Berkeley
# Mathematics
Newsletter

A newsletter of the Department of Mathematics and Center for Pure and Applied Mathematics at the University of California, Berkeley

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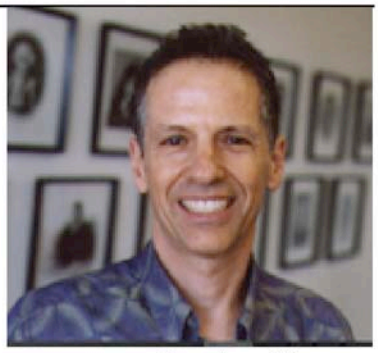
## MESSAGE FROM THE CHAIR



CHAIR ALAN WEINSTEIN

Dear UC Berkeley Math Department alumni and other friends,

There's a lot to report about the two years which have passed since the last edition of this newsletter.

ALUMNI NEWS

In the last newsletter, I asked readers to report on what they had been doing. I got just a few replies, which I'll summarize here. I hope that more of you will send news for the next issue.

Clark Abrahams (BA 1973) is Director for Fair Banking at SAS Institute in North Carolina and came out in 2008 with a book on the timely subject of "Fair Lending Compliance, Intelligence and Implications for Credit Risk Management". Frederic Alzofon (PhD 1956, the last student of Griffith Evans!) has had a career spanning "thirty years in industry and more than twenty years in 'retirement'", including engineering work in the aerospace industry, teaching relativity at San Jose State, and a 2003 book on radiation scattering. Janet Murry (BA 1975) wrote, "Though I did not go on as so many profiled in the newsletter, I do count Math as a special gift. It has been a ballast throughout my career in business for which I am profoundly grateful." I was person-

*(continued on page 2)*

## FIFTY YEARS OF LEWY'S COUNTEREXAMPLE

*by Maciej Zworski*

MACIEJ ZWORSKI

Just over fifty years ago, Hans Lewy [2] – in Berkeley since 1935 – published one of the most famous papers in the history of partial differential equations – and it was only 4 pages long. I will describe the result he obtained and review the history of the problem he created. For a detailed discussion and references I suggest [3] and [1].

Let us consider the simplest partial differential equation:

$$Vu = f, \ V = \sum_{j=1}^{3} a_j(x)\partial_{x_j}\,,$$
$$a_j \in C^\infty(\mathbf{R}^3), \ f \in C^\infty(\mathbf{R}^3),$$

where $V \neq 0$. Here $C^\infty$ denotes the space of infinitely differentiable complex valued functions. Can we always solve it locally?

*(continued on page 3)*

## Highlights

*What's inside:*

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## FACULTY HONORS AND AWARDS
### 2007/2008 Academic Year

**UCB PhD Henrique Bursztyn and Miller Fellow Marius Crainic** were the first 2 recipients of the André Lichnerowicz prize in Poisson Geometry, awarded in July 2008 at the conference, Poisson 2008, in Lausanne, Switzerland.

**Professor Ed Frenkel** was the first recipient of the Chair of Excellence of the Mathematical Sciences Foundation of Paris.

**Professor Jenny Harrison** was elected to the FXQi Foundation, or the Foundational Questions Institute, a non-federal agency affiliated with the Templeton Foundation.

**Associate Professor Olga Holtz** was awarded one of the 10 European Mathematical Society Prizes for 2008 at the meeting of the EMS in Amsterdam, 2008. She was also elected to the Jünge Akademie of Germany 2008-2013.

**Professor Richard Karp** is this year's winner of the Kyoto Prize in Advanced Technology.

**Professor Beresford Parlett** shared the 2008 Hans Schneider Prize in Linear Algebra with Cleve Moler (who created Matlab).

**Professor James Sethian** was elected to the National Academy of Engineering - 2008.

**Professor Bernd Sturmfels** was elected as VP of the American Mathematical Society for the period 2/1/2008 – 1/31/2011. ◆

*(Chair's Letter, continued from page 1)*

ally pleased to learn that I "caught" Janet as her Math 1A teacher in the Fall of 1971 and led her to major in math, though it was not part of her original plan.

It has been a particularly good time for the Class of 1978. Previously, I reported in this space that Andrew Fire (BA 1978) was awarded the 2006 Nobel Prize in Physiology of Medicine. Since then, the 2007 Sundance Film Festival's Special Jury Prize for Documentary has been awarded to "No End in Sight," written, directed, and produced by Charles Ferguson (BA 1978). The film, which tells the story behind the US involvement in Iraq, also won a string of Film Critics' awards. Andrew and Charles were our Commencement speakers in 2007 and 2008, respectively.

FRIENDS OF BERKELEY MATH

The Friends of Berkeley Mathematics is an informal organization created in Fall 2007 to bring together supporters and other friends of our Department. We have so far had two meetings, in October 2007 and November 2008. Each meeting included short talks on their research by some of our faculty, lunch and/or dinner, informal discussion among faculty, students, and Friends on issues of current concern to the Department, and attendance at a special lecture. In 2007, the lecture was Ken Ribet's colloquium talk on Serre's Modularity Conjecture. This was recorded (with the help of Will Hearst, one of our Friends) and is available for viewing on the FORA.tv website at http://fora.tv/search_video?q=ribet&x=0&y=0. In 2008, the lecture was by Peter Jones of Yale University, in the annual Serge Lang Undergraduate Lecture series. The title was "Divide and Conquer"; you can find an abstract of this talk (in which fractals played a central role) at http://math.berkeley.edu/index.php?module=announce&ANN_user_op=view&ANN_id=137.

We plan to continue these meetings each fall. Please contact us if you are interested in participating.

A NEW VICE-CHAIR POSITION

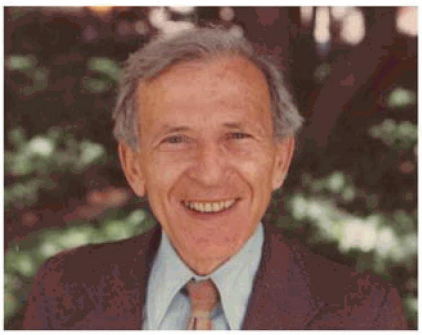
Since the Spring of 2008, **Ken Ribet** has occupied the newly-created position of Vice-Chair for Development. Together with the Director of the Center for Pure and Applied Mathematics (currently Craig Evans), the Vice-Chair is responsible for coordinating efforts to secure outside support for our research and instructional activities. These responsibilities include planning the annual meetings of the Friends of Berkeley Mathematics and overseeing the production of this Newsletter. Ken is also the chair of the new Distinguished Lectures Committee.

NEW FACULTY

**Ian Agol**, who was appointed on July 1, 2006, arrived from the University of Illinois at Chicago in the Fall of 2007, after a year of leave. He works in low-dimensional geometry and topology. Although Ian was largely occupied during his first semester here with the MSRI programs on Geometric Group Theory and on Teichmuller

*(continued on page 6)*

(Fifty Years, continued from page 1)



Hans Lewy
Breslau, 1904 – Berkeley, 1988

Solving an equation locally at $x_0$, means finding $u$ such that the equation is satisfied in a neighbourhood of $x_0$. We can demand that $u \in C^1$, that is that $u$ has one continuous derivative, or even ask simply for some weaker form of a solution.

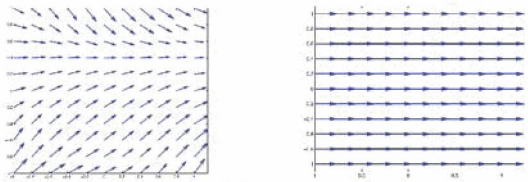


Figure 1

Suppose that $a_j(x) \in \mathbb{R}$. Then we can locally straighten $V$ out as shown in Fig.1 Hence all we have to solve is the equation

$$\partial_{x_1} u = f,$$

and that is done by simple integration.

Now suppose that the coefficients and the right hand side in

$$\sum_{j=1}^{3} a_j(x)\partial_{x_j} u = f$$

are real analytic, that is that, at every point their Taylor series converge in some neighbourhood. Already in the 19th century Cauchy and Kovalevskaya gave us local real analytic solutions. In fact, the Cauchy-Kovalevskaya Theorem gives local analytic solution to any reasonable partial differential equation:

$$P(x,D)u = f, \;\; P(x,D) = \sum_{|\alpha|\leq m} a_\alpha(x) D_x^\alpha, \;\; D_x = \frac{1}{i}\partial_x$$

One condition to guarantee it is that for some $\beta \in \mathbf{N}^n$, $|\beta| = m$, we have $a_\beta(x) \neq 0$.

What about the case of smooth coefficients $a_j(x)$ and non-homogeneities $f$?

Smooth functions are a more abstract notion than analytic functions, and one standard example is a function equal to $e^{-1/x}$ for $x > 0$ and to 0 for $x \leq 0$. They play a rôle in the definition of generalized functions, or distributions, which are their dual space. The theory of the latter was developed by Laurent Schwartz who, in the words of Louis Nirenberg spoken at the Schwartz Memoral Meeting, "changed the way we, analysts, think about functions". A famous example is the $\delta$ "function" defined in physics by

$$\delta_0(x) = \begin{cases} \infty & x = 0 \\ 0 & x \neq 0 \end{cases}, \;\; \int_{-\infty}^{\infty} \delta_0(x)dx = 1.$$

As an element of the dual of $C^\infty$ it assigns to $\phi$ the number $\phi(0)$.

Following the work of Schwartz, Ehrenpreis (1954) and Malgrange (1955) showed that, for any non trivial polynomial $P(\xi)$, there exists a distribution E such that

$$P(D)E = \delta_0(x), \;\; D = \frac{1}{i}\partial.$$

This quickly shows that $P(D)u = f$ is locally solvable.

A small digression about the notation $D_{x_j} = (1/i)\partial_{x_j}$. This last operator is the quantized momentum:

$$\hat{f}(\xi) = \int_{\mathbf{R}^n} f(x)e^{-ix\xi}dx, \;\; \widehat{D}_{x_j} f(\xi) = \xi_j \hat{f}(\xi).$$

This is why we write our operators as

$$P(x,D) = \sum_{|\alpha|\leq m} a_\alpha(x) D_x^\alpha, \;\; P(x,\xi) = \sum_{|\alpha|\leq m} a_\alpha(x)\xi^\alpha.$$

Reasonable functions, not just polynomials in $\xi$, can be quantized as operators,

$$a(x,\xi) \;\longmapsto\; a(x,D),$$

resulting in the class of *pseudodifferential* operators.

Because of the theorems of Cauchy-Kovalevskaya (local solvability in the real analytic case) and of Malgrange-Ehrenpreise (local solvability for constant coefficients and with smooth, or distributional, right hand side) it was widely believed that all operators satisfying some simple nondegeneracy conditions were locallly solvable.

It came as a great surprise when fifty years ago Hans Lewy, here in Berkeley, showed that for

$$V = D_{x_1} + iD_{x_2} + i(x_1 + ix_2)D_{x_3}$$

the equation $Vu = f$ has no solutions near any point for most $f \in C^\infty$. He arrived at the equation above in his work on several complex variables. He could not prove the existence of a solution and was audacious enough to see that it could fail to have one.

Soon after, Hörmander provided a general and beautifully clear explanation. For $P(x,D)$ we define the principal symbol:

$$p(x,\xi) = \sum_{|\alpha|=m} a_\alpha(x)\xi^\alpha, \quad \text{and assume } p = 0 \Rightarrow p'_\xi \neq 0.$$

Then a necessary condition for solvability near $x_0$ is given as follows

$$p(x,\xi) = 0 \implies \{p,\bar{p}\}(x,\xi) = 0, \;\; \xi \in \mathbf{R}^n, \;\; x \text{ near } x_0.$$

Here, $\{f,g\}$ is a principal object of classical mechanics, the Poisson bracket:

$$\{f,g\} = \sum_{j=1}^{n} \frac{\partial f}{\partial \xi_j}\frac{\partial g}{\partial x_j} - \frac{\partial f}{\partial x_j}\frac{\partial g}{\partial \xi_j}$$

This is an invariantly defined object in symplectic geometry. We also define the Hamilton vector field of $f$, $H_f$, by

$$H_f g = \{f,g\}.$$

The flow of $H_f$ is the classical flow of the Hamiltonian $f$.

For Lewy's example,

$$P(x,D) = D_{x_1} + iD_{x_2} + i(x_1 + ix_2)D_{x_3},$$

we have

$$p(x,\xi) = \xi_1 + i\xi_2 + i(x_1 + ix_2)\xi_3.$$

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# POSTDOCTORAL FACULTY AND FELLOWS

**Marco Aldi** is a Visiting Assistant Professor who received his PhD in 2007 from Northwestern University. His fields of interest include Algebraic and geometric applications of string theory.

**Trevor Bruen** is a NSERC fellow who received his PhD in 2007 from McGill University. His fields of interest include computational biology, computational phylogenetics, and evolutional biology.

**Calder Daenzer** is a NSF fellow who received his PhD in 2007, University of Pennsylvania. His fields of interest include non-commutative geometry as it pertains to mathematical physics.

**Christopher Douglas** is a Miller Research Fellow who received his PhD in 2005 from MIT. His fields of interest lie in the area of algebraic topology and its application to problems in geometry and mathematical physics.

**Sebastian Herr** received his PhD in 2006 from Universität Dortmund. His fields of interest lie in the area of partial differential equations.

**David Hill** is a Visiting Assistant Professor who received his PhD in 2007 from the University of Oregon. His fields of interest include representation theory and Lie theory, using techniques also from combinatorics and the theory of symmetric functions.

**Lek-Heng Lim** is a Visiting Assistant Professor who received his PhD in 2007 from Stanford University. His fields of interest include numerical analysis and applied math.

**Robert Martin** is a NSERC Fellow who received his PhD in 2008 from the University of Waterloo. His fields of interest are in the areas of sampling theory, applied harmonic analysis, sampling theory on manifolds, de Branges spaces, Hilbert spaces of analytic functions, self-adjoint extensions of symmetric operators, spectral theory, physics on curved manifolds, and quantum gravity.

**Chang Pang Mok** is a Visiting Assistant Professor who received his PhD in 2007 from Harvard University. His fields of interest include special values of L-functions, and the applications of theta-lifting in arithmetic geometry.

**Martin Olbermann** is a Visiting Assistant Professor who received his PhD in 2007 from the University of Heidelberg. His fields of interest include algebraic, differential and geometric topology.

**Brett Parker** is a Visiting Assistant Professor who received his PhD in 2005 from Stanford University. His fields of interest are in the areas of symplectic topology and holomorphic curves.

**Alexander Paulin** is a Visiting Assistant Professor who received his PhD in 2008 from Imperial College, London. His areas of research interest lie in the interaction between number theory, representation theory and geometry.

**Alvaro Pelayo** is an NSF Fellow who received his PhD in 2007 from the University of Michigan. His areas of interest lie in geometry, integrable systems, and group actions.

**Jan Reimann** is a Visiting Assistant Professor who received his PhD in 2004 from the University of Heidelberg. His fields of interest include recursion theory, theories of algorithms.

**Brendon Rhoades** is a NSF Fellow who received his PhD in 2008 from the University of Minnesota. His research interests are in the area of algebraic combinatorical representation theory.

**Daniel Robertz** is a DAAD fellow who received his PhD in 2006 from RWTH Aachen University. His fields of interest lie in the areas of asymptotic behavior of Castelnuovo-Mumford regularity using Janet bases, commutative algebra, and algebraic geometry.

**Marcus Roper** is a Miller Research Fellow who received his PhD in 2007 from Harvard University. His areas of interest are applied math, fluid dynamics, and bio-mechanics.

**Michael Rose** is a Visiting Assistant Professor who received his PhD in 2007 from the University of Wisconsin-Madison. His fields of interest include algebraic geometry, mainly Gromov-Witten theory, quantum cohomology, and mirror symmetry.

**Raman Sanyal** is a Miller Research Fellow who received his PhD in 2008 from Technical University, Berlin. His research interests lie in discrete geometry and topology.

**Joshua Sussan** is a Visiting Assistant Professor who received his PhD in 2007 from Yale. His fields of interest include representation theory, low dimensional topology, and categorification.

**Mauricio Velasco** is a Visiting Assistant Professor who received his PhD in 2007 from Cornell University. His fields of interest include commutative algebra, combinatorics, and algebraic geometry.

**Konrad Waldorf** is a Feodor Lynen Research fellow who received his PhD in 2007 from the University of Hamburg. His areas of research interest are topology and quantum field theory.

**Christian Zickert** is a Visiting Assistant Professor who received his PhD in 2008 from the Columbia University. His areas of research interest are hyperbolic manifolds, low dimensional topology, and knot theory. •

## The Berkeley Math Circle – High Expectations in Years Ahead

*by David Wertheimer, BMC Assistant; Ivan Matic, BMC Associate Director; and Zvezdelina Stankova, BMC Director*

ZVEZDELINA STANKOVAI

Every professional and academic will be the first to recognize that the desire for someone to learn and to actually love what they learn is vital for success. And almost every person will agree that to see that desire to learn in children is even greater, because at that young age their ambition can be nurtured and molded into something that will make them excel. And every Tuesday evening from 6 to 8 pm in Evans Hall on the UC Berkeley campus, 50 to 60 of those children come to participate in the Berkeley Math Circle (BMC).

The BMC is a program that gives kids with a love for mathematics a place to come and listen to some of the top mathematicians in their field talk about various topics. In the past ten years during which the program has existed, the BMC has had extraordinary success. Several of the students who have come to the circle have moved on to become the best and the brightest mathematicians, physicists, and businessmen in the nation. Among them, four have gone on to the International Mathematical Olympiad: Gabriel Carroll, Tiankai Liu, Oaz Nir, and Yi Sun. Joining last year, but already gaining national fame, is Evan O'Dorney from Danville. Evan won as an 8th grader the Bay Area Math Olympiad (BAMO), ranked nationally very high in the USA Math Olympiad (USAMO), and championed the 2007 Scripps National Spelling Bee. Those who watched Evan's win are not likely to forget his brave words on national television and his eloquent and passionate description of his love for math and music.

From its beginning, the Berkeley Math Circle has been supported by the UC Berkeley Math Department, the Mathematical Sciences Research Institute (MSRI), and parents' contributions.

As far as classroom demographics go, this is likely the most diverse classroom any one of the kids has been or will ever be in. Students range in grade from elementary all the way through their last year of high school, and come from all over the larger Bay Area. There is an almost even split between male and female, as well as a broad mix of ethnicities.

There is also a broad range of experience among the BMC students, as evidenced by the Circle's Monthly Contests. Each month, Associate Director Ivan Matic gives the students 5 problems to solve on their own for 4 weeks. Then the contests are graded and the top scores receive math books as prizes. The results are more than unexpected. This year, for example, two girls tied for first place in the first contest of the year: 6th grader Sahana Vasudevan and 11th grader Jennifer Thompson. The students come up with a huge number of different ideas for solving the problems, and it is a great pleasure to look at the solutions they are discovering. Quite frequently the BMC instructors are amazed by the non-standard and innovative paths that these middle and high school students develop for solving the problems; we have witnessed students' complete discoveries and utilization of various topics in combinatorics and linear algebra, all on their own. Evan O'Dorney once recreated the theory of Lagrange multipliers (without being aware of it!) just for the purpose of solving one problem.

The sessions are delivered by a number of mathematicians, prominent high school teachers, and problem solvers from around the Bay Area, including a number of UC Berkeley faculty. For those who are interested in the topics of recent sessions, here are some samples from the fall semester:

- Monovariants, culminating with the famous "Conway's checkers", by Program Director Zvezdelina Stankova (Mills College and UC Berkeley).
- Combinatorics, by Paul Zeitz (University of San Francisco).
- Frobenius Problems, by Matthias Beck (San Francisco State University).
- Rubik's Cube and Group Theory, by Tom Davis (founder of Silicon Graphics).
- The Infinity, by Quan Lam (Office of the UC President).
- Combinatorial Geometry, by Federico Ardila (San Francisco State University)
- History of Complex Numbers, by Robin Hartshorne (UC Berkeley)

The spring semester will hold a number of exciting lectures at the BMC from UC Berkeley Professors Elwyn Berlekamp, Vera Serganova, Alexander Givental, and Bjorn Poonen, as well as a number of other instructors from the larger Bay Area, from San Jose all the way to Davis.

BMC students have been able to understand and apply the concepts that most people would consider to be way too complicated even for undergraduates. A number of our circlers will have covered so much advanced mathematics, to name a few basics like real analysis, abstract algebra, topology and algebraic topology, and number theory, that by the time they enter college, they will be conquering graduate-level courses.

Math competitions are usually the first and primary goal associated by the general public with math circles. Even though the BMC's main purpose is to deepen and expand the mathematical horizons of talented young students and prepare and encourage them to continue with careers in mathematical research or research in other related sciences and disciplines, we are proud that a wonderful "by-product" of the circlers' training is their inevitable domination in various mathematical contests, Olympiads and other events. In the recent past, half of the USA team at the International Mathematical Olympiad in Washington D.C. 2001, originated from the Berkeley Math Circle (that year, USA tied with Russia for the second place among 80+ countries). We expect great results from our Olympians in the next few years, further growth of their mathematical knowledge, and a deeper understanding of and appreciation for the beauty of mathematics.

If you would like to contribute to the Berkeley Math Circle with a session, learn more about the circle, enroll a child or recommend it to someone else, or attend the Circle as a student helper, please visit the BMC's website: http://mathcircle.berkeley.edu. You may also contact Director Zvezdelina Stankova (stankova@math.berkeley.edu), or Associate Director Ivan Matic (matic@math.berkeley.edu), with any questions. We always welcome fresh ideas, constructive input, and new lecturers. Everyone at the Circle - administrators, parents, and especially the kids - is very grateful for the support, help, and hospitality that the UC Berkeley Mathematics Department has provided over the last 10 years. ◆

## Visiting Faculty

**Bruce Driver** visited from UC San Diego. His fields of interest include geometric analysis associated to heat kernel and Wiener measures on path and loop spaces of Riemannian manifolds.

**Irwin Kra** is emeritus at SUNY, Stony Brook. He is, currently, the Executive Director of Math. for America, a non-profit organization working to improve math education in secondary public schools in the United States. His areas of research interests are complex analysis, Kleinian groups and deformations of complex structures.

**Richard Melrose** visited from MIT. His research interests lie in the areas of topology, partial differential equations, analysis, and microlocal analysis.

**Ivan Penkov** visited from Jacobs University. His fields of interest include representations of finite and infinite dimensional Lie algebras, generalized Harish-Chandra modules, representations of Lie superalgebras and Lie super-groups, geometry of supermanifolds, homogeneous superspaces, super D-modules, homogeneous ind-spaces and geometry of ind-varieties. ◆

## OUTSTANDING GRADUATE STUDENT INSTRUCTOR AWARDS

**2007**

Jomy Joseph Alappattu
Adam Booth
Taiyo Inoue
Ivan Matic
Arturo Prat-Waldron
Janak Ramakrishnan
Darren Rhea
Anthony Varilly
Martin Vito Cruz
David Zywina

**2008**

Meghan Anderson
Khalilah Beal
Jennifer Berg
Stephen Canon
Kiril Datchev
Jeffrey Doker
Daniel Erman
Erica Isaacson
Emily Peters
Cinna Wu
Guoliang Wu

*(Chair's Letter, continued from page 2)*

Theory and Kleinian Groups, he was already spending lots of time in Evans Hall, meeting with colleagues and students.

**Robert Bryant** of Duke University arrived in the Summer of 2007 to take up the positions of Director of MSRI (75% time) and Professor in our Department (25% time). (At the same time, outgoing Director David Eisenbud has returned full-time to the Department.) With his appointment, and that of John Lott (see below), our Department is back on track toward regaining the eminence in differential geometry which it enjoyed in the days of S.-S. Chern.

**Olga Holtz**, who originally arrived as a Morrey Assistant Professor in 2004, was appointed as an Associate Professor, effective July 1, 2007. For the first couple of years of her appointment, she has been dividing her time between Berkeley and the Technical University of Berlin, where she holds a prestigious Sophia Kowalewskaja Fellowship. Among Olga's broad research interests are numerical linear algebra, matrix and operator theory, enumerative combinatorics, and compressive sensing.

**John Lott** of the University of Michigan was appointed on July 1, 2008, as a Professor and arrived here in January, 2009. John is a differential geometer and geometric analyst who was deeply involved in the activities surrounding Perelman's solution of the Poincaré Conjecture but whose work covers a wide swath of geometric analysis, from transportation problems to index theory.

**Per-Olof Persson** arrived this Fall from MIT as an Assistant Professor. He is interested in high-order methods for fluid and solid mechanics, in particular techniques based on the Discontinuous Galerkin method. Between his Master's degree from Lund in his native Sweden, and his PhD from MIT, he worked for several years as a Senior Development Engineer at the software company Comsol.

ENDOWED CHAIRS

In 2007, the William and Flora Hewlett Foundation gave UC Berkeley a gift of $113 million to support the creation of 100 new endowed chairs. Half of each chair is funded from this gift, with the other half coming from a matching contribution from another source. I am pleased to report that the family of James Simons has provided funding for the James H. Simons Chair in Mathematics and the Chern-Simons Chair in Mathematical Physics. These will be the first endowed chairs in our Department and will be held for five-year terms. We expect to appoint the holders of these chairs in

*(continued on page 12)*

MARK HAIMAN

NICOLAI RESHETIKHIN

## RESEARCH TRAINING GROUP

*by Mark Haiman & Kolya Reshetikhin*

We--Mark Haiman and Kolya Reshetikhin--are the organizers of a Research Training Group (RTG, for short) that brings together a number of us within the Mathematics Department whose research interests involve Representation Theory, Geometry and Combinatorics. The other faculty members affiliated with the group are Richard Borcherds, Edward Frenkel, Sasha Givental, Martin Olsson, Vera Serganova, Bernd Sturmfels, Constantin Teleman, and Joe Wolf. Allen Knutson was also a member until he moved to UC San Diego. The chair has asked us to give an introduction here to what our group is and what it does.

Our RTG is supported by a grant from the National Science Foundation program called "Enhancing the Mathematical Sciences Workforce in the 21st Century." This same NSF program awards the perhaps more familiar VIGRE grants. Unlike VIGRE, however, which supports undergraduate, graduate, and postdoctoral education across a whole department, the smaller RTG grants support activities by a group of faculty, graduate students and postdocs organized around a common research interest.

The common interest in our case is the interactions of representation theory, geometry and combinatorics, an area which has been highly active in recent years. Among the subjects encompassed by or having close contact with this area are Kac-Moody algebras and their q-analogs (quantum groups), finite and infinite-dimensional flag varieties and Schubert varieties, Schubert calculus, Hecke algebras and Cherednik algebras, Kazhdan-Lusztig polynomials, Macdonald polynomials, toric varieties, quiver varieties, Hilbert schemes and other moduli spaces, Gromov-Witten invariants, mirror symmetry, integrable systems, and the geometric Langlands correspondence.

As one can imagine, young researchers need to become conversant with a lot of mathematics in order to prepare for work in these areas. The activities of the RTG are directed towards helping them do so. The group's central activity is our seminar, which meets for two hours each week and features talks by a mix of outside speakers and local faculty, grad students and postdocs. Ordinarily we have just one speaker each week. We encourage our speakers to use the two hours to keep the pace leisurely, pause frequently to answer questions, and incorporate lots of background material and context in their talks. In our experience this makes a big difference in helping those attending to get some real understanding out of the talk.

Apart from its two-hour format, the main seminar is a traditional research seminar, with talks on current work and a new topic each week. We also run at least one instructional seminar each semester, with several weeks or the whole semester devoted to studying a single topic in depth. Talks in the instructional seminars are given by the participants. Sometimes one of the faculty members in our group organizes an instructional seminar, but recently they have for the most part been organized by the students themselves.

Finally, each year at or just after the end of the spring semester, we hold a week-long workshop-style conference with participation by people both from outside and from on campus. Each workshop features two lecture series by distinguished invited speakers, plus talks by the participants. The 2005 workshop concentrated on representations of non-commutative algebras, with Victor Ginzburg and Claudio Procesi as the main speakers. The themes of the 2006 workshop were Lie algebras and Coxeter groups, with main speakers Alexei Borodin and Alexander Goncharov.

While the RTG grant provides some travel support for seminar speakers and workshop participants, the bulk of its funds go to fellowship support for graduate students and postdocs. It has also supported postdoctoral fellows. Included are Dagan Karp, now in his third year with us and second on the RTG (Dagan had an NSERC fellowship for his first year), Beth Samuels, who to our great sorrow died of cancer during her second year, David Hill and Joshua Sussan, currently in their first year, and Michael Rose, who joined us in Fall 2008 after a year at UBC.

The 2008-09 academic year will be the fifth and final year of the current RTG grant. With luck we hope to renew it and continue our activities at full strength. In any event, whether or not we succeed in renewing the grant, we will try to sustain the sense of community that our activities have engendered by keeping at least the RTG research and instructional seminars alive in the future. ◆

## *GRATEFUL THANKS TO OUR FRIENDS*

*The Department of Mathematics extends heartfelt thanks to all our donors over the past years for their generous support. Our donors have contributed to the strength and vitality of our students and the Department. The list of our donors from 1996 on can be found on the departmental website at http://math.berkeley.edu/aboutus_gifts_donors.html.*

*We apologize if we have omitted anyone. Please do let us know if that is the case. A special thanks to all our donors who wish to remain anonymous.* ◆

# MANAGER'S REPORT

*by Mary Pepple*

MARY PEPPLE, MANAGER

**Facilities Update**

The second phase of the 7th floor renovation project was completed in August 2008. The finished space includes a computer lab, and the desperately needed addition of two seminar rooms, a conference room and an interactive lounge for faculty and graduate students. The Mathematical and Computational Biology lab located in 748 Evans, and conference room located in 762 Evans, were completed in January.

**Fond Farewell**

The Spring 2007 semester began with the retirement of **Bernice Gangale** from the Center for Pure and Applied Mathematics. Bernice began her UC Berkeley/Mathematics career twenty-nine years ago as the Graduate Assistant, and became the Contracts and Grants Administrator for the Center for Pure and Applied Mathematics in 1982. Bernice collaborated successfully with the full range of faculty, staff, students and visitors.

In June 2007, **Linda Jarvis** retired from the Chair's office. Linda was the Academic Personnel and Chair's Assistant in the Department of Mathematics for 9 years. Previous to joining us, she worked for the Department of Molecular and Cell Biology, the Department of Zoology, and the School of Education.

On September 9, 2007, **Stephanie Caselli** died from an inoperable malignant brain tumor. Stephanie worked in the Math Department as the Purchasing/Travel Assistant for 8 years. We will always remember her.

STEPHANIE CASELLI

**Changing Places and New Faces**

During the last year and a half six staff personnel changes have taken place in the Department.

On September 26, 2007, **Kim Oyler** was hired as the Academic Personnel Analyst and Chair's Administrator to replace Linda Jarvis. Kim has 9 years of Academic Personnel experience with Environmental Science Policy Management and 18 years of UC Berkeley experience.

On October 1, 2007, **Judie Welch Filomeo** was hired to replace Eva Wong as the Payroll/Travel Assistant III for the Center for Pure and Applied Mathematics. Judie was the Assistant II for the Mathematics Diagnostic Testing Project for the last three years. Congratulations to Judie on her promotion.

On November 5, 2007, **Korinne Reyes** joined our staff as the Purchasing/Travel Assistant III replacing Stephanie Caselli. Korinne had worked for 5 months as an Accounting Assistant at UC Irvine and before that she was an Accounting Clerk at the Alameda County Public Health Department. Korinne graduated from UC Riverside in 2005 with a BA in Political Science.

On December 5, 2007, **Jacqueline Bonds** was hired to work as the Assistant II for MDTP to replace Judie Welch Filomeo. Jacqueline graduated from Emery High School in Emeryville, California in 2004. She has worked as a Student Loan Counselor, a Retail Store Manager and a Bank Teller.

On January 14, 2008, **Elma Serrano** joined the Center for Pure and Applied Mathematics as our new Research Center Manager replacing Bernice Gangale. Elma brings 10 years of UC Berkeley experience to this position. She worked as a Contracts and Grants Administrator for the Department of Plant and Microbial Biology and has a BA in Accounting from Holy Angel University.

On June 2, 2008, **Lynn Greene** joined the department as our new Events/Payroll Specialist. Lynn has a BA in Art History and Photography from Syracuse University and 12 years of work experience including bookkeeping, events planning, pastry chef, human resources and payroll.

We are delighted to welcome all of our new staff members!

I'd also like to take this opportunity to acknowledge the efforts of all of our hardworking staff that have held this operation together during our severe staffing shortage. In view of the current budget climate, we are especially grateful to have these vacancies filled.

**Staff Awards**

The Mathematics Department has one of the finest staffs on campus.

In 2006-07, **Marsha Snow**, **Kathy Santos** and **Henrietta Williams** each received $250 Spot Awards for their commendable service during the year.

In May 2007, **Mary Pepple** was nominated by the math staff and affirmed by the Berkeley Staff Assembly with an Excellence in Management Award. The theme for the 2006-2007 Excellence in Management Award was "Leading by Mentorship and Example".

In 2007-08, **Michael Kim**, **Nancy Palmer** and **Barbara Peavy** each received Campus $250 Spot Awards recognizing their noteworthy service during the year.

In February 2008, **Barbara Peavy** was selected by the Chancellor's Advisory Committee to receive a 2008

*(continued on page 13)*

(Fifty Years, continued from page 3)

Hence,

$$\{p, \bar{p}\}(x, \xi) = -4i\xi_3.$$

But

$$p(x_1, x_2, x_3; x_2\xi_3, -x_1\xi_3, \xi_3) = 0,$$

and we do not have solvability near any point $x \in \mathbf{R}^3$.

One conceptual explanation of Hörmander's bracket condition uses normal forms in the symplectic category. A locally defined $\kappa : \mathbf{R}^n \times \mathbf{R}^n \to \mathbf{R}^n \times \mathbf{R}^n$, is called symplectic if it preserves the symplectic form $\omega$:

$$\kappa^*\omega = \omega, \quad \omega = \sum_{j=1}^{n} d\xi_j \wedge dx_j.$$

A classical theorem of Darboux states that

$$p(0) = 0,\ dp(0) \neq 0 \implies \exists\, \kappa,\ \kappa(0) = 0,\ \kappa^* p = \xi_1.$$

Hörmander (1971) and Duistermaat-Hörmander (1972) showed that this normal form can be implemented on the level of operators by quantizing nonlinear symplectic transformations using Fourier integral operators:

$$p(x, \xi) \text{ real}, dp|_p = 0 \neq 0,\ H_p \not\parallel \xi\partial_\xi \implies P(x, D) \simeq D_{x_1}.$$

Hence, any real principal type operator is solvable (just as for vector fields).

But how to consider functions and operators which are only local as function of $(x, \xi)$, position and momentum? Functions of $x$ have structure in phase space $(x, \xi)$ and an example of that is given in Fig.2. On the left are the real and imaginary parts of a function of $x$, and on the right the density plot indicating where the function concentrates in the $(x, \xi)$ space, that is in position and frequency. This particular example arising in physics (first resonant state of the Eckart barrier) was computed by D. Bindel (2006 Ph.D. from Berkeley in computer science), and the phase space density plot waas provided by L. Demanet (who despite being at Stanford helps us out occasionally!).

This type of localization in phase space allows us to make sense of the local equivalence of operators. Pseudodifferential operators, $a(x, D)$, which generalize differential operators $P(x, D)$ by allowing more general functions $a$, are essential for that.

For operators with complex $p(x, \xi)$ and $\{p, \bar{p}\} \neq 0$ as in the nonsolvability condition, a normal form was provided by Duistermaat-Sjöstrand (1973):

$$\pm i\{p, \bar{p}\} > 0 \implies P(x, D) \simeq D_{x_1} \pm i x_1 D_{x_2},$$

near $\xi_2 \gg 0$. If we take Fourier transform in $x_2$, write $h = 1/\xi_2$, we obtain annihilation and creation operators:

$$A = hD_{x_1} - ix_1, \quad A^* = hD_{x_1} + ix_1.$$

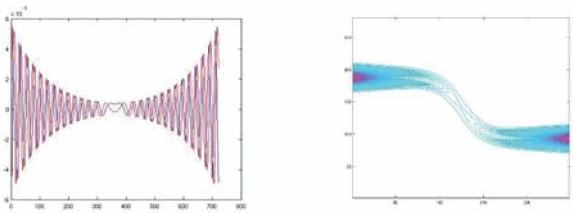


Figure 2

This "explains" nonsolvability as $A$ has a kernel and hence $A^*$ is not onto.

A conjecture on a necessary and sufficient condition for local solvability of any pseudodifferential equation,

$$P(x, D)u = f,$$

was formulated by Nirenberg and Treves in 1970. It involved the mysterious condition $\Psi$:

> Suppose that for $\mathbf{C} \ni a \neq 0$,
>
> $$H_{\mathrm{Re}(ap)}(x_0, \xi_0) \neq 0\,, \quad p(x_0, \xi_0) = 0\,.$$
>
> Condition $\Psi$ requires that on $\mathrm{Re}(ap) = 0$, $\mathrm{Im}\, ap$ does not change sign from $-$ to $+$, along oriented trajectories of $H_{\mathrm{Re}(ap)}$.

The condition is illustrated in Fig.3 where we show the plots of $\mathrm{Im}(ap)$ as functions of the parameter on the integral curves of $H_{\mathrm{Re}(ap)}$. On the left is a change of sign banned by condition $\Psi$, and on the right an allowed change of sign. The most difficult case is that of smooth functions with infinitely many zeros.

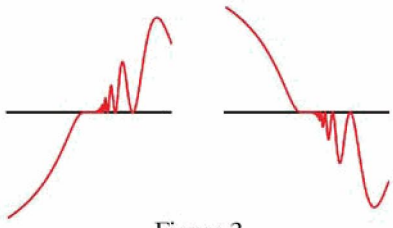


Figure 3

The conjecture can be motivated by considering a simple model:

$$(hD_t + ia(t))u(t) = f(t), \quad f(t) = 0 \text{ for } |t| \geq T.$$

When can we solve this equation without introducing exponential growth in $1/h$? Here, as before, $h = 1/\xi_2$, and an exponential growth prevents us from taking inverse Fourier transforms (in the analytic case such exponential growth can still be OK). The answer, which can be obtained by Math 1B methods is: when $a(t)$ does not change sign from $-$ to $+$.

A stronger condition is the condition $P$:

$\mathrm{Im}\, ap$ does not change sign on integral curves of $H_{\mathrm{Re}(ap)}$.

Since the principal symbol, $p(x, \xi)$, of a differential operator is either odd or even in $\xi$ it is not difficult to check that

$$P \iff \Psi \quad \text{for differential operators.}$$

Solvability on a compact subset, $K$, of $\mathbf{R}^n$ means that

$$P(x, D)u = f,$$

is verified in a neighbourhood of $K$ by some distribution $u$ for any $f$ in a subspace of finite codimension in $C^\infty$ (this means all functions near any point, but this more general statement is needed for a formulation with a set $K$).

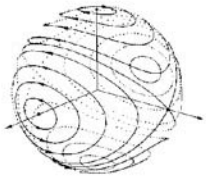
In this sense the Nirenberg-Treves Conjecture can be formulated as follows: for principal type operators (i.e. for which $dp \neq 0$, $H_p \not\parallel \xi\partial_\xi$ when $p = 0$),

$$\Psi \text{ in a neighbourhood of } K \iff \text{solvability at } K.$$

Nirenberg and Treves (1970) proved invariance of condition $\Psi$:

(continued on page 10)

THE DEPARTMENT OF MATHEMATICS



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*(Fifty Years, continued from page 9)*

it is not at all obvious that the property of $p$ demanded by $\Psi$ does not change when we multiply $p$ by a nonvanishing complex function (solvability does not). In particular it is enough to check $\Psi$ for $a = 1$ and $a = i$ so that it is more easily verifiable. They also proved (1971) that the condition $P$ is sufficient for operators with real analytic coefficients.

In 1978 Moyer (Ph.D. from Berkeley Math in 1964) for dimension two, and in 1981 Hörmander for all dimensions, showed that

$$\text{solvability at } K \implies \Psi \text{ in a neighbourhood of } K.$$

Beals and Fefferman (1974) pushed the uncertainty principle to a limit in phase space analysis and showed that

$$P \text{ in a neighbourhood of } K \implies \text{solvability at } K.$$

This settled the problem for differential operators. In many situations the solvability problem for pseudodifferential operators appears, but it remained open.

In dimension two, there are many simplifications: from the semiclassical point of view (with $h = 1/\xi_2$ playing the rôle of the Planck constant), the problem is essentially one dimensional. In that case, Nicolas Lerner proved the sufficiency in 1988 and a simple proof was also provided by Hart Smith (who obtained his B.Sc. from Berkeley in math in 1984).

Nils Dencker concluded this long quest by publishing in 2006 the proof of sufficiency of $\Psi$ for solvability of operators of principal type. Berkeley's math colloquium (Spring 2002) was one of the first places where he lectured on this work.

Many techniques developed in the investigation of solvability are now useful in mathematical physics, study of nonlinear waves, spectral instability, and other branches of mathematics. Among current faculty in our department, Mike Christ and Daniel Tataru have made contributions to solvability, in the case of multiple characteristics and principally normal operators respectively. My own connection to the subject comes through the pseudospectra in the semiclassical limit [4].

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(Chair's Letter, continued from page 6)

the near future and look forward to the creation of further such positions.

SPECIAL LECTURES

Stop by our Department and you'll find a busy calendar of seminars that have been organized by faculty members and graduate students. Traditionally, seminar announcements are posted near the elevators on the 9th floor. Increasingly, however, the best place to find the schedule of the week's talks is becoming the Department's web site. Daily, weekly and monthly calendars are available from the home page http://math.berkeley.edu/; meanwhile, information about a particular seminar (or the departmental colloquium) is best obtained by clicking the "Events, Seminars, Etc." link on the home page.

In addition to seminar schedules, you'll find links to the "Annual events" -- the special lecture series that we have developed over the years. During each academic year, we host the Bowen lectures, the Lang lecture, the DiPerna lecture, the Chern lectures, and the Tarski lectures. The links for each of the series explain the origin of the series and list of lecturers.

The first special lecture of the academic year was the Serge Lang undergraduate lecture; this year's speaker was Peter Jones, who was Serge's colleague at Yale. Peter spoke on the "Divide and Conquer" philosophy of dividing hard problems into smaller pieces and then assembling the results at the end. Quite a few of his examples had to do with fractals -- which also appeared in the Bowen lectures by Hillel Furstenberg of the Hebrew University of Jerusalem! Indeed, the theme of those lectures was in fact the role of ergodic theory in the geometry of fractals. Next on the calendar is the annual DiPerna lecture, which is held late in January each year on a Thursday afternoon. This year's speaker was Andy Majda from the Courant Institute, who was our colleague at Berkeley from 1978 to 1984. The title of Majda's talk, "Applied and theoretical challenges for multi-scale hyperbolic PDEs in the tropics," gives some hint of the subject, which stems from the lack of Coriolis forces near the equator. As Majda explained, this phenomenon has important implications for weather prediction and climate change in mid-latitudes.

The Chern lectures this year will be given by Richard Taylor of Harvard University. Taylor is known for his pioneering work on connections between automorphic representations and Galois representations. The Taylor-Wiles systems that underpinned the proof of Fermat's Last Theorem in 1994 have played a central role in subsequent developments in the subject. Finally, the Tarski lectures will be delivered by the eminent model-theorist Anand Pillay, who moved recently to the University of Leeds from the University of Illinois.

A NEW NAME

In 1971, the College of Letters and Science was divided for administrative purposes into four Divisions, one of which was the Division of Physical Sciences. The first Dean of this Division was Cal Moore (who reports that in the early days, these Divisional Deans had limited authority, but that over time as the College decentralized and flattened its structure, the Divisional Deans gained much more authority). Last year, with the full support of Divisional Dean Mark Richards, we succeeded in having our Division renamed the Division of Mathematical and Physical Sciences. Our proposal for this change, originally promoted by Moore when he was Department chair, gained quick approval from the Berkeley Campus, not surprisingly since Mathematics and Statistics make up about half of the Division by virtually any measure. (The other three departments are Astronomy, Earth and Planetary Sciences, and Physics.)

THE CURRICULUM

In keeping with the growing importance of discrete mathematics in science and engineering (as well as within mathematics itself), we have made Math 55, Discrete Mathematics, a required course for both the Mathematics and Applied Mathematics majors.

The upper division program has been enriched by the addition of several new courses, including:

Math 116 - Cryptography
Math 127 - Mathematical and Computational Methods in Molecular Biology
Math 136 - Incompleteness and Undecidability
Math 143 - Elementary Algebraic Geometry

We also have two new courses which are still under the "Experimental" rubric of Math 191. One is in Mathematical Problem Solving, an outgrowth of the Putnam Exam preparation class. The other is Projects in Mathematics, an opportunity for students to work in teams on open-ended research problems.

At the graduate level, new additions include:

Math 203 - Asymptotic Analysis in Applied Mathematics
Math 239 - Algebraic Statistics

EVANS HALL

Much has happened to make Evans Hall a more attractive and functional place. The Big Clean was followed by the repainting of all the corridors in Evans Hall, and the renovation of Room 939. The large space in the middle of the 7th floor, which old-timers may remember as the site of graduate student carrels, and more recent Evans denizens recall as the scene of a computer lab and a vast storage space for old furniture, has been completely renovated. A corridor was built through the middle of the space, which was then divided into six rooms. We now have a new computer lab, two new seminar rooms, a conference room, and a lounge for impromptu discussions, all of these open since the beginning of Fall Semester 2008. The sixth space, opened in January, is the Laboratory for Computation in Biology. This activity, run by Steve Evans, Lior Pachter, and Bernd Sturmfels, will have ongoing funding for graduate students and postdocs, some it provided through the generous support of donors David Desjardins

(continued on page 13)

(Chair's Letter, continued from page 12)

(PhD 2002 with Elwyn Berlekamp) and his wife Nancy Blachman. The remainder of the funding for the 7th floor project came from savings during the term of a more frugal chairman, Ted Slaman, and from a contribution from Dean Richards.

THANKS

During my chairmanship, I have been assisted by a great team of Vice-Chairs --- Ken Ribet (Development), Maciej Zworski (Faculty Affairs), Mike Christ and Dan Tataru (Graduate Affairs), Bjorn Poonen, Jamie Sethian, and John Steel (Undergraduate Affairs). Some of these Vice-Chairs will be continuing under the coming (in July 2009) old/new regime of Ted Slaman (2009-10) and Hugh Woodin (2010-13). I would like to thank all of them, as well as all of the Department staff led by Mary Pepple, for their contributions to Mathematics at UC Berkeley. Finally, I would like to thank all those who have supported the Berkeley Math Department over the past years. Especially, but not only, in times when the State of California is cutting back on its support, these contributions by alumni and other friends are essential in keeping this one of the world's leading places to do and learn mathematics. ◆

(Manager's Report, continued from page 8)

Chancellor's Outstanding Staff Award. As each of you knows, Barbara has done a remarkable job developing the student services programs over the last 10 years. Recognition of her ongoing exemplary service was long overdue!

This Spring, the Chancellor's Advisory Committee has selected **Faye Yeager** to receive a 2009 Chancellor's Outstanding Staff Award. Faye has worked tirelessly to support the needs of the Mathematics Department for the last 20 years. She is our Webmaster and faculty technical manuscript specialist and the sole provider of this kind of support for the entire faculty including 55 faculty, 33 emeriti and 20 post doctorate fellows and visiting scholars. Needless to say, Faye has an enormous workload. The quality of her work is consistently excellent. In January 2008, her husband was diagnosed with a life threatening illness. Faye insisted that working through her husband's medical treatments would be best for all involved. She purchased a laptop, and for the last year, has maintained a full-time alternative work schedule while caring for her husband. Faye's perseverance and courage has been an inspiration for all of us. Her dedication and commitment to the Department of Mathematics and the Berkeley campus community is noteworthy, and well deserving of a Chancellor's Outstanding Staff Award. ◆

## IN MEMORIAM

***David Gale***
**(1921-2008)**

***Murray Protter***
**(1918-2008)**

***John Stallings***
**(1935-2008)**


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