The
Pacific Institute for the Mathematical Sciences
Newsletter

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Contents

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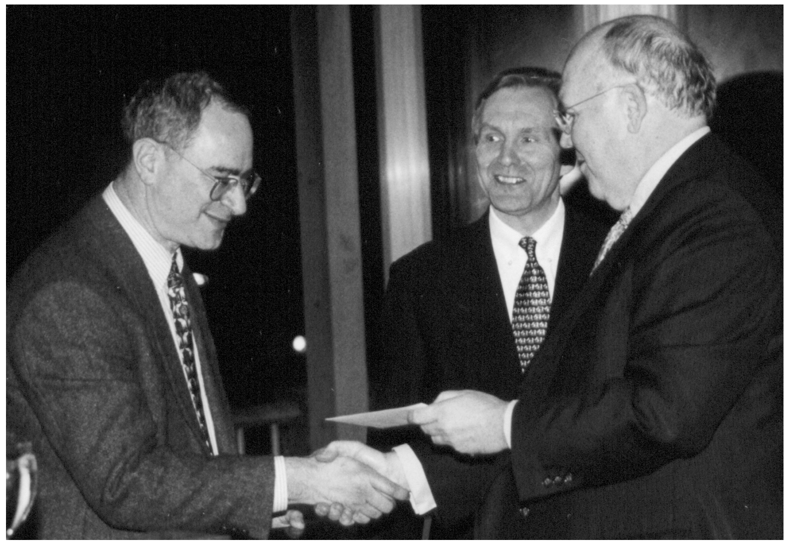
- **Simon Fraser University**, **The University of Alberta**, **The University of British Columbia**, **The University of Calgary**, **The University of Victoria**, **The University of Washington**, **The University of Northern British Columbia** and **The University of Lethbridge**.

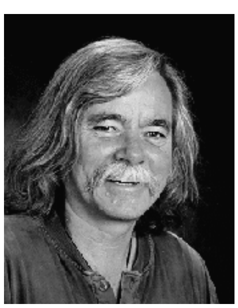
PIMS Awards Its Prizes for 2000



George Bluman receives PIMS Education Prize from Martin Taylor (VP Research, Univ. of Victoria) and Ken Foxcroft (TD Securities).

*Please see **PIMS Awards,** page 14.*

Bob Russell, New PIMS Site Director at SFU



In December, Bob Russell was appointed as the new Site Director for PIMS at SFU. He replaces Peter Borwein, who is currently on a sabbatical leave. Bob has been active in PIMS for some time. Currently, he is a member of the Local Organizing Committee

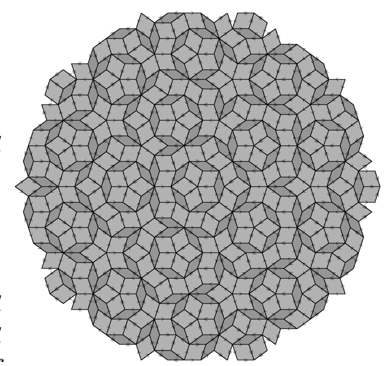
*Please see **Bob Russell,** page 2.*

Entering Mathematical Sciences at the Graduate Level

*Address given by Robert V. Moody, Univ. of Alberta, at the recent **PIMS Graduate Information Week**.*

A little while ago I came across a definition of mathematics that I like and that seems quite appropriate here. However, let me start with the usual sort of definition.

According to my Oxford Dictionary, mathematics is: *the abstract deductive science of number, quantity, arrangement, and space.* The authors are obviously not content with this since there is an attached note: *Mathematics is customarily divided into pure mathematics, those topics studied in their own right, and applied mathematics, the application of mathematical knowledge in science,*

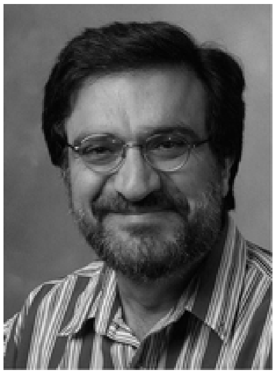


Penrose Tiling
(Image courtesy of Uwe Grimm.)

*Please see **Mathematical Sciences,** page 9.*

Director's Notes

Nassif Ghoussoub, FRSC



Quelle année sensationelle pour les mathématiques Canadiennes. Notre communauté a réagi avec vigueur et passion à l'appel de l'Union Mathématique Internationale et de L'UNESCO. À commencer par la campagne des posters dans le métro de Montréal dirigée par le Centre de Recherches Mathématiques, la grande réunion de la Société Mathématique du Canada à Hamilton, le défilé époustouflant des medailles Fields au Fields Institute et bien sûr, the myriad of educational initiatives that PIMS spearheaded all year long: The **Mathematics is Everywhere** campaign on buses in Vancouver and Victoria, **Hypatia's Street Theatre** staged at UBC's Frederic Wood Theater, and the **Pi in the Sky** magazine distributed to every school in Alberta and BC.

This year is likely to be even more exciting for world mathematics. Our efforts toward establishing an **International Research Station for Mathematical Innovation and Discovery** in the Canadian Rockies are well under way. More details will be given in the next newsletter but I can report that most hurdles regarding international partnerships and funding are being resolved. We expect a joint announcement from the various partners well before the end of this year.

A few words to our young future leaders, especially now that a change of the guard is already under way. Being a militant for mathematics in Canada is not a crime and —unlike Hypatia— there is no danger of being crucified. To the contrary, gratifications abound and there are some secret pleasures.

Indeed, there is nothing more rewarding than the enlightened smile of UBC's provost, Barry McBride when you hit him with a good idea on how to promote interdisciplinary research through the mathematical sciences. There is nothing more pleasureful than seeing Univ. of Alberta's Dean of Science, Dick Peter, a distinguished life scientist, lecturing policy makers on the importance of mathematics. There is nothing more gratifying than witnessing Univ. of Alberta's VP-Research, Roger Smith and Univ. of Calgary's acting VP-research, Keith Archer, both social scientists, passionately and convincingly describing the "Oberwolfach concept" to the Alberta minister for Innovation and Science so that we can get one going in the Rockies. There is nothing more gratifying than watching NSERC's Director Danielle Menard and Nigel Lloyd telling senior NSF officials about the admiration they have for the efforts and successes of the Canadian mathematical community. We will always be grateful to them for helping us arrange such a meeting and also for accompanying us to Washington DC so as to jumpstart a major Canada-US collaborative effort.

These are true pleasures my friends and these people and many others like them should always have the gratitude of the mathematical research community.

These notes are excerpted from the Director's speech at the CMS meeting in Vancouver, December 10–12, 2000

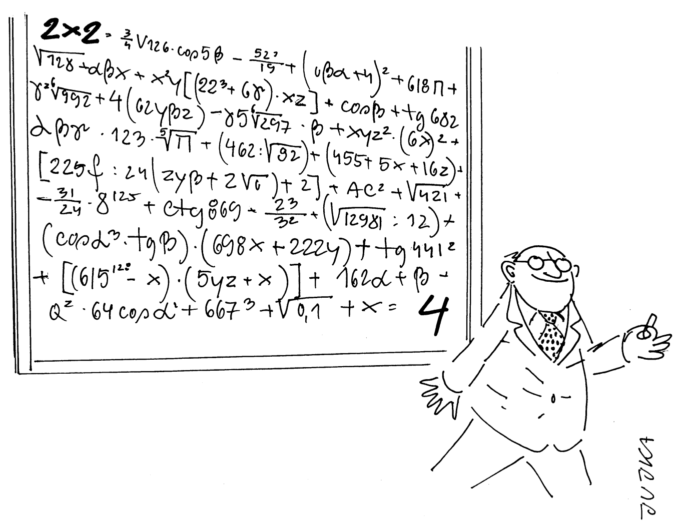
Bob Russell, PIMS-SFU Site Director

Continued from page 1.

and the Scientific Committee of the PIMS-sponsored **International Conference on Scientific Computation and Differential Equations** for 2001. Furthermore, along with Keith Promislow, he cosponsors the PIMS PDF Ricardo Carretero. Bob is also a member of the MITACS research team on Mathematical Modelling and Scientific Computation.

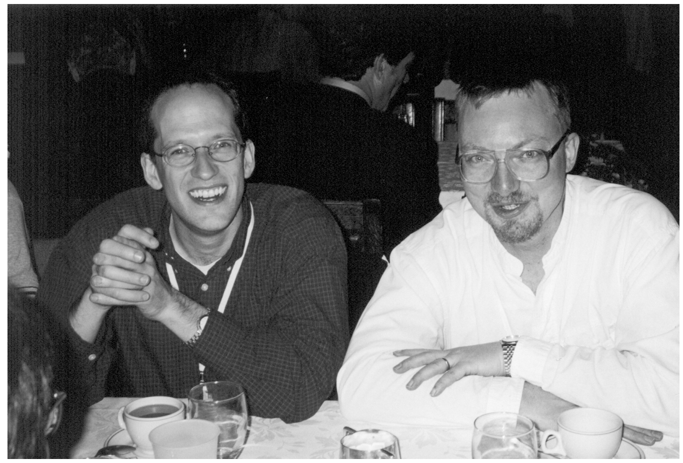
Bob Russell has been Professor of Mathematics and Computing Science at Simon Fraser University since 1981. He is currently a member of the SFU Board of Governors and Senate. He is also the Director of the proposed PIMS **Centre for Scientific Computing**. Bob is also the editor of various journals, including the SIAM Journal on Numerical Analysis, and a past editor for SIAM Journal for Scientific Computing. He is on the IMACS Board of Directors and is currently the Canadian Applied and Industrial Mathematics Society's official representative for ICIAM.

His main area of research is scientific computing, particularly the numerical solution of differential equations. He has published two books — one in the SIAM Classics series — and over 70 journal articles.



MITACS Team Wins PIMS Industrial Outreach Award

The PIMS Industrial Outreach Prize was recently awarded to the research team consisting of Huaxiong Huang (York), Keith Promislow (SFU), John Stockie (New Brunswick) and Brian Wetton (UBC) from the MITACS Mathematical Modeling and Scientific Computation Group. In the article below they describe their research with Ballard Power Systems.



Keith Promislow (left) and Brian Wetton at the 2000 MITACS Annual General Meeting.

The Mathematics of Fuel Cells:
An Overview of the MITACS-Ballard Power Systems Collaboration

Contributed by Brian Wetton and Keith Promislow.

Ballard Power Systems is the world leader in the development of fuel cell technology. Their designs promise cleaner, more efficient power for the automotive industry and for stationary generators for today's deregulated electrical market. The PIMS-affiliated Mathematical Modeling and Scientific Computation (MMSC) Group is a team of Math faculty, post-doctoral fellows, graduate students and support staff from UBC, SFU, York University, the University of New Brunswick and the University of Calgary. The expertise of our group is in the application of modeling and scientific computing methods to the area of material science in its broadest sense. The MITACS NCE has provided a forum for collaboration between this academic group and Ballard. The current joint project centers on the convective/diffusive transport of reactant gases (hydrogen and oxygen) in conjunction with condensation and water management in fuel cell stacks. Mathematical modeling captures the interconnections between the important elements of complicated physical systems, yielding equations amenable to numerical methods. These models are helping Ballard to improve cell efficiency and durability, while speeding up the design process.

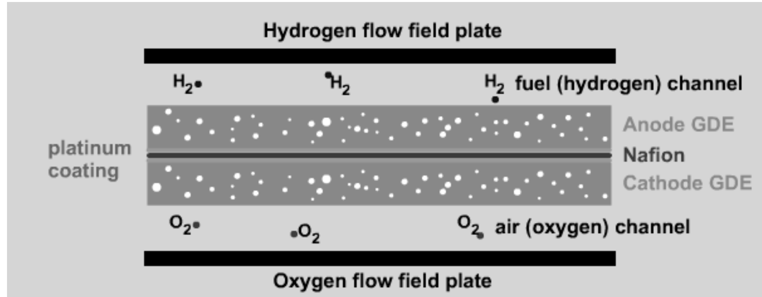
The research collaboration with Ballard was highlighted at the recent AGM meeting of the MITACS NCE. A presentation by Randy Savoie, the Ballard Director of Product Commercialization and Quality (and MITACS board member) described the broad sweep of applications of PEM fuel cell technology. His presentation was followed by Keith Promislow (SFU) and John Stockie (University of New Brunswick), who outlined the model development and presented results of numerical simulations.

The first Ballard-MMSC project (now complete) involved the modeling, analysis and computation of the flow of reactants through the Gas Diffusion Electrode (GDE), a layer of porous, conducting material (currently carbon fibre paper) on either side of the catalyst and membrane in the fuel cell. Mathematical analysis of the models highlighted the sensitivity of fuel cell performance to certain GDE parameters, giving insight into the performance of various possible GDE materials. Numerical computations focused on the importance of various geometrical parameters (channel width and spacing, etc.).

John Stockie (left) and Huaxiong Huang at the 2000 MITACS Annual General Meeting.

Our initial modeling of gas flow was limited to two component isothermal gas flows. In this year's project, the model and computations have been extended to include thermal effects, multi-component gases, and condensation in the GDE. Condensation and water management are crucial issues in fuel cells. Sufficient water must be present to keep the membrane (typically Nafion) wet. Too much water will block pores and prevent gases diffusing to the catalyst sites. Condensation modeling in porous media is complicated by the capillary pressure, the pressure difference between gas and liquid phases. The widely used models of capillary pressure for wetting media are not valid in the teflonated carbon fibre paper of the GDE. In addition, the modeling and computation of the movement of boundaries between wet and dry zones inside the GDL present a considerable scientific challenge.

We are also pursuing the modeling of water movement in the graphite channels which contain the flowing reactant gases. Water generated by the reaction enters the main gas flow channels and is blown out of the fuel cell. Liquid water moving in the channels will either be in droplets or rivulets. A study of rivulet flow in the channel geometry, with the critical dependence on the liquid-solid contact angle properties of the material, is being undertaken. The motion of droplets in the channel in a shear flow is also being considered, with the goal of estimating droplet size at shear-off.



GDE membrane in a fuel cell.

The Ballard project is just one of the industrial collaborations of the MMSC group. To find out more details about this project and others, please visit our web page **www.math.ubc.ca/∼wetton/mmsc**.

Report on Biophysics and Biochemistry of Motor Proteins Workshop

Sponsored by MITACS and PIMS, this workshop took place from August 27 to September 1, 2000 at the Banff Conference Centre in Alberta, Canada. The main objectives were to review the state of the art of the field from many different vantage points and to stimulate a multidisciplinary investigation into the area.

The meeting provided a fruitful multi-disciplinary forum for discussions on the biophysics and biochemistry of motor proteins. In addition to lectures and communications given by leading molecular and cell biologists, biophysicists, applied mathematicians, experimental physicists and representatives of other disciplines, there were a number of contributed talks and posters presented by other participants.

The workshop attracted a distinguished group of more than 70 researchers from several fields connected to the studies of motor protein family of molecules. They came from premier scientific institutions in North America, Europe, Asia and Australia representing 14 countries on 4 continents.

The interdisciplinary nature of the gathering was much in evidence as can be ascertained by inspecting the department names represented by the participants. These included: mathematics, applied mathematics, biomathematics, physics, biophysics, bioengineering, chemistry, biochemistry, botany, anatomy, physiology, pathology, oncology, biotechnology, cytology, pharmacology and biology.

The members of the local organizing committee were R. S. Hodges (Biochemistry, University of Alberta and PENCE), G. de Vries (Mathematical Sciences, University of Alberta) and J. A. Tuszynski (Physics, University of Alberta). The members of the international organising committee were R. Vallée (University of Massachusetts, USA), D. Astumian (University of Chicago, USA), D. Sackett (NIH, Bethesda, USA) and R. Vale (UC San Francisco, USA).

The 26 speakers who gave invited talks were D. Astumian (Chicago), S. Block (Stanford), T. Duke (Cambridge, UK), Y. Engelborghs (Leuven, Belgium), H. Flyvbjerg (Risoe, Denmark), E. Frey (Harvard), R. Goldman (Northwestern), L. S. Goldstein (UC San Diego), R. Hodges (Alberta), J. Howard (Washington), F. Jüelicher (Curie Institute, France), R. Kelly (Boston College), E. M. Mandelkow (represented by A. Hoenger, DESY, Germany), A. Maniotis (Iowa), A. Mogilner (UC Davis), C. D. Montemagno (Cornell), D. Odde (Minnesota), G. Oster (Berkeley), D. Sackett (NIH), J. Spudich (represented by W. Shih, Stanford), E. Unger (IMB, Germany), R. Vallée (Massachusetts), R. Vale (represented by S. Rice, UC San Francisco), T. Vicsek (Eötvös, Hungary), R. H. Wade (represented by F. Kozielski, Institute for Structural Biology, France) and T. Yanagida (Osaka, Japan).

The invited lectures were videotaped and will be available soon for viewing by streaming video at **www.pims.math.ca/video**.

R. Douglas Martin Speaks at PIMS-MITACS, UBC

On January 25, Doug Martin, Professor of Statistics at the University of Washington and Chief Scientist in the Data Analysis Products Divisions at MathSoft, spoke in the PIMS-MITACS Computational Statistics and Data Mining Seminar Series at UBC. In his talk he examined the problem of modeling stock market returns, given that the data is often non-Gaussian. He demonstrated how stock market data could be better understood by using robust factor models and Trellis graphics methods. Prof. Martin's lecture may be viewed via streaming video at **www.pims.math.ca/video**.

Information on the Computational Statistics and Data Mining Seminar Series is available at **www.pims.math.ca/industrial/2001/mitacs**.

Fourth Annual PIMS Graduate Industrial Mathematical Modelling Camp

University of Victoria
June 11–15, 2001

The format of the fourth **PIMS Graduate Industrial Mathematical Modelling Camp** (GIMMC) will be similar to that of previous years. Eight or nine "mentors" will be on site to lead groups of graduate students through a mathematical modelling problem chosen by the mentor. A maximum of 60 student participants will ensure a small student/mentor ratio. Confirmed mentors this year include: Chris Budd (Bath, UK, Fluids), John Chadam (Pittsburgh, Finance), Uli Haussmann (UBC, Finance), Tim Myers (Cranfield, UK, Fluids), and Miro Powojowski (Calgary, Statistics).

In past years, problems in both discrete and continuous optimisation, graph theory, mathematics of finance, stochastic optimisation and applied statistics have been presented, to name a few. Detailed reports on problems treated in previous year's camps may be found at **www.pims.math.ca/publications**.

Student participants at the GIMMC are expected to also particpate in the **PIMS Industrial Problem Solving Workshop** to be held in Seattle the following week. They will be automatically registered for this workshop. Students accepted for the GIMMC will be fully supported by PIMS during the two weeks of workshops, including reimbursement for travel expenses.

Graduate students wishing to participate should pay particular attention to the application procedure. One letter of recommendation will be required, and completed applications will be reviewed for acceptance on the following dates: **February 15**, **March 15** and **April 15**. Once the cap of 60 participants has been reached, we will no longer accept applications, so it is advisable to apply at the earliest possible time. Application to the camp is open to Graduate students at any US or Canadian University. For more information and details on the application procedure, please see the webpage **www.pims.math.ca/industrial/2001/gimmc**.

Fifth Annual PIMS Industrial Problem Solving Workshop

PIMS at University of Washington
June 18–22, 2001

Since its inception in the Summer of 1997 with the first PIMS-IPSW at UBC, the PIMS industrial workshops have been a spectacular success. We expect to continue this year with an outstanding workshop, and are particularly excited to have the IPSW as the Premier PIMS event at our newest PIMS institution, the University of Washington. Please consider joining us for what will certainly be an outstanding week of applied mathematics.

This, the fifth PIMS-IPSW, will follow a similar format to that of previous workshops. Six industrial scientists will present real mathematical problems that are current and relevant to their companies. The workshop participants (both faculty and graduate students) then spend the rest of the week working on these unsolved problems with the help of a company representative and some selected academic "mentors".

Four full days are reserved for work on the problems. On the fifth day, oral presentations from each group will be made before the whole assembly. A Conference Proceedings will be compiled and published by PIMS after the workshop. Proceedings from previous PIMS-IPSW's may be viewed at **www.pims.math.ca/publications**.

Graduate student participation is encouraged. All graduate students should apply to attend the training camp, PIMS-GIMMC 2001 at the University of Victoria during the previous week. Graduate participants at the GIMMC are automatically registered for the IPSW and will be fully supported for both events.

Limited funds in the form of travel reimbursements and accommodation expenses are available for other participants. Details about the administration of the workshop, financial support and problem descriptions may be found at the main PIMS-IPSW 2001 web site, **www.pims.math.ca/industrial/2001/ipsw**.

PIMS-IAM Joint Distinguished Colloquium Series

PIMS and the Institute for Applied Mathematics at UBC jointly sponsor six distinguished colloquiums each year. The speakers for the year 2000–2001 are:

Carlo Cercignani (Politecnico di Milano): "Kinetic Models for Granular Materials; An Exact Solution", September 13, 2000.

David Brydges (Univ. of Virginia): "Gaussian Integrals and Mean Field Theory", September 27, 2000.

Linda Petzold (Univ. of California at Santa Barbara): "Algorithms and Software for Dynamic Optimization with Application to Chemical Vapor Deposition Processes", November 1, 2000.

David Baillie (Simon Fraser University): "Comparative Genomics", January 16, 2001.

Gunther Uhlmann (Univ. of Washington): "The Mathematics of Reflection Seismology", March 6, 2001.

Bengt Fornberg (Univ. of Colorado): "Radial Basis Functions — A future way to solve PDEs to spectral accuracy on irregular multidimensional domains", March 27, 2001.

See **www.pims.math.ca/industrial/2000/iampims_lect** for more information.

PNW String Theory Seminar

PIMS at UBC
March 13, 2000

The first Pacific Northwest String Theory Seminar will be hosted by PIMS at UBC. This one-day meeting will feature 6 talks focusing on recent developments in string theory. The lectures will be videotaped and made available on the PIMS streaming video web page, **www.pims.math.ca/video**.

Organizing Committee: Konstantin Zarembo (chair, PIMS-UBC), Gordon Semenoff (UBC) and Sandy Rutherford (PIMS).

Invited Speakers Include:
H. Ooguri (Caltech)
W. Taylor (MIT)
K. Skenderis (Princeton)
A. Peet (Toronto)

For further information, please see the webpage **www.pims.math.ca/science/2001/pnwstring** or contact Konstantin Zarembo ⟨zarembo@pims.math.ca⟩.

For a complete list of upcoming scientific activities at PIMS, please visit the webpage **www.pims.math.ca/science**.

Joint SSC-WNAR-IMS Meeting

Simon Fraser University
June 10–14, 2001

Contributed by Tim Swartz, SFU.

The 29^{th} annual meeting of the Statistical Society of Canada (SSC) is being held jointly with the Western North American Region of the International Biometric Society (WNAR) and the Institute for Mathematical Statistics (IMS). It is expected to attract approximately 500 registrants and will bring together researchers and users of statistics and probability from academia, government and industry. Simon Fraser University is especially pleased to host the meeting as it celebrates the creation of its newly formed Department of Statistics and Actuarial Science.

The meeting will hold four workshops on the topics Statistical Genetics, Data Mining, Survey Methods and Beyond MCMC. In addition to invited paper sessions, the organizers are calling for contributed papers and are holding a poster session. The meeting will host a Job Fair, special WNAR events and various social events.

Special thanks are extended to the Pacific Institute for the Mathematical Sciences, the Centre de Recherches Mathematiques, the Fields Institute, SFU, the Faculty of Science at SFU and the Department of Mathematics and Statistics at SFU for their support of the conference.

More details concerning the conference are available at the webpage **www.math.sfu.ca/∼tim/sscmtg.html**.

PIMS Thematic Programme on Nonlinear PDE

PIMS at UBC, July 2 – August 18, 2001

More than 400 researchers from 15 countries will be participating in the PIMS Thematic Programme for 2001. The program will concentrate on several interrelated topics originating in finance, physics, chemistry, biology and material sciences as well as in geometry. The common feature of these topics is that they involve the interplay between nonlinear, geometric and dynamic components of partial differential equations. There will be emphasis on: **Viscosity Methods in Partial Differential Equations**, **Phase Transitions**, **Variational Methods in Partial Differential Equations**, **Concentration Phenomena and Vortex Dynamics**, as well as **Geometric PDE**. A number of mini-courses will be offered during the thematic program.

Mini-course Lecturers:

Panagiotis Souganidis (Austin): 5 lectures on “Fully nonlinear stochastic PDEs”.

Craig Evans (Berkeley): 2 lectures on “Hamilton-Jacobi equations and dynamical systems”.

Thaleia Zariphopoulou (Austin): 2 lectures on “Viscosity Solutions in Finance”.

Andrzej Swiech (Georgia Tech): 5 lectures on “Viscosity solutions in infinite dimensional spaces and optimal control of PDEs”.

Pierre-Louis Lions (Paris): 3 lectures on topics to be announced.

Henri Berestycki (Paris): 4 lectures on “Propagation of fronts in excitable media”.

David Kinderlehrer (Carnegie-Mellon): 4 lectures on “Topics in metastability and phase changes”.

Michael Struwe (ETH): 4 lectures on “Concentration problems in two dimensions”.

Wei-Ming Ni (Minnesota): 4 lectures on “Diffusions, cross-diffusions and their steady states”.

Fang-Hua Lin (Courant Institute): 4 lectures on “Vortex Dynamics of Ginsburg-Landau and related equations”.

Yann Brenier (Paris): 4 lectures on “Variational problems related to fluid and plasma modelling”.

Eric Séré (Paris): 3 lectures on “Variational problems in relativistic mechanics: Dirac-Maxwell equations”.

Maria Esteban (Paris): 3 lectures on “Variational problems in relativistic quantum mechanics: Dirac-Fock equations”.

Cliff Taubes (Harvard): 4 lectures on “Pseudoholomorphic geometry as a tool to study smooth 4-dimensional manifolds”.

Gang Tian (MIT): 4 lectures on “Recent progress in Complex Geometry”.

Rick Schoen (Stanford): 4 lectures on “Geometric Variational Problems”.

For further details, please check the webpage **www.pims.math.ca/pde**.

Second Canada-China Mathematics Congress

August 20–23, 2001 in Vancouver, BC, Canada

This initiative builds on the success of the first Congress held at Tsinghua University, Beijing, in August 1999, and is aimed at developing further the collaborative research effort between the two countries. It is sponsored by The 3×3 Canada-China initiative, the Centre de Recherches Mathématiques, the Fields Institute for the Mathematical Sciences, the Pacific Institute for the Mathematical Sciences and the MITACS Network of Centres of Excellence. Funds have been set aside by the five organisations not only for the actual meeting but also to support the local and travel expenses within Canada of selected Chinese mathematical scientists who are planning extended visits to Canadian Universities around the dates of the Congress.

Organizing Committee: Nassif Ghoussoub (PIMS Director and National Math. Coordinator for 3x3 Canada-China Initiative), Arvind Gupta (MITACS program leader), Bradd Hart (Director, Fields Institute), Jacques Hurtubise (Director, CRM), K. C. Chang (Peking University), Lizhong Peng (Peking University), Dayong Cai (Tsing Hua University), XingWei Zhou (Nankai University), JiaXing Hong (Fudan University)

Officers of the Chinese Delegation: Chen Jia-Er, President of the Natural Science Foundation of China, Qing Zhou (Officer of mathematical and physical division of NSF of China), Zixin Hou (President of Nankai University), Zhiming Ma (President of the Mathematical Society of China)

Chinese Plenary Speakers:

Weiyue Ding (Peking University): Geometric Analysis
Jie Xiao (Tsinghua University): Algebra
Yiming Long (Nankai University): Topology
Xiaoman Chen (Fudan University): Operator Theory
Zhiming Ma (Chinese Academy of Sciences): Probability

Session Speakers

I. Algebra and Number Theory:

Qingchun Tian (Peking University): Number Theory
Xingui Fang (Tsinghua University): Group Theory
Mingyao Xu (Tsinghua University): Group Theory
Jie Xiao (Tsinghua University): Algebra

II. Mathematical Physics and PDE:

Yingbo Zeng (Tsinghua University): Math. Physics
Zhangju Liu (Peking University): Math. Physics
Peidong Liu (Peking University): Math. Physics
Youjin Zhang (Tsinghua University): Math. Physics
Chengming Bai (Nankai University): Math. Physics
Songmu Zheng (Fudan University): PDE
Jiayu Li (Fudan University): Geometric Analysis
Weiyue Ding (Peking University): Geometric Analysis

III. Probability and Statistics:

Guanglu Gong (Tsinghua University): Probability
Zhi Geng (Peking University): Statistics
Yongjin Wang (Nankai University): Superprocesses
Tianping Chen (Fudan University): Neuro Networks
Zhiming Ma (Chinese Academy of Sciences): Probability

IV. Wavelets and their Applications:

Xingwei Zhou (Nankai University): Wavelets
Lizhong Peng (Peking University): Harmonic Analysis and Wavelets
Heping Liu (Peking University): Harmonic Analysis

V. Computational, Industrial and Applied Analysis:

Houde Han (Tsinghua University): Computational Mathematics
Dayong Cai (Tsinghua University): Computational Mathematics
Fengshan Bai (Tsinghua University): Computational Mathematics
Jianwei Hu (Nankai University): Numerical Analysis
Runchu Zhang (Nankai University): Numerical Analysis
Yongji Tan (Fudan University): Mathematics in Industry
Zongmin Wu (Fudan University): Approximation Theory and Data Treatment
Yangfeng Su (Fudan University): Computational Mathematics
Xunjing Li (Fudan University): Control Theory

VI. Geometry/Topology:

Yiming Long (Nankai University): Symplectic Topology
Lei Fu (Nankai University): Algebraic Geometry
Jinkun Lin (Nankai University): Homotopy Theory
Xiaojiang Tan (Peking University): Algebraic Geometry
Haizhong Li (Tsinghua University): Geometry
Zhiying Wen (Tsinghua University): Fractal Geomtry
Shaoqiang Deng (Nankai University): Kahler Manifolds
Qing Ding (Fudan University): Differential Geometry

VII. Operator Theory/Functional Analysis:

Guanggui Ding (Nankai University): Operator Theory
XiaomanChen (Fudan University): Operator Theory
Shufang Xu (Peking University): Numerical Algebra

VIII. Mathematical Finance:

Jiongmin Yong (Fudan University): Mathematical Finance
Duo Wang (Peking University): Mathematical Finance

IX. ODE and Dynamical systems:

Weigu Li (Peking University): ODE
Zhiming Zheng (Peking University): ODE
Meirong Zhang (Tsinghua University): Dynamical Systems

Junior High Math Nights at Mount Royal College, Alberta

Junior high school students, their teachers, and parents are invited to Mount Royal College for six Monday nights from January 29 through March 4 to take part in mathematical exploration activities. The emphasis is on removing the myth that mathematics is a set of facts that are innate to certain individuals and the myth that mathematics is not an experimental discipline.

PIMS Elementary Mathematics Nights in Alberta

The highly popular **Elementary Mathematics Nights** involve volunteers from Mount Royal College and the University of Calgary who assist the teachers to guide participants through a variety of activities. Activities such as map colouring, games on graphs, dominating sets of graphs, Fibonacci numbers, binary numbers, patterns in Pascal's triangle, the traveling salesman problem, and finite state automita may be included.

The success of these evenings can be directly attributed to the volunteers: Robert Petzold, Jean Springer, Laura Marik, Peter Zizler, Scott Carlson, Charles Hepler, and Sharon Friesen. PIMS would like to thank them and acknowledge their contribution to these evenings.

Current Schedule of Evenings:

Feb. 13, Science Alberta School, Calgary

Feb. 22, Sunnyside Community School, Calgary

May 15, Westmount Elementary School, Strathmore

Math Mania: An Alternative Math Education Event

Sir James Douglas Elementary School, Victoria
7:00–8:00pm, February 28, 2001

At the Math Mania evenings, "fun" methods are used to teach math and computer science concepts to children (and adults!) using games and art. This Math Mania will feature exciting geometrical models from straws and paper, mathematical puzzles, the slingshot effect of celestial bodies, the guessing game, a sorting network, the penny game, the set game, bubbles and more! For more details please see the webpage **www.pims.math.ca/education/2001/mathmania/february28.html**.

For a complete list of upcoming education activities at PIMS, please visit the webpage **www.pims.math.ca/education**.

Greater Vancouver Regional Science Fair

University of British Columbia
April 5–7, 2001

At the upcoming Greater Vancouver Regional Science Fair, PIMS will supply judges, mathematical expertise, and prizes for the mathematics component of the Fair. By promoting mathematics within the Science Fair context, PIMS encourages students to develop a feel for the adventure of a self-directed exploration in longer-term projects in the mathematical sciences.

More information on the Greater Vancouver Regional Science Fair is available at **www.sciencefairs.bc.ca/regions/gvrsf/Vancouver_info.html**.

Changing the Culture 2001

SFU at Harbour Centre
May 11, 2001

The Fourth Annual Changing the Culture conference, organized and sponsored by PIMS, has as its theme *Writing, Speaking and Thinking Mathematics*. The conference will explore connections between numeracy and literacy, mathematics and language, mathematics and literature, and how we can use language to teach mathematics.

The conference is free, but registration is required because space is limited.

For further information please see the webpage **www.pims.math.ca/education/CtC/CtC01.html** or contact Malgorzata Dubiel ⟨dubiel@math.sfu.ca⟩.

Third Annual PIMS Elementary Grades Math Contest

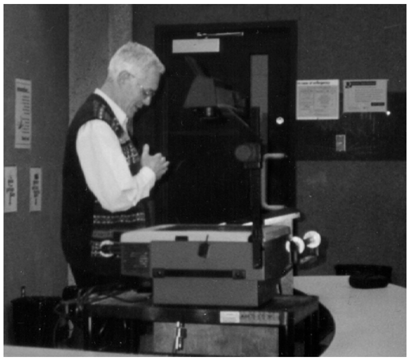
University of British Columbia
May 26, 2001

This contest — open to students in Grades 5 to 7 — gives elementary school students an opportunity to experience mathematics as an exciting sport! Like the **MathCounts** competition, which is available only to high school students, it determines the winners right on the spot — after three problem-solving rounds, the last of which is a series of mathematical duels among the top performers in the different grades. Even for those who do not make it to the top it is instructive, inspiring and entertaining.

The event is organized by PIMS under the guidance of Dr. Cary Chien of David Thompson Secondary School in Vancouver, in collaboration with the BC Association of Mathematics Teachers and volunteers from Lower Mainland schools of all levels. Details can be found on our website at **www.pims.math.ca/elmacon**.

Entering Mathematical Sciences at the Graduate Level

Continued from page 1.



Robert Moody speaking at the **PIMS Graduate Information Week**.

technology, and other areas. The main parts of pure mathematics are algebra (including arithmetic), analysis, geometry (including topology), and logic. Applied mathematics includes the various forms of mechanics (hydromechanics, elasticity, etc.), statistics, and many other newer areas of application to computing, economics, biological sciences, etc. I am sure that you can think of lots of things that could be added on: the mathematics of finance, actuarial mathematics, control theory, dynamical systems, relativity theory, crystallography, mathematical physics including particle physics, quantum mechanics, and string theories, operations research, information theory, encryption, and so on and on. In other words, it is very hard to define mathematics.

In a recent article by the famous mathematician David Mumford, he recalls the definition that Davis and Hersh give of mathematics: *Mathematics is the study of mental objects with reproducible properties.* This is so much nicer: rather than simply saying what present mathematical knowledge consists of, it opens the doors for the possibilities of what it might also be. And this I think is exactly the right position for any one entering graduate studies in the Mathematical Sciences. Certainly there is much to learn that is now the standard repertoire of working mathematicians and scientists, but this is also the time when you have a chance to do something totally new and perhaps totally unexpected. If we match this definition with the usual definition: *science is the study of physical objects with reproducible properties* then we see how inevitably mathematics and science are linked.

This is something that I would like to emphasize. One of the most persistent and tiresome debates is over the relative importance of pure and applied mathematics. Neither would be very much without the other, though individuals obviously differ in taste and style. Let's look at some examples.

David Mumford himself is an interesting example. He became famous (Fields Medalist) as an algebraic geometer, and several of his books in this area are classics. However, in mid-career he switched his interest to the mathematics of vision and has established a name for himself in this difficult area of biological mathematics. The article that I quote from (which, by the way, is in a very interesting book of essays: *Mathematics: Frontiers and Perspectives,* AMS Publ.) is entitled, "The dawning of the age of stochasticity." His point, stressing the importance of stochastic (random) processes, is something that I also find myself coming to appreciate.

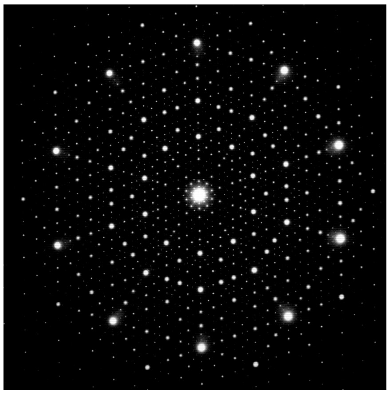
The subject of fractals is relatively new — something like 25 years. Its father was Benoit Mandelbrot, a mathematician at IBM. Fractals are not intrinsically so difficult. What was hard was the realization that self-similarity at different scales is manifest all over Nature: branching trees, spiral shells, decaying mountains, rivers and rivulets, in crystallization of materials, Brownian motion, in the morphology of plants, animals, and minerals. This could have been noticed by anyone at any time. The strange thing is that up to Mandelbrot no one really saw it. More fascinating is that the mathematics used to describe it comes from some of the most arcane parts of point set topology: Cantor sets, Hausdorff dimensions, and self-similar measures. It seems certain that Nature is at least as discontinuous as it is continuous (think of quantum mechanics) and that this new mathematics will have more importance, not less as time goes by. What's more fractals are strongly linked to chaos theory which is another of those "obvious" phenomena of Nature that no one noticed until a few years ago!

My third example is from my own experience. The illustration at the beginning of this article is a Penrose tiling (that's Sir Roger Penrose, famous for his books on the mind and artificial intelligence). The origins of this tiling are totally unexpected. The logician Hao Wang had asked the question of whether or not an algorithm existed which, given any finite number of polygon tile shapes, could decide whether or not the plane could be tiled without gaps or overlaps with copies of these tiles, i.e. could a machine figure out this out for us? He could not prove or disprove this, but he did prove that it would be true (an algorithm would exist) if whenever a set of tiles could tile the plane in some way then it could also tile it in a periodic way. He also conjectured that this was true.

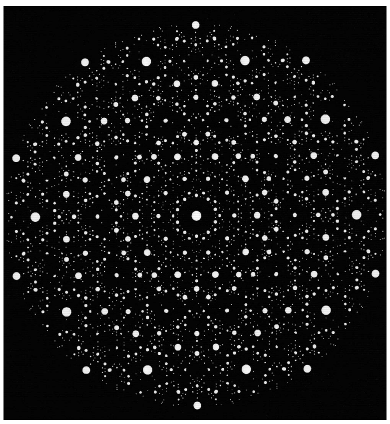
Now that would mean that aperiodic sets of tiles would NOT exist. It is hard to believe that up to the 1960's the answer to this was not known (or even thought about). Wang's student Berger finally proved that in fact Wang's conjecture was false! — and then went on to construct an aperiodic tiling set with some 20,000 or so tile types. Rafael Robinson reduced it to 6 and showed that the tiling problem was equivalent to the famous Halting Problem of Turing. Penrose worked on the problem and reduced it to 2!

This is piece of pure mathematics. However in 1984 new forms of solid state metallic materials were discovered that shook the world of crystallography: purely diffractive materials with symmetries that cannot arise from periodic (crystallographic) arrangements of atoms. I don't think that you will disagree that there is something profoundly mathematical about the picture below which is the diffraction image of a real quasicrystal.

The amazing thing is that the Penrose tiling is also pure point diffractive, something that mathematicians might never have guessed, even though it is a purely mathematical construct of Fourier analysis. (It was a crystallographer who first suggested it). So a whole new area of aperiodic order was created.



Diffraction image of the quasicrystal $Al_{70}Co_{11}Ni_{19}$.
(Image courtesy of Conrad Beele.)



Diffraction image of Penrose tiling.
(Image courtesy of Moritz Hoeffe.)

What are the primary mathematical tools? Discrete geometry (whose origins, as its name suggests come from the measurement of land), point set topology (a product of pure mathematics), Fourier analysis (developed from physical ideas around heat, sound and waves), harmonic analysis — especially in the general context on locally compact Abelian groups (more pure mathematics), dynamical systems (originated by Poincaré in his study of the orbits of the planets), ergodic theory (developed in statistical mechanics to study the statistical properties of large ensembles), C^*-algebras (developed out of quantum mechanics and analysis), algebraic-number theory (developed out of pure interest in numbers and in particular Fermat's Last Theorem), and stochastic processes (developed originally from the study of games of chance). And don't forget the original inputs from logic, algorithms, and solid-state physics.

Amazing, isn't it?

I have spent a lot of time talking on this. What is my point?

Quite simply that mathematics is an evolving process that is incredibly rich, incredibly linked with all of the rest of science, technology, and human culture. That there are mathematical things around us that have not been discovered, not because they are deep, but because no one has had the eyes to see them or the mind to think on them.

You should keep your mind wide open. Don't narrow your vision too quickly; don't shut doors on this and that type of mathematics. Take a variety of subjects. Whatever mathematics you study will likely come in useful.

In fact I would go further: in graduate school you have a chance to learn all sorts of up-to-date mathematical ideas from real experts. Unlikely as it may seem to you, you have one huge advantage over these experts. Though they probably know more about their own subject than you ever will, you will also be learning from your variety of classes things that they do not know, or have completely forgotten. Each person has a collection of knowledge and ideas different from every other. You may see connections that no one else has even a chance to see. Never forget this, however discouraged you may get.

Also in graduate school you will have more freedom to think and to do your own thing than you will have again until you retire.

Finally, the concentration and energy that you can bring to bear on problems is almost optimal at your age. (Older mathematicians are more wily and use intuition built out of many years of experience to make up for their declining brain power).

Put this all together and you realize that during these graduate years you actually have the potential to make very significant contributions. I mean VERY significant. Do not underestimate the possibilities that are there. Of course significant discovery is also a matter of chance and being in the right place at the right time, but there is no denying the importance of a prepared and open mind. The fact is that there things like fractals all around us for those with the right eyes to see them.

So much for the heroic side. But not everyone can be a hero. What about fears and doubts about entering graduate school?

Certainly research is not everyone's thing. It can be lonely and very frustrating. Most ideas will not work out. The slick proofs of classes do not magically appear; they are only the product of many years of refinement. Research is not like solving homework problems! Researchers generally learn to live with problems for long periods at a time. One prominent researcher told me: "it is not that the highs are so high and the lows are so low, but that the highs are so short and the lows are so long". One word of advice: keep several problems going at once. It helps to be able to get off a problem that is not going anywhere.

Here are some suggestions. A Master's Degree is a good way to find out what you like to do and what is not for you. You will have to take a bunch of core courses. These make a great foundation for you whatever you do that involves mathematics, even if you only use them indirectly. I don't think that you need to worry about this knowledge being useless or too refined and so on. As much as you can, try to see how the different courses that you take fit together. Mathematics is not a collection of disjoint subjects.

If you want to test your tolerance and enthusiasm for research, take the thesis option. There is much to be said for it. Anyone who completes a thesis has proven that they can undertake and complete a major task of organization and presentation. This is a valuable asset and I think employers of all types also recognize the logistical and problem solving skills that are acquired in the process. You will also most likely learn some brand of TEX, which is a good thing. If you are fortunate, you will have a publishable paper out of it too.

If you are in the straight mathematical side of things, I would encourage you to also get some background in statistics and probability theory, as well as some background in computer science. Not only will you find these useful in your mathematical endeavours, you will find that they are good items at job interview time. The same applies to those of you in computer science or in statistics. Take some mathematics classes. It is amazing how the store of techniques and problem-solving abilities developed in mathematics can help in unexpected ways.

Some people skip over the Masters degree and go straight to the Ph.D., but I think it is better not to be in a big rush.

In fact, I have different thoughts on the Ph.D. If you are not certain of your ambitions, I think that it may not be the best use for 3 or 4 years of your time. At this level you are becoming a real expert in some part of the mathematical sciences. Unless you see some career goal at the end of it, this knowledge may not be of further direct value to you. However, if you are thinking of a career in academia, a Ph.D. is essential. It is also a fact that it is very hard to come back to graduate school after you have been out of it for a few years.

Other thoughts about the world of mathematics. There is no doubt that there are many kinds of mathematician and many levels of ability. The best research mathematicians are awesome and can be intimidating. However, mathematics is a huge endeavour of human culture. People find many important and satisfying niches: education, writing and exposition, public dissemination, research, organization, as well as in the numerous branches of knowledge to which mathematics can be applied.

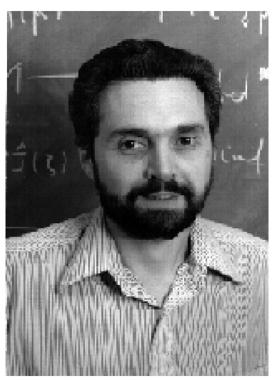
Persistence, patience, diligence, and a little daring can make up for lack of genius: I can assure you that I am living proof of this!

This is a good time to be going into graduate school in the Mathematical Sciences. Mathematics of all flavours is flourishing and is well supported here in Canada. The applications of mathematics to other areas of science have never been more diverse, more profound, nor more public ally recognized.

It is true that mathematics is a hard task-master. Her secrets are reluctantly revealed. However, she will never fail you as a source of wonderful and beautiful ideas. Over the ages, mathematics has attracted some of the finest minds the world has known. Unlike almost every other branch of science, these ideas never fade with time.

I can tell you that I still love the subject after working non-stop in it for 42 years, and if I were to be going to university today, I would be studying mathematics. The difference is that I would try to learn as many different parts of it (including mathematical physics and some stochasitics) as I could.

Tudor S. Ratiu: PIMS Distinguished Lecture at the University of Victoria



On January 12, Professor Tudor S. Ratiu (Ecole Polytechnique Federale de Lausanne) gave a lecture on “Variational Principles, Groups, and Hydrodynamics” as part of the PIMS Distnguished Lecture Series at the University of Victoria. In his lecture, he presented Hamiltonian systems whose configuration space is a Lie group. The systems discussed were all geodesic flows of certain metrics with a number of common characteristics. He began with the classical example introduced by Euler: a free rigid body whose configuration space is a proper rotation group. Then he discussed a homogeneous incompressible fluid flow whose configuration space is a group of volume preserving diffeomorphisms of a smooth manifold. The Arnold-Ebin-Marsden program for the analysis of the equations of motion was also presented. Another example was the Korteweg-de Vries equation whose configuration space is the Bott-Virasoro group. Generalization of this is the Camassa-Holm equation, and Prof. Ratiu discussed its possible choices of configuration spaces. The averaged incompressible Euler flow and recent results about it were presented. Finally, Prof. Ratiu showed that the Euler-Poincare equation could be an abstract tool that easily enables one to recognize such systems.

Prof. Ratiu received his B.Sc. and M.A. at the University of Timisoara, Romania, and his Ph.D. at the University of California, Berkeley. His main area of research is Hamiltonian systems. He held visiting positions at prestigious research centres such as Max Planck Institute for Mathematics (Germany), Mathematical Sciences Institute at Cornell University, Erwin Schrodinger Institute for Mathematical Physics (Austria), Institute des Hautes Etudes Scientifiques (France), Isaac Newton Institute for Mathematical Sciences in Cambridge (England). His contribution to mathematics was recognized by numerous awards and prizes. Among other honors, he was an A. P. Sloan Foundation Fellow in 1984–1987, a Humbold Prize winner in 1997, and won a Ferran Sunyer i Balaguer Prize for the year 2000. Prof. Ratiu is an editor for 5 research journals. He has published over 100 scientific papers and 6 books, among which is the well-known Introduction to Mechanics and Symmetry, written with J. E. Marsden in 1994.

The lecture was videotaped and is available in streaming video from **www.pims.math.ca/video**.

Strings and D-branes

Contributed by K. Zarembo, PIMS-PDF.

String theory emerged in the early 70's, but was widely appreciated only fifteen years later, after it was shown to provide a consistent theory of quantum gravity and to be capable of unifying all of the fundamental forces in nature. Since then, string theory has undergone several periods of intensive development. During the breakthrough of the mid 80's, sometimes referred to as the "first superstring revolution", supersymmetric string theory was established as a basis for the unification of fundamental forces. The "second superstring revolution", that began few years ago, has led to the discovery of unexpected and profound links between gravity and other types of interactions. Recent developments in string theory have shed new light on some old problems in theoretical physics, most notably on the black hole entropy problem and on strong coupling dynamics in gauge theories.

The modern theory of fundamental interactions is geometric in nature and is based on certain symmetry principles. The symmetry that underlies electromagnetic, weak and strong interactions is gauge invariance. In its simplest form pertinent to electromagnetic interaction, gauge invariance is equivalent to the statement that the phase of the wave function of a charged particle is not observable. The possibility of choosing this phase arbitrarily at each point requires a compensating vector field A_μ. From a mathematical point of view, A_μ defines a connection in the principal bundle $U(1)$. For a physicist, the field A_μ describes massless particles, photons, which transmit electromagnetic interactions. Theories of weak and strong interactions are gauge theories based on non-abelian Lie groups. In principle the gauge fields of these interactions could also describe massless particles, but certain dynamical effects make weak gauge bosons massive and permanently confine carriers of strong interaction inside hadrons.

The symmetry principle responsible for gravity is different. Gravity is essentially a consequence of general covariance, the independence of the physics on the choice of the coordinate system in space-time. General covariance is in many respects similar to gauge symmetry, but there is a fundamental difference between gravity and all other interactions in that gravity is related to the geometry of space-time itself – the gravitational field is the space-time metric $g_{\mu\nu}$.

A unification of gauge interactions does not require any new principles beyond gauge symmetry. One can imagine (and there are indications that this may indeed be true) that gauge groups of individual interactions are subgroups of a unique Lie group of a unified theory. A unification that would include gravity is more tricky and possibly will require a new fundamental principle beyond what we currently know. The mathematical grace of string theory and its success in solving several puzzles encountered in the quantization of gravity make string theory the most promising idea in the search for such a principle.

In string theory, a point-like particle is substituted by an object extending in one dimension, a string. Fundamental strings can vibrate much like the strings in a violin. In fact, the motion of a violin string and of the fundamental string are described by the same differential equation, but oscillations of the fundamental string are constrained by a condition that they do not transmit energy and momentum along the string. Also, the ends of the string in a violin are fixed, while the ends of the fundamental open string can move freely, or the ends of the strings can be glued together to form a closed string. Upon quantization, the string oscillations lead to an infinite set of discrete energy levels. A string in a definite quantum state of its internal motion will behave like a particle with a definite mass and spin, so different particle species in string theory arise as different vibrational modes of a unique object, the string. Typical masses of string excitations are supposed to be large and, in many cases, it is enough to consider only massless states. Remarkably, massless modes of an open string behave exactly like photons or, in a slightly more complicated setting, like non-abelian gauge bosons, while the spectrum of massless modes of a closed string contains a graviton. Therefore, the theory of closed strings is essentially a theory of quantum gravity.

String theory appears to be very restrictive and the simplest versions of it suffer from various instabilities. The consistency of string theory uniquely fixes space-time dimensionality and requires supersymmetry, the extension of Poincare invariance that unifies particles of different spins and statistics. Superstring theory can only be well defined in 9+1 (9 space, 1 time) dimensions, 6 of which are supposed to be compactified and invisible because of their very small size. There are five distinct superstring theories in ten dimensions, but it has become clear that all of them are related by certain symmetry transformations and, in fact, they are different pieces of a more general structure known as M-theory.

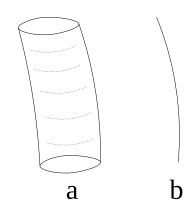


Fig. 1: String world sheet (a) vs particle world line (b).

The interaction of strings can be introduced in a purely geometric manner. When a string propagates in time, it sweeps out a two-dimensional surface, a world-sheet, just like a particle's trajectory forms a world-line (Fig. 1). For a free closed string, the world-sheet is a cylinder, topologically a sphere with two holes. A sphere with four holes then naturally describes the string scattering: two incoming strings join together to form an intermediate one-string state which then splits into outgoing strings (Fig. 2). Thus strings interact via elementary processes of joining and splitting. It is possible to develop a systematic string perturbation theory similar to the Feynman diagram technique in quantum field theory by allowing world-sheets of all possible topologies.

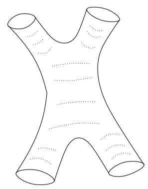


Fig. 2: $2 \to 2$ string scattering.

Similar rules for the interaction of open strings have a simple but surprising consequence: even if one studies the scattering of only open strings, one can see closed strings emerging in intermediate states. This means that open strings will interact gravitationally, since closed strings transmit gravitational forces. Therefore, gravity is an inevitable consequence of string theory. As an illustration, consider $2 \to 2$ scattering. This process, in particular, can proceed via splitting into two intermediate strings which then annihilate. The intermediate state forms an open string loop, but, alternatively, it can be viewed as a world sheet of a closed string, so the closed string exchange (roughly speaking, gravitational interaction) and scattering via the intermediate open strings (roughly speaking, gauge interaction) are two equivalent descriptions of the same process (Fig. 3). Many of the recent achievements in string theory rely on this simple observation, sometimes referred to as channel duality.

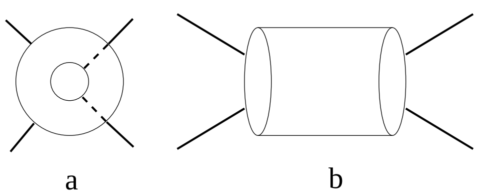


Fig. 3: An illustration of channel duality: the same amplitude is open string loop in one channel and a closed string exchange in another channel.

The idea of channel duality has proven especially fruitful in the context of D-branes, stringy analogs of black holes. A D(irichlet)p-brane is a p-dimensional dynamical object in closed string theory. The world volume of a D-brane is a $(p+1)$-dimensional hypersurface in ten-dimensional space, on which strings can begin and terminate. Coordinates of the string world-sheet that are perpendicular to the D-brane satisfy Dirichlet boundary conditions, as opposed to the Neumann boundary conditions for an open string which can freely move in all of ten-dimensional space-time. In a sense, D-brane dimensionally reduces open string theory. Open string excitations cannot leave the world volume of a D-brane because of the Dirichlet boundary conditions, so the theory of Dirichlet strings becomes effectively $(p+1)$-dimensional. At energies too small to excite higher string modes, this theory can be well approximated by $(p+1)$-dimensional gauge field theory. In particular, the world-volume theory of a D3-brane is a certain field theory in $(3+1)$ dimensions.

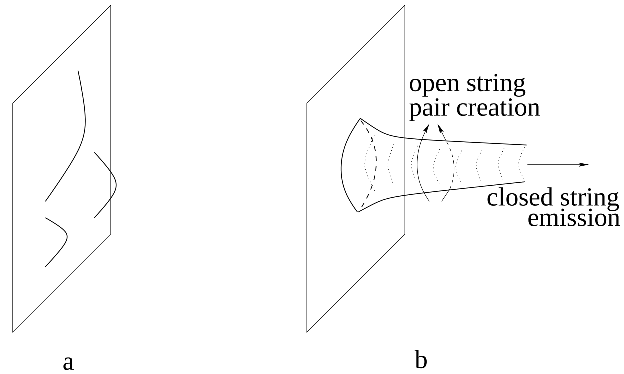


Fig. 5: A D-brane is a hypersurface on which strings can end or begin (a). The world sheet on an infinite open string ending on a D-brane can simultaneously be interpreted in terms of a closed string emission (b).

How can D-branes be identified with black holes? The reasoning follows from the space-time picture of the creation and the subsequent annihilation of a pair of open strings with one end attached to the D-brane. By channel duality, this process can alternatively be interpreted as the emission of a closed string. Consequently, D-branes can emit closed string states and, in particular, gravitons. Anything capable of emitting gravitons carries mass (gravitational charge), so D-branes have tension, mass per unit volume. More careful analysis shows that they also carry analogs of electric or magnetic charges. From the point of view of classical gravity, which well approximates string theory at large distances, Dp-branes have δ-functional mass and charge distributions extending in p dimensions. Such a distribution will curve space and from a large distance will look like a charged black p-brane, an extended analog of a black hole. The two entirely different pictures, that of the black p-brane in $(9+1)$ dimensions and the world-volume picture based on $(p+1)$-dimensional gauge theory, are complementary to one another. This complementarity in many cases was shown to imply tight links between gravity and gauge theories and, indeed, the study of D-branes uncovered many unexpected interrelations.

The idea that has attracted, perhaps, the most attention was put forward by J. Maldacena in 1997 and exploited some earlier work on the comparison between the gravitational and world-volume pictures of a D3-brane. According to Maldacena's conjecture, classical gravity acting on the direct product of the five-dimensional sphere and the five-dimensional Anti-de-Sitter (AdS) space is exactly equivalent to the $(3+1)$-dimensional gauge theory of a D3-brane in the limit when gauge interactions become infinitely strong and therefore very complicated from the usual point of view.

*Please see **Strings,** page 17.*

PIMS Awards Prizes for 2000

Continued from page 1.

The first annual PIMS Prizes in Education, Research and Industrial Outreach were awarded on December 10 at a Banquet held at the UBC University Centre. The prizes, valued at $3000 each, were donated by the Toronto Dominion Bank Financial Group and TD Securities.

The **PIMS Education Prize** rewards individuals 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. The review committee for the PIMS Education Prize was Michael Lamoureux (chair of the committee and PIMS Deputy Director), Florin Diacu (PIMS-UVic Site Director), Arvind Gupta (MITACS Programme Leader), Bryant Moodie (PIMS-UA Site Director) and Dale Rolfsen (PIMS-UBC Site Director).

The PIMS Education Prize was awarded to **George Bluman**, who is the chair of the UBC Math Department. George Bluman's lifetime commitment to mathematics education in British Columbia, both in the public school system and at the University of British Columbia, make him an outstanding recipient for the PIMS Education Prize. Many aspects of his activities were highlighted by his nominees, including: providing stimulating mathematics experiences for students, through the Euclid contest and various school workshops; supporting math teachers in the schools; working to raise and maintain high standards in the school system; developing a healthy dialogue with the BC Ministry of Education; encouraging math students at UBC to pursue careers in teaching; and encouraging a strong commitment to teaching at UBC.

Typical of his activities and impact is his over-twenty-year involvement with the Euclid contest as the BC and Territories organizer for this high school enrichment contest in mathematics. George supports the idea that the Euclid contest is an event every Math 12 student should be able to enter and, in doing so, feel a sense of accomplishment. Beyond organizing the contest, he has developed three levels of School Workshop programs which give students (elementary, junior high, and senior high) the opportunity to participate in problem solving workshops with university faculty and students. BC enjoys the highest level of participation, per capita, in the Euclid contest and its universities benefit from the excellent preparation these students receive through the program. In the words of the nominators, much of the BC success in Euclid can be directly attributed to George's efforts.

George personally knows most of the mathematics teachers from around the province and uses this network to provide a dialogue between the BC secondary school system and the universities. He has been tracking high school students' performance at university for over twenty year, and often makes personal phone calls or writes to high schools to give suggestions on how to improve their students' performance. Again, his nominators attest to

Hugh Morris (Chairman of the PIMS Board of Directors) congratulates George Bluman (right).

Terry Gannon (left) receives the PIMS Research Prize from PIMS Director Nassif Ghoussoub (centre), Ken Foxcroft (TD Securities) and Indira Samarasekera (VP Research, UBC).

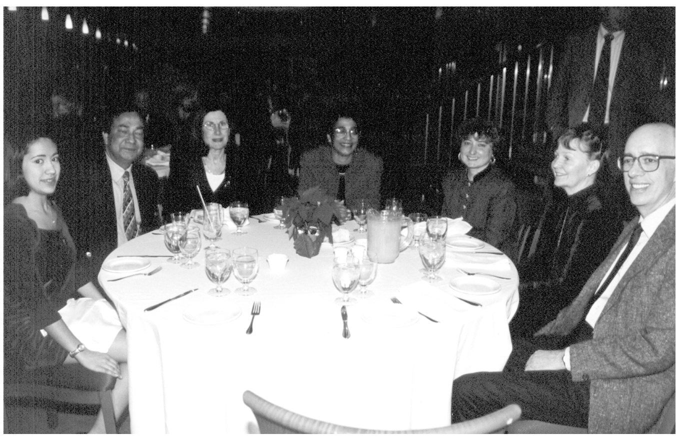
the positive impact his work has had on the designs, and successes, of their mathematics program. The scope and magnitude of his service to mathematical education over the past twenty years is phenomenal.

In his comments after receiving the award, George Bluman states that, "It is not easy for mathematicians to be involved in educational activities. Education issues are often very sensitive with many different (often unfairly stereotyped) 'conflicting' groups and interests—pontificating university professors, strict union mentalities of teachers, anxious students and parents, scandal-seeking media, politicking Ministries of Education paying little attention to common sense and giving lip-service to the opinions of informed teachers and professors. It is essential that all such special interest groups trust each other and stop bickering for the common good. After all we should want our students to have the best education possible within our means."

"PIMS is to be congratulated for taking a sincere

From left, Brian Wetton, Huaxiong Huang, and Keth Promislow receive the PIMS Industrial Outreach Prize from Murray Margolis (Powerex Corp.) and Ken Foxcroft (TD Securities).

NSERC Director, Danielle Menard speaking at the PIMS Awards Ceremony.



From left are Shahid Hussain (Telus Corp.), Frieda Granot (Dean of Graduate Studies, UBC), Indira Samarasekera (VP Research, UBC), Danielle Menard (Director, NSERC) and Charles Lamb (Math, UBC).

Indira Samarasekera (VP Research, UBC) congratulates PIMS Research Prize winner Terry Gannon (left).

interest in Education with its various Education activities including the recognition of those involved through this Award."

He drew particular attention to the semi-annual publication of **Pi in the Sky**, prizes for Math projects in Science Fairs, the support of elementary school Math activities such as the **PIMS Elementary Grades Math Contest**, the **Mathematics is Everywhere** poster campaign, the **Senior Undergraduate Industrial Math Workshop**, and the **Graduate Industrial Math Modeling Camp**.

"All of the above are new initiatives and continuing activities which certainly would not have happened without the existence of PIMS. Moreover PIMS is very fortunate to have the services of Klaus Hoechsmann for developing and promoting its educational activities. We all now know that Klaus is also a budding playwright from his very well-written and PIMS-sponsored play Hypatia which should be performed for students in schools around the world."

The **PIMS Research Prize** is given for a particular outstanding contribution to the mathematical sciences, disseminated during the past five years. Nominations for the Research Prize were adjudicated by the PIMS Scientific Review Panel, the members of which are chair Nassif Ghoussoub (PIMS Director), David Boyd (UBC), David Brillinger (Berkeley), Ron Graham (UCSD), Alistair Lachlan (SFU), Richard Karp (Berkeley), Bernard Matkowsky (Northwestern), Robert Moody (Univ. of Alberta), Nicholas Pippenger (UBC), Ian Putnam (Univ. of Victoria), Gordon Slade (UBC), and Gian Tian (MIT).

The Research Prize was awarded to **Terry Gannon** of the Dept. of Mathematical Sciences, University of Alberta. Terry's accomplishments cover two separate directions, both of which have won him international recognition. The first accomplishment is his work on the "Moonshine Conjectures", which concern a fantastic connection between the representations of the Monster Group and certain classes of modular forms. Richard Borcherds was awarded the Fields Medal in 1998 for his proof of these conjectures. However, Borcherds' proof contained one part that was non-conceptual and had to be shown by brute force computation. Terry provided a conceptual argument to replace this computation. The second and more extensive of Terry's accomplishments concerns the classification of two-dimensional conformal field theories. The problem involves determining all modular invariants which can be constructed from characters of the representations of the underlying affine Kac-Moody Lie algebras. The first success in classifying two-dimensional conformal field theories was the A-D-E classification of Capelli, Itzykson and Zuber for affine-$SU(2)$. In 1994, Terry discovered a solution to the affine-$SU(3)$ problem and has since made enormous advances towards a solution of the general problem.

In describing his research, Terry states, "My bias as a mathematician is toward breadth. Most mathematicians, it seems, try to strike oil by drilling deep wells. This strategy makes a lot of sense. But actually I'm more drawn towards half-completed bridges and wobbling fences. The theory in those places is relatively undeveloped, so there's a lot of basic results still open. And I get a little restless staying too long in one place."

"Some of my work which attracted a little attention was in an area called Monstrous Moonshine. It was noticed that 196 884 –the first interesting coefficient of a function (the j-function) important to classical number theory– equals $1 + 196\,883$, the sum of the first two dimensions of representations of a very special symmetry (the Monster group). The second, third,... coefficients of that function were likewise related to the higher dimensions. The challenge was to explain what that classical number theory had to do with this newly discovered symmetry. A bridge had to be built! Borcherds did most of the work, and for this was awarded a Fields Medal in 1998. He showed that there's a new and very complicated algebraic structure (a vertex operator algebra) whose symmetry is that Monster group, and whose 'graded dimension' is the j-function. If we twist the graded dimension by various elements of the Monster, we get other special functions (Hauptmoduls) of classical number theory. The best known way to show this is by a theorem I found with Chris Cummins."

"But much of my work thus far has occurred near a certain wobbling fence separating math from physics. String theory, or more precisely, conformal field theory (CFT), was created by physicists for their own shady purposes, but its impact has been far greater in math. Five of the twelve Fields medals awarded in the 1990s were to men whose work directly concerned CFT (namely, Drinfeld, Jones, Witten, Borcherds, Kontsevich). I've tried to clarify some of the algebra and number theory in CFT, but mostly I've been working towards the classification of all CFTs related to a class of infinite symmetries called Kac-Moody algebras. These CFTs seem to be the fundamental ones, and their classification is uncovering unexpected (and unexplained!) links with other areas of math. I hope to complete this classification within the next couple years."

"Research for me is something like chasing squirrels. As soon as you spot one and leap towards it, it darts away, zigging and zagging, always just out of reach. If you're a little lucky, you might stick with it long enough to see it climb a tree. You'll never catch the damn squirrel, but it'll lead you to a tree. Chasing squirrels is a way to find trees! In math, the trees are called theorems. The squirrels are those nagging little mysteries we write at the top of many sheets of paper. We never know where our question will take us, but if we stick with it, it'll lead us to a theorem, and to our next paper. That I think is what research in math is like."

"Receiving the PIMS Research Prize has been enormously significant for me personally, and surprisingly humbling. Recognition from our peers is notoriously rare for those of us near the beginnings of our careers, and now I have some expectations other than my own to live up to (yikes!). Validating and supporting research is the biggest role PIMS can play, in my view. The PIMS post-doc program is wonderful, and the plan for an Oberwolfach-style institute is really very exciting. But one thing which is still quite disappointing in western Canada is the intellectual isolation of the universities from each other. For instance, Calgary and Edmonton are only 3 car-hours apart and yet it's exceptionally rare when one of us gives a talk at the other university. I wonder if PIMS could actively encourage more of these grassroots interactions, e.g. by supplying each local PIMS office with funds whose sole purpose is to invite other westerners to give colloquium talks. Maybe this could help build more of a western mathematical sciences community."

The **PIMS Industrial Outreach Prize** recognizes individuals who have employed mathematical analysis in the resolution of problems with direct industrial, economic or social impact. The review panel for this prize was chaired by the MITACS Programme Leader Arvind Gupta (SFU). The other members of the panel were Don Denney (Syncrude, Inc.), Shahid Hussain (Telus Corp.), Murray Margolis (Powerex Corp.), Brian Seymour (UBC) and Rex Westbrook (Univ. of Calgary).

The prize was awarded to Dr. Huaxiong Huang (York), John Stockie (University of New Brunswick), Keith Promislow (SFU) and Brian Wetton (UBC). This team of researchers are part of the PIMS-affiliated Mathematical Modeling and Scientific Computation Group in MITACS. They are working with Ballard Systems, the world leader in hydrogen fuel cell design, to develop models to help Ballard improve the efficiency and durability of fuel cells.

Using parabolic poles, they modeled the reactant gas flow through the Gas Diffusion Electrode (GDE), a layer of porous, conducting material on either side of the catalyst and membrane in the fuel cell. Mathematical analysis of the models highlighted the sensitivity of fuel cell performance to certain GDE parameters, giving insight into the performance of various possible GDE materials.

The Mathematics of Voting

Contributed by Florin Diacu,
PIMS Site Director, University of Victoria

Did your vote in the recent federal election convey your will? Think of the ballot. You had to say: I like candidate x and I reject all the others. You may have wished to make y your second choice or tell that z was unacceptable. Unfortunately you couldn't. Our system is not that flexible. Let us improve it then. But how?

Donald Saari

In a recent lecture given at the University of Victoria, Donald Saari, a distinguished mathematician from the University of California at Irvine, addressed this issue and showed the advantages and drawbacks of different democracies. Is there a best voting system, and if so, how good is it? The problem is difficult. An entire branch of mathematics is researching it today. Let us follow some ideas and see how we can use them.

The beginnings of voting are lost in history. Written sources attest to the existence of voting procedures in Antiquity and all through the Middle Ages. Confusion in choosing the right system was common. In 1130, for example, the ambiguity of voting led to the election of two Popes, an event that created a rift within the Catholic Church.

In 1770 the French mathematician Jean-Charles Borda (1733–1799) proposed a new rule. He asked that voters assign points according to their ranking of the candidates. For example, in a 3 candidate election, the first ranked on a ballot received 3 points, the second obtained 2, and the third got 1. The candidate with more points won.

But we could use different point rules: 6 for the first place, 5 for the second, and 0 for the third; or 10 for the first, 2 for the second, and 1 for the third. In fact our present system gives 1 for the first place and 0 for the others. Which one is better?

Though we can see some pros and cons in each case, it is hard to choose the best. But mathematicians found the answer. They have bad and good news for us. The bad news: Borda's count 3,2,1 is not ideal; it can still lead to distorted results. The good news: within the point method, the Borda count is by far the best. Moreover, our voting rule 1,0,0 is the worst; it gives the least amount of information about what voters want and can yield results that speak against the people's will.

This becomes clear from the following examples. In 1970 the centre-right candidate Buckley won the New York senate election even though more than 60% of the votes went for either of the two centre-left candidates. A less obvious but even more disturbing case is the recent Bush-Gore race. If those voting for Nader could have made Gore their second choice (which is a reasonable assumption), the democrats would have won without trouble, as the popular vote suggests.

There are more complicated systems. The run-off method, for example, uses the 1,0,0 point rule in combination with several rounds of vote. Only a more than 50% support makes the winner. Otherwise the last candidate is dropped and the vote is repeated. An alternative is to exclude all but the first two candidates and vote a second time.

This system, however, has its flaws too. The first version takes too long to be efficient in a national election, whereas the second can bring weird outcomes. In the 26 November 2000 election for the Romanian Presidency, this method led to a run-off between a left wing extremist and a right wing one. The centre vote had been split among several candidates.

The only simple and efficient method that in most cases expresses the will of the majority is the Borda count. Ranking the candidates and assigning a balanced rule of points, as in the 3,2,1 example, would make our elections fairer. Further, information on the mathematics of voting may be found in the following references:

D. G. Saari, *Basic Geometry of Voting* (Springer Verlag, 1995).

D. Black, *The Theory of Committees and Elections* (Cambridge University Press, 1958).

Streaming video of an earlier lecture given by D. Saari at the **PIMS Opening Meeting** (University of Victoria, October 4, 1996) is available on the webpage **www.pims.math.ca/video**.

Strings and D-branes

Continued from page 13.

The AdS/CFT (CFT stands for 'Conformal Field Theory') correspondence was generalized to accommodate some other types of gauge theories, and a variety of dynamical phenomena in gauge theories were shown to have their counterpart in gravity. Nevertheless, many questions in the gauge theory/gravity correspondence still remain open. In particular, it is not known how far the AdS/CFT correspondence can be extended beyond the conformally invariant gauge theories and the strong coupling limit. The study of these issues may lead to further insights on the interplay between gauge theories and gravity.

References:

B. Greene, *The Elegant Universe: Superstrings, hidden dimensions, and the quest for the ultimate theory* (Norton, 1999).

M. B. Green, J. H. Schwarz and E. Witten, *Superstring Theory* (Cambridge Univ. Press, 1987).

J. Polchinski, *String Theory*: *Vol. 1, An Introduction to the bosonic string* and *Vol. 2, Superstring theory and beyond* (Cambridge Univ. Press, 1998).

O. Aharony, S. S. Gubser, J. Maldacena, H. Ooguri and Y. Oz, "Large N field theories, string theory and gravity," *Physics Reports,* **323**, 183 (2000).

The Amazing Number π

Contributed by Peter Borwein,
Dept. of Math. and Statistics, Simon Fraser University

The history of π parallels virtually the entire history of Mathematics. At times it has been of central interest and at times the interest has been quite peripheral (no pun intended). Certainly Lindemann's proof of the transcendence of π was one of the highlights of nineteenth century mathematics and stands as one of the seminal achievements of the millennium (very loosely this result says that π is not an easy number). One of the low points was the Indiana State legislatures attempts to legislate a value of π in 1897: an attempt as plausible as repealing the law of gravity.

The amount of human ingenuity that has gone into understanding the nature of π and computing its digits is quite phenomenal and begs the question "why π?". After all there are more numbers than one can reasonably contemplate that could get a similar treatment. Furthermore, π is just one of the very infinite firmament of numbers. Part of the answer is historical. It is the earliest and the most naturally occurring hard number (technically, hard means transcendental which means not the solution of a simple equation). Even the choice of label "transcendental" gives it something of a mystical aura.

What is pi? First and foremost it is a number, between 3 and 4 (3.14159...). It arises in any computations involving circles: the area of a circle of diameter 1 or equivalently, though not obviously, the perimeter of a circle of diameter 1/2. The nomenclature π is presumably the Greek letter "p" in periphery. The most basic properties of π were understood in the period of classical Greek mathematics by the time of the death of Archimedes in 212 BC.

The Greek notion of number was quite different from ours, so the Greek numbers were our whole numbers: 1,2, 3... . In Greek geometry the essential idea was not number but continuous magnitude, e.g. line segments. It was based on the notion of multiplicity of units and, in this sense, numbers that existed were numbers that could be drawn with just an unmarked ruler and compass. The rules allowed for starting with a fixed length of 1 and seeing what could be constructed with straight edge and compass alone. (Our current notion is much more based on counting.) The question of whether π is a constructible magnitude had been explicitly raised as a question by the sixth century BC and the time of the Pythagoreans. Unfortunately π is not constructible, though a proof of this would not be available for several thousand years. In this context there isn't a more basic question than "is π a number?" Of course, our more modern notion of number embraces the Greek notion of constructible and doesn't depend on construction. The existence of π as a number given by an infinite (albeit unknown) decimal expansion poses little problem.

Very early on the Greeks had hypothesized that π wasn't constructible, Aristophanes already makes fun of "circle squarers" in his fifth century BC play "The Birds."

Babylonians	2000? BCE	1	3.125 ($3\frac{1}{8}$)
Egyptians	2000? BCE	1	3.16045 ($4(\frac{8}{9})^2$)
China	1200? BCE	1	3
Bible (1 Kings 7:23)	550? BCE	1	3
Archimedes	250? BCE	3	3.1418 (ave.)
Hon Han Shu	130 AD	1	3.1622 ($=\sqrt{10}$?)
Ptolemy	150	3	3.14166
Chung Hing	250?	1	3.16227 ($\sqrt{10}$)
Wang Fau	250?	1	3.15555 ($\frac{142}{45}$)
Liu Hui	263	5	3.14159
Siddhanta	380	3	3.1416
Tsu Ch'ung Chi	480?	7	3.1415926
Aryabhata	499	4	3.14156
Brahmagupta	640?	1	3.162277 ($=\sqrt{10}$)
Al-Khowarizmi	800	4	3.1416
Fibonacci	1220	3	3.141818
Al-Kashi	1429	14	
Otho	1573	6	3.1415929
Viete	1593	9	3.1415926536 (ave.)
Romanus	1593	15	
Van Ceulen	1596	20	
Van Ceulen	1610	35	
Newton	1665	16	
Sharp	1699	71	
Seki	1700?	10	
Kamata	1730?	25	
Machin	1706	100	
De Lagny	1719	127	(112 correct)
Takebe	1723	41	
Matsunaga	1739	50	
Vega	1794	140	
Rutherford	1824	208	(152 correct)
Strassnitzky and Dase	1844	200	
Clausen	1847	248	
Lehmann	1853	261	
Rutherford	1853	440	
Shanks	1874	707	(527 correct)

History of calculating the digits of π (Pre 20th Century).

Lindemman's proof of the transcendence of π in 1882 settles the issue that π is not constructible by the Greek rules and a truly marvelous proof was given a few years later by Hilbert. Not that this has stopped cranks from still trying to construct π.

Does this tell us everything we wish to know about π. No, our ignorance is still much more profound than our knowledge! For example, the second most natural hard number is e which is provably transcendental. But what about $\pi+e$? This embarrassingly easy question is currently totally intractable (we don't even know how to show that $\pi+e$ is irrational). The number π is a mathematical apple and e is a mathematical orange and we have no idea how to mix them.

Why compute the digits of π? Sometimes it is necessary to do so, though hardly ever more than the 6 or so digits that Archimedes computed several thousand years ago are needed for physical applications. Even far fetched computations like the volume of a spherical universe only require a few dozen digits. There is also the "Everest Hypothesis" ("because its there"). Probably the number of people involved and the effort in time has been similar in the two quests. A few thousand people have reached the computational level that requires the carrying of oxygen – though so far I know of no π related fatalities. There has been significant knowledge accumulated in this slightly quixotic pursuit. But this knowledge could have been derived from computing a host of other numbers in a variety of different bases. Once again the answer to "why π" is largely historical and cultural. These are good but not particularly scientific reasons. Pi was first, pi is hard and pi has captured the educated imagination. (Have you ever seen a cartoon about $\log 2$ - a number very similar to π?)

Whatever the personal motivations π has been much computed and a surprising amount has been learnt along the way.

In constructing the all star hockey team of great mathematicians, there seems to be pretty wide agreement that the front line consists of Archimedes, Newton, and Gauss. Both Archimedes and Newton invented methods for computing pi. In Newton's case this was an application of his newly invented calculus. I know of no such calculation from Gauss though his exploration of the Arithmetic-Geometric mean iteration laid the foundation of the most successful methods for doing such calculations. There is less consensus about who comes next. I might add Hilbert and Euler next (on defense). Both of these mathematicians also contribute to the story of π. Perhaps von Neumann is in goal – certainly he is a candidate for the most versatile and smartest mathematician of the twentieth century. One of the first calculations done on ENIAC (one of the first real computers) was the computations of roughly a thousand digits of π and von Neumann was part of the team that did the calculation.

One doesn't often think of a problem like this having economic benefits. But as is often the case with pure mathematics and curiosity driven research the rewards can be surprising. Large recent records depend on three things: better algorithms for pi; larger and faster computers; and an understanding of how to do arithmetic with numbers that are billions of digits long

The better algorithms are due to a variety of people including Ramanujan, Brent, Salamin, the Chudnovsky brothers and ourselves. Some of the mathematics is both beautiful and subtle. (The Ramanujan type series listed in the appendix are, for me, of this nature.)

The better computers are, of course, the most salient technological advance of the second half ot the twentieth century.

Understanding arithmetic is an interesting and illuminating story in its own right. A hundred years ago we knew how to add and multiply — do it the way we all learned in school. Now we are not so certain except that we now know that the "high school method" is a disaster for multiplying really big numbers. The mathematical technology that allows for multiplying very large numbers together is essentially the same as the mathematical technology that allows image processing devices like CAT scanners to work (FFTs). In making the record setting algorithms work, David Bailey tuned the FFT algorithms in several of the standard implementations and saved the US economy millions of dollars annually. Most recent records are set when new computers are being installed and tested. (Recent records are more or less how many digits can be computed in a day — a reasonable amount of test time on a costly machine.) The computation of pi seems to stretch the machine and there is a history of uncovering subtle and sometimes not so subtle bugs at this stage.

What do the calculations of π reveal and what does one expect? One expects that the digits of pi should look random — that roughly one out each ten digits should be a 7, etc. This appears to be true at least for the first few hundred billion. But this is far from a proof — an actual proof of this is way out of the reach of current mathematics. As is so often the case in mathematics some of the most basic questions are some of the most intractable. What mathematicians believe is that every pattern possible eventually occurs in the digits of pi — with a suitable encoding the Bible is written in entirety in the digits, as is the New York phone book and everything else imaginable.

The question of whether there are subtle patterns in the digits is an interesting one. (Perhaps every billionth digit is a seven after a while. While unlikely, this is not provably impossible. Or perhaps pi is buried within pi in some predictable way.) Looking for subtle patterns in long numbers is exactly the kind of problem one needs to tackle in handling the human genome (a chromosome is just a large number base 4, at least to a mathematician).

I have included two tables giving a chronology of the computation of digits of π. They are from David H. Bailey, Jonathan M. Borwein, Peter B. Borwein, and Simon Plouffe, "The Quest for Pi," (June, 1996) *The Mathematical Intelligencer*. The first table shows pre 20^{th} century computations and the second shows computations done in the 20^{th} century. The chronology in these tables is for the problem of computing all of the initial digits of pi. There is also a shorter chronology of computing just a few very distant bits of pi. The record here is 40 trillion and is due to Colin Percival using the methods described in the reference above. It is surprising that this is possible at all.

I have also included a list of significant mathematical formulae related to π. It is taken from Lennert Berggren, Jonathan M. Borwein and Peter B. Borwein, *Pi: A Source Book* (Springer-Verlag, 1988)[†].

This text accompanied an address given at the celebration to replace the lost tombstone of Ludolph van Ceulen at the Pieterskerk (St Peter's Church) in Leiden on the fifth of July, 2000. A version of this paper appears in the Nieuw Archief voor Wiskunde **1** *(2000), pp. 254–258.*

It honours the particular achievements of Ludolph as well as the long and important tradition of intellectual inquiry associated with understanding the number π and numbers generally. The author would like to pay tribute to the mathematical community of the Netherlands on the occasion of its honouring one of its founding fathers the mathematician, Ludolph van Ceulen (1540–1610).

Selected Formulae Related to π

Archimedes (ca 250 BCE):
Let $a_0 := 2\sqrt{3}$, $b_0 := 3$ and

$$a_{n+1} := \frac{2a_n b_n}{a_n + b_n} \quad \text{and} \quad b_{n+1} := \sqrt{a_{n+1} b_n}.$$

Then a_n and b_n converge linearly to π (with an error $O(4^{-n})$.)

Francois Viète (ca 1579):

$$\frac{2}{\pi} = \sqrt{\frac{1}{2}}\sqrt{\frac{1}{2}+\frac{1}{2}\sqrt{\frac{1}{2}}}\sqrt{\frac{1}{2}+\frac{1}{2}\sqrt{\frac{1}{2}+\frac{1}{2}\sqrt{\frac{1}{2}}}}\cdots$$

John Wallis (ca 1650):

$$\frac{\pi}{2} = \frac{2\cdot 2\cdot 4\cdot 4\cdot 6\cdot 6\cdot 8\cdot 8\cdots}{1\cdot 3\cdot 3\cdot 5\cdot 5\cdot 7\cdot 7\cdot 9\cdots}$$

William Brouncker (ca 1650):

$$\pi = \cfrac{4}{1+\cfrac{1}{2+\cfrac{9}{2+\cfrac{25}{2+\cdots}}}}$$

Mādhava, James Gregory, Gottfried Wilhelm Leibnitz (1450–1671):

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \cdots$$

Isaac Newton (ca 1666):

$$\pi = \frac{3\sqrt{3}}{4} + 24\left(\frac{2}{3\cdot 2^3} - \frac{1}{5\cdot 2^5} - \frac{1}{28\cdot 2^7} - \frac{1}{72\cdot 2^9} - \cdots\right)$$

Machin Type Formulae (1706–1776):

$$\begin{aligned}
\frac{\pi}{4} &= 4\arctan(\frac{1}{5}) - \arctan(\frac{1}{239})\\
\frac{\pi}{4} &= \arctan(\frac{1}{2}) + \arctan(\frac{1}{3})\\
\frac{\pi}{4} &= 2\arctan(\frac{1}{2}) - \arctan(\frac{1}{7})\\
\frac{\pi}{4} &= 2\arctan(\frac{1}{3}) + \arctan(\frac{1}{7})
\end{aligned}$$

Leonard Euler (ca 1748):

$$\begin{aligned}
\frac{\pi^2}{6} &= 1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \frac{1}{5^2} + \cdots\\
\frac{\pi^4}{90} &= 1 + \frac{1}{2^4} + \frac{1}{3^4} + \frac{1}{4^4} + \frac{1}{5^4} + \cdots\\
\frac{\pi^2}{6} &= 3\sum_{m=1}^{\infty} \frac{1}{m^2\binom{2m}{m}}
\end{aligned}$$

Srinivasa Ramanujan (1914):

$$\frac{1}{\pi} = \sum_{n=0}^{\infty} \binom{2n}{n}^3 \frac{42n+5}{2^{12n+4}}.$$

$$\frac{1}{\pi} = \frac{\sqrt{8}}{9801}\sum_{n=0}^{\infty} \frac{(4n)!}{(n!)^4}\frac{[1103+26390n]}{396^{4n}}$$

Each additional term of the latter series adds roughly 8 digits.

Ferguson	1946	620
Ferguson	Jan. 1947	710
Ferguson and Wrench	Sep. 1947	808
Smith and Wrench	1949	1,120
Reitwiesner et al. (ENIAC)	1949	2,037
Nicholson and Jeenel	1954	3,092
Felton	1957	7,480
Genuys	Jan. 1958	10,000
Felton	May 1958	10,021
Guilloud	1959	16,167
Shanks and Wrench	1961	100,265
Guilloud and Filliatre	1966	250,000
Guilloud and Dichampt	1967	500,000
Guilloud and Bouyer	1973	1,001,250
Miyoshi and Kanada	1981	2,000,036
Guilloud	1982	2,000,050
Tamura	1982	2,097,144
Tamura and Kanada	1982	8,388,576
Kanada, Yoshino and Tamura	1982	16,777,206
Ushiro and Kanada	Oct. 1983	10,013,395
Gosper	1985	17,526,200
Bailey	Jan. 1986	29,360,111
Kanada and Tamura	Sep. 1986	33,554,414
Kanada and Tamura	Oct. 1986	67,108,839
Kanada, Tamura, Kubo, et. al	Jan. 1987	134,217,700
Kanada and Tamura	Jan. 1988	201,326,551
Chudnovskys	May 1989	480,000,000
Chudnovskys	Jun. 1989	525,229,270
Kanada and Tamura	Jul. 1989	536,870,898
Kanada and Tamura	Nov. 1989	1,073,741,799
Chudnovskys	Aug. 1989	1,011,196,691
Chudnovskys	Aug. 1991	2,260,000,000
Chudnovskys	May 1994	4,044,000,000
Takahashi and Kanada	Jun. 1995	3,221,225,466
Kanada	Aug. 1995	4,294,967,286
Kanada	Oct. 1995	6,442,450,938
Kanada	Jun. 1997	51,539,600,000
Kanada	Sep. 1999	206,158,430,000

History of calculating the digits of π (20th Century).

Louis Comtet (1974):

$$\frac{\pi^4}{90} = \frac{36}{17}\sum_{m=1}^{\infty}\frac{1}{m^4\binom{2m}{m}}$$

Eugene Salamin and Richard Brent (1976):
Set $a_0 = 1, b_0 = 1/\sqrt{2}$ and $s_0 = 1/2$. For $k = 1, 2, 3, \ldots$ compute

$$\begin{aligned}
a_k &= \frac{a_{k-1} + b_{k-1}}{2} & s_k &= s_{k-1} - 2^k c_k\\
b_k &= \sqrt{a_{k-1}b_{k-1}} & p_k &= \frac{2a_k^2}{s_k}\\
c_k &= a_k^2 - b_k^2
\end{aligned}$$

Then p_k converges *quadratically* to π.

Jonathan Borwein and Peter Borwein (1985):
Set $a_0 = 6 - 4\sqrt{2}$ and $y_0 = \sqrt{2} - 1$. Iterate

$$\begin{aligned}
y_{k+1} &= \frac{1-(1-y_k^4)^{1/4}}{1+(1-y_k^4)^{1/4}}\\
a_{k+1} &= a_k(1+y_{k+1})^4 - 2^{2k+3}y_{k+1}(1+y_{k+1}+y_{k+1}^2)
\end{aligned}$$

Then a_k converges *quartically* to $1/\pi$.

David Chudnovsky and Gregory Chudnovsky (1989):

$$\frac{1}{\pi} = 12\sum_{n=0}^{\infty}(-1)^n\frac{(6n)!}{(n!)^3(3n)!}\frac{13591409+n545140134}{(640320^3)^{n+1/2}}$$

Each additional term of the series adds roughly 15 digits.

*Please see **Selected Formulae,** page 25.*

Report on the PIMS Algebra 2000 Summer School at the University of Alberta

Contributed by Akbar Rhemtulla, Robert Moody, and Bruce Allison, Dept. of Math. Sciences, University of Alberta.

The PIMS Thematic Programme in Algebra called Algebra 2000, took place at the University of Alberta over a 4-week period from June 19 to July 14. The programme consisted of summer schools and workshops in three areas of algebra: Lie Theory, Group Theory and Representations and the Mathematics of Aperiodic Order. Each area was featured for 2 (overlapping) weeks. The programme was very successful and attracted over 100 participants.

In the first week, the *Lie Theory* summer school featured 2 series of introductory talks for graduate students. Stephen Donkin (Queen Mary and Westfield College) gave 5 lectures on Algebraic Groups and Arturo Pianzola (University of Alberta) gave 5 lectures on Lie Algebras. The Lie Theory workshop in the second week included one-hour talks by experts from Europe, United States and Canada on recent developments in the subject. Topics included vertex operator algebras and various infinite dimensional generalizations of finite dimensional simple Lie algebras. Many of the talks, as well as much informal discussion, focused on the increasing interplay between Lie theory and mathematical physics.

The *Groups and Representations* summer school started in the second week with introductory lectures for graduate students given by Peter Kropholler (Queen Mary and Westfield College), Gerald Cliff (University of Alberta), Alexander Turull (University of Florida). The workshop in the following week was devoted to hour long talks. Half of these were in representation theory and the rest in infinite groups. Topics included representations of finite groups, profinite groups and Burnside problems.

In the third week of the programme we began the summer school on *Aperiodic Order*. This school included four lecture series (a total of 10 lectures):

Michael Baake (Universität Tübingen): "Introduction to long-range aperiodic order"

Jeffry Lagarias (AT & T Research Labs): "The geometry of point sets"

Boris Solomyak (University of Washington): "Tilings and dynamical systems"

Michael Baake (Universität Tübingen): "Stochastic and other directions"

These beautifully prepared talks were of a consistently high standard. Because the subject is new and has quite diverse mathematical components, these lectures were enjoyed immensely by students and researchers alike. In addition, Uwe Grimm gave several hands-on computer demonstrations illustrating the main features of aperiodic tilings.

The final week of the programme consisted of a workshop on Aperiodic Order with 4 to 5 one-hour talks per day. The talks from the participants covered the entire spectrum of the subject from the spectral theory, through diffraction, substitution systems, automatic sequences, random tilings, aperiodic Schröedinger operators, and aperiodic approaches to random number generators.

Many of the participants in Algebra 2000 took advantage of the weekend between their summer school and workshop to go to Jasper where they stayed in the Palisades Science Centre. This retreat provided continued discussions throughout the weekend and helped enormously to develop the fine spirit of the entire programme.

Report on the Fall 2000 Pacific Northwest Statistical Meeting

Contributed by Carl Schwarz,
Dept. of Mathematics and Statistics, SFU

The Pacific Northwest Statistical Meeting (PNWSM) for the fall of 2000 was held on November 17 at the newest member of PIMS — the University of Washington. The PNWSM gratefully acknowledges financial help from PIMS to assist graduate students in attending the talks.

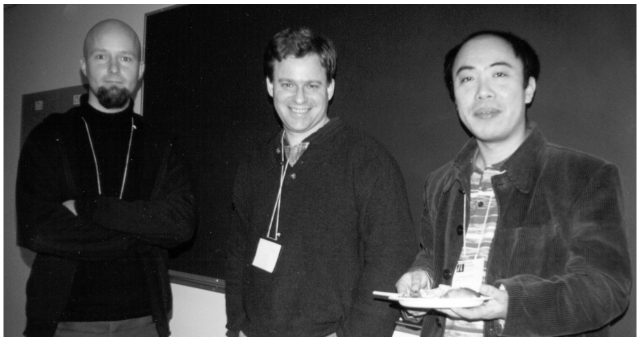
The first of two featured speakers was June Morita, University of Washington-Bothell who spoke on Contributions to Statistical Literacy. In her talk, she outlined some educational outreach activities being used to assist local teachers in understanding many of the new threads of mathematics and statistics that are entering the curriculum. The age-level of the activities ranged from K-12, but some of the activities could be used at all levels. The activities ranged from edible classroom materials (histograms), to TrashBall (paired experiments), to the probability that a space object would hit the ocean rather than falling on land (survey sampling).

The second speaker was Constance van Eeden (University of British Columbia), who spoke on "Estimation in Restricted Parameter Spaces: Some History and Some Recent Developments". The addition of seemingly trivial information often makes development of a trivial procedure much more difficult. For example, consider the simple case where X has a N(θ,1) distribution and θ is to be estimated when one knows that $\theta \geq 0$. That is, one is looking for an estimator $\hat{\theta}$ of θ satisfying $\hat{\theta} \geq 0$. Finding "good" estimators for such situations is a difficult problem. Standard results, e.g. maximum likelihood estimators become inadmissible, but estimators that do dominate the MLE have recently been found.

The PNWSM are held three times per year rotating among the universities in British Columba, Alberta and Washington state. The next meeting is scheduled for this spring and will be held at Simon Fraser University. For details about the next meeting, please check **www.stat.sfu.ca/stats**.

Report on the PIMS PDF Workshop

The third Annual PIMS Postdoctoral Fellow Workshop was hosted by PIMS-SFU on December 9–10, 2000. The first day of this two-day workshop was held in the PIMS facility on the SFU main campus and the second day was held at the SFU Harbour Centre in downtown Vancouver.



From left, Jorgen Rasmussen (U. Lethbridge), Sandy Rutherford (PIMS Sci. Exec. Officer) and Ji-Guang Bao (PIMS-UBC) at the PIMS PDF Workshop.

This workshop gives PIMS postoctoral fellows an opportunity to present their research to each other in an informal setting. The following seventeen talks were presented over the course of two very long days:

Siva Athreya (PIMS-UBC): "Ballistic deposition on a planar strip"

Ji-Guang Bao (PIMS-UBC): "Surfaces with Prescribed Gaussian Curvature"

Ricardo Carretero (PIMS-SFU): "Bose-Einstein condensates: breathing lumps of coherent matter"

Wai-Shun Cheung (PIMS-UC): "Introduction to Numerical Range and Its Generalizations"

Antal Jarai (PIMS-UBC) "Invasion percolation and the incipient infinite cluster"

Benjamin Klopsch (PIMS-UA): "Counting Groups — all your fingers are needed"

Luis Lehner (PIMS-UBC): "Numerical Relativity: a laboratory for General Relativity"

Sam Lightwood (PIMS-UVic): "Embedding Theorems for d-Dimensional Symbolic Dynamics, $d > 1$"

Miro Powojowski (PIMS-UC): "Random processes and stochastic PDEs in applications"

Jorgen Rasmussen (U. Lethbridge): "Algebraic aspects and string theory applications"

Sujin Shin (PIMS-UVic): "Invariant Measures for Piecewise Convex Transformations of an Interval"

Ladislav Stacho (PIMS-SFU): "On factor d-domatic colorings of graphs"

Joachim Stadel (PIMS-UVic): "The Big and Small N of Astrophysical N-body Simulations"

Sumati Surya (PIMS-UBC): "Topology Change and Causal Continuity"

Yuqing Wang (PIMS-UBC): "Synchronous phase clustering in pulse-coupled neurons with spatially decaying excitatory coupling"

Bert Wiest (PIMS-UBC): "Orderability of fundamental groups of 3-manifolds"

Konstantin Zarembo (PIMS-UBC): "On quantization condition for a magnetic charge"

Second Pacific Rim Conference on Mathematics

Contributed by Robert Miura,
Dept. of Mathematics, UBC

Approximately 150 mathematicians from Australia, Canada, China, France, Hong Kong, India, Japan, Korea, New Zealand, the Philipines, Singapore, Switzerland, Tajikstan, the United States, and Uzbekistan attended the Second Pacific Rim Conference on Mathematics on January 4–8, 2001 at Academia Sinica in Taipei, Taiwan. The six main themes of the Conference were Combinatorics, Computational Mathematics, Dynamical Systems, Integrable Systems, Mathematical Physics, and Nonlinear Partial Differential Equations.

There were 12 one-hour plenary talks, approximately forty 45 minute invited talks, and 55 contributed papers. The plenary talks were excellent with each speaker giving a general background for the audience and then presenting more details later in the talk. The Plenary Speakers were Ian Affleck (UBC), Craig Evans (UC Berkeley), Joel Feldman (UBC), Genghua Fan (Academia Sinica, China), Alberto Grunbaum (UC Berkeley), Song-Sun Lin (Chiao Tung University, Taiwan), Junkichi Satsuma (Univ. of Tokyo), Leon Simon (Stanford), Stephen Smale (City U, Hong Kong), Gilbert Strang (MIT), Yingfei Yi (Georgia Tech), and Xuding Zhu (Sun Yat-Sen University, Taiwan).

The two plenary speakers from Canada were in the Mathematical Physics Session, along with Izabella Łaba (UBC), Robert McCann (Toronto), and Gordon Semenoff (UBC), who were invited speakers. Brian Alspach (Regina) and Rong-Qing Jia (Alberta) were invited speakers in the Combinatorics and Computational Mathematics Sessions, respectively. The Canadian Representative on the Organizing Committee was Robert Miura (UBC). PIMS provided support for the Canadian participants in the conference.

The local organizers from the Institute of Mathematics at Academia Sinica led by Fon-Che Liu, former Director of the Institute, and Tai-Ping Liu, current Director, did a superb job of making sure that all the needs of the conference participants were met. All talks were given at the Activity Centre of Academia Sinica where most participants had their accommodations. The lecture rooms were ideal and had a full complement of audio-visual equipment. The Conference Reception, Conference Banquet, and Excusion to an art gallery, temple, pottery town, and a night market were the highlights of the social activities.

A committee meeting was held after the Conference Reception to discuss the site of the Third Pacific Rim Conference on Mathematics and was attended by representatives from Australia, Canada, China, Hong Kong, Japan, Taiwan, and the United States. It was proposed that the next Conference be held in Vancouver in the summer of 2004 under the sponsorship of PIMS. This was accepted enthusiastically and unanimously by the committee, as well as by the participants after it was announced at the Conference Banquet.

PIMS Graduate Information Week 2001

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

The Pacific Institute for the Mathematical Sciences Graduate Student Information Seminar, held at the Universities of Alberta and Calgary on January 9–12, was a great success. Twenty-four top fourth year undergraduates in mathematics, statistics, and computer science from universities all across Canada arrived in Calgary on the Tuesday afternoon.


Visiting students attend a lecture at the University of Alberta.

After a welcoming student/faculty mixer that evening, the students were treated on Wednesday to a full program of presentations about graduate studies at the University of Calgary, including talks by research groups in discrete math, analysis, industrial and collaborative mathematics, the math finance lab, the statistical consulting lab, computer graphics, quantum computing, and several others.

The Dean of Graduate Studies, James Frideres, outlined some of the many attractions in studying at Calgary, while the PIMS Deputy Director, Michael Lamoureux, described the advantages of joining the PIMS team of western universities. The departments' Director of Graduate Programs, John Collins, detailed the scholarship possibilities and amenities of each of the programs. Gary MacGillivray gave a presentation on programs at the University of Victoria. At a western-style dinner that evening, the Associate Dean of Science, Robert Woodrow, discussed additional funding opportunities from the Government of Alberta that make graduate study in the province particularly rewarding for prospective students.

After further informative sessions and meetings with faculty members on Thursday morning, the students went by bus to Edmonton that afternoon. Dick Peter, Dean of Science, and Peter Steffler, Associate Dean of Graduate Studies, along with faculty and graduate students from the departments of Computing Science and Mathematical Sciences welcomed them to the University of Alberta campus at a banquet at the Faculty Club. Bryant Moodie, PIMS University of Alberta Site Director, gave a brief account of PIMS and its particular relevance to graduate studies in the mathematical sciences.

Friday morning activities were kicked off with a presentation by Bob Moody (University of Alberta) on "Graduate Studies in Mathematical Sciences: 2001"[†]. Jim Hoover (Univ. of Alberta) talked about "The relationship between theoretical computer science and 'standard' mathematics". Presentations on graduate studies at PIMS universities were given by Denis Sjerve (UBC), Randy Sitter (SFU), Lorna Stewart (Univ. of Alberta) and Jim Muldowney (Univ. of Alberta).


Students discuss with Akbar Rhemtulla, Chair, Dept. of Math. Sciences, University of Alberta.

After a lunch with local CS and MathSci faculty and graduate students, the visitors had a full afternoon of small group meetings, interviews and tours scheduled to address their individual interests. Over 100 meetings with local researchers and representatives of the other PIMS sites were arranged by PIMS staff.

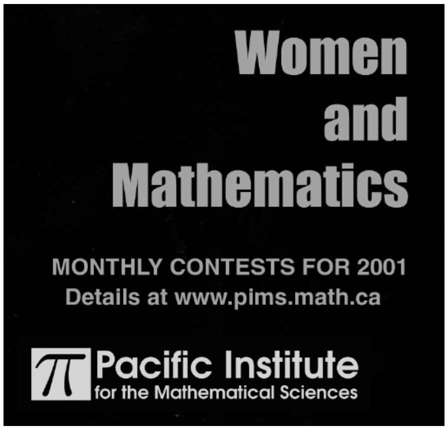
A farewell party and supper was held at the Varscona Hotel on Whyte after which some participants were said to have explored the attractions of Whyte Avenue late into the evening.

Financial support for the seminar was provided by PIMS and each of the two host universities. Travel and accommodation for the whole event as well as the Calgary program were arranged by John Collins, Sheelagh Carpendale and Marian Miles (PIMS Administrator, Univ. of Calgary). Local arrangements in Edmonton were taken care of by Jim Muldowney, Lorna Stewart, Martine Bareil and Lina Wang (PIMS Administrator, Univ. of Alberta).

[†] The text of this lecture is reprinted in this newsletter.

Women and Mathematics: New Posters and Contests in 2001

Contributed by Krisztina Vásárhelyi



Hypatia of Alexandria

Ada Lovelace Byron

Building on the momentum generated by the **Mathematics is Everywhere** poster campaign, PIMS is continuing the project in 2001 with a new theme and new format. Klaus Hoechsmann's innovative poster series, blending the appeal of a public contest with advertising on city transit, and the internet, has demonstrated that given the right approach, it is possible to rouse interest in the "terminally unpopular". The new series will attempt to convey a different, yet from a public perspective, equally challenging message, utilising the proven formula of the previous series.

With the intention of introducing the public, and in particular young people, to the idea that mathematics is a career asset, a colourful palette of biographies will be presented monthly. The poster series **Women and Mathematics** will showcase portraits of twelve women who have made contributions to the broad field of the mathematical sciences. Biographies of famous historical figures as well as accomplished contemporary mathematicians will be presented together with women who are well-known to the public but who are primarily recognised for their achievements in fields other than mathematics.

Mathematics is expanding rapidly beyond its traditional domains. The importance of mathematics in engineering, physics, chemistry and computer science for example is obvious, but mathematical competence is becoming increasingly important in other fields including biology, medicine, public health, psychology and even journalism. With the growth of information technologies in all fields, the demand for mathematically trained individuals in the work force will continue to rise. Ironically, mathematics still suffers from a bad reputation. Fear and loathing of the subject is firmly established already at the elementary school level. The attitude that mathematics is a career obstacle continues to influence education choices. Girls are especially susceptible to rejecting a course of study which favours mathematical content. The "smart girl" stigma among teenagers can be a powerful deterrent.

The **Women and Mathematics** campaign will present an alternative, much more positive, image of mathematics in the lives of women. Mathematics can involve lifelong dedicated research, it can be an enjoyable pursuit and it can represent a valuable tool in a variety of endevours. The last point is aptly illustrated by the case of Florence Nightingale. She is a prominent figure and role model, widely acknowledged for her achievements in the fields of nursing and public health. Yet her perhaps less well known contributions to statistics have been pivotal to her other accomplishements. Possessing mathematical skills is an asset and can enrich and promote success in virtually all fields. This is one of the main messages of the campaign.

The target audience for this project includes students in elementary and secondary schools as well as the general public of any age or gender. However, by focusing on women we want to draw attention to the problem of low female participation in the mathematical sciences. Therefore, a primary and important goal of this project is to reveal to girls the appealing and attractive sides of a life involving mathematical study or activities.

The women featured on the posters represent many levels of mathematical pursuit. The inclusion of established role models is an attempt to create a link to other women not well known to those outside of scientific circles and whose work is not easily appreciated by non-specialists. Effort will be focused on presenting the topics in a colourful and interesting manner, exploiting the advantages of the visual medium. The posters will be designed to capture the attention of the observer and invite further exploration on the website.

The contest itself will promote internet-based biographical research in addition to problem-solving. A set of five quiz questions will be posted on the contest website. One of the questions will be a mathematics problem, highlighting the field of involvement of the featured individual. Answers to the remaining biographical questions can be found by searching the web. This approach will hopefully encourage contestants to read and learn about women in mathematical pursuits. At the end of the month a short biography along with the correct answers will be posted on the web and a prize will be drawn among the correct entries. The poster-campaign will be advertised in schools in BC and Alberta to encourage initiatives for class projects.

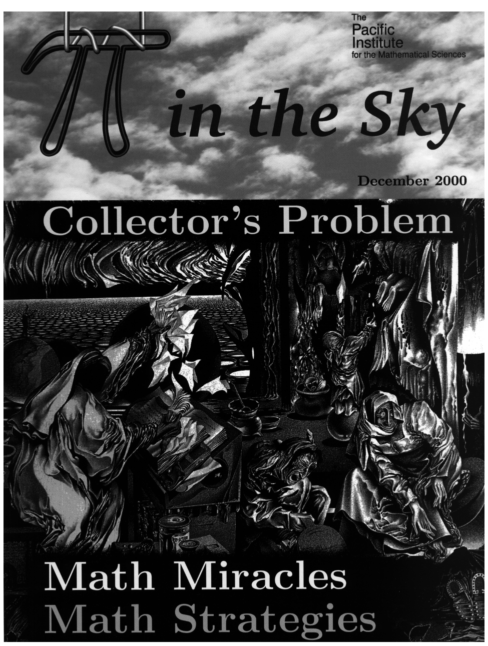
The first two posters in the series will feature Hypatia of Alexandria and Ada Lovelace Byron. Hypatia was the last of the Alexandrian scholars and her murder by a fundamentalists mob in 415 AD is often taken as the onset of the Dark Ages. Ada Lovelace Byron is widely regarded as one of the founders of computer science. In the 1840's she wrote the first computer computer algorithm — an algorithm to compute the Bernoulli numbers on the Analytical Engine designed (but never built) by Charles Babbage.

Izabella Łaba of the UBC Department of Mathematics will oversee the project which will be carried out at the PIMS-UBC site in a a team effort by Heather Jenkins and Krisztina Vásárhelyi, with input from Klaus Hoechsmann.

Pi in the Sky: December 2000 issue

The second issue of the PIMS Education Magazine, *Pi in the Sky*, features a variety of interesting articles as well as challenging problems and numerous jokes which will interest young and old mathematicians alike. Akbur Rhemtulla writes about *Counting with Base Two and the Game of Num*, and Byron Schmuland about the *Collector's Problem.* Learn about π in *The Number π and the Earth's Circumference* by Wieslaw Krawcewicz. How many digits in the decimal expansion can you remember? Find out more about triangles in *The Anatomy of Triangles* by Klaus Hoechsmann. After reading *Relating Mathematical Ideas to Simple Observations* by Jim G. Timourian, try your hand at physics in *The Slingshot Effect of Celestial Bodies* by Florin Diacu.

The picture on the cover page is a fragment of a painting by prominent Russian mathematician Anatoly T. Fomenko which was inspired by mathematical ideas.



Selected Formulae for Pi

Continued from page 20.

Jonathan Borwein and Peter Borwein (1989):

$$\frac{1}{\pi} = 12\sum_{n=0}^{\infty} \frac{(-1)^n(6n)!}{(n!)^3(3n)!}\frac{(A+nB)}{C^{n+1/2}},$$

where

$$\begin{aligned} A &:= 212175710912\sqrt{61} + 1657145277365 \\ B &:= 13773980892672\sqrt{61} + 107578229802750 \\ C &:= [5280(236674 + 30303\sqrt{61})]^3. \end{aligned}$$

Each additional term of the series adds roughly 31 digits.

Roy North (1989):
Gregory's series for π, truncated at 500,000 terms gives to forty places

$$4\sum_{k=1}^{500{,}000} \frac{(-1)^{k-1}}{2k-1}$$
$$= 3.14159\underline{0}65358979324\underline{04}6264338326\underline{9}502884197$$

Only the underlined digits are incorrect.

Jonathan Borwein and Peter Borwein (1991):
Set $a_0 = 1/3$ and $s_0 = (\sqrt{3}-1)/2$. Iterate

$$\begin{aligned} r_{k+1} &= \frac{3}{1+2(1-s_k^3)^{1/3}} \\ s_{k+1} &= \frac{r_{k+1}-1}{2} \\ a_{k+1} &= r_{k+1}^2 a_k - 3^k(r_{k+1}^2 - 1) \end{aligned}$$

Then $\frac{1}{a_k}$ converges *cubically* to π.

David Bailey, Peter Borwein and Simon Plouffe (1996):

$$\pi = \sum_{i=0}^{\infty} \frac{1}{16^i}\left(\frac{4}{8i+1} - \frac{2}{8i+4} - \frac{1}{8i+5} - \frac{1}{8i+6}\right)$$

Mathematics on Stage

Contributed by Klaus Hoechsmann

In the spring of 1999, we at PIMS were wondering with what kind of special event we should mark the year 2000 as the UNESCO World Year of Mathematics. Should we host yet another great lecture, another workshop or panel discussion? The idea of a theatre performance presented itself.

Every practitioner knows that mathematical work, with its twists and turns, its sudden impasses and breakthroughs, is highly dramatic, yet can such drama be staged? There are several excellent recent plays (e.g., Tom Stoppard's "Arcadia" and David Auburn's "Proof") which do revolve around mathematics — using it as a source of anecdote and speculation, but never quite getting to the source itself. Within our cultural horizon, we could not find anything ready-made, so we turned to home cooking. Fortunately, we were able to enlist the guidance and extensive collaboration of Ted Galay, who is a mathematician as well as an experienced playwright.

The mathematics presented would have to be simple, precise, elegant, but without the formalisms which are the dreaded heart of "math" to graduates of modern schools. We looked to the past for a mathematical story which would meet these criteria. Our protagonist would be Hypatia, the last leading intellectual of the cosmopolitan city of Alexandria (Egypt): mathematician, astronomer, and philosopher, savagely murdered in 415 AD by a fundamentalist mob.

A major proponent of Neoplatonism, she is said to have wandered in crowds of strangers to engage them in philosophical debate. The play imagines this outreach effort extended to mathematics itself — i.e., thought without ideological wrapping. Nonetheless, she gets entangled in the power struggle between burgeoning Church and moribund State. Half of the play deals with this conflict.

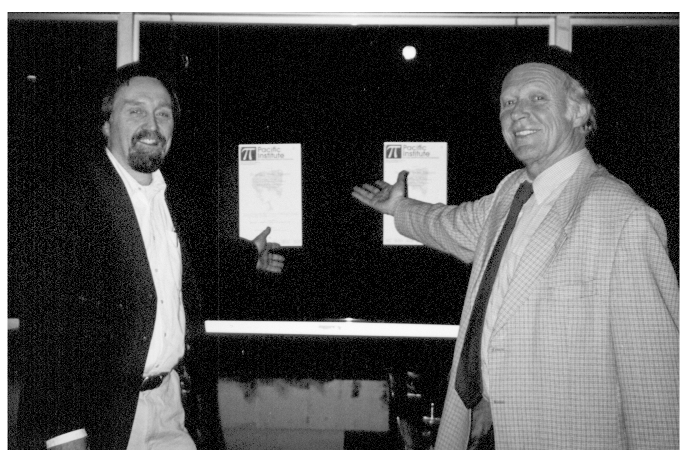
The other half consists of three (originally four) mathematical skits — staged by Hypatia and three likeminded friends as comical street theatre. The first shows the well-known measuring of the earth's circumference by Eratosthenes. The third moves from the earth to the heavens — first estimating the distances between earth, moon, sun, and then showing how to gauge interplanetary distances — based on the ideas of Aristarchos. Between those two "applied" skits, the second one shows off the two major ingredients of mathematics: insight and reason — the former in a take-off on Plato's "Meno" dialogue, the latter in a hands-on proof of the impossibilty of arithmetically doubling a square.

The third skit is the most ambitious, as it tries to show the elegant simplicity of ancient thought. How far is the moon? By timing a solar eclipse, you see that it moves eastward by one diameter an hour. Therefore the number of hours in a sidereal month tells you the length of its circuit — hence also its distance from the earth — in moon diameters. Since a lunar eclipse lasts thrice as long, the earth is three times wider than the moon – and now you have these distances in terms of earth diameters. Then follow Eratosthenes to convert it all to miles.

In technical terms, the demonstrations on stage mainly use the visually obvious fact that small angles are roughly proportional to their sines and tangents, and the more subtle (but visually demonstrable) fact that the slices of a regular 25-gon are about four times as high as they are wide, whence the ratio of circumference to radius is $\frac{25}{4}$, a fairly good approximation to 2π. In Hypatia's time, it was already well known (cf. Claudius Ptolemy) that an astronomy based on combinations of uniform circular motions is a woefully coarse mathematical model. Its great advantage, however, is that it opens the door to a relatively sophisticated understanding by the mathematical novice — and even allows some choreographic representation.

Apart from its length (30 minutes), the most serious shortcoming of the third skit is the underplaying of the main difference between the systems of Aristarchos and Hipparchos: the question is not whether the earth moves or stands still, but whether the other planets move about a common, observable centre (the sun) or about individual, imaginary points on "deferent" circles. In our next production of the play, we shall try to do this better with a slightly modified script.

Even in its present state, the play was warmly received by an almost full house at UBC's Frederic Wood Theatre, on December 10, 2000. Available funds allowed only a staged reading — with off-book action in the mathematical skits, and minimal props and costumes — but an amazingly quick-witted group of professional actors, who were also eager learners of mathematics, and a director whose generosity was matched only by his command of stage craft.



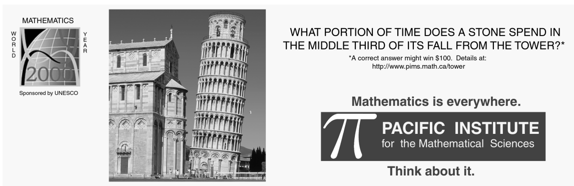
Director Bryan Wade (left) with author Klaus Hoechsmann.

For further details, including the complete script, please see **www.pims.math.ca/education/drama**.

Mathematics is Everwhere Campaign Concludes

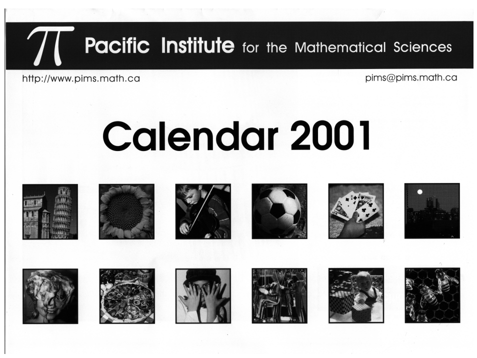
Contributed by Krisztina Vásárhelyi

The last contest in the **Mathematics is Everywhere** poster campaign is currently underway with an image of the leaning tower of Pisa and a question about calculus.



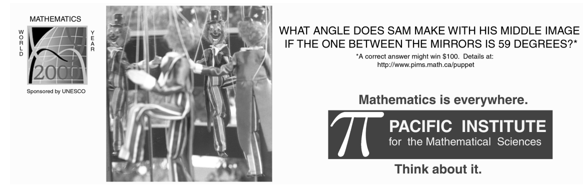
On the buses in January.

The contest series has been very successful and its closing is marked by the publication of a year 2001 wall calendar. The calendar, designed by Heather Jenkins, PIMS Communications Officer, was distributed to numerous schools and mathematics departments in Canada and USA. It is a complete collection of the pictures and associated questions of the poster campaign.



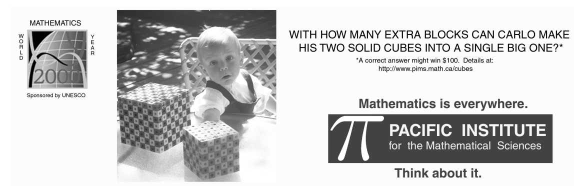
PIMS Calendar for 2001.

In previous issues of the PIMS Newsletter we ran profiles of the monthly contests from February to September 2000. In October, reflected images of a puppet between two mirrors were used to explore “mappings”. Paige Zanewick from Calgary won that contest. Paige is a 14 year old student in Grade 8 who has always enjoyed math and tries to incorporate it into her life every day. Paige says that if she had a choice in selecting her courses, she would choose all those that deal with mathematics. In addition to her love of math, Paige enjoys horse back riding, skating, skiing, tennis, badminton, soccer and surfing the net. She learnt about the contest from her teacher, who challenged the students to participate and, as a reward, offered a free period to all if someone from the class won the $100 prize. In her own words, Paige thinks “...that this contest is a really great way to get interested in math. It challenges people to try their hardest to figure out the answer to the question”.



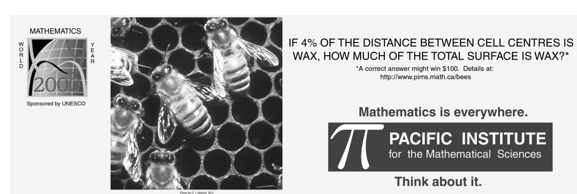
On the buses in October.

Bus passengers in November saw a child with two different-sized cubes, both made out of small blocks. “With how many extra blocks can Carlo make his two solid cubes into a single big one?” Those curious enough to follow the links on the contest webpage were treated to a thrilling detective story, spanning over 300 years, which culminated in the triumphant proof of Fermat’s Last Theorem by Andrew Wiles. The November winner was Yakov Shklarov of Calgary.



On the buses in November.

In December an image of bees on a honeycomb (contributed by C. Keeling of SFU) was shown to represent a packing problem. “If 4% of the distance betweeen cell centres is wax, how much of the total surface is wax?” The winner of the December contest was Vancouver native Tom Watson (43), who is employed at the Canada Customs and Revenue Agency. Tom has always liked numbers but notes that there are many who claim to have hated math in school because they don’t understand the subject. While he had a natural affinity for mathematics from an early age on, Tom says that kids may become interested if the topic was presented in a more exciting way. Tom remembered a teacher from elementary school who regularly gave students a math problem to solve before recess and the winner recieved a chocolate bar or, at the very least, was allowed to leave the classroom first! Tom was alerted to the poster by a relative who spotted it on the bus and he says he finds the contest a good idea. Tom’s other interests include music, old movies, puzzles and of course anything that makes him think.



On the buses in December.

Rita Aggarwala, a leader of tomorrow

The Alberta Science and Technology Foundation has selected Rita Aggarwala as the recipient of their new **Leader of Tomorrow Award**. Aggarwala is an associate professor in the Department of Mathematics and Statistics at the University of Calgary.

"It was exciting," Aggarwala says of the gala event on October 20 at the Shaw Conference Centre, Edmonton, where she was presented the award by Lorne Taylor, Minister for Innovation and Science. "It's great for mathematics and statistics to be recognised; and it was very inspiring to see all the amazing research going on."

At the 11^{th} annual awards ceremony, approximately 20 different individuals, businesses or research groups were finalists in 10 categories including Technology, Industrial Research Innovation, and Public Awareness. In the **Leader of Tomorrow** category there were 2 other finalists, John Doucette, a graduate student at the University of Alberta who works in the engineering field, and Veer Gidwaney of Calgary who at just 21 is on his third company producing business-to-business software.

At the age of 29, Aggarwala has already established herself as a leader in her field of research which includes progressive censoring, including its application to warranty development, applied statistics and statistical quality improvement. She accelerated through high school and university then joined the math faculty at the University of Calgary as an assistant professor at the age of 24 and was granted tenure at 28. Her young career has been very productive with numerous publications including a recently co-authored a book which is aimed at statistical practitioners in research and industry who need sophisticated scientific tools to analyse data in the development of their products and services.

In her acceptance speech, Rita thanked PIMS for its impact on her own career and on the research life at the University of Calgary. In particular, she singled out the support of PIMS to the **Statistical Consulting and Research Group** at the University of Calgary. This group was established with the aim of providing graduate students and other academics-in-training with valuable computing, applied research and consulting experience. This is achieved by working with real, current data and design problems posed by other experimental researchers and industrial organisations who are in search of this type of expertise. Students benefit from the these "real-world" problems which are often messier than the textbook examples and a few of these have resulted in research projects for graduate students.

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