Spring 2007

EMISSARY

Mathematical Sciences Research Institute

www.msri.org

Bryant Named Next Director

Jim Sotiros

Robert Bryant (left) and David Eisenbud share a toast. See page 7 for article.

Notes from the Director

David Eisenbud

. . . if I could prophesy, and understood all secrets, and had all knowledge, and had faith that could move mountains, but had not love, I would be nothing.

(I Corinthians 13:2)

I'm amazed, but it's ten years since I came to Berkeley. I've had the time of my life at MSRI, and no doubt the high point of my career. With Robert Bryant coming as the new Director I feel that I'm leaving the Institute in *very* good hands, and I do so with a light heart: I look forward immensely to being able to spend more time on research, teaching, and mentoring graduate students. I've had a regular faculty position all this time at Cal, but I've been a ghost in the department; now I'll materialize — boo!

Much has happened in these years. A good part of it represents the further development of what Chern, Kaplansky and Thurston started. None of it is my accomplishment alone, but that of many people working in concert. I'm proud of it nonetheless: proud to have helped the community do these things.

The Institute's mission is to advance research mathematics, interpreted broadly. Pursuit of research itself, especially in a collaborative mode, remains and should remain the Institute's central activity. But the needs of research mathematics

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Simons' Record Gift Caps a Week of Celebration

Dana Mackenzie

The first week of May was a time of celebration for MSRI. The attendees of a workshop on Advances in Algebra and Geometry came to commemorate a rare convergence of events: the sixtieth birthday of Director David Eisenbud, his retirement from the directorship effective in August, and his ten years of exemplary service to MSRI. And it could not have been too far from many people's minds that MSRI itself will be celebrating an anniversary soon, its 25th year of existence.

"I'm particularly honored and gratified that Jim Simons has chosen to place a professorship in my name, as part of his phenomenal generosity toward mathematics and MSRI," Eisenbud responded. The second part of Simons' gift is equally important, he added. "The institutions that do well over the long term, through good times and bad, are the ones that

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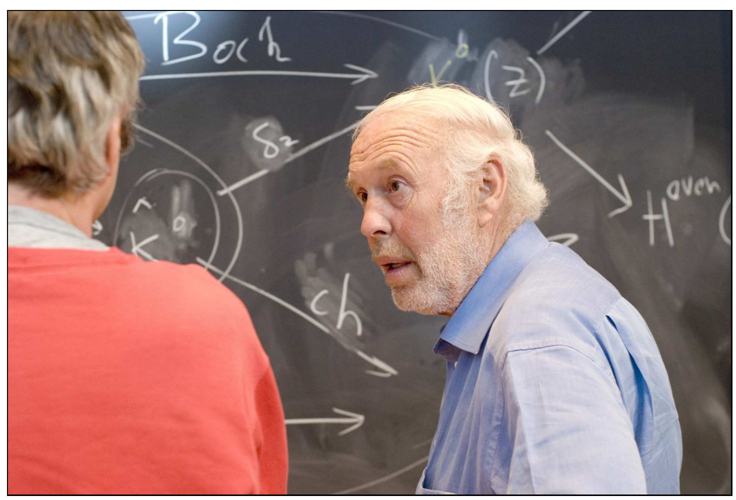


David Eisenbud/

Jim Simons does mathematics with John Lott

Contents

Notes from the Director

(continued from page 1)

include the training of postdocs, the encouragement of underrepresented groups, and the place of mathematics in society — hence the participation of mathematicians in math education and our involvement in the public understanding of mathematics.

Major Research Programs

One of the things that has been most fun these years has been working with the Scientific Advisory Committee (SAC), a strong-willed, active and ever-changing group of fine mathematicians from around the country, who have worked intensely together, and with me on scientific planning. The SAC has full responsibility for choosing the science and scientific personnel supported by MSRI.

I've learned that programs, like children, come with personalities etched in their genes, one quite different from the other. Some are more outgoing, engaging with all sorts of mathematics "over the border"; some are introverted, and focus deeply on their precisely defined subjects. Some develop a fever pace, with increasing numbers of seminars and working groups (everyone goes home exhausted, and the postdocs are particularly happy.) Others keep cool, and one sees lots of thoughtful folks working at their own office desks (everyone goes home refreshed, and the senior people are particularly happy.)

At the risk of seeming to prefer one child over another, I will dare to single out two programs that I enjoyed particularly, among the thirty or so that I've helped run. I'd list many more but for lack of space!

Random Matrix Models. Eugene Wigner proposed in the 1940's that the spectral lines of heavy atoms should be distributed statistically according to a law determined by the eigenvalues of random matrices, and observed quite close agreement of this with experiments.

Running a program on this topic proved to be an inspired choice: it brought physics, integrable systems, number theory, combinatorics and statistics (even solitaire!) together in a remarkable mix. There were substantial advances at the program, and results later on that came about because of collaborations and discussions that happened at MSRI. Perhaps even more important: in some sense, I think the MSRI program can be said to have "created" Random Matrix Models as a coherent field.

Commutative Algebra. Surely part of what I liked about this program was that I took part myself — I had a sabbatical year, when Michael Singer was Acting Director (friends told me I was crazy not to get out of Berkeley, that I would never get any peace; friends told Michael that he would never be able to run the place with me in the building. But in the end I think both he and I were happy about the experience. We had such trust in one another that it was easy to limit and enjoy our interaction.)

Beyond my own participation, I greatly appreciated the open view of commutative algebra that the program expressed: topology, representation theory and algebraic geometry all took their places. I think that literally hundreds of new collaborations were formed. And the program effected at least one systematic change in the field: the extensive use of the arXiv to post preprints. This was a change of state that would not have happened any time soon without the MSRI program.

Another important aspect of the Commutative Algebra program was the very extensive participation of the established experts, a large number of whom came for a semester or more, often without very much support from MSRI. Since MSRI has not had resources to pay many established people reasonable salaries, this participation is somewhat variable. The SAC and the organizers work hard every year on getting commitments from established workers, and in the last ten years the results have always been at least satisfactory; but in some programs they are great.

Hot Topics

A new feature of MSRI that Hugo Rossi and I introduced in 2000 is the systematic encouragement of Hot Topics Workshops, organized on very short notice around breaking developments. Such workshops soon appeared at the other Institutes, too, often with the same name. Imitation between institutes — the sincerest form of flattery — is good. MSRI has picked up lots of good ideas from the others as well. From the first Hot Topic workshop, on Homotopy of Algebraic Varieties, through Semidefinite Programming and, most recently, the Finite Generation of the Canonical Ring, I think it's been a splendid series.

MBone to Vmath

Just before I came to MSRI, David Hoffman, Bob Osserman and Joe Christy, working with my predecessor, Bill Thurston, had put together the Institute's first systems for getting mathematics lectures on the web. After some bad experiences with the MBone, they had switched to streaming video. This was a novelty at the time, and they had to solve many problems to make a system that could really convey the sense of an advanced mathematics lecture.

The system has come a long way in the last 10 years. Most recently, with very substantial help from Trustee Will Hearst, we made the change to a much higher-quality format, with better cameras and production. You can now pretty easily download the videos to watch in peace on your next plane ride, too (even on your ipod, if you print out the notes ahead of time). I think the New Frontiers in Undergraduate Education series (so far one disk on Gröbner Bases, with Bernd Sturmfels, and one on Algebraic Topology and its Applications, with Gunnar Carlsson) should prove quite valuable as well. And there are videos for the public too.

Human Resources

Among the most serious human resource problems for mathematics is the fact that talented women and minority members tend not to choose this field. Under Bill Thurston and his Deputy, Lenore Blum, MSRI became a national leader in efforts to improve the situation. Among their accomplishments of lasting importance was

Ed Baker (left), a long-time supporter and trustee of MSRI, is Chairman of The Cambridge Strategies.

the establishment of the first Human Resources committee at any of the math institutes (now almost all the institutes have them, another example of the spread of good ideas), the first of a long-running series of Conferences for African American Researchers in the Mathematical Sciences (CAARMS), and the beginning of a series of conferences focused on the achievements of women in mathematics. These activities continue today, and MSRI's HRAC keeps adding to the list. Some series I'm particularly proud to have helped with are the Blackwell–Tapia Prize and Conference, established in a cooperation between MSRI and Cornell; the Connections Program for Women that now takes place at the beginning of nearly every MSRI program; the Workshops on Modern Mathematics that bring some of our program leaders together each year in a workshop at a minority-serving institution (or, most recently, a SACNAS meeting); and MSRI UP, an undergraduate research program for minority students that will debut in the summer of 2007.

The evolution of MSRI's mission was codified recently in a long-range plan for MSRI that I developed with the Board of Trustees. An important section is called "Mathematics in Society", encompassing education and the public understanding of mathematics, or "education for adults".

Education

K-12 Mathematics education is a huge enterprise, on which the United States spends enormous effort. How can a tiny organization like MSRI make a difference? How can it take part in the field without being swallowed up? MSRI does have one substantial advantage: it has the attention and respect of the research mathematics community. And since MSRI is not identified with any of the factions in the "math wars", the Institute can serve as a meeting place where the warriors from various camps can come together and discuss issues on a (more) scientific basis.

Accordingly, the math education activities at MSRI have been focused on just two carefully chosen programs. One is an annual series of high-level conferences on Critical Issues in K-12 Education that attracts a substantial number of mathematicians *and* a substantial number of the specialists on educational research and policy. The topics that have been addressed will speak for themselves: Assessing Students Mathematics Learning: Issues, Costs and Benefits (2004); The Mathematical Knowledge for Teaching (K-8): Why, What and How? (2005); Raising the floor: Progress and setbacks in the struggle for quality mathematics education for all (2006); and Teaching Teachers Mathematics (2007).

The other prime education activity at MSRI is a program called Math Circles. Borrowed from a tradition that was (and still is) fantastically successful and influential in Eastern Europe, this after-school activity connects kids directly with mathematicians. The program is organized around exciting and often very challenging problem areas, and the kids work both individually and collaboratively as well as hearing presentations from research mathematicians and other mathematically sophisticated lecturers. The Berkeley Math Circle was started by Zvezdelina Stankova and Hugo Rossi (both then at MSRI), along with Paul Zeitz, almost 10 years ago. More recently MSRI has provided very substantial financial support for it and other Math Circles in the Bay area.

We are now working toward the development of a National Math Circles program. To this end MSRI has created the Circle in a Box, a kit for those who want to start a Math Circle in their own region, complete with videos of successful Circles and even a sample grant proposal to help obtain funding...

Public Understanding of Mathematics

Many of MSRI's programs for the Public Understanding of Mathematics have been led and organized by Bob Osserman. I've enjoyed collaborating with him in these ventures a great deal, and we've explored quite a range of activities. One of my favorites was the program Mathematics in Arcadia (organized with the help of David Hoffman), in which Bob interviewed Tom Stoppard about his great play *Arcadia*, which treats some substantial mathematics with an extraordinarily deft hand (a video of this event is available from MSRI). Another was Funny Numbers — in which Bob Osserman tries to do the impossible and interview *both* Steve Martin and Robin Williams. The papers referred to them afterwards as "the three comedians," and it sure was funny (you can see for yourself — the video is available through the AMS.) The most recent events have been in our Math and Music series, including the lecture "Music of the Primes", by mathematician and trumpet player Marcus du Sautoy this past April — complete with an illustrative performance of the connections between the two apparently disparate subjects.

We've produced a number of other videos for the public, too. Among my favorites: *porridge, pulleys and Pi* (a dual biography of Vaughan Jones and Hendrik Lenstra); *Invitation to Discover* (about MSRI itself); and *The Right Spin*, the hair-raising story of how the American astronaut Michael Foale saved the Russian space station by making good use of mathematics.

But public understanding of mathematics is not only fun and games. We've had many wonderful didactic lectures, from Jeff Weeks' on The Shape of Space and John Horton Conway's on The Free Will Theorem to the public lectures in the current Simons Biology Colloquium series and the recent MSRI Symposium on Climate Change.

Setting and Facilities

Mathematics is surely the most "in the head" of all the sciences. But good facilities — lecture halls, blackboards, projectors, offices and computing resources — are important, and I believe strongly that the quality and beauty of the facility and setting makes a difference. MSRI has occupied a glorious setting since 1987, when it moved to its current perch on the ridge above the main Berkeley campus. With the opening of the new wing of the building in 2006, and the recently finished improvements in the old wing, I feel that MSRI's physical plant lives up to that setting. The new building showcases the superb mathematics done here, and supports the mathematicians who come in the way they need and deserve.

The principal features of the new construction recognize the most generous contributors to the building campaign. In every case they are contributors to the intellectual life of MSRI as well. The Simons Auditorium is designed to be comfortable for both large and small lectures, and its wonderful acoustics were designed to accommodate musical performances too. The Austine McDonnell Hearst Library, named after Will Hearst's mother, with its fine finishes and video room, has three times the capacity of our old library. The Baker Seminar and Board Room, allows us to keep the seminars of the major programs running happily even while simultaneous hosting a large workshop, and also provides a wonderful space for the many committees that meet for the governance of the Institute. The tranquil Berlekamp Garden, the new home of Helaman Ferguson's *Eightfold Way* sculpture, features, of course, an outdoor blackboard. The Strauch Auditorium Outlook is perfect for discussing ideas over lunch and also for celebrating, when they pan out! All these new spaces get a lot of use and admiration. These generous supporters and many dozens of others have partnered with me in making the new building a reality, a project that occupied a good fraction of my time over four years. I'm proud to have helped in the design, and to have helped raise the $12 million that was necessary to realize it.

The mathematical visitors have shown great appreciation for the changes, which allow MSRI to do more: for example, MSRI can now comfortably run a workshop outside the major programs without disrupting those programs at all. And with the new construction and renovation, MSRI takes in the glorious outdoor views as never before.

The Next Challenge

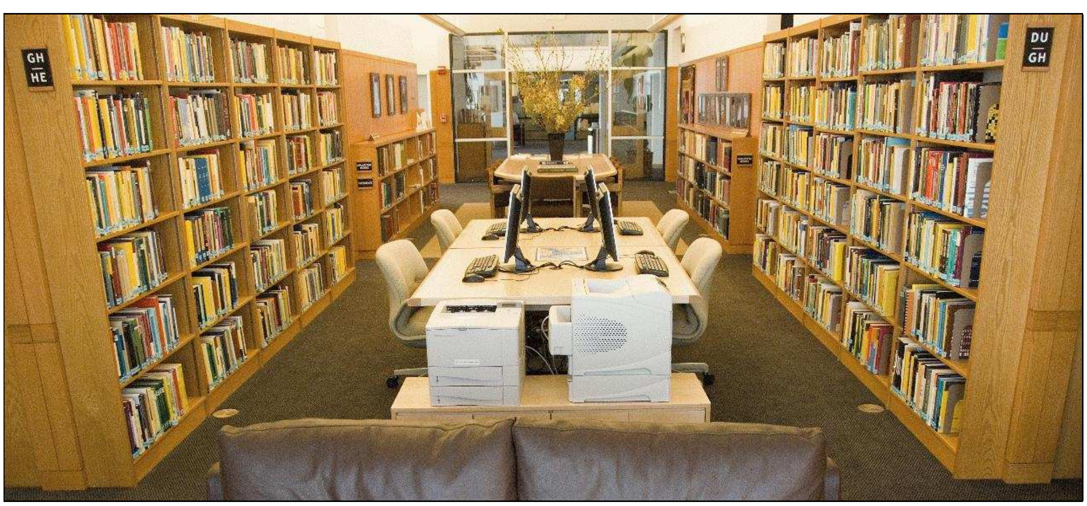
The building is done (as nearly as any building is ever done), but MSRI faces another great challenge. The NSF has been a fine patron over the 25 years of programs that MSRI has hosted, and I hope it will continue to provide major support for a very long time. But the institutions that remain important and effective through hard times and good are generally those with something MSRI does not yet have: an endowment. The Institute for Advanced Study, for example, has a major endowment. So does every university of importance in this country.

I believe that the next great challenge for MSRI is to raise such an endowment, and on this matter there is great news: as a first substantial step toward that goal, we have a $10 million matching challenge from the Simons Foundation. (See page 1.) I am truly delighted to be able to announce this wonderful beginning.

And About That Quotation...

The chronicle above omits many details and events that have engaged me and MSRI in these ten years, but perhaps the reader has a sense already of the scope and pace of MSRI's activities on behalf of Mathematics. Such activities are only possible with the engagement and concerted action of a large community. All those scientific organizers, all those devoted staff, all that attention and, yes, love, lavished on great ideas and great projects. Love is a big word, embarrassingly so. But I believe that in this context it is authentic. I think the mathematical community sees MSRI as one of the great world centers of mathematics, in some ways the greatest, and that is why the community is willing to spend so much effort on making its programs succeed.

I've put my love into it, too.



David Eisenbud

The Austine McDonnell Hearst Library is wood-paneled, has comfortable seats and ample space. The couch on the foreground faces a wall-sized window with a stunning view.

Puzzles Column

Joe P. Buhler and Elwyn Berlekamp

1. You are given 100 marbles, of which 50 are red and 50 are blue. You may distribute the 100 marbles into two jars in any way you wish. Someone else will then select one of the two jars at random. She will then select a marble from within that jar at random. Your goal is to gerrymander this experiment in such a way as to maximize the probability that the selected marble is *blue*. How well can you do?

2. An *amazon* is a chess superpiece who combines the powers of a queen and a knight. What is the maximum number of amazons that can be placed onto a 8 by 8 chessboard so that no two attack each other?

3. How many clock positions (of an analog clock with the usual hour and minute hands) have the property that the result of switching the two hands is also a legal clock position?

4. Let $V = \{1, 2, 3\}^4$ be the set of 4-tuples in which each coordinate is 1, 2, or 3. A combinatorial plane inside V is a set of 9 points in which two of the four coordinates are constant. There are 6 flavors of combinatorial planes, according to which 2 of the 4 coordinates are fixed; we will say that a plane is, e.g., of type 13 if its first and third coordinates are constant. A "sudoku solution" is a function from V to $\{1, 2, \ldots, 9\}$ that is a bijection on planes of types 13, 24, and 12. (The diligent reader will easily be able to interpret V as a sudoku board, and a sudoku solution to be a filled in board without repeated elements in a row, column, or square.)

Find a sudoku solution which is a bijection on all combinatorial planes.

Remark: This problem is due to Vaughan Jones, and the jumbo solutions that are asked for are sometimes called full monty solutions. One might well ask for the smallest partial solution that has a unique extension to a jumbo solution.

5. How many ways are there to put go stones on an n by n go board so that every position (occupied or not) is adjacent to an odd number of stones?

6. Four blue stickers and four red stickers are placed in a bowl. The master of ceremonies (MC) recruits three players, A, B, and C. All are brilliant logicians with impeccable powers of deduction. He then places two of these stickers, chosen at random, on each of the players' foreheads, leaving two stickers hidden in the bowl. Players can then see the stickers on the others' foreheads, not their own.

The MC then asks A if she can deduce the colors of the stickers on her forehead. He then asks the same question of B, then C, then A, then B, then C, then $A, \ldots$.

Determine (a) for each player, the probability that the player will be the first to deduce the colors on his or her forehead, and (b) the probability that no player will ever be able to deduce these colors.

Remark: An earlier version of this problem was due to M. Carver and appeared in the February, 1989, issue of *Discover* Magazine. The book *Reasoning About Knowledge* by Fagin, Halpern, Moses, and Vardi (MIT Press, 1995) covers the representation of knowledge in computer programs, and gives a variant of the problem.

7. A function on $[0, 1]$ is said to be strictly unimodal if it has a unique maximum point $x_{\max}$, and the function is strictly increasing on $[0, x_{\max}]$ and strictly decreasing on $[x_{\max}, 1]$.

You are allowed to query a strictly unimodal function f on $[0, 1]$ by asking for $f(x)$ given an x of your choosing. You are allowed n queries and want to find an interval of smallest possible width known to contain the maximum.

Your queries can be adaptive (i.e., depend on answers to earlier queries), but the function f is also adaptive and is out to thwart you: it can cunningly change itself at will, consistent with unimodality and the answers given previously.

What is the smallest interval width possible with n queries?

Remark: Larry Carter rediscovered this problem and brought it to our attention, but, not surprisingly, it turns out to have a long and colorful history.

Players A, B, C of puzzle 6. Can you identify each brilliant logician? (Answer on page 8).

Simons' Record Gift

(continued from page 1)

have substantial endowments. MSRI is of enormous importance to the mathematics community, so it gives me the greatest pleasure to see this first major step toward an endowment that can sustain MSRI in the long run."

Simons, the founder and president of Renaissance Technologies Corporation, says that the gift was a natural idea to recognize Eisenbud's 10 years of leadership. "Not only did David do an excellent job at the expected — attracting and organizing outstanding mathematics and programs — he also did wonderfully at the unexpected," says Simons. "He reached out to the public in a variety of innovative ways to put a human face on mathematics. This two-pronged approach both deepened and broadened the impact of MSRI, and David will leave it a substantially stronger institution than it was when he joined."

The Once and Future Mathematician?

Though Simons has shunned the public spotlight, his name is well known to all friends of MSRI. He has been a generous contributor to MSRI over the years. His largest previous gift was a $3.5 million contribution towards the completion of Chern Hall, and he served as co-chairman of the building renovation campaign. His generosity was recognized by the dedication of the Simons Auditorium in Chern Hall last year.

It was not the first time that Simons' name has been paired with that of Shiing-Shen Chern, one of MSRI's founders. In 1974, when Simons was the chair of the mathematics department of the State University of New York at Stony Brook, he collaborated with Chern on the discovery — or is it creation? — of the differential forms that bear their names. Chern–Simons forms lead to important topological invariants of spaces, and have become essential tools in fundamental physics, geometry, and topology (see sidebar).

Simons gave up mathematical research not long after his groundbreaking paper was published. (See the June 1998 Emissary for a fascinating interview where he explains why.) For more than 30 years he has quietly built a reputation and a considerable personal fortune as the president of Renaissance Technology, a private investment firm that manages a portfolio of more than $30 billion. The company uses mathematical models to identify patterns in commodity prices that other experts miss. However, Simons himself seldom gets to do the mathematics; that is left to the talented people he hires.

Recently, the mathematics bug bit Simons once again. A paper by Reese Harvey, Blaine Lawson, and John Zweck demonstrated several alternative approaches to the ring of "differential characters," which Simons and Jeff Cheeger had defined in terms of the Chern–Simons invariants. All of the resulting functors were isomorphic, and all fit into an identical commutative diagram involving cohomology and differential forms. "It occurred to me that satisfaction of the diagram itself might uniquely specify this functor," says Simons. "I hadn't done any serious mathematical research for almost thirty years, and I was amazed to find that I could do anything at all. I am definitely rusty and clearly hampered by an almost complete lack of knowledge of what happened mathematically during all those years." However, Cheeger put him in touch with a collaborator, Dennis Sullivan of Stony Brook, who was able to fill in the gaps and help him prove that his conjecture was correct. At the Advances in Algebra and Geometry workshop, on the day after his $10 million gift to MSRI was announced, Simons and Sullivan gave two lectures at MSRI on their characterization of differential characters (and several other new ideas as well).

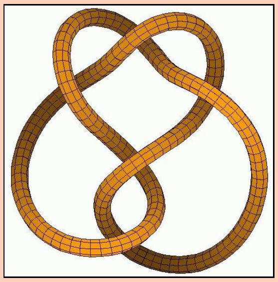
Of course, Simons still has a company to run, but this long-time supporter of mathematics clearly enjoyed doing research again. "Whether I will really stay in, who knows," he says. "Still, I have always asked David to keep a spare office for me!"

The Chern–Simons form

Chern–Simons forms live on principal G-bundles, which are manifolds acted on nicely by a Lie group G. The forms are related to the characteristic classes of the bundle, and may be nonzero even when the characteristic class is zero. For example, one might take the bundle of all orthonormal bases of tangent spaces on a compact Riemannian three-manifold. Chern–Simons theory associates with the (vanishing) first Pontryagin class of this bundle a differential form. Integration of this form over any section of the bundle yields a well defined element of $\mathbb{R}/\mathbb{Z}$ that is a homotopy invariant of the original three-manifold.

This construction was introduced in the paper "Characteristic forms and geometric invariants" (*Annals of Mathematics* **99** (1974), 48–69), by Chern and Simons. Its importance was quickly recognized by mathematicians, who applied the invariant in many fields, such as knot theory (extending the definition to noncompact manifolds such as knot complements).

Chern–Simons theory has also been applied to many branches of physics that use manifolds and Lie groups — or gauge groups, as they're often known in those parts: condensed matter physics (via the quantum Hall effect), quantum field theory, superstring theory, and more esoteric ones. Thus it has become an essential ingredient in modern attempts to understand and model the behavior of matter.



The unique five-crossing hyperbolic knot has Chern-Simons invariant 0.3467958667028481317030645121... (mod $\frac{1}{2}$). Standard conjectures say this number should be irrational. Courtesy Walter Neumann and KnotPlot by Rob Scharein.

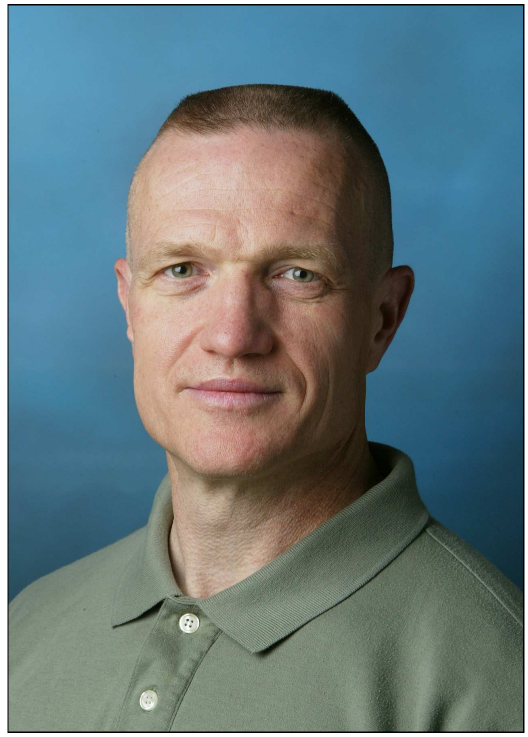
A New Director for MSRI

Lawrence C. Evans and Dana Mackenzie

On August 1, 2007, Robert L. Bryant will become the Director of MSRI and Professor of Mathematics at UC Berkeley. He is currently the J. M. Kreps Professor of Mathematics at Duke University. As Director, he will succeed David Eisenbud, who has served MSRI as Director since 1997. Eisenbud will continue as a member of the Berkeley Mathematics Department.

Bryant is a distinguished differential geometer, with extensive publications in the areas of Finsler geometry, exterior differential systems, holonomy, and the geometry of nonlinear partial differential equations. He is currently Vice President of the American Math Society, the Director of the Park City/IAS Mathematics Institute, and a former Chair of the Board of Trustees at MSRI.

The new Director is an "academic grandchild" of Shiing-Shen Chern, the founding Director of MSRI — his dissertation advisor, the late Robert Gardner, was a student of Chern at UC Berkeley — and he has been deeply influenced by Chern. His recent work on Finsler geometry, for example, was inspired by his conversations with Chern, who revived interest in this field in the late 1980s. Bryant is eager to carry Chern's legacy as Director forward: "After its founding by Chern, Calvin Moore, and Isadore Singer, MSRI developed a powerful scientific tradition. In an amazingly short time, it began to have a major impact on mathematical research in the US and around the world. Over the years, it has benefited from the talents of, not only a string of great Directors, but innumerable mathematicians, scientists, educators, and trustees, who have believed strongly in its value to the mathematics community. The scope of MSRI's achievements has been recognized with moral and, increasingly, financial support from a broad and expanding community. The Institute continues today to develop in dramatic and important ways. Kaplansky and Thurston, the directors after Chern, did remarkable jobs, and David Eisenbud's accomplishments during his Directorship have been inspiring. It is an honor to be invited to direct MSRI and I am both humbled and excited by the challenge."



Robert Bryant's selection as Director follows a year long evaluation process conducted by a search committee chaired by Julius Krevans, with other members Deborah Ball, Craig Evans, Charles Fefferman, Dusa McDuff, Don Saari and Roger Strauch. The committee was gratified that so many truly outstanding candidates allowed themselves to be considered for this position, and the choice among them was difficult. The Committee thanks them all for their patience with the process!

Speaking of the final decision, Fefferman, who is also current Chair of the Board of Trustees, commented: "Robert Bryant is a brilliant mathematician, and has very broad interests in science and culture as well. He will be a strong leader for MSRI, one who will maintain the breadth and depth of programs that have made the Institute such a vital organization."

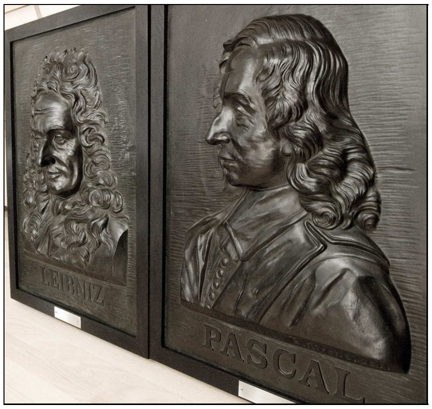
MSRI Honors Julia Robinson with High-School Festival

April 22 was the date of the first Julia Robinson Mathematics Festival. Some 350 middle and high school students and their parents came to Google Headquarters in Mountain View, where Josh Zucker, of Castileja High School, the main organizer, and a crowd of mathematicians and volunteers, set up fun, open-ended problems for the kids to work on. Writer Constance Reid, Julia's sister, spoke, remembering the honoree's accomplishments: MacArthur Fellow, first woman elected to the National Academy of Sciences, first woman president of the AMS, famous logician, and major contributor to the solution of Hilbert's Tenth Problem. Computer Scientist and MSRI Trustee Don Knuth was on hand to help out, and Paul Zeitz gave a wonderful mathematics lecture. Our special thanks to David des Jardins, Nancy Blachman, and Google for supporting this event, and to all who took part!

David Eisenbud

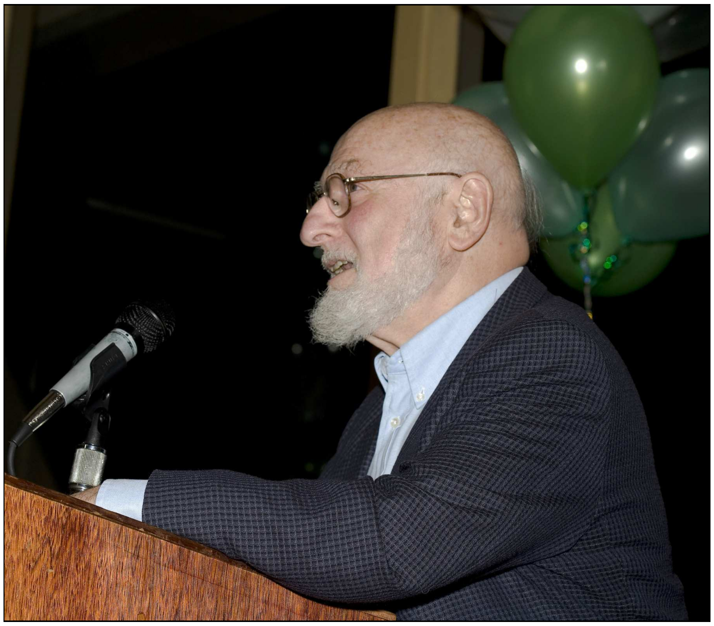
David's Birthday Celebration

On the evening of May 3, during the workshop on Advances in Algebra and Geometry, a dinner was held for workshop participants and friends of MSRI and its director, celebrating his sixtieth birthday. It was there that Jim Simons announced his generous gift to MSRI's endowment (see page 1), but there was much else to contribute to the joyful atmosphere: the presence of many old and new friends, who reminisced from the podium about events in David's career; his singing of Ralph Vaugh Williams songs; the delicious food and the unveiling of the lovely gift of 19th century bas-relief busts of Pascal and Leibniz, a present made by Ed Baker and Will Hearst on behalf of the Board of Trustees.

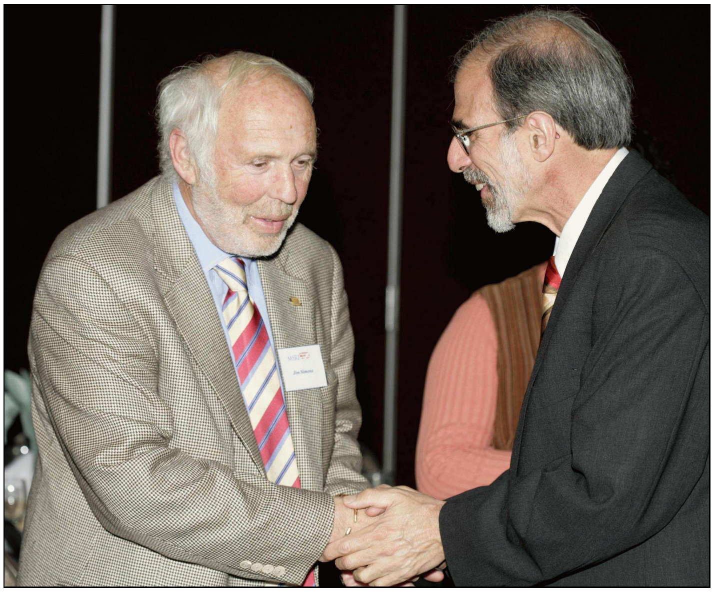


Photos by Kim Harrington

Daniel, David and Monika Eisenbud, next to Jill and Don Knuth. Also at the table: Hugo Rossi, David Bayer, Ed Baker.



Mentor and collaborator David Buchsbaum invited Eisenbud to Brandeis, where he went on to teach for 27 years.



David thanks Jim Simons on behalf of MSRI.

With Bill Glass, MSRI's architect.

Answers to last puzzle on page 5: A is the American mathematician and psychologist Christine Ladd-Franklin; see bio at http://turnbull.mcs.st-and.ac.uk/~history/ and the article by Eugene Shen, "The Ladd-Franklin formula in logic", *Mind* **36** (1927), 54–60, dx.doi.org/10.1093/mind/XXXVI.141.54. B is the British writer Charles Lutwidge Dodgson, better known as Lewis Carroll. C is the German philosopher Gottlob Frege.

From Flu to Lobsters to DNA

Dana Mackenie

This February, the Mathematical Sciences Research Institute launched a new public lecture series, designed to bring leading biologists to MSRI for a dialogue with mathematicians. The Simons Biology Colloquia, funded by Jim Simons, provided the speakers an opportunity to explain recent findings and issues in biology to mathematicians, and may in some cases foster an ongoing collaboration between the two sciences.

"Jim's philosophy is that it's hopeless to teach biologists mathematics, so we'll have to teach mathematicians some biology," said director David Eisenbud in his introduction to the first colloquium. Eisenbud also cited as inspiration the title of a 2004 article by Joel Cohen, head of the Laboratory of Populations at the Rockefeller Institute in New York: "Mathematics is biology's new microscope, only better; biology is mathematics' new physics, only better."

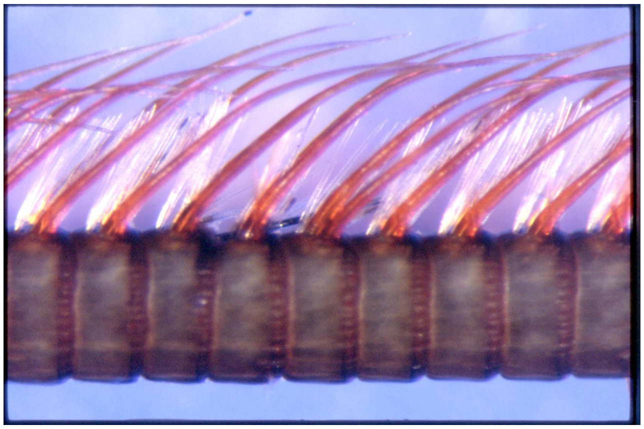
At the time of writing of this article, three speakers have visited MSRI to give Simons Biology Colloquia: Arnold Levine, the head of the new biology department at the Institute for Advanced Study in Princeton; Mimi Koehl, a biodynamics expert at the University of California at Berkeley; and Robert Schleif of Johns Hopkins University, who studies molecular dynamics. The fourth and final colloquium speaker for the spring semester will be Sydney Brenner, the winner of the 2002 Nobel Prize in Physiology or Medicine.

Smells Like a Lobster

You might not think that a sense of smell would be very useful underwater. The human nose, after all, has evolved to breathe air. One deep inhalation of seawater is likely to be your last. However, lobsters have evolved a very different method of olfaction: instead of "innies" (nostrils), they use "outies" (antennules) to smell their surroundings.

In her Simons Biology Colloquia, Mimi Koehl, a professor of integrative biology at Berkeley, discussed her work on sea creatures' complex olfactory environment. Several years ago, she and Angela Cheer, a mathematician at the University of California at Davis, studied how the odor-sensing hairs on an antennule interact with the surrounding fluid. The flow pattern changes significantly, depending on its Reynolds number. This is a dimensionless number that expresses whether an object moving through a fluid tends more to keep going through inertia or to slow down due to the fluid's viscosity. Smaller or slower-moving objects tend to have lower Reynolds numbers. The lobster can, of course, control how quickly it moves its antennules.

Koehl and Cheer discovered that at Reynolds numbers less than 1, water cannot flow between the hairs but only around them. But at Reynolds numbers above 1, water can pass between hairs, which makes it possible for the antennule to detect spatial differences in the concentration of odor molecules. Therefore the lobster flicks its antennules rapidly (high Reynolds number) to "sniff," and then relaxes them slowly (low Reynolds number) so the odors trapped

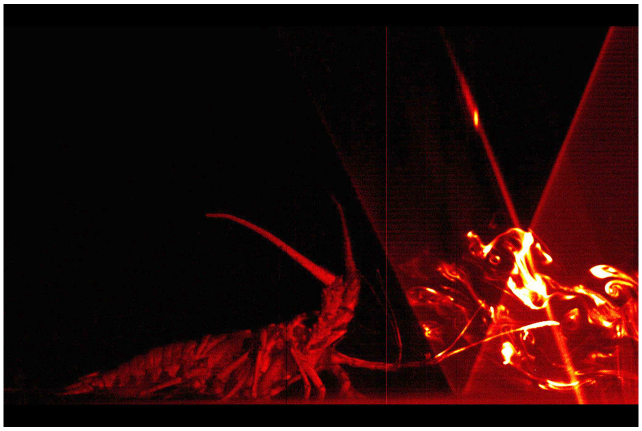


Lobster antennule with odor-sensing hairs.

in the brush of sensory hairs do not escape. "Each flick is like a snapshot of a 1-mm thick slice of water at one point in time," Koehl said.

But is there really information contained in the snapshot? In the past, biologists have assumed that odors diffuse in a cloud, which would make one slice the same as another. With laser imaging experiments using fluorescent dye as an analog for odor molecules, Koehl has shown that is not correct. In the turbulent water currents in a lobster's habitat, filaments of concentrated odor swirl around in a pattern that changes as a lobster nears the odor source. It remains to be seen how and whether lobsters use this detailed information. However, in her second lecture she described an even simpler organism that definitely uses it. Swimming larvae of a sea slug, which eats coral, use chemosensors to detect reefs that they can colonize. When exposed to coral odor, the larvae stop swimming and sink; when they leave an odor filament, they start swimming again. Computer simulations show that this simple behavior enables the larvae to land on wave-swept reefs.

Mathematicians in the audience were not surprised to hear about the complex odor patterns. Using methods from dynamical systems, it may be possible to describe their structure theoretically, rather than empirically, and better explain how the sea slug's simple programming enables it to find and land on the coral. On a followup visit to MSRI in March, Koehl and her colleague Bob Full, who works on the locomotion of terrestrial organisms, explored the possibilities for collaboration with dynamical systems experts.



Lobster with a laser-lit plume of fluorescent dye.

One Flu Over the Chicken's Nest

Arnold Levine is best known among biologists for discovering the p53 tumor suppressor gene and understanding its function, but at Berkeley he gave lectures devoted to a new line of research that he has begun with three physicists at the Institute for Advanced Study: Michael Krasnitz, Raul Rabadan, and Harlan Robins. Using ideas from statistical physics, they have discovered a new way to distinguish between human and bird flu chromosomes. "What we did was to take a fresh approach, using mathematics that's not pioneering, to a problem that has never been treated that way," says Levine. "In the future we may need more pioneering methods."

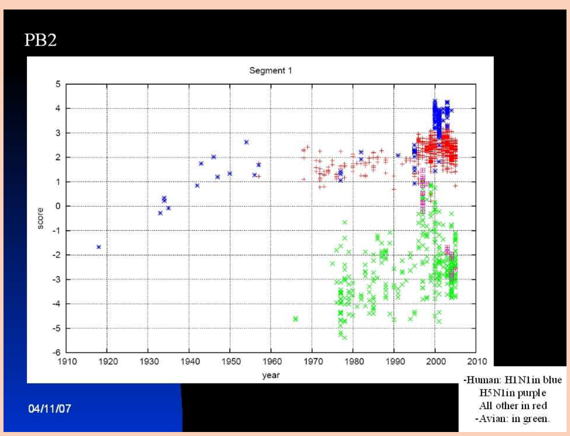
The influenza virus, Levine explained, contains eight chromosomes, two of which code for the proteins hemagglutinin (H) and neuroaminidase (N) that dangle off the outside of the virus. These are the proteins that the human immune system sees. Therefore, from the immune system's point of view, a different subtype of H or N proteins corresponds to a different strain of flu virus. Among the earliest flu viruses isolated is the H1N1 type, which caused the pandemic of 1918. The Asian flu of 1957 was type H2N2, and the Hong Kong flu of 1968 was type H3N2. Public health officials are currently worried about the so-called bird flu, type H5N1, which has a high mortality rate among humans but does not seem able yet to pass from one human to another.

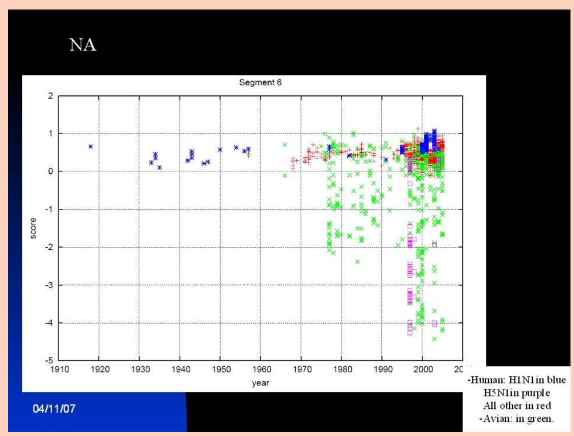
Levine's recent work showed that there is important information on the other six chromosomes, the ones that code for proteins our immune system doesn't see. Flu RNA, like human DNA, employs four different bases to code for the various proteins it makes; the letters representing them are A, C, G, and U. The code has a certain flexibility; two sequences of three letters or codons, such as GAA and GAG, can stimulate the insertion of the same amino acid into a protein. Thus the frequency of A's and G's in the genetic code can drift over time, without affecting the proteins or the organism. This happens about 80% of the time in a chromosome.

To their surprise, Levine and his colleagues found that the more generations a virus spends in human cells, the more its G's tend to be replaced by A's. He calls the phenomenon directed evolution. Human cells have an enzyme that changes G's to A's, and the mutations get passed on to later generations of virus. Interestingly, this directed or guided style of evolution happens only in the chromosomes that do not code for the H or N proteins. In the other two chromosomes, the substitution of A for G that occurs is then selected against by the human immune system. Therefore the proportion of G's does not decrease over time.

In bird flu viruses, the proportion of A's does not increase for a different reason: The bird immune system appears to lack the enzyme to convert G's to A's. Thus, Levine can tell the difference between a bird-flu chromosome and a human-flu chromosome. In the 1918 Spanish flu virus, at least six of the chromosomes came from bird flu viruses. This chromosome-swapping occurs when birds (such as chickens) and humans live in close proximity, and a bird becomes infected with both viruses. If the H5N1 virus changes to become a little bit more human-like, Levine believes, it may become capable of starting a new pandemic. At this point he cannot predict when that might happen, but the tools from statistical physics may allow him to track its progress.

The plots tell the story





Left: Changes in the proportion of A's to G's (vertical scale) in samples of flu virus taken over time (horizontal scale, 1910–2010), restricted to a segment of RNA that does not code for external proteins that the human immune system can detect. In the blue H1N1 virus (a human flu) the ratio of A's to G's started out very birdlike, but has evolved over time to a higher score, a process that Levine calls "directed evolution." (The score is a measure of the entropy of the information contained on the chromosome, a concept derived from statistical physics.) Other human flus (red) have a high score. Avian flus (green) have a low score, and the H5N1 strain that is of current concern (purple) also has a low, birdlike score. **Right:** Same kind of data on a portion of the flu RNA that does affect the virus's ability to elude the human immune system. Here we see some difference between human flu viruses (blue, red) and avian (green), but we see no tendency for the score to change over time. Presumably this is because changing G's to A's in this part of the flu genome would adversely affect its ability to survive. H5N1 (purple) still looks quite different from human flu viruses.

Inside the DNA Toolshop

Imagine that you have a workshop, Robert Schleif asked his MSRI audience, and you want it to be totally self-contained. In other words, you want to be able to use the tools in the workshop to build new copies of every tool. How many tools would you need? "It's not a small number, but not an infinite number, either," he said.

This is exactly the problem that living cells solve every day. Their tools are genes, and the simplest cellular workshops known contain about 500 to 2000 tools. In his Simons Colloquia, Schleif took his mathematical audience on a guided tour of the cell's workshop.

In one lecture, Schleif described two of the machines in the cell's workshop, the copying machine and the clock. Then he explained how biologists have developed a third machine that doesn't exist in nature: a DNA sequencing machine, which translates the DNA code into letters that humans can understand.

The cell's copier, for instance, takes a double-helix strand of DNA, unzips it, and then creates a complementary copy of each of the two unzipped pieces (like a photographic positive made from a negative). It does this at an amazing speed: roughly 1000 pairs of amino acids are copied per second. Since each turn of the double helix takes about 10 to 11 base pairs, the entire molecule is spinning around at a rate of 100 revolutions per second at the same time that it is being unzipped and copied.

Under such circumstances, quality control is crucial, and Schleif described how the cell keeps the error rate under one per million. An incorrectly matched base pair creates a kink in the DNA, which the cellular machinery can sense and repair. But how does it know which strand of the DNA is the old, correct one, and which is the new, incorrectly copied one? The answer is methylation. Old DNA has methyl groups attached to it everywhere that the letters GATC appear; freshly made DNA does not.

The reason nature has chosen GATC has to do with symmetry. When you take the "photographic negative" of GATC, you get CTAG. And then when you read it backwards (because the cell's reading machinery reads the two strands in opposite directions), you get GATC again. Thus GATC should appear in the same place in both strands. GATC, Schleif said, is just one example of a recognition sequence, and most known recognition sequences obey the same symmetry principle.

According to Schleif, there are lots of mathematical principles like this to be discovered in biology. The toughest part is getting mathematicians over the linguistic hurdles created by terms like "methylation" and "recognition sequence." Schleif knows this from personal experience, as a physics major who studied molecular biology as a graduate student at Berkeley. "The first steps are really unpleasant, learning the 2000 or so compounds that are important in biochemistry," he says. "But as you learn more and begin to see the underlying principles, it becomes easier."

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