent initial data* after some free functions have been specified (since one has n constraint equations and $(n)(n-1)$ unknowns).

A more difficult problem is formulating consistent boundary conditions. If there were no constraints, consistent boundary data would be obtained straightforwardly if employing symmetric hyperbolic evolution equations. Basically, given a boundary, one determines which modes enter the domain of interest and define them via maximally dissipative boundary conditions [6]. However, as already discussed, we deal with a constrained system which implies that the modes entering the domain are not all independent. It is an involved process to discern which of the modes are indeed independent and which are fixed by requiring no constraint violations at boundaries. These complications prevented for decades a rigorous treatment of the initial boundary value problem and the search for consistent boundary data relied heavily in numerical experimentation of different options. Quite recently, thanks to the work of Friedrich and Nagy [7], well posedness for the initial boundary value problem was established and has spurred a number of investigations to incorporate this knowledge in current applications.

3.3 Singularity treatment

It is a well established fact that every black hole has a singularity in it [1, 2]. At a singularity, fields diverge and the simulation will undoubtedly break. Given that many interesting systems do contain black holes or will form one during the evolution, one must somehow address this problem. The "cosmological censorship conjecture" [1] provides a way to do this, as it implies that singularities must be hidden inside black holes. This property can be exploited to effectively get rid of the problem. Namely, we know that an event horizon hides anything inside it; so, in principle, one could introduce an inner boundary placed inside the event horizon surrounding the singularity. The presence of the inner boundary, would prevent the simulations from getting 'too close' to the singularity and the simulation "should perform well". This idea, originally suggested by Unruh [8], known as *singularity excision*, is at present the most promising strategy to deal with the singularities that might be present in the simulation. There are two basic issues in implementing this idea:

First, one needs to know where the black hole (event horizon) is at each time of the evolution. The concept of a black hole is global and can only be rigorously found **after** the evolution has been carried over. In order to obtain a 'local' notion (i.e. on each hypersurface), in practice one looks for trapped surfaces. These surfaces are such that orthogonal *null rays* (i.e. propagating at the speed of light) do not diverge (i.e. the rays have been trapped). In particular the outer most surface is referred to as an *apparent horizon*. Under certain reasonable conditions, one can prove that indeed the apparent horizon will always lie inside the event horizon [2] and therefore can be used as a 'marker'. The region inside of it is excised from the computational domain, defining an *inner boundary*.

The second issue, which is more delicate, has to do with the fact that somehow values at this boundary must be prescribed. The basic strategy for this is *a priori* quite simple; since the past domain of dependence at this boundary is 'tilted' off this boundary (reflecting the causal structure of the spacetime interior to the event horizon), one could provide these values using the evolution equations, as this boundary is of *outflow* type. The numerical implementation of this strategy, on the other hand, is quite difficult as it must be capable of dealing with moving boundaries (resulting from singularities moving through the grid), merging of initially disconnected inner boundaries (like those present in binary black hole spacetimes which merge at later times), 'sudden' appearance of inner boundaries (which result in collapse situation), etc.

4 Getting the simulations going

The task at hand now is to produce a numerical code implementing the above-mentioned equations to study systems of interest. Among the most attractive systems are those containing binary black holes which require accurate full three-dimensional simulations for considerably long evolutions. The code needs to resolve the different scales of the problem appropriately (namely the region around the black holes, the far zones where the gravitational waves are to be measured and the typical dynamical time scales). The computational demands for such a task are tremendous [3]. In fact, the most powerful supercomputers today are a few orders of magnitude short of the needed power. Given the importance and urgency of having knowledge of the dynamics of such a system, significant resources are being spent in this problem. Adaptive mesh refinement, aggressive parallelism and different numerical techniques are all being pursued [3].

4.1 An example of what might come

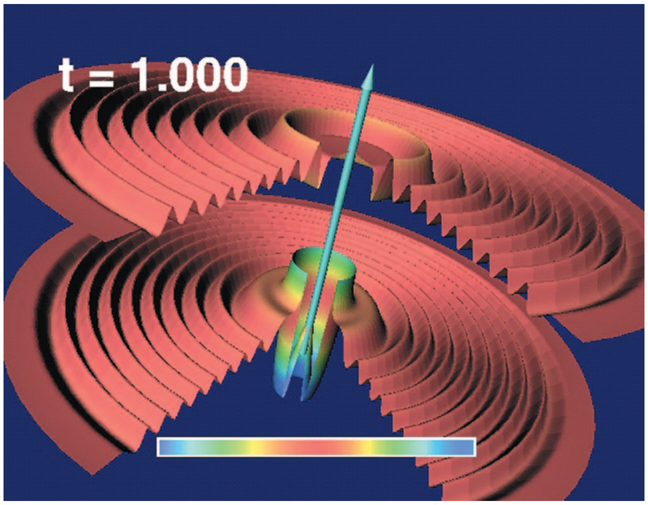
In lower dimensional settings, where computational resources do allow for achieving adequate resolution, significant phenomena have been discovered and questions resolved thanks to numerical simulations of Einstein equations. As an example we mention here perhaps the most representative case of major breakthroughs obtained via simulations:

- *Critical behavior in GR:* Numerical simulations were responsible for unraveling a rich and unexpected phenomena in the formation of black holes. Choptuik in [9] carefully studied the (spherically symmetric) collapse of a scalar field coupled to General Relativity (this is a non-vacuum case). In the simulations, the initial configuration of the field is followed as it propagates towards the origin. Intuitively only *two* scenarios are allowed in the dynamics of the system. Either a black hole forms (when enough energy is accumulated in a small compact region) or the field bounces back and disperses away. Choptuik carefully studied what happens at the boundary between black hole formation and dispersion and discovered a rich and unexpected phenomenon. It was observed that the mass M of the final collapsed black hole obeys a scaling relation $M = C(p - p_*)^\gamma$, where γ results *completely independently of the initial data configuration employed*. Moreover, the solution that gives rise to such a relation displays a scale-periodic (self-similar) dependence of the spacetime for $p \approx p_*$. The existence of such a phenomenon was first discovered numerically and only later analytically explained via a dynamical systems analysis when appropriate anzats, inspired from the numerical simulations, are employed.

4.2 Still missing pieces beyond just resolution

Numerical simulations in 3D are still not robust enough to meet the challenge. There are a number of still unresolved issues both of analytical and numerical origins. A few of these are:

- *Formulation suitability:* Numerical evolutions of three dimensional black hole spacetimes in the Cauchy formulation display spurious exponential growth which eventually are responsible for the codes' crash. As a result, accurate evolutions today last for too short a time for the ultimate goal. This problem can be alleviated considerably by a more convenient form of the evolution equations. As mentioned, the evolution equations are not unique, because the constraints can be added arbitrarily to them to obtain a completely analytically equivalent system. Furthermore, there always exists the possibility of 'dropping' some of the evolution equations in favor of some of the constraint equations and hence consider a mixed elliptic-hyperbolic system. The possibilities are certainly endless. Only a few have been considered so far and mostly through the 'painful' way of trial and error as no analytic and systematic way has been devised to study the different systems yet. In particular, the mathematical theory of PDEs can only give us a rough estimate of the expected growth of solutions by analyzing primarily the principal part of the system. The importance of gaining deeper understanding on the behavior of the different (but analytically equivalent) systems has been highlighted from these trials as they have shown remarkably different behavior of different systems. Namely, given the *same* discretization of the system of equations, only differing in how the constraints have been added (which does not affect the principal part of the equations) accurate simulations of single black hole systems have been obtained



Critical phenomena in GR. Simulations performed by M. Choptuik (UBC) showed remarkable phenomena; not only were they capable of showing formation of arbitrarily small mass black holes but also display the self-similar structure of the spacetime near the verge of black hole formation. In the picture the upper plot corresponds to the 'above-critical' case while the lower one the 'sub-critical' case. The 'echoing' behavior is clear from these.

lasting as little as a few M to as long as thousands of Ms. This indicates that the form of the equations can have a strong impact in our ability to implement Einstein equations. An ideal tool would be one that can provide a sharp growth estimate which takes into account the lower order terms, this can be a difficult enterprise, but its impact in this field and others would likely be profound.

Less attention has been devoted to the elliptic-hyperbolic problem (known as constrained evolutions) in part due to the possible conceptual difficulties associated with boundary conditions for elliptic equations (especially at the inner boundary). The 'intuitive' strategy of using evolution equations to update inner boundary points and elliptic equations is being used with promising results [10]; however, a rigorous analysis of this is still lacking. Preliminary investigations of this strategy in simpler systems of equations [11] point towards this being a well defined strategy but the details for the G.R. case need to be worked out.

- *Physical initial and boundary data:* In physics, consistency of initial/boundary data is rarely enough as this data must conform to the physical situation in mind. Consistent initial data has been known for decades; even in the particular case of binary black hole systems [5]. However, in all these, it is unclear how much spurious gravitational radiation content these data have. Since one needs to fix several arbitrary functions and provide appropriate boundary conditions in order to solve the elliptic problem, the burden is on these to conform to the physical situation in mind. Considerable work is being invested in this area but the ultimate test of the proposed options will reside in actual evolutions and comparison of different outcomes.

  As far as boundary data, the picture is considerably more obscure. The work presented in [7] has managed to present a treatment of the boundary data that manages to provide consistent data (i.e. guaranteeing constraints are satisfied at the boundary) and making a connection to the physics (i.e. that the only two free modes can be specified which are related, in the appropriate limit, to incoming flux of gravitational radiation). Unfortunately, this work requires a very specific choice of coordinates (particularly well adapted to the boundary) a particular form of Einstein equations and the enlargement of the number of variables considered (which put further pressure on the already scarce computational resources). Different attempts to incorporate this knowledge in formulations closer to those being presently pursued numerically have succeeded in defining a well-posed initial boundary value problem, but unfortunately boundary conditions needed for this do not allow for gravitational waves to leave the computational domain. This in turn implies that as outgoing waves hit the boundary they will be reflected back, as opposed to the real problem where they would continue, which will spoil the physical meaning of the evolution [12]. If computational resources allowed us to place boundaries very far, the reflections can be forced not to represent a problem for the length of time of interest, but as mentioned this is hardly the case.

- *Numerical Issues:*. The topics above reside mostly in the analytical realm, and as anyone that has ever coded even just the advection equation knows, a well-defined and understood problem analytically still needs considerable work for a satisfactory (stable and accurate) implementation. In different areas of computational physics or applied mathematics, a starting point to achieving robust algorithms, especially in non-linear problems, is to employ some conservation law typical of the system under consideration and produce schemes that, at the discrete level, reproduce this exactly. This dictates things like how to group terms in the discretization, which particular algorithm to choose for the evolution equations and the discretization strategy to guarantee strict stability of the numerical solution. In the case of G.R., however, there does not exist a convenient conserved quantity. A recent effort is concentrating in at least employing schemes guaranteeing summation by parts [6], a discrete form of integration by parts which guarantees the discrete energy agrees in the continuous limit to that used in proving well-posedness of the system. Hence, together with the formulation(s) addressing the first point above one would obtain a much better controlled implementation.

5 Conclusion

The numerical construction of spacetimes will allow researchers to finally probe deep into this beautiful theory. Simulations will likely be key to discovering new and unexpected phenomena. Additionally they will serve a very practical purpose in the detection and analysis of gravitational waves measure by new detectors and aid in a new form of astronomy. The numerical implementation of Einstein's equations poses an exciting challenge. It requires major advances in computational science, 'pure' and 'applied' mathematics, general relativity and astrophysics. The multidisciplinary character of research in this area is thus an added incentive to get our attention on it. The challenge is in front of us and the ground is fertile for new ideas.

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PIMS Prizes for 2002 Awarded in Banff

The PIMS Research Prize selection committee for 2002 was chaired by **Robert Moody**, the Scientific Director of BIRS. The committee members were **Gunther Uhlman** (U. Washington), **Gang Tian** (MIT), **David Brillinger** (Berkeley), **Randy Goebel** (U. Alberta), **Ian Putnam** (U. Victoria), **Hugh Williams** (U. Calgary) and **Bob Russell** (SFU).

The **2002 PIMS Research Prize** went to **Changfeng Gui**, now at the University of Connecticut after having spent several years at the University of British Columbia.

Changfeng Gui

Gui is one of the leading researchers of his generation in the field of nonlinear partial differential equations. He is truly exceptional in his capacity to successfully tackle the most difficult problems in this central area of mathematics.

Two recent results of Gui were cited by the committee for the award.

The first is his proof of the existence of high energy solutions for a class of nonlinear Neumann problems. This analysis is relevant to the study of pattern formation in biology, confirming computer simulations that indicate the existence of multi-peak solutions.

The second is his solution, with his collaborators, of the De Giorgi Conjecture about the transition profile in the Allen-Cahn model for anti-phase transitions, in several important space dimensions. Since its formulation by De Giorgi in 1978, this conjecture has attracted the efforts of many leaders in the field of partial differential equations. In a 1998 paper with Nassif Ghoussoub, Gui proved this conjecture in 2 dimensions. More recently, they have also established this conjecture in dimensions 4 and 5 under symmetry conditions.

In a continuation of this work, Gui together with **Martin Barlow** at UBC and **Richard Bass** at Connecticut have completely solved the Gibbons conjecture in all dimensions. To accomplish that, they first prove a general Liouville theorem for harmonic functions associated with non-uniform elliptic operators in divergence form. This type of Liouville theorem is itself groundbreaking, important, and quite difficult.

With his collaborators Gui has made fundamental contributions to the study of multiple phase dynamics by establishing rigorously the existence of basic configuations near multi-junctions and non-trivial transition layers for vector-valued Allan-Cahn systems.

He has also done important work in understanding the stability and blow-up phenomema of nonlinear heat equations and porous media equations, in classifying the coexistence states of Lotka-Volterra competition system.

Gui and his collaborator **Wei** also settled the issue of the best constant in the Moser-Aubin-Onofri inequality for radially symmetric functions on the 2-dimensional sphere.

Gui has devoted himself to some of the most difficult problems in nonlinear partial differential equations. For his success in solving these problems, he is richly deserving of the PIMS Research Prize.

Ted Lewis

The **2002 PIMS Education Prize** was awarded to **Ted Lewis**.

Math Fairs are the brainchild of Ted Lewis, the PIMS Education Coordinator at the University of Alberta. The idea has evolved over a lifetime of passionate commitment to the provision of quality mathematics courses for teacher trainees and outreach to schools.

The Math Fair is similar in many ways to a science fair. Two important differences set the concept apart. Math fairs concentrate on the problem solving aspect of mathematics, and the fairs are officially non-competitive, so there are no awards or prizes. While the problems are accessible to children, they are uncompromisingly non-trivial and adults usually are also intrigued and challenged by them.

Lewis realized early on that an efficient way of delivering the concept to the schools was to concentrate on training teachers to organize fairs in their schools and districts. The most important vehicle for this is MATH 160, a mathematics course for students in teacher training in Elementary Education at the University of Alberta. This non-required course was in trouble due to low enrolment. Since the introduction of the math fairs unit it has grown to two over-subscribed sections of 60–90 students each and is now very popular. This is important from several points of view, not least in that it has gone a long way to allay ‘math anxiety’ among these student teachers who would later communicate that feeling to their pupils.

The practicum portion of the course involves the organization of a math fair for invited schools. These fairs are held on campus and competition among schools to participate is keen. Because of space limitations, participation is usually limited to about 650 students. The schools in turn are expected to later organize their own math fair with support from PIMS for the purchase of problem solving resource materials. An added benefit is the heightened awareness among teachers of PIMS as a resource.

Another important vehicle for the promotion of math fairs has been the organization of model fairs at teachers’ conventions.

A valuable resource for the math fairs became available when Lewis’ *The Math Fair Booklet* was designed and produced with private funding and printed by PIMS last year. It is a very high quality publication available at nominal cost in hard copy and soon as a free download from the web.

Of course Lewis has not been alone in this endeavor. Colleagues **Andy Liu** from the University of Alberta and **Indy Lagu** from Mount Royal College in Calgary have collaborated actively in the development of the concept from the beginning along with a host of former students who have now joined the teaching profession. By now thousands of students across Alberta have participated in Math Fairs. The home departments and institutions of these individuals must also be recognized along with PIMS for their support of the school projects.

Another essential partner for the past four years has been the Alberta Science and Research Authority (ASRA) whose funding for PIMS education outreach activities in Alberta has been indispensable. The energy of this partnership of creative individuals and organizations would not have been so readily and effectively tapped without ASRA.

The 2002 PIMS Education Prize selection committee members were the PIMS Site Directors: **Manfred Trummer** (SFU), **Jim Muldowney** (U. Alberta, Chair), **Dale Rolfsen** (UBC), **Gary Margrave** (U. Calgary) and **Florin Diacu** (U. Victoria).

Are our Mathematics Natural?

by Ivar Ekeland, University of British Columbia

Ivar Ekeland

Several years ago, David Ruelle (*Bull. Amer. Math. Soc.* **19** (1988), no. 1, 259–268) published a beautiful paper entitled: *"Are our mathematics natural?"*. He contended that if somewhere there is a planet, gravitating chaotically around three suns, and where the physical conditions on the surface, although very different from the ones we experience on Earth, do support some form of intelligent life, then the mathematics developed on that planet are likely to be quite different from the ones we know.

Not that there would be different ideas of what is correct and what is not. There would be a general agreement on what a theorem is, but not on what is an interesting result. Ruelle proves his point by stating a theorem which no one in his right mind would want to prove, and then disclosing that it plays an important role in equilibrium statistical mechanics.

It strikes me that, although we are not likely to travel out of our solar system in the near future, we can still experiment with different mathematics by moving out of our immediate intellectual neighbourhood. Ruelle's example comes from physics, but there are more distant solar systems in economics, and in the other social sciences. It certainly has been my experience that basic problems in economic theory give rise to quite difficult mathematical problems with the unmistakable flavour of the exotic. Who would ever have thought of restricting variational principles (such as Dirichlet's principle) to convex functions? Except for some very early work by Isaac Newton, there is nothing like this in the classical literature on the calculus of variations, probably because it was not considered an interesting or natural problem. And yet it has emerged in the past years as a mathematical model of a basic problem in economics, namely informational asymmetry: people will lie to you if it is in their own interest, and contracts should take that possibly into account.

Similar things are happening in econometrics. Certain goods, houses for instance, are priced according to a complex bundle of qualities. You buy only one house, but you take into account its location, proximity to schools, shops, public transportation, the view, the neighbours, the size and interior distribution, and so forth. Is it possible to observe the market price of houses, and infer the prices of all these different qualities? For instance, could one find out in this way how much people are willing to pay for an unpolluted environment? Models to do that have been developed in the seventies, by the late Sherwin Rosen in Chicago. They are called hedonic models, and they have become very popular in recent years, because of the needs of environmental studies. However, there are great mathematical difficulties at all levels, and only recently have they begun to be cleared, under the impulse of Nobel Laureate Jim Heckman. The mathematical structure is similar to the classical optimal transportation problem of Monge and Kantorovich, again with an added twist that would have been judged uninteresting or unnatural if it had come from mathematics alone.

And there is, of course, the case of mathematical finance: the first documented appearance of Brownian motion in the mathematical literature is in the 1900 thesis of Louis Bachelier, who was trying to model financial markets. Unfortunately, neither the financial nor the mathematical community were ready for him, and it was only in the seventies that the importance of his work became clear. It does not always pay to come in from another planet.

30th Annual Meeting of the Statistical Society of Canada

McMaster University, May 26–29, 2002

Contributed by Bruce Smith, Dalhousie University

The 30th Annual Meeting of the Statistical Society of Canada (SSC) was held on May 26–29, 2002, on the campus of McMaster University, in Hamilton, Ontario. The conference was generously supported by grants from the National Program Committee (NPC) of the CRM, Fields and PIMS, and McMaster University.

This meeting was an unequivocal success, with 379 registered participants. There were three workshops held:

i) *Design and Analysis of Cluster Randomization Trials* by **A.Donner** (U. Western Ontario) and **N.Klar** (Cancer Care Ontario)
ii) *Design and Analysis of Computer Experiments for Engineering* by **J.Sachs** (Duke University) and **W. Welch** (U. Waterloo)
iii) *Handling Missing Data* by **K.Nobrega** and **D.Haziza** (Statistics Canada)

There were 46 scientific sessions in total, plus a poster session. Topics ranged from theoretical probability, inference, and stochastic processes to applied sessions on environmental issues, statistical genetics, and statistics and governmental policy.

Thanks in no small part to the funding from the NPC, the meeting included a large number of internationally known speakers. The particular speakers whose funding was wholly or partially covered by the grant from NPC, by session, were:

i) *Probability*: **Ilie Grigorescu** (U. Miami)
ii) *Statistical Inference*: **Chris Klaassen** (U. Amsterdam) and **William Strawderman** (Rutgers U)
iii) *Statistics for Microarray Data Analysis*: **Michael Newton** (U. Wisconsin, Madison) and **Terry Speed** (UC, Berkeley)
iv) *Statistics and Brain Mapping*: **Pedro Valdes-Sosa** (Cuban Neuroscience Center) and **Moo Chung** (U. Wisconsin, Madison)
v) *Statistics and Public Policy*: **Miron Straf** (National Academy of Sciences)
vi) *Split Plot Experiments in Industry*: **Robert McLeod** (PhD student at U. Manitoba)
vii) New Research Findings in Analysis Methods for Survey Data: **Christian Boudreau** (PhD student at U. Waterloo)

The complete program is available on the web at **www.mscs.dal.ca/~bsmith/ssc2002/program.html**.

PIMS 2003 Thematic Programme on Inverse Problems & Applications

Inverse problems are those in which either the goal is to find the material or biological properties of objects or information about the objects' surrounding environment which is not possible or convenient to measure directly. These problems arise in many areas of applications including geophysics, medical imagining, remote sensing and non-destructive evaluation of materials.

During the last twenty years or so there have been remarkable developments in the mathematical theory of inverse problems. These developments together with the enormous increase in computing power and new powerful numerical methods have made possible significant progress on increasingly more realistic and difficult inverse problems. Five workshops on inverse problems are being held at different locations during 2003, each emphasizing different application. **Gunther Uhlmann** is the coordinator of the PIMS thematic year.

Please see **www.pims.math.ca/inverse/** for more information.

Pan-American Advanced Studies Institute (PASI) on PDEs, Inverse Problems and Non-Linear Analysis

CMM, Universidad de Chile,
January 6–19, 2003

Participants in the PASI on PDEs, Inverse Problems and Non-linear Analysis in Chile

BIRS workshop on Scattering and Inverse Scattering

Banff Conference Centre,
March 22–27, 2003

Participants in workshop on Scattering and Inverse Scattering at BIRS

Geophysical Inversion Workshop

PIMS at University of Calgary,
July 20–25, 2003

The Geophysical Inversion Workshop will be an exciting mix of invited speakers presenting tutorial or summary papers and contributed research papers from leading researchers. The invited speakers will address a range of topics including: exploration seismology, seismic imaging, global seismology, e-m methods, Bayesian methods, microlocal analysis, and more. Contributed papers are now being accepted. All aspects of Geophysical Inversion, from theory to practice, are welcome topics. Student attendance is encouraged. You need not present a paper to attend.

The workshop is being organized by **Gary Margrave** (University of Calgary), **Martijn de Hoop** (Colorado School of Mines) and **William (Bill) Symes** (Rice University).

The Invited Speakers are:

Norman Bleistein (Colorado School of Mines)
Michael Bostock (UBC)
Hans Duistermaat* (U. Utrech) *not confirmed
Louis Fishman (MDF International, previously at NRL)
Larry Lines (U. Calgary)
Doug Oldenburg (UBC)
Christiaan Stolk (Ecole Polytechnique)
Gunther Uhlman (U. Washington)
Tad Ulrych (UBC)
Rob van der Hilst (MIT)

The deadline for registration and submission of abstracts is May 15, 2003.

For more information and to register see **www.pims.math.ca/inverse/giw-index.html**.

PIMS-MITACS Workshop on Inverse Problems and Medical Imaging

PIMS-UBC, August 4–8, 2003

This workshop will focus on recent developments in medical imaging, particularly the advances in mathematics which have allowed for significant enhancement of widely used imaging techniques such as x-ray tomography, magnetic resonance imaging, and ultrasonic imaging. Mathematical developments in emerging medical imaging modalities will also be surveyed. The aim of the workshop is to bring together investigators working on different aspects of these fields and to encourage interaction between mathematicians, physicists and physicians.

The organizers are **John Schotland** (Chair, Biomedical Engineering, U. Pennsylvania), **Richard Albanese** (Armstrong Research Lab, Brooks AFB), **Tom Budinger** (Biomedical Engineering, Berkeley), **David Isaacson** (Rensselaer Polytech), **Amir Gandbakhche** (National Institute of Health) and **Gunther Uhlmann** (U. Washington).

Please fill out the registration form on-line. If you would like to stay on-campus during the workshop please indicate this on the registration form no later than June 30.

The Invited Speakers are:
Simon Arridge (UCL), **Yoram Bresler** (UIUC), **Andrei Bronikov** (KEMA), **Thomas Budinger** (Berkeley), **Scott Carney** (UIUC), **Emmanuel Candes** (Cal Tech), **Rolf Clackdoyle** (Utah), **Charles Epstein** (Penn), **Mathias Fink** (ESPCI), **Amir Gandjbakhche** (NIH), **Frederick Greensite** (Irvine), **Alberto Grunbaum** (Berkeley), **David Isaacson** (RPI), **Brian Litt** (Penn), **Michael Miller**

continued on the next page

(Johns Hopkins), **Frank Natterer** (Muenster), **Joseph O'Sullivan** (WashU), **George Papanicolau** (Stanford), **Sarah Patch** (GE), **Keith Paulsen** (Dartmouth), **Todd Quinto** (Tufts), **Yoram Rudy** (CWRU), **John Schotland** (Penn), **Meir Shinnar** (UMDNJ) and **Gunther Uhlmann** (Washington).

Optimal Transportation and Nonlinear Dynamics Workshop

PIMS-UBC, August 10–14, 2003

The theme around which this conference revolves is a transportation problem having its roots in economics, statistics, and geometry. Given two probability measures on a curved landscape M, the problem is to determine the most efficient way to rearrange the mass of the first distribution to yield the second. Efficiency is measured against a function c(x,y) >= 0 which specifies the cost per unit mass for transporting material from x to y on M. The research theme proposed for this meeting focuses on applications to models for atmospheric pressure fronts, the kinetic theory of gases, and the theory of stochastic mechanics. This meeting is a natural follow up of one previously held at the Fields Institute in August 2001. It is intended to help update the community on advances in this rapidly developing field, while at the same time focusing attention on key subjects which could not be covered in detail at the August 2001 meeting.

The organizers are **Michael Cullen** (U. Reading), **L. Craig Evans** (UC, Berkeley) and **Wilfrid Gangbo** (Georgia Tech).

Minicourse lecture series are being given by **Eric Carlen** (Georgia Tech) and **John Urbas** (Australian National U.).

Lectures are being given by:

Yann Brenier (U. de Nice Sophia-Antipolis), **Luis Caffarelli** (U. Texas, Austin), **Peter Constantin** (U. Chicago), **David Kinderlehrer** (Carnegie Mellon), **Felix Otto** (U. Bonn), **Neil Trudinger** (Australian National U.), **Xu-Jia Wang** (Australian National U.), **Jean-David Benamou** (INRIA), **Lorenzo Giacomelli** (U. di Roma), **Steve Haker** (Brigham and Women's Hospital), **John Norbury** (U. Oxford), **Adam Oberman** (U. Texas), **Vladimir Oliker** (Math & Science Center, Atlanta, Georgia), **Ian Roulstone** (U. Reading), **Giuseppe Savare** (U. degli Studi di Pavia) and **Vladimir Zeitlin** (Ecole Normale Superieure).

Deadlines for PIMS Opportunities

Call for Proposals for PIMS Conferences, Workshops, Seminars and Related Activities

PIMS is now welcoming applications for support for conferences, workshops, seminars and related activities in the Mathematical Sciences, to occur after April 1, 2004. The deadline for applications is **October 15, 2003**. After being reviewed by the PIMS Scientific Review Panel, the decisions will be announced by January 31, 2003.
For further information please see **www.pims.math.ca/opportunities/proposals.html.**

Call for Proposals for BIRS 2005 Season

The Banff International Research Station is now accepting proposals for the 2005 season which runs March 12–December 15, 2005. The deadline for workshop proposals is **October 15, 2003**. This is the optimal, but not necessary, date for other types of programs too. If possible, proposal submissions should be made online using the Online Submission Forms. Please see the website **www.pims.math.ca/birs/proposals_menu/** for further details including descriptions of the various BIRS programmes and guidelines for submitting proposals.

Call for Nominations for PIMS Prizes

PIMS is now accepting nominations for:

1. PIMS Research Prize
Awarded for a particular outstanding contribution to the mathematical sciences that was disseminated during the five-year period prior to the award being given. Open to Canadian citizens, permanent residents of Canada and residents of Pacific Rim countries who maintain academic ties to the Canadian mathematical sciences community.

2. PIMS Education Prize
Awarded to a member of the PIMS community who has made a significant contribution to education in the mathematical sciences. This prize is intended to recognize individuals from the PIMS member universities or other educational institutions in Alberta and British Columbia, who have played a major role in encouraging activities which have enhanced public awareness and appreciation of mathematics, as well as fostering communication among various groups and organizations concerned with mathematical training at all levels.

3. PIMS Industrial Outreach Prize
Awarded to an individual who has employed mathematical analysis in the resolution of problems with direct industrial, economic or social impact. This prize is intended for individuals from the academic, private or government sectors. This prize may be given to individuals who at the time of nomination are Canadian citizens or permanent residents of Canada.

Candidates for each prize should be nominated by three sponsors. Sponsors are to provide a cover letter explaining the nominee's contribution, impact and relevance for the prize. The nomination should also include a CV of the nominee, a publication list, a list of creative works or list of industrial products, and relevant samples of the nominee's work, such as reprints, patents or educational materials.

Nominations should be sent to:

Attention: PIMS Prizes
PIMS Central Office
Room 200–220, 1933 West Mall
University of British Columbia
Vancouver BC V6T 1Z2
Canada

Nominations must be received by **October 15, 2003**. For more information, please see the webpage **www.pims.math.ca/prizes/**.

2nd Canadian Conference on Nonlinear Solid Mechanics

June 19-23, 2002, Simon Fraser University

Contributed by Elena Croitoro, University of Victoria

From June 19th to June 23rd, 2002, Simon Fraser University hosted the *2nd Canadian Conference on Nonlinear Solid Mechanics/ 2ème Conférence canadienne sur les aspects non-linéaires de la Mécanique des Solides, CanCNSM-2002*.

An event of the Pacific Institute for the Mathematical Sciences, the Conference was a high profile, very successful international meeting. **Bruce Clayman**, Vice-President Research of Simon Fraser University, took the time to welcome the delegates.

World leaders in the field and distinguished scientists from around the world honoured the *2nd Conference on Nonlinear Solid Mechanics* with their presence and contributions. Fellows of the Royal Society of London, winners of the prestigious Max Plank international research award, NASA scientists, NSERC doctoral award recipients, inventors, well established scientists, and rising stars participated in the meeting.

The conference provided a unique opportunity for communicating recent and projected advances in the novel field of Nonlinear Solid Mechanics.

It brought together researchers from academia, laboratories, and industry working on common themes from complementary perspectives into an exciting, truly multidisciplinary programme .

Plenary Speakers:

Eduardo Dvorkin (Centre for Industrial Research, Buenos Aires)
Roger Fosdick (Aerospace Engineering and Mechanics, University of Minnesota)
Paolo Podio-Guidugli (Civil Engineering, University of Rome Tor Vergata)
Patrick Selvadurai (Applied Mechanics and Civil Engineering, McGill University)
John R. Willis (Applied Mathematics and Theoretical Physics, University of Cambridge)

Mini-Symposia on specific topics were organized by:

Frederic Féyel and **Jean-Louis Chaboch** (Office National d'Etudes et de Recherches Aérospatiales)
Michael Hayes (University College Dublin)
Kamran Behdinan (Ryerson University)
Masayoshi Kitagawa (University of Kanazawa)
Gianni Royer-Carfani (University of Parma) and **Roger Fosdick** (University of Minnesota)
Erol Sancaktar and **Arcady Leonov** (University of Akron)
Peter Schiavone (University of Alberta)
Patrick Selvadurai (McGill University)

The two Proceedings Volumes (over 700 pages, ISBN 0-86491-232-3) contain the edited versions of the full papers presented at the Conference including Plenary Lectures, invited presentations within Mini-Symposia, and Contributed papers—149 authors from 23 countries and 5 continents.

The comments received were extremely positive with special praise going towards the high scientific level of the Conference, the excellence of the presentations, the format of the Conference, the organization, and the technical and social programs.

The CanCNSM 2002 builds on the success and reputation established by the first-ever *Conference on Nonlinear Solid Mechanics* held in 1999 at the University of Victoria, Canada, that had a remarkable impact on the international research community. Special Lecture series were presented at the International Centre for the Mechanical Sciences (Udine, Italy, 2000) in the field of Nonlinear Solid Mechanics. On the Pacific Rim, the City University of Hong Kong dedicated the year 2000 to workshops on thematic areas in Nonlinear Mechanics. Major meetings, workshops, and seminars were further organized around the world. Eminent scientists and world leaders in the field, who came here first, were instrumental in planning the follow-up events. The initiative of the CanCNSM Conferences, the Canadian leadership, and the support offered by PIMS has been broadly acknowledged.

The CanCNSM-2002 Organizing Committee and the International Technical Committee would especially like to thank the Pacific Institute for the Mathematical Sciences for sponsoring the CanCNSM Conferences and for its continuing support and assistance. We would like to extend our thanks to Simon Fraser University and the Department of Mechanical Engineering of the University of British Columbia for their support, and to express a warm gratitude to the many individuals who assisted with the organization of the Conference and made the 2nd Canadian Conference on Nonlinear Solid Mechanics a very successful scientific event.

Minicourse Lecture Notes Online

Lecture notes for minicourses offered by PIMS Distinguished Chairs are available online at **www.pims.math.ca/publications/distchair.**
The following minicourses are currently available:

David Brydges (PIMS Distinguished Chair at UBC, Sept.-Oct., 2000)
Self-Interacting Walk and Functional Integration

Yuri Matiyasevich (PIMS Distinguished Chair at University of Calgary, Feb.-Mar., 2000)
Hilbert's Tenth Problem

Herb Wilf (PIMS Distinguished Chair at University of Victoria, June 2000)
Integer Partitions

Donald Saari (PIMS Distinguished Chair at University of Victoria, Sept. 2002)
Mathematical Social Sciences; An Oxymoron?

Yuri Matiyasevich

Design and Analysis of Experiments

Coast Plaza Suites Hotel, Vancouver, July 14–18, 2002

Contributed by Randy Sitter (SFU)

The organizers of the *PIMS Workshop on Design and Analysis of Experiments* (DAE 1) were **Randy Sitter** (SFU), **Derek Bingham** (Michigan), **Bruce Ankenman** (Northwestern) and **Agnes Herzberg** (Queen's U.).

Many industrial problems are not well-explored in the statistical literature. To help North American industry compete globally, advanced statistical methods suitable for real applications need to be further developed. Statistical experimental designs, developed by Sir Ronald Fisher in the 1920's, largely originated from agricultural problems. Although the design of experiments for industrial and scientific problems may have the same basic concerns as design for agricultural problems, there are many differences:
(i) industrial problems tend to require investigation of a much larger number of factors and usually involve a much smaller total number of runs (observations)
(ii) industrial results are more reproducible
(iii) industrial experimenters are obliged to run their experimental points in sequence and are thus able to plan their followup experiments guided by previous results, unlike agriculture, in which all results are often harvested at one time
(iv) models can be very complicated in industrial and scientific experimentation, sometimes requiring the need for nonlinear models or the need for computer modelling and finite element analysis

The purpose of the DAE 1 workshop was to begin a series of workshops to provide support and encouragement to junior researchers in the field of design and analysis of experiments, and to stimulate interest in topics of practical relevance to science and industry. In the summer of 2000, researchers from North America and abroad in the area of experimental design, including a large group of young talented new researchers, attended the *First Midwest Conference for New Directions in Experimental Design* in Columbus, Ohio organized by Angela Dean (Ohio State University), Kathryn Chaloner (University of Minnesota), Dibyen Majumdar (University of Illinois Chicago) and Dennis Lin (Penn State University). This workshop had a focus on applications of design in industry and was well received. It was sponsored by the National Science Foundation, the Ohio State University and Executive Jet Corp with a small award from Stat-Ease. A discussion group reached consensus that a series of similar workshops should be held every 2 or 3 years at different locations in North America. DAE 1 is the first workshop in this series in Canada. The bulk of its sponsorship came from PIMS with an additional contribution from Graduate Studies at SFU.

The next workshop in the series is being organized by Angela Dean, Kathryn Chaloner and Dibyen Majumdar and will be held in Chicago in 2003 (*New Directions in Experimental Design, DAE2003,* May 15-18, Chicago), with focus on medical applications. There was a roundtable discussion during the DAE 1 workshop in Vancouver to discuss general future structure and to determine interest among volunteers to host and organize the next in the series, following Chicago. This resulted in a commitment from researchers at Los Alamos National Laboratories to host DAE 3 in 2005 in Sante Fe, NM. Thus the PIMS support for this initial endeavour appears to have achieved its goal. An infrastructure and framework was established for continuing such series at locations throughout North America to be held about every 2 years.

The DAE 1 workshop itself was a huge success. The invited speakers, the invited poster presenters and the attendees represented precisely the cross-section of young junior researchers and experienced world leaders in areas of both design and analysis of experiments that was hoped for. Visitors travelled from various sites in Canada and the US, as well as from Belgium, Sweden, Germany, the Netherlands, Italy, the United Kingdom, New Zealand and Taiwan; and represented both academia and industry. The talks and posters included such wide-ranging topics as Computer Intensive Methods for Design Selection, Design of Experiments in Bioinformatics, Drug Discovery and Marketing, Mathematical Theory of Design Construction and Bayesian Analysis of Designed Experiments, and represented leading research in these areas.

The Invited Speakers were:

Sabyasachi Basu (Boeing), **Scott Beattie** (Eli Lilly), **Ching-Shui Cheng** (Univesity of California, Berkeley), **Shaowei Cheng** (Academia Sinica, Taiwan), **Abdel El-Shawaari** (National Water Research Institute), **Valeri Fedorov** (Smith Kline), **Paul Green** (Wharton School, Penn State University), **Mike Hamada** (Los Alamos National Labs), **Joel Huber** (Wharton School, Penn State University), **David Hunter** (Penn State University), **Stephen Jones** (Boeing), **Abba Krieger** (Wharton School, Penn State University), **Warren Kuhfeld** (SAS Institute), **Raymond Lam** (GlaxoSmithKline), **Nhu Le** (BC Cancer Agency), **Robert Mee** (University of Tennessee-Knoxville), **Saumen Mandal** (University of Manitoba), **Max Morris** (Iowa State University), **Bill Notz** (Ohio State University), **Greg Piepel** (Pacific Northwest Labs-Battelle), **Giovanni Pistone** (Politecnico di Torino), **Shane Reese** (Brigham Young University), **Louis-Paul Rivest** (Laval University), **Kirti Shah** (University of Waterloo), **Bikas Sinha** (University of Waterloo), **John Stufken** (Iowa State University), **Winson Taam** (Boeing), **Boxin Tang** (Memphis State University), **Randy Tobias** (SAS Institute), **Ben Torsney** (University of Glasgow), **Joe Voelkel** (Rochester Institute of Technology), **Marcia Wang** (University of Waterloo), **C.F. Jeff Wu** (University of Michigan), **Huaiqing Wu** (Iowa State University), **Don Ylvisaker** (University of California, Los Angeles), **Kenny Ye** (SUNY-Stony Brook), **Hongquan Xu** (University of California, Los Angeles), **Hongtu Zhu** (University of Victoria), **Lei Zhu** (GlaxoSmithKline) and **Jim Zidek** (University of British Columbia).

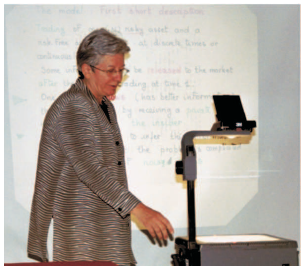
PIMS-MITACS Workshop on Filtering Theory and Applications

Edmonton and Jasper, July 25–30, 2002

Contributed by Hongwei Long and Mike Kouritzin (University of Alberta)

Organizers: Robert Elliott (U. Calgary), Michael Kouritzin (U. Alberta), Tom Kurtz (U. Wisconsin-Madison) and Hongwei Long (U. Alberta).

Filtering theory is an active and current research field attracting many probabilists. In particular, there is increasing interest in applying filtering theory to real-world problems in areas such as mathematical finance, target detection and tracking, communication networks, pollution tracking, weather prediction, traffic management, and search and rescue. The main goal of the Conference was to bring current problems and theory together, benefiting all researchers, especially those new to filtering theory.



Nicole El Karoui

The four keynote speakers were:

Nick Duffield (AT&T): talk series entitled *Revealing the detail in network measurements*

Tyrone Duncan (University of Kansas): talk series entitled *Fractional Brownian motion and applications*

Gopi Kallianpur (U. North Carolina): talk series entitled *Lectures on nonlinear filtering theory*

Nicole El Karoui (Ecole Polytechnique): talk series entitled *Pricing and hedging financial products with partial information*

They are outstanding experts in their fields. Their lectures focused on the most recent development of filtering theory and applications to communication networks and mathematical finance. There were many established researchers from five continents, who presented their recent and most exciting research accomplishments in the conference and exchanged their ideas with other participants. The conference attracted students and postdoctoral researchers from universities across North America, which will encourage future research activity in Canada. The conference benefited from industrial participants including AT&T, Lockheed Martin and Raytheon, who showed great interests in the conference and indicated desire to have more interaction and collaboration with scientists from academic institutions. We believe that the conference helped to advance the scientific development of filtering theory and its applications as well as offering benefits to industry.

Gopi Kallianpur

The meeting was held at the University of Alberta from July 25–27 and was concluded in Jasper, Alberta from July 28–30.

The conference was cosponsored with the University of Alberta and the Applied Mathematics Institute of the University of Alberta.

The Invited Speakers included: **D. Blount** (Arizona State), **A. Budhiraja** (U. North Carolina), **H. Chan** (U. Alberta), **P. Del Moral** (Toulouse), **R. Elliott** (U. Alberta), **W. Engler** (Vision Smart), **D. Kenway** (Vision Smart), **V. Krishnamurthy** (U. Melbourne), **H. Long** (U. Alberta), **M. Kouritzin** (U. Alberta), **M. Prefontaine** (U. Alberta), **B. Remillard** (HEC, Montreal), **W. Sun** (U. Alberta), **A. Tsoi** (U. Missouri, Columbia), **F. Viens** (Purdue), **P. Wiebe** (U. Alberta) and **Xun Yu Zhou** (Chinese U. Hong Kong).

Tyrone Duncan

SARA'02 Symposium on Abstraction, Reformulation and Approximation: Co-Sponsored by PIMS

Kananaskis, August 2–4, 2002

Contributed by Robert C. Holte (University of Alberta) and Sven Koenig (Georgia Tech)

The fifth *Symposium on Abstraction, Reformulation and Approximation (SARA)* was held at Kananaskis Mountain Lodge, Kananaskis Village, Alberta (Canada), August 2-4, 2002. SARA's aim is to provide a forum for intensive interaction among researchers in all areas of AI with an interest in the different aspects of AR&A techniques.

SARA'02 was the most successful of the five meetings held so far. Fifty-one researchers attended from countries around the globe and twenty of the attendees were Ph.D. students. There were three invited technical talks, 14 technical presentations selected on a peer-review basis, and 14 presentations of "late breaking results" in a lively poster session. The proceedings of the meeting are published under the title *Abstraction, Reformulation and Approximation* as volume 2371 in Springer's LNAI series (Lecture Notes in Artificial Intelligence). Many details about the meeting, including some of the presentations made, are available through the conference's web page: **http://www.cs.ualberta.ca/~holte/SARA2002/**.

SARA-02 is an affiliate of the American Association for Artificial Intelligence (AAAI), and as such received free advertising through AAAI and a very generous grant for supporting student attendance. NASA's Ames Research Center provided financial support for two of the invited speakers. The University of Alberta provided a conference grant. PIMS handled the pre-registration of all attendees.

The next SARA will be run by Jean-Daniel Zucker of the Universite Paris VI (Pierre & Marie Curie) in Paris, France. For more information, contact **Jean-Daniel.Zucker@lip6.fr**.

Recent Pacific Northwest Seminars

PNW Numerical Analysis Seminar, University of Victoria, September 28, 2002

The speakers were:

Mike Foreman (Institute of Ocean Sciences, Victoria): *Modelling tidal resonance and tidal power around Vancouver Island*

John Fyfe (Canadian Centre for Climate Modelling and Analysis): *Numerical methods in climate research*

Joerg Gablonsky (Boeing): *Effective parallel optimization of expensive functions*

John Gilbert (MIT Laboratory for Computer Science and UC, Santa Barbara): *Graph algorithms in numerical linear algebra: past, present and future*

Chen Greif (UBC): *On the solution of indefinite linear systems*

Tom Hogan (Boeing): *Fitting position, direction and curvature with a* C^2 *quartic spline*

Volker Mehrmann (Technical University Berlin): *Numerical methods for model reduction and the control of partial differential equations*

PNW Probability Seminar, University of Washington, October 19, 2002

The speakers were:

Martin T. Barlow (UBC): *Random walks on supercritical percolation clusters*

Scott Sheffield (Microsoft Research): *Crystal facets and the amoeba*

Hao Wang (U. Oregon): *A class of interacting superprocesses*

PNW Algebraic Geometry Seminar, Western Washington University, October 20, 2002

There were three speakers at this meeting:

Tom Graber (UC, Berkeley): *Generalizations of Tsen's Theorem*

Karen Smith (Michigan): *A non-vanishing conjecture of Kawamata and the core of an ideal*

Bill Fulton (Michigan)

PNW Number Theory Seminar, Western Washington University, November 2, 2002

The speakers at this meeting are:

Bisi Agboola (U. Santa Barbara): *Galois structure, Galois representations and metrised line bundles*

Will Galway (PIMS-SFU): *The pseudoprimes below* 2^{64}

Jim Mailhot (U. Washington): *Selmer groups of elliptic curves with p-isogenies*

Cascade Topology, University of British Columbia, November 2–3, 2002

The speakers at the 29th meeting of the Cascade Topology Seminar were:

David Gillman (UCLA): *The best picture of Poincare's homology sphere*

Ian Hambleton (McMaster): *Homotopy self-equivalences of 4-manifolds*

Vaughan Jones (UC Berkeley): *Skein theory in knot theory and beyond*

Dev Sinha (U. Oregon): *New perspectives on self-linking*

Catherine Webster (UBC): *Cryptography and the braid groups*

Sergey Yuzvinsky (U. Oregon): *Topological robotics; topological complexity of projective spaces*

All these lectures were taped and can be watched by going to **www.pims.math.ca/video/meetings/**.

Martin T. Barlow (UBC), Scott Sheffield (Microsoft Research) and Hao Wang (U. Oregon), PNW Probability Seminar speakers.

Combinatorial Potlatch, University of Victoria, November 9, 2002

The speakers were:

Andrzej Proskurowski (U. Oregon): *Width parameters of graphs and discrete optimization problems*

Clockwise from top left: David Gillman (UCLA), Ian Hambleton (McMaster), Vaughan Jones (UC Berkeley), Sergey Yuzvinsky (Oregon), Dev Sinha (Oregon) and Catherine Webster (UBC).

Branko Grunbaum (U. Washington): *Polyhedra: Combinatorial and Geometric*

Jozef Siran (Slovak University of Technology): *Links between graph theory, group theory, geometry, Riemann surfaces, and Galois theory*

Seventh Pacific Northwest Number Theory Conference, University of Washington, April 5–6, 2003

Lectures were given by **Karl Rubin** (Stanford), **Joe Buhler** (Reed College), **David Boyd** (UBC), **CheeWhye Chin** (Princeton), **Henry Cohn** (University of Washington) and **Stephen Choi** (SFU).

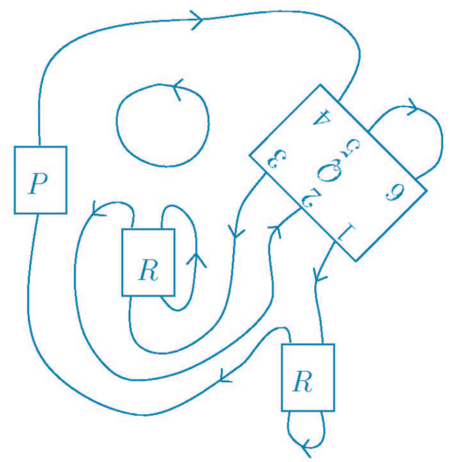
Pacific Northwest Geometry Seminar Spring Meeting, PIMS-UBC, April 26–27, 2003

At the 2003 Spring Meeting of the Pacific Northwest Geometry Seminar the speakers were **Tobias Colding** (Courant Institute), **Jim Isenberg** (U. Oregon), **Misha Kapovich** (U. Utah), **Jun Li** (Stanford) and **Shing-Tung Yau** (Harvard).

Fields Medalist Lectures on Planar Algebras

Contributed by Dale Rolfsen, University of British Columbia

We all learned algebra as a sort of linear activity. Equations, like sentences in English, are written from left to right on a line, with few deviations, perhaps for exponents and fractions. If you want to compute, for example, x minus y, the order in which you write x and y makes a big difference. What if you could write x ABOVE y, or to the northeast? What if you could turn the variables upside-down? A new version of algebra, Planar Algebras, developed by Fields medalist **Vaughan Jones**, allows exactly that to happen. A poet may think of this as a liberation of algebra from the tyranny of linear thinking. In the language of planar algebra, an algebraic expression might look like this:



On a more mathematical level, Jones showed how doing algebra in the plane is connected to a central idea in the theory of operator algebras, the type II_1 subfactors which go back to the work of von Neumann. Jones argues that every finite index subfactor arises from a type of planar algebra and vice-versa, a remarkable correspondence, which is not yet clearly understood.

Jones recently discussed these ideas at UBC in November 2003, in the *Cascade Topology Seminar* and as PIMS Distinguished Lecturer in the UBC Mathematics Colloquium. The work brings together ideas from operator theory, quantum physics, statistical mechanics and the more geometric theory of knots and tangles. The planar approach was inspired by John Conway in his skein theory developed in the late 1960's, which converts geometric and topological pictures of bits of knots into algebraic objects, which can then be studied more precisely and are more amenable to actual calculation, using for example powerful methods of linear algebra. On the other hand, some arguments that might be quite complicated algebraically are much simplified by the geometric point of view. This gives a fruitful interplay between ideas of algebra and methods of geometry and topology.

Because of Jones' earlier work—most famously the Jones polynomial—the theory of knots has undergone a revolution in the last two decades. His current work in planar algebras is but one direction of the vast amount of research currently going on in this fascinating circle of ideas.

Many of the new knot invariants can be understood in terms of planar algebras, and Jones' approach has facilitated the use of geometric and combinatorial methods in solving algebraic problems.

Vaughan Jones was born on New Year's eve in 1952 in Gisborne, New Zealand. After undergraduate studies at the University of Auckland, he went on to graduate school at the University of Geneva, first in the Ecole de Physique and later the Ecole de Mathematiques, under the supervision of Professor Andre Haefliger, where he received his doctorate in 1979. Following positions at UCLA and University of Pennsylvania, Jones became Professor of Mathematics at the University of California, Berkeley in 1985, shortly after his ground-breaking work in knot theory.

Jones was awarded the Fields medal in 1990, and in the same year became a Fellow of the Royal Society. Among other awards, Jones was a Sloane Fellow, a Guggenheim Fellow, and has been elected to the US National Academy of Sciences, the Norwegian Royal Society of Letters and Sciences, the London Mathematical Society and the American Academy of Arts and Sciences. He has honorary doctorates from the University of Auckland and the University of Wales and he is the winner of the Onsager medal from Trondheim University. Jones is also an Honorary vice-president for life of the International Guild of Knot Tyers.

Fields medalist Vaughan Jones

He is the Director of the New Zealand Mathematics Research Institute and a strong friend of PIMS.

Alberta Conference on Industrial Organization

University of Calgary, November 29-30 2002

Organisers: **Aidan Hollis** (U. Calgary) and **Andrew Eckert** (U. Alberta).

Competition policy is the means through which national governments control the behaviour of firms to ensure that consumers receive a low price and yet investors receive a fair return on their investment. This workshop explored several different aspects of competition policy by drawing on examples from specific industries (such as gasoline and automobiles) in which there is systematic useful data, and by theoretical modelling applied to explore problems such as competition in the patent system and competition in industries with upgrades.

The speakers at this conference were:

John Boyce (U. Calgary): *Novelty and usefulness in patents*

Jeffrey Church (U. Calgary): *Competitive upgrades*

Andrew Eckert (U. Alberta): *Retail gasoline price cycles and cross-sectional price dispersion*

Robin Lindsey (U. Alberta): *Predatory pricing in differentiated products retail markets*

Moez Kilani (Universite du Centre a Sousse, Tunisia): *Price and product line competition in automobile markets*

Special Functions in the Digital Age Workshop

SFU, January 23-24, 2003

Contributed by Edgardo S. Cheb-Terrab (UERJ, Brazil, CECM and Maplesoft)

The workshop was cosponsored by the Centre for Experimental and Constructive Mathematics and the Pacific Institute for the Mathematical Sciences. It was organized by Professor Jonathan Borwein (SFU).

This meeting was motivated by the large number of recent developments in computational techniques for special functions, and to take advantage of the visit to SFU by professor Daniel Lozier from NIST, where the Digital Library of Special Functions Project is being developed. The idea was to hold a meeting with a small number of participants, to exchange information, gather opinions and relate a number of different projects going on, including some at CECM.

The meeting happened in an informal and friendly atmosphere, with excitement about the opportunity of hearing about the different projects, and included the following talks:

David Jeffrey (University of Western Ontario): *Elementary functions in an automatic symbolic context, Part I: Inverse functions and the unwinding number*

Rob Corless (UWO): *Elementary functions in an automatic symbolic context, Part II: Closure, continuity and correctness*

These two talks discussed the current limitations of computer algebra systems with regards to inverse functions, as well as the possible use of the unwinding number to tackle these problems.

Edgardo Cheb-Terrab (UERJ Brazil, CECM and Maplesoft): *Special functions & Maple*

This talk presented a large number of new special function developments happening in the Maple system. The presentation focused on a new network of routines for relating special functions and for computing differential polynomial forms for non-polynomial objects, as well as on the "Function Advisor" Maple project: an interactive computational assistant with respect to mathematical functions.

Victor Adamchik (Carnegie-Mellon University): *The multiple gamma function: Theory, computation and applications*

Victor Adamchik discussed the theory of the Multiple Gamma function, illustrating its use in edge problems in exact integration of special functions. He showed how this function can also be used in numerical evaluation algorithms and presented benchmarks showing that these algorithms perform significantly better than those available in current computer algebra systems.

Dan Lozier (NIST): *Digital library of special functions (DLMF) technical issues*

The popular Abramowitz and Stegun Handbook of Mathematical Functions was first published in 1964. It remains a technical best-seller and is among the most widely cited of all mathematical reference compendia. But the Handbook is increasingly out-of-date. Lozier presented an ongoing project at the National Institute of Standards and Technology (NIST) to develop a Digital replacement for it with impressive computational features; this is expected to be available on the internet and so become a major resource of math reference data for special functions and their applications.

Jon Borwein (CECM, SFU): *Experiments in mathematics*

Closing the meeting, Jon Borwein, from CoLab, CECM, SFU, presented a thorough and lively talk on experiments in computational mathematics, with varied philosophical and historical insights regarding the subject, its evolution and its future.

BIRS Inaugural Speeches and Lectures

The speeches and lectures from the opening of the Banff International Research Station in February 2003 are now online and can be found at:
www.pims.math.ca/birs/opening/Agenda_BIRS.html

PIMS Postdoctoral Fellows for 2003

PIMS is pleased to announce the PIMS Postdoctoral Fellows for 2003. The members of the review panel for this year's competition were Ivar Ekeland (Chair, UBC), Eric Woolgar (UA), Peter Zvengrowski (UC), Binay Bhattacharya (SFU), Julie Zhou (UVic), and Michael Doebeli (UBC).

It was a very competitive process this year. The following people have accepted positions as PIMS Postdoctoral Fellows:

Gregory Berhuy: algebraic geometry. Supervised by Zinovy Reichstein (UBC).

Ariel Blanco: functional analysis, banach algebras. Supervised by Anthony Lau (UA) and Nicole Tomczak-Jaegermann (UA).

Lyonell Boulton: spectral theory of linear operators. Supervised by Paul Binding (UC).

Thomas Britz: applied mathematics, combinatorial mathematics, graph theory . Supervised by Pauline van den Driessche (UVic) and Dale Olesky (UVic).

Dimitar Grantcharov: algebra, Lie theory. Supervised by Arturo Pianzola (UA).

Jae-Hun Jung: theoretical chemistry, spectral methods. Supervised by Bernie Shizgal (UBC).

Kyungkeun Kang: nonlinear PDEs. Supervised by Stephen Gustafson (UBC) and Tai-Peng Tsai (UBC).

Jan Manuch: computer science, communication complexity. Supervised by Arvind Gupta (SFU).

Eugene Radu: general relativity, quantum field theory in curved spacetime Supervised by Hans-Peter Künzle (UA).

Bahram Rangipour: algebraic topology. Supervised by John Phillips (UVic).

Anne-Gaelle Rolland-Lagan: computer science, modeling and simulation in mathematical biology. Supervised by Przemyslaw Prusinkiewicz (UC).

Jacob Shapiro: algebraic geometry, Gromov-Witten invariants. Supervised by Kai Behrend (UBC) and Jim Bryan (UBC)

Suneeta Vardarajan: theoretical physics, quantum gravity. Supervised by Don Page (UA).

Ten additional PIMS PDFs have been assigned to the CRGs and can be found in the articles on pages 7–11.

MITACS Fourth Annual Conference: Mathematics of Risk & Security

National Arts Centre, Ottawa, May 8–10, 2003

The MITACS 4th Annual Conference will be taking place in Ottawa, Canada from May 8–10, 2003. This year's conference will focus on the **Mathematics of Risk & Security**. Join MITACS and the best and the brightest in the mathematical sciences community in Canada's capital to explore such diverse topics as computer security, financial risk and biological risks. International experts, workshops and Canadian scientific leaders will be featured at this event. MITACS events have been designed with one common purpose - to bring together partner organizations in the academic, public, private and not-for-profit sectors with university researchers to generate solutions. The 4th Annual Conference is the opportunity to participate with others in the mathematical community by listening to top speakers, network at the Ottawa Interchange, showcase research work by presenting a poster, and socialize with peers at a national level.

MITACS Director Arvind Gupta

This year's speakers are:

Aviel Rubin (John Hopkins): *Network security*
David Whyte (Carleton U.): *Protecting Canada's cyberspace*
Sally Blower (UCLA): *Security/risk in biology*
Andrew Odlyzko (U. Minnesota): *Networks, security and economics*
Moti Yung (Columbia): *Crypto-integrity and its applications*
Phelim P Boyle (U. Waterloo): *Risk in finance*

This year's Annual Conference will also include the inaugural Ottawa Interchange on Thursday May 8. The Interchange is a one-day networking event that brings together the best and the brightest from across the region including: leading-edge industry, government labs, funding agencies, university professor and research associates, and graduate and undergraduate students. The Annual Conference will also include a poster and demo exhibit, where students and postdoctoral fellows can display their recent work and results. And of course, there will be the opportunity to mingle and network with other researchers and experts during the planned social events.

For many more details and registration, visit **www.mitacs.math.ca/AC2003/** .

MITACS 2003 Co-Sponsored Summer Schools

MCDA 2003: Concerted Resource Management and Sustainable Development: Processes and Tools

GERAD-HEC Montréal, Québec,
May 26–June 6, 2003

Cosponsored with the Centre de Recherches Mathématiques in Montreal.

The aim of the school is to give a state-of-the-art presentation of multiple criteria methods, applications and software. Multicriteria decision aid (MCDA) is a rapidly evolving domain where scientific developments are based on fundamental sciences (mathematics, computer science, operation research, engineering, etc.) and on social sciences and management science (sociology, management, political sciences, etc.).

The specific objectives of the school are:
* to exchange knowledge to provide an efficient approach to real life decision problems;
* to present recent developments in MCDA methods and practices;
* to present software developments;
* to analyse and discuss several applications of MCDA to complex evaluation situations.

Guest Lecturers: **Jonathan Barzilai, Valérie Belton, Jose Figueira, Florent Joerin, Marc Kilgour, Ralph E. Steuer, Alexis Tsoukias, Philippe Vincke, Jean-Philippe Waaub**.

For more information, please visit: **www.gerad.ca/mcda/en/index.php**.

Introduction to Mathematical Medicine

University of Waterloo,
July 21–26, 2003

Cosponsored with the Fields Institute

The five mini-courses that make up this school are introductory and given by leading researchers in their fields. The prerequisite for the courses is a strong 4th year level undergraduate background in Applied Mathematics.

Mini Courses:
1. Introduction to Mathematical Neurophysiology by **G. deVries**
2. Modelling Solid Tumour Growth by **H. Byrne**
3. Physiological Fluid Dynamics by **O. Jensen**
4. Mathematical Modelling and Design of Medical Diagnostic Tools by **S. McKee**
5. Medical Image Processing by **H. Zhu**

This summer school will be followed by the Applications of Mathematics in Medicine Workshop at the Fields Institute, June 28-30, 2003.

For more information, please visit: **www.fields.utoronto.ca/**

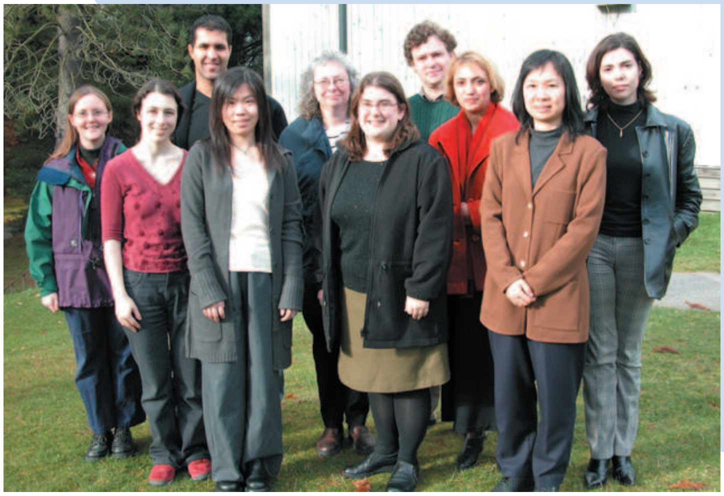
See Seismic Wave Simulation and Seismic Imaging on page 32 and PIMS-MITACS Summer School on Quantum Information Science on page 33 for more MITACS-sponsored summer schools.

Meet the PIMS & BIRS Staff

You have interacted with many of them before by phone and e-mail.

Here is the chance to put the face...

The BIRS Staff (from left to right):
Brent Kearney, Robert Moody, Andrea Lundquist, Amanda Shepard



The PIMS Staff (from left to right):
Heather Jenkins, Jessica Douglas, Derek Bideshi, Fanny Lui, Marian Miles, Andrea Hook, Sandy Rutherford, Dil Bains, Clarina Chan, Olga German
Missing: Kelly Choo, Shirley Mitchell, Karen van Vogt

... to the name!

Find their contact information on page 40...

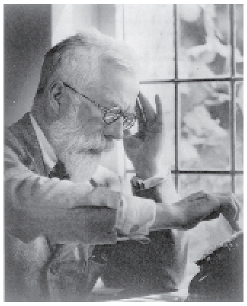
The National Program on Complex Data Structures

Contributed by Jamie Stafford, University of Toronto

The National Program was conceived as a model for a national network in the Statistical Sciences in partnership with Canada's three Mathematical Sciences Institutes. The program was funded by NSERC during the recently completed reallocations exercise and received funding for four years for a total of $687,000 with an additional $200,000 committed to the program by the Institutes. **Jamie Stafford** (U. Toronto) is the Director of the National Program and chairs its Scientific Committee. The Scientific Committee and the Institute Directors are working intensively to establish what is expected to be a very successful program.

The broad goal of the program is to foster nationally coordinated projects with substantial interactions with the large community of scientists involved in analysis of complex data sets, and to establish a framework for national networking of research activities in the statistical community. The original proposal targeted the development and application of statistical methods for the analysis of data obtained from complex survey sample designs and longitudinal biological, epidemiological and medical studies. More specific objectives of the program include the development of collaborations between university and extra-university researchers, and the provision of training for graduate students in important scientific areas through these collaborations.

The working plan for 2003 is to promote collaborative research opportunities in thematic areas through two inaugural workshops/projects. One is in complex survey data analysis for population health and social science, and the other is in statistical genomics/bioinformatics. In partnership with the National Program and Statistics Canada, the project on complex survey data has successfully sought further support from MITACS and has established research positions for students.



Fisher, father of modern statistics

The National Program is a unique opportunity to advance the statistical sciences in Canada and its success depends crucially on the active involvement of statisticians and scientists from a variety of sectors across the country. Those interested in providing input on important directions for the program are welcome to do so by contacting Jamie Stafford. Information about the program may be found at **www.pims.math.ca/NPCDS**/.

Lunchbox Lecture Series Continues at the University of Calgary

Contributed by Gary Margrave, University of Calgary

The PIMS/Shell Lunchbox Lecture series continues to be a very popular event in the Calgary downtown core. Shell Canada provides an excellent physical facility and an enjoyable lunch. Attendance often exceeds 100 people which is attributable to both the excellence of the speakers and to the fact that the downtown Calgary area is the workplace for many professional scientists, engineers, and mathematicians. Somewhat surprisingly, the most popular talks are often not focussed on practical topics but instead concentrate on the grand ideas and beauty of mathematics.

This year's speaker list is quite diverse and will conclude with eagerly anticipated presentations on "Quantum Algorithms" (Richard Cleve) and "The Birth of Chaos" (Florin Diacu). Shell is committed to supporting the series again next year and the speaker list is in preparation. Suggestions for topics and speakers are most welcome.

The recent lectures in this series were:

Len Bos (Mathematics and Statistics, University of Calgary): *Fitting surfaces to data*

Christian Jacob (Computer Science, University of Calgary): *Design by evolution: The art and science of genetic computer programming*

Tony Ware (Mathematics and Statistics, University of Calgary): *Changing your point of view: modern Fourier analysis and other techniques for seeing data in a new light*

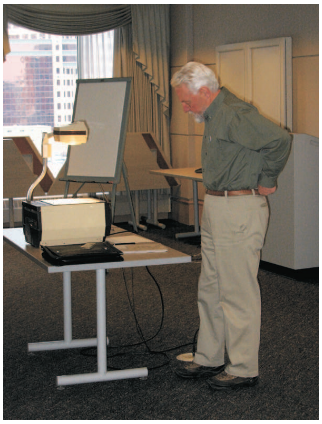
Edward S. Krebes (Geology and Geophysics, University of Calgary): *Seismic waves in a layered earth*

Peter Lancaster (Mathematics and Statistics, University of Calgary): *From quadratic equations to transfer functions*

Melvin J. Hinich (Department of Government, University of Texas): *Detecting random modulated cycles*

Richard Cleve (Computer Science, University of Calgary): *Quantum algorithms*

Florin Diacu (Mathematics and Statistics, University of Victoria): *The birth of chaos*



Peter Lancaster, Mathematics, University of Calgary

Seismic Wave Simulation and Seismic Imaging: A PIMS Summer School

University of Calgary, July 14–18, 2003

Contributed by Gary Margrave, University of Calgary

Instructors: **Gary F. Margrave** (Geology and Geophysics, University of Calgary), **Len P. Bos** (Mathematics and Statistics, University of Calgary) and **Robert J. Ferguson** (Jackson School of Geosciences, University of Texas at Austin).

The first part of this school will examine real seismic data and present several mathematical models for the forward problem: the simulation of seismic waves. Wave equations and their solutions will be explored. Essential mathematical techniques such as Green's functions, Kirchhoff diffraction theory, and ray theory will be developed and examined. In the second part, these concepts and tools will be applied to develop the prototypical approaches to the seismic imaging problem. The Born and Kirchhoff approximations will be shown to lead to direct schemes for the estimation of subsurface reflectivity that are the basis for modern imaging techniques. The strengths and weaknesses of these techniques will be examined and a survey of more advanced, emerging methods will be presented. Emphasis will be placed upon understanding the assumptions and limitations of each technique. The successful student will obtain both an understanding of the basis and mechanics of the major imaging techniques and will appreciate the outstanding problems at the forefront of research.

This course is intended for mathematicians and mathematically skilled physical scientists who wish for a fast technical introduction to the seismic imaging problem. Students in the mathematical sciences at the advanced undergraduate or beginning graduate level should have the appropriate prerequisites. It will be helpful to have some previous exposure to elementary mathematical analysis (calculus, linear algebra, ordinary and partial differential equations, and Fourier analysis) as well as experience with basic physical theory. Also some familiarity with Matlab will be helpful. However, no prior exposure to geophysics, seismology, or continuum mechanics is needed. PIMS will pay the travel and accommodation expenses of students who are accepted for attendance.

The deadline is May 1, 2003.

Please see **www.pims.math.ca/science/2003/seismic/** for more information.

6th PIMS-IMA Graduate Mathematics Modelling Camp

BIRS, Banff, Alberta, May 17–22, 2003

The GIMMC is the first leg of the PIMS-IMA Industrial Mathematics Forum which also includes the PIMS-IMA Industrial Problem Solving Workshop (IPSW7).

The Graduate Mathematics Modelling Camp is designed to give graduate students in the Mathematical Sciences an opportunity to learn techniques of mathematical modelling under the supervision and guidance of experts in the field.

In the first session, the mentors will present the problems, and for the remainder of the week, they will each guide a group of graduate students through to a resolution, culminating in a group presentation and a written document at the end of the week.

The mentors and problems this year are:

Emily Stone (Utah State U.): *Modelling PCR devices for fun and profit*
Richard Braun (U. Delaware): *Thin fluid film drainage*
Sonja Glavaski (Honeywell): *Stability of hybrid systems using sum of squares (SoS) programming approach: VCCR system example*
David Misemer (3M): *Modeling polymer purification by counter-current extraction*
Fadil Santosa (IMA & U. Minnesota): *Solar car racing strategy*
Robert Piché (Tampere U. Technology, Finland): *Natural frequency of a fluid carrying plate*

GIMMC is being organized by **Rachel Kuske** (UBC), **Fadil Santosa** (IMA), **Jack Macki** (U. Alberta), **Chris Bose** (U. Victoria), **Huaxiong Huang** (York) and **Ian Frigaard** (UBC).

For more information please see **www.pims.math.ca/industrial/2003/gimmc/.**

PIMS-MITACS Summer School on Quantum Information Science

University of Calgary, June 23–27, 2003

Contributed by Richard Cleve, University of Calgary

The goal of the PIMS-MITACS Summer School on Quantum Information Science is to introduce a general audience of computer scientists, physicists, and mathematicians with little or no background in quantum information science to this exciting field. The school will consist of five days of talks that will cover the basics of quantum computation and information as well as several advanced topics.

Specific topics to be covered include:

- quantum algorithms: quantum Fourier transforms and Shor's algorithm
- quantum algorithms: amplitude amplification and continuous time paradigms
- quantum information theory and entanglement
- quantum cryptography
- quantum error correcting codes
- fault-tolerant quantum computation
- physical implementations of quantum information processing devices
- non-locality and quantum communication complexity
- quantum complexity theory

The organizers are **Richard Cleve**, **Peter Høyer** and **John Watrous** (U. Calgary).

The speakers include: **Andrew Childs** (MIT), **Richard Cleve** (U. Calgary), **Peter Høyer** (U. Calgary), **Brian King** (McMaster U.), **Raymond Laflamme** (U. Waterloo and Perimeter Institute), **Michele Mosca** (U. Waterloo and Perimeter Institute), **John Preskill** (Caltech), **Alain Tapp** (U. Montreal), and **John Watrous** (U. Calgary).

For more information and registration please see **www.pims.math.ca/industrial/2003/ssqis/**.

7th PIMS-IMA Industrial Problem Solving Workshop

University of Calgary, May 25–29, 2003

PIMS and the Institute for Mathematics and its Applications (IMA) are jointly organizing the **7th PIMS-IMA Industrial Problem Solving Workshop** which will be held at the the University of Calgary, May 25–29, 2002.

The presenters and problems include:

Lalitha Venkataram (Schlumberger): *Solving Fredholm integral of the first kind in two dimensions*
Veena B. Mendiratta (Lucent): *Modeling quality and warranty cost*
Bruce McGee (McMillan-McGee Corp.): *The thermodynamic bubble problem for the in-situ thermal remediation of conatminated soils*
John R. Hoffman (Lockheed-Martin): *Problems associated with the probability hypothesis density function approach for multi-target tracking*
Edward Keyes (Orisar)**:** *Methods to localize inadvertent power and ground connections on intergrated circuits*
Carlos Tolmasky (Cargill)**:** *Correlation structures corresponding to forward rates*
TBA (Manifold Data Mining)**:** *Identifying drivers for consumer behavior via projection to latent spaces method*

Academic Experts: **Robert Piche** (Tampère UT, Finland), **Fadil Santosa** (Minnesota), **Nilima Nigam** (McGill), **Sean Bohun** (Penn State), **Rita Aggarwala** (U Calgary).

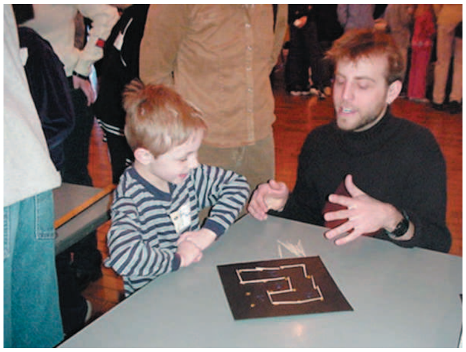
Organizing Committee: **Rachel Kuske** (UBC), **Fadil Santosa** (IMA), **Jack Macki** (U. Alberta), **Chris Bose** (U. Victoria), **Huaxiong Huang** (York U.), **Ian Frigaard** (UBC), **Tony Ware** (U. Calgary).

For more information please see
www.pims.math.ca/industrial/2003/ipsw/

PIMS/University of Alberta Math Fairs

Univerity of Alberta, November 5, 2002 and March 7, 2003

Contributed by Ted Lewis, University of Alberta



Discussing a problem at the March 2003 Math Fair

Just under 700 elementary and junior high students from 25 schools visited the PIMS/University of Alberta Math Fair in November 2002. This all day event was was sponsored by PIMS and presented by the Math 160 students of Venera Hrimiuc and Ted Lewis, and was held in Dinwoodie Lounge in the Student Union Building. At the same time, in the other half of Dinwoodie, Andy Liu ran a problem solving session for the children. The students spent 2–2.5 hours at the event, splitting their time between the math fair and the problem solving session.

On Friday March 7, 2003 the Math 160 students of Venera Hrimiuc presented a second PIMS/U of A Math Fair. Just under 500 enthusiastic students visited the fair, from Grade 3 to Grade 9. At the math fair, the children could try their hand at solving many math puzzles, and were guided in their endeavours by the university students.

A new component has been added to the popular event. As well as applying their talents to the puzzles, the visitors also played a mathematical game. Their opposition was provided by 40 U of A student volunteers, both graduate and undergraduate. Each university student played against a dozen children in a setting somewhat like simultaneous chess. Any visitor who won a game was invited to challenge Andy Liu. The game is most commonly known “hare and hounds”, and it is rumoured that Andy never loses. Because of this, the games component of the math fair has been dubbed the “Math Unfair”.

Students enjoying activities at the March 2003 PIMS/University of Alberta Math Fair

ESSO-CMS-PIMS Alberta Math Camp

University of Alberta, August 17–24, 2002

Contributed by Ted Lewis, University of Alberta

Each year, ESSO and CMS sponsor a national and several regional math camps. The Alberta Math camp alternates between the Universities of Alberta and Calgary. In addition to ESSO and CMS, the event is sponsored by the Faculty of Science at the U. Alberta, PIMS, the Edmonton Public School Board and the Mathematical Council of the Alberta Teachers Association. The camp organizers were Ted Lewis and Andy Liu.

The camp is intended for students from grades 7–10. Twenty-seven students attended the camp.

The morning programme consisted of a three-hour workshop centered on a lecture. Andy Liu gave a lecture on *Coding*, Hans Brungs spoke about the *History of Mathematics*, Edit Gombay gave a lecture on *Probability*, Sudarshan Sehgal talked about *Number Theory*, Dragos Hrimiuc gave a lecture on *Diophantine Equations*, and Volker Runde spoke about the *Banach-Tarski Paradox*. The afternoon programme was a mixture of academic and extracurricular activities including individual and team contests.

Alberta High School Math Competition

Contributed by Ted Lewis, University of Alberta

The first part of the 47th Alberta High School Mathematics Competition was written on November 19, 2002 by 948 students representing 43 schools from Alberta. The competition consisted of 16 multiple choice questions. Although part I serves as a gateway to part II, the book prizes are substantial, with the total value exceeding $1200.

There was one perfect paper, by Robert Barrington Leigh from Old Scona Academic High School. This year also featured several competitors from junior high school who fared very well.

Part II of the Alberta High School Mathematics Competition was written on February 5, 2003 by 75 students representing 26 schools.

The awards dinner, which is sponsored by PIMS, was held on March 29 in Edmonton.

For a list of top finishers, please see the website **www.math.ualberta.ca/~ahsmc**.

PIMS Graduate Studies Information Week

Universities of Calgary and Alberta, January 7–11, 2003

Contributed by John Collins, University of Calgary, and Jim Muldowney, University of Alberta

Enjoying the reception.

For the last several years PIMS has sponsored an annual Graduate Studies Information Week. The objective is to recruit top undergraduate students from across Canada to enrol in graduate studies in mathematics, statistics and computing science at the PIMS universities.

This year's PIMS Graduate Studies Information Week was held in Calgary and Edmonton from January 7–11. The event was funded by PIMS and the two host universities.

The 25 students arrived in Calgary on the afternoon of Tuesday, January 7, and a welcoming reception was held that evening. Then all day Wednesday and Thursday morning, the visiting students had a full programme that included information sessions about graduate studies in the Department of Mathematics and Statistics and in the Department of Computer Science.

They had opportunities to talk to faculty members and graduate students about their research interests. The students were also given a tour of the campus. Representatives of other PIMS universities who met the students and made presentations about their programmes were Chris Bose (University of Victoria) and Randy Sitter (Simon Fraser University). A farewell banquet was held on Wednesday evening at the University Club.

When the students arrived in Edmonton they attended a welcoming banquet hosted by the Vice-President (research). The students were welcomed by Acting Dean of Science Gregory Taylor and by Associate Dean of Graduate Studies and Research Ellen Macdonald.

On Friday morning students were addressed by BIRS Scientific Director Robert Moody on the nature of graduate studies and research in the mathematical sciences and by Jin Hoover on the types of mathematical problems being considered by computing scientists. They then heard 40-minute presentations by representatives of PIMS universities. They heard about UBC programmes from David Brydges. Simon Fraser University was represented by Imin Chen and Steven Ruuth and Lorna Stewart. Yau Shu Wong represented the University of Alberta.

At noon, following the formal presentations, all local graduate students and faculty in math, statistics and computing science were invited to meet the guests for lunch in the Department of Mathematical and Statistical Sciences.

For the afternoon students followed individual itineraries that had been prepared for them based on their expressed interests (in universities, programmes etc). They took campus and facility tours and/or had individual or small group meetings with PIMS graduate programme representatives and with local scientists and graduate students.

The event concluded with a farewell supper at the Heritage Lounge. Students expressed their excitement and interest in the experience and most of them declared their intention to apply for admission to one or more graduate programmes at a PIMS university.

Discussing graduate studies.

Math Mania invades George Jay Elementary School

Victoria, January 28, 2003

Contributed by David Leeming, University of Victoria

The activitiy "A Sorting Network."

Thanks to the promotion efforts of Janine Roy, Vice Principal of George Jay, there were about two hundred and seventy five students, parents and teachers at the most recent Math Mania event. It was one of the most successful to date.

Some new activities were introduced at Math Mania this time, including the *"Bridges of Königsberg"* and several hands on mathematical puzzles.

Math Mania presents a variety of interactive demonstrations, puzzles, games and art such as 'goats and gold', the 'set game', the 'game of 24' kaliedoscopes and hexaflexagons, and a variety of mathematical puzzles and paradoxes. These activities are designed to demonstrate to children and their parents fun ways of learning both math and computer science concepts.

Math Mania is sponsored by PIMS and the presenters are enthusiastic volunteers from the faculty, staff and students (and some family members) of the Department of Mathematics and Statistics at the University of Victoria.

Students playing the Set Game.

IAM-CSC-PIMS Senior Undergraduate Math Modelling Workshop

UBC and SFU, February 15–16, 2003

The **2003 IAM-CSC-PIMS Undergraduate Math Modelling Workshop** held during the weekend of February 15–16, 2003 was a great success. Ten of the very best undergraduate mathematics students in Canada, and one from the Washington State participated in the workshop.

The workshop was organized by PIMS along with the Institute of Applied Mathematics (IAM) at UBC and the PIMS Centre for Scientific Computing (CSC) at SFU.

Faculty mentors first outlined each of the applied problems to all the participants. The students then chose one of the problems to work on each day. Lectures on each of the problems were presented by the mentors in which the tools for the modelling and analysis of the problem were developed. The mentors then helped the students develop the models and answer the questions posed. The workshop culminated with presentations by each of the groups working on the problems.

The problems the students looked at were:

Image Restoration using PDE-based Methods

Mentor: ***Chen Greif*** *(CS, UBC)*

In many applications there is a need to produce a clean image out of a given blurred, noisy input image. This situation occurs, for example, for satellite or space-shuttle images that get contaminated while being broadcast to earth.

Denoising and deblurring those images involves a non-trivial numerical inversion operation, which needs to be implemented using sensible and robust mathematical models, in order to accomplish high-quality results.

In this project the students looked at a few image restoration methods that are based on partial differential equations (PDEs) and applied the methods to reconstruct images.

Optimal Scheduling Policies in Networks with Multi-task Servers

Mentor: ***Rachel Kuske*** *(Math, UBC)*

In this project the students developed models for queueing networks in which "customers" may return to a server with requests for different tasks or "jobs". Examples of such systems occur in manufacturing processes and design of disk controllers. In semi-conductor device manufacture, where there are many steps in the manufacturing process, the same machine is used for several of these steps. Similarly, disk controllers are dedicated processors for efficient reading and writing data to a hard disk; the efficiency depends on implementing efficient algorithms for storage, so that writing data results in an additional service request for applying the smart algorithm.

Students built simple models which illustrate the the bottleneck problems described above. By viewing these models as sub-networks in a larger network, the team developed optimal priorities for job processing in these small sub-networks, as a basis for constructing an overall optimal policy.

Characterization of Internet Traffic and its Impact on Network Performance

Mentor: ***Ljiljana Trajkovic*** *(CS, SFU)*

Traditional queuing theory techniques based on Poisson traffic models were essential for the development of telephone networks. Today's multimedia applications produce complex traffic patterns that result from the statistically multiplexed data, voice, image, and video patterns. For networks carrying such diverse applications, traditional traffic models have proved inadequate and incapable of capturing essential characteristics of the traffic patterns. Internet traffic characterization work has only recently been shown to be promising due to the presence of the traffic "invariants" detected in traffic traces.

In such an environment, computer simulation and empirical techniques play an important role in understanding networks' behavior. The use of genuine traffic traces to simulate loss in packet networks such as Internet were described. Simulation results indicate that underlying transport protocols and time scales are essential for understanding loss behavior in packet networks.

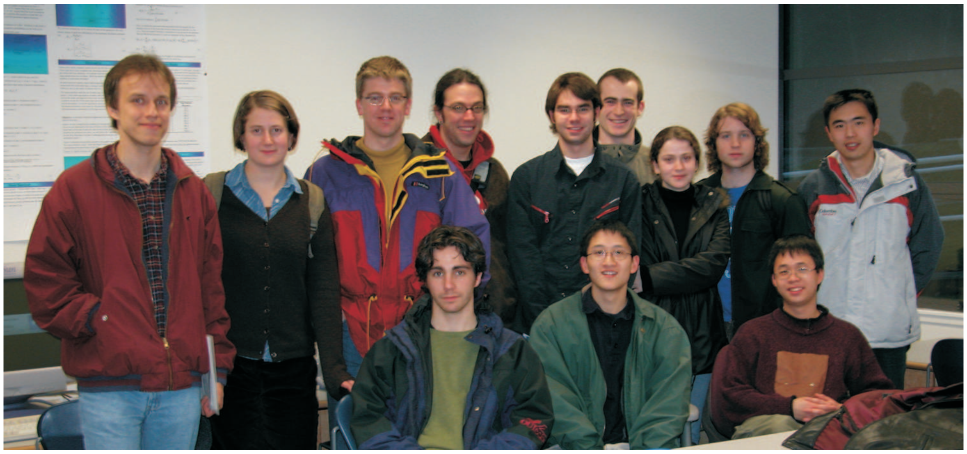
Pedestrian Flow and Cellular Automata

Mentor: ***Peter Berg*** *(MITACS Postdoc, SFU)*

Recently, pedestrian flow has received much attention in the mathematical modeling community, e.g. in simulations of emergency exits, subway pedestrian traffic and handling large crowds.

Essentially, there are three different ways of modeling such discrete stochastic 2-D systems of interacting "particles": deterministic continuum models, deterministic discrete models and cellular automata. So far, only cellular automata models allow for the inclusion of stochastic effects and are an easy method for numerical simulation.

Some features of pedestrian flow and how they are modelled were presented. The students worked in a team to simulate pedestrian counter-flow along a long thin stretch using Matlab. They observed the phase transition from individual free walking to lane formation, an organized form of flow. This is an exciting example of how unpredictable individuals can become organized without any leader's decision or other obvious causes.



Undergraduate Modelling Workshop participants at SFU.

Summer Institute for Mathematics for High School Students

University of Washington, July 22–August 2, 2003

Getting a glimpse of the depth and beauty of mathematics can be a transforming experience for a student, whatever interests the student may intend to pursue in the future. The Summer Institute for Mathematics at the University of Washington (SIMUW) is intended to provide talented, enthusiastic students with just such a glimpse.

The SIMUW programme will bring together twenty-four students from Washington, Oregon, British Columbia, and Alaska with a mathematical background of at least three years of high school mathematics and who have not yet completed high school. Admission is competitive, based on an assessment both of ability in mathematics and enthusiasm for an intensive mathematical experience.

The SIMUW program is organized by three University of Washington faculty members: Ron Irving, Sándor Kovács and James Morrow. Six mathematicians from UW, Microsoft, and the University of Chicago will serve as the instructors. In addition, other mathematicians and scientists from UW and elsewhere will participate as special lecturers.

The following lectures are planned:

Tim Chartier (U. Washington): *Vectors and the mathematics of computer graphics*
Dave Collingwood (U. Washington): *Mathematical modeling and problem solving*
Ginger Warfield (U. Washington): *Probability—thinking with your bare hands*
Robert Pollack (University of Chicago): *Elliptic curves—a mix of algebra and geometry*
Sándor Kovács (U. Washington): *The mathematics of internet security*
Henry Cohn (Microsoft Research): *Combinatorics*
Tom Daniel (U. Washington): *Movement in biology: math meets massive muscles*
Judith Arms (U. Washington): *The mathematical theory of knots*
Pat Averbeck (U. Washington): *The mathematics that orc-like bankers and car dealers don't want you to know*
Sara Billey (MIT): *Zometool competition*
Kristin Lauter (Microsoft Research): *Cool ways to factor large numbers*
Eric Babson (U. Washington): *Juggling mathematics*
Tatiana Toro (U. Washington): *Image segmentation*
Brian Marcus (UBC): *Encoding data on disk drives: (2,) and beyond*
Nathan Kutz (U. Washington): *Lightwave communications and the physics behind the internet*
Richard Ladner (U. Washington): *The mathematics of data compression*

For more information please see **www.math.washington.edu/~simuw/**

Other Upcoming Education Activities

- May 2, 2003: **Changing the Culture VI**, SFU Harbour Centre. The theme this year is: *"Do we need to teach algebra?"*
- May 24, 2003: **5th Annual PIMS Elementary Grades Mathematics Contest**, UBC
- June 12-13, 2003: **Connecting Women in Mathematics Across Canada**, University of Alberta. The Canadian Mathematical Society and PIMS are organizing a workshop for women graduate students in the mathematical sciences at Canadian universities. Fifty women will be selected to participate in the workshop. They will attend plenary talks in mathematics, and panel and small group discussions on issues of career development and balancing career and personal and family life.
- June 23-27, 2003: **ESSO-CMS-PIMS Math Camp for High School Students**, SFU
- November 18, 2003: **Alberta High School Mathematics Competition**, Part I of the 2003–2004 Season

The March 2003 Issue of Pi in the Sky Magazine

The sixth issue of the PIMS educational magazine **Pi in the Sky** came out in March 2003. The cover was specially created by Czech artist Gabriela Novakova. The scene depicted was inspired by the article *"Gambling with Your Future—Knowing the Probabilities"* by Garry J. Smith and Byron Schmuland, which features in the magazine.

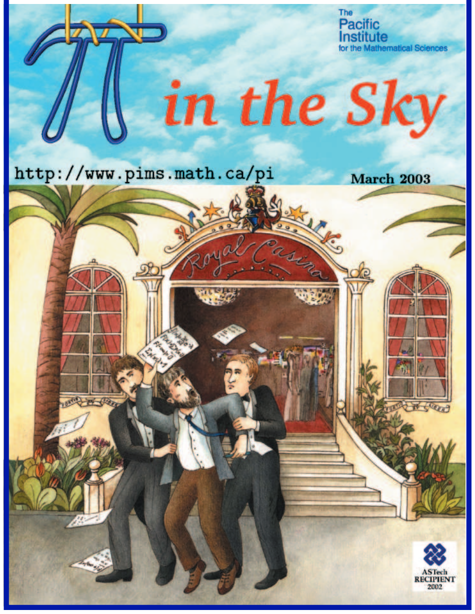
The Magic of Numbers section features *"Divisibility of Prime Numbers"* by Edwin D. Charles and Jeremy B. Tatum.

The Math Strategies section contains the article *"Inequalities for Group Folding and Groups Unfolded"* by Andy Liu, which explains "Scientific Origami".

Other articles include *"On the Dynamics of Karate"* by Florin Diacu, *"Be Careful with that Axe, Eugene"* by Thomas Hillen, *"Leonard Euler"* by Alexander and Alina Litvak, *"Vedic Mathematics"* by Jeganathan Sriskandarajah, *"Mathematics in Today's Financial Markets"* by Alexandar Melnikov, and *"Am I Really Sick?"* by Klaus Hoechsmann.

Pi in the Sky continues to be distributed to schools in British Columbia, Alberta and Washington State as well as to individuals across North America who have requested a copy.

This issue and all the previous issues are available for download on the website **www.pims.math.ca/pi/**.

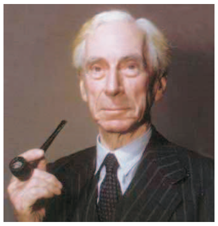


A la recherche du plan perdu

This article is based on a talk given in French at the CMS Summer Meeting in June 2002.

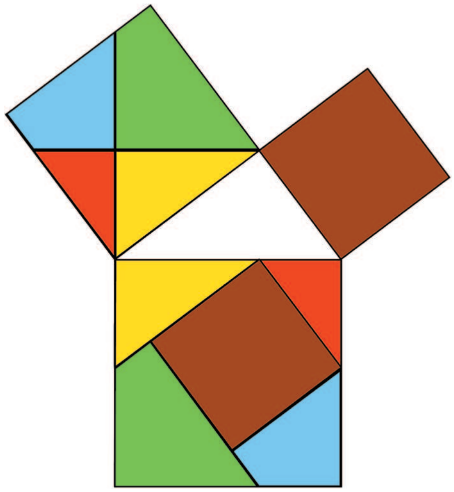
by Klaus Hoechsmann, PIMS Education Facilitator

To answer the basic question of this meeting: *"What geometry should be taught to prospective teachers?"* it is often suggested that the focus should be on more Dynamic and/or Analytic Geometry. Software like Cabri, Cinderella, or Sketchpad can indeed be invaluable at certain stages of learning. Geometry does have strong connections to coordinate systems, vectorspaces, transformation groups, etc., and can even be presented as sprouting from any one of these. But today I wish to put in a word for good old-fashioned, hands-on, Euclidean geometry, which has all but disappeared from the curriculum.

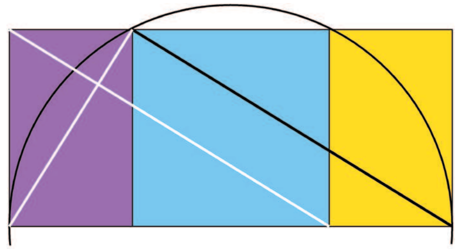


Bertrand Russell

One of the most important events of his life "as dazzling as first love"—that is how Bertrand Russell characterises his encounter with Euclid. No doubt young Bertie's cognitive libido was set ablaze by the seamless perfection and the sheer cleverness of it all. For lesser mortals, the old Greek master's mixture of ontological naiveté and sophistcated problem-solving may form a similar attraction. Moreover, here is a wide panorama of classical mathematics with not a number or formula in sight. As René Thom once remarked: it has no heuristics, every problem starts from zero.



***Pythagoras Theorem**: For a right angle triangle the sum of the areas of the two smaller squares equals the area of the largest square.*



***Golden Rectangles**: The two white lines cross at right angles (Thales). Therefore the large blue and magenta rectangle is similar to the rectangle obtained by removing a square (the magenta one).*

Euclid's geometry has two advantages over more "modern" ones: it is construction oriented, hence gets manual tools involved; it allows (mentally) moving single objects without moving the whole plane (a difficult notion).

The theorems about adding squares (Pythagoras) and about angles on a circular segment (Thales) already suffice for solving a great variety of problems. For instance in the construction of golden rectangles as shown above. The concurrence of medians, perpendicular bisectors and altitudes and is unexpected—and the collinearity of the points of concurrence (Euler) even more so. Proofs are short and elegant. In algebra, mathematical beauty appears much later.

In the course of his strong engagement in curricular reform around 1900, the great Felix Klein, pointed out a double discontinuity: the freshman at university must forget his math habits from school; returning to school as a teacher, the alumnus quickly learns to forget his (useless and alienating) university math.

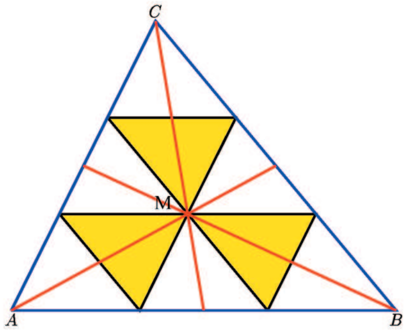
Universities offer a plethora of geometry courses: linear, algebraic, differential, axiomatic—each in several flavours—plus topology, graph theory, etc. Most of them demand a prior, and often advanced, study of algebra and analysis; all of them require a rigour unattainable in school. The student (e.g., the future teacher) has to learn a different way of thinking—about mental constructs with very scant sensory support.

Mathematics progresses by developing new perspectives. That is why the average student of today can routinely handle problems which Newton found hard. As you climb a mountain your experience remains rich and intense—but you no longer hear the sounds of the villages below. The prospective teacher, however, must not lose that connection. Teachers can be enthusiastic only about what they know well and love. They cannot be expected to turn group characters into trigonometry or compact manifolds into ellipsoids. Adding water to brandy does not make wine.

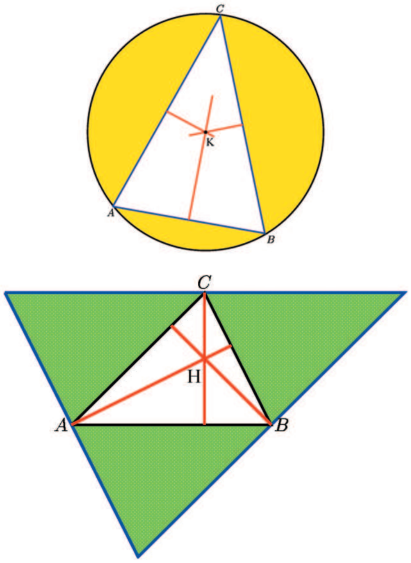
There was a time when teachers taught teachers. In the book [3], the expert teacher, Philipp Maennchen, keeps students interested by asking them to perform constructions around ever increasing obstacles: drawing lines from a given point inside a semi-disc toward its missing corners; drawing a tangent near the edge of a circular arc, etc. In another part of the book, he uses the surprise effect: every student draws an arbitray triangle, selects any point on each of the three sides, and draws a circle around each of the three resulting corner triangles. They all report that their three circles intersect in one point, and are now curious to know the reason. This is used in preparation for a study of Fermat's Point.

Today's math educator, having to publish research articles, can ill afford to write such "expository" books. Math departments must now do *their* share. The feasibility of a junior/senior level course, thoughtfully and creatively following Euclid and his moderniser Hilbert, is being demonstrated by Berkeley's Robin Hartshorne [1].

Besides the two already mentioned, Euclid-



***Medians**: The three medians go through a point M two-thirds of the way down on each.*



***Perpendicular Bisectors** (top) **and Altitudes** (bottom): The altitudes are the perpendicular bisectors of the double triangles.*

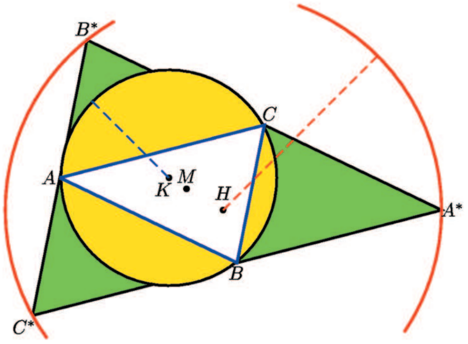
ean synthetic geometry has a third advantage: it is well tested, has a large crowd of fans, and a huge body of problems which are neither isolated nor algorithmic. Though scarcely present in recent Western curricula, it is still flourishing in under-developed countries and on the International Mathematical Olympiad. Hartshorne's lecture notes have grown into a stately Springer book. A revival may be in the offing: the drought might soon be over.

References

[1] Robin Hartshorne, *Companion to Euclid*, Berkeley Mathematics Lecture Notes, American Mathematical Society, **9**, 1997

[2] Klaus Hoechsmann, *Anatomy of Triangles*, Pi in the Sky, December 2000, 18–19

[3] Philipp Maennchen, Methodik des mathematischen Unterrichts, Diesterweg, Frankfurt/Main, 1928



***Euler's Line**: Reflect the figure through the meeting point of the medians and stretch it by the factor 2.*

Numeracy and Beyond: A Two-Part Workshop

Contributed by Klaus Hoechsmann, PIMS Education Facilitator

The main question this workshop will address is what minimum numeracy is required of the average citizen in this computer age, and how does it relate to the more advanced needs of the engineer or scientist?

The goal of this general analysis is to derive concrete suggestions which should be applicable to any educational system. Thus the first priority will be to identify key principles, which are simple, widely acceptable, practical, yet fundamental, which should guide the teaching of school mathematics independent of the particular school context.

Some topics that will be looked at are:

- *Numeracy: computation as an intelligent activity*
- *Arithmetical and geometric aspects*
- *The first hurdle: proportion, ratio, fractions*
- *The second hurdle: symbolic calculation*
- *Problem solving as vehicle and goal*

Numeracy and Beyond Workshop: Part I, PIMS-UBC, July 8–11, 2003

This workshop will include two public lectures:

Bernard Madison (U. Arkansas): *Numeracy and Democracy*

Yoram Sagher (U. Illinois, Chicago): *Lessons from the Singapore Curriculum*

There will be keynote lectures by

Tony Gardiner (U. Birmingham, UK)

Günter Törner (Duisburg, Germany)

Workshops will be held on the topics:

- *Propaedeutics of counting and measuring*
- *Taking care of the gifted young*
- *The challenge of multiplicative thinking*
- *Problem solving as a vehicle and goal*

There will be panel discussions on

- *The political dimensions of numeracy*
- *Algebra, geometry, statistics: how much and what?*

Bernard Madison

Yoram Sagher

Numeracy and Beyond: Part II, BIRS in Banff, December 5–9, 2004

The first part of the workshop is necessary for the preparation of the second. The reason is that the latter will be a kind of retreat in the style of Oberwolfach—though not for the communication and creation of new theorems in a well-defined mathematical specialty, but for the articulation of a sequence of reflections on the state and direction of mathematics education—intended as a tiny link in its long history, from Euclid to Hypatia, through the Indo-Iranian and Arabic teachers, to the European Renaissance and the present, with scant attention to other parts of the world. Without a firm and yet supple framework, such a workshop could, in five short days, produce no more than well-intentioned brain-storming. The meeting of July 2003 is intended to create this framework.

This two-part workshop is being organized by **Tony Gardiner** (Birmingham), **Klaus Hoechsmann** (PIMS), **Bernard Madison** (Arkansas)**, Yoram Sagher** (Chicago) and **Günter Törner** (Duisburg).

For more information please see **www.pims.math.ca/numeracy/**.

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