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February 1999

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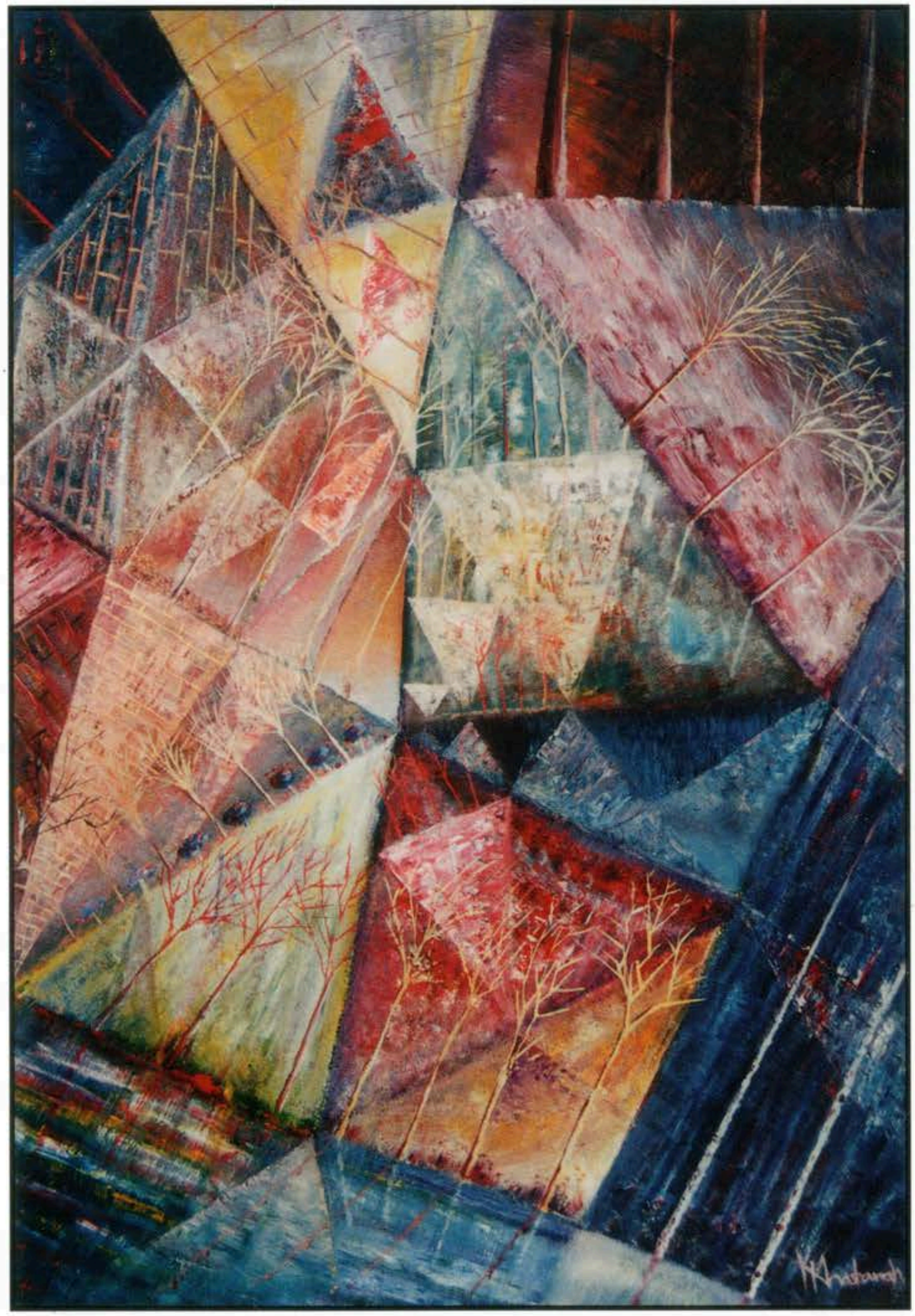
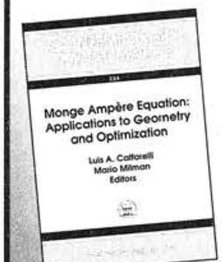
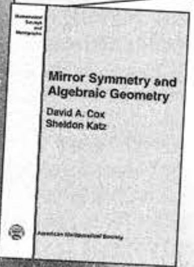


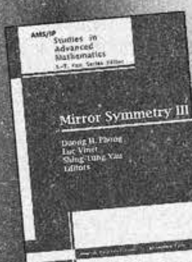
Sierpinski Garden (See page 245)

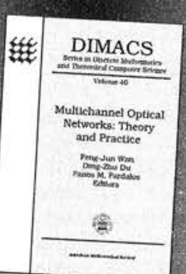
AMERICAN MATHEMATICAL SOCIETY

New Titles from the AMS









Monge Ampère Equation: Applications to Geometry and Optimization

Luis A. Caffarelli, *New York University, Courant Institute*, and **Mario Milman**, *Florida Atlantic University, Boca Raton*, Editors

In recent years, the Monge Ampère Equation has received attention for its role in several new areas of applied mathematics:

- As a new method of discretization for evolution equations of classical mechanics, such as the Euler equation, flow in porous media, Hele-Shaw flow, etc.,
- As a simple model for optimal transportation and a div-curl decomposition with affine invariance and
- As a model for front formation in meteorology and optimal antenna design.

These applications were addressed and important theoretical advances presented at a NSF-CBMS conference held at Florida Atlantic University (Boca Raton). L. Cafarelli and other distinguished specialists contributed high-quality research results and up-to-date developments in the field. This is a comprehensive volume outlining current directions in nonlinear analysis and its applications.

Contemporary Mathematics, Volume 226; 1999; 172 pages; Softcover; ISBN 0-8218-0917-2; List $39; Individual member $23; Order code CONM/226NT92

Mirror Symmetry and Algebraic Geometry

David A. Cox, *Amherst College, MA*, and **Sheldon Katz**, *Oklahoma State University, Stillwater*

This book is the first completely comprehensive monograph on mirror symmetry, covering the original observations by the physicists through the most recent progress made to date. Subjects discussed include toric varieties, Hodge theory, Kähler geometry, moduli of stable maps, Calabi-Yau manifolds, quantum cohomology, Gromov-Witten invariants, and the mirror theorem.

Mathematical Surveys and Monographs; 1999; 467 pages; Hardcover; ISBN 0-8218-1059-6; List $69; All AMS members $55; Order code SURV-COXNT92

Mirror Symmetry III

Duong H. Phong, *Columbia University, New York*, **Luc Vinet**, *University of Montreal, PQ, Canada*, and **Shing-Tung Yau**, *Harvard University, Cambridge, MA*, Editors

This book presents surveys from a workshop held during the theme year in geometry and topology at the Centre de recherches mathématiques (CRM, University of Montréal). The volume is in some sense a sequel to *Mirror Symmetry I* (1998) and *Mirror Symmetry II* (1996), co-published by the AMS and International Press.

Included are recent developments in the theory of mirror manifolds and the related areas of complex and symplectic geometry. The long introductory articles explain the key physical ideas and motivation, namely conformal field theory, supersymmetry, and string theory. Open problems are emphasized. Thus the book provides an efficient way for a very broad audience of mathematicians and physicists to reach the frontier of research in this fast expanding area.

This book is co-published by the AMS, International Press, and Centre de Recherches Mathématiques.

AMS/IP Studies in Advanced Mathematics, Volume 10; 1999; 312 pages; Hardcover; ISBN 0-8218-1193-2; List $42; All AMS members $34; Order code AMSIP/10NT92

Introduction to Geometric Probability

AMS Video

Gian-Carlo Rota, *Massachusetts Institute of Technology, Cambridge*

This lecture examines the notion of invariant measure from a fresh viewpoint. The most familiar examples of invariant measures are area and volume, which are invariant under the group of rigid motions. Master expositor Gian-Carlo Rota shows how, starting with a few simple axioms, one can concoct new invariant measures and explore their properties. One set of such measures, known as the intrinsic volumes, are quite new and still somewhat mysterious. However, they have intriguing probabilistic interpretations and in fact can be shown to form a basis for the space of all continuous invariant measures. Rota also discusses the remarkable connection between the intrinsic volumes and the Euler characteristic. Reaching deep ideas while remaining at an elementary level, this lecture would be accessible to undergraduate mathematics majors.

1998; NTSC format on one-half inch VHS videotape, approximately 60 minutes; ISBN 0-8218-1351-X; List $54.95; Individual member $34.95; Order code VIDEO/102NT92

Multichannel Optical Networks: Theory and Practice

Peng-Jun Wan, *Illinois Institute of Technology, Chicago*, **Ding-Zhu Du**, *University of Minnesota, Minneapolis*, and **Panos M. Pardalos**, *University of Florida, Gainesville*, Editors

Time division multiplexing (TDM) has been the fundamental basis for adding capacity to digital telecommunications networks for decades. However, within the past two years, wavelength division multiplexing (WDM) has been emerging as an important and widely deployed complement to TDM. Sales of systems based on the new technology have risen at breathtaking speed. The driving force behind this sales explosion was the unexpected rapid exhaustion of long distance fiber network capacity. This fiber exhaust, combined with favorable economics for WDM, led to the use of this technology over other alternatives.

The WDM deployment raises fundamental and challenging problems that require novel and innovative solutions. This volume presents papers from an interdisciplinary workshop held at DIMACS on multichannel optical networks. Leading computer science theorists and practitioners discussed admissions control, routing and channel assignment, multicasting and protection, and fault-tolerance. The book features application of theoretical and/or algorithmical results to practical problems and addresses the influence of practical problems to theoretical/algorithmic studies. The volume can serve as a text for an advanced course in computer science, networking, and operations research.

DIMACS: Series in Discrete Mathematics and Theoretical Computer Science, Volume 46; 1998; 249 pages; Hardcover; ISBN 0-8218-1004-9; List $55; Individual member $33; Order code DIMACS/46NT92

Selections from MSRI's Video Archive, Volume 2

The Chern Symposium, March 5–7, 1998

A publication of MSRI.

This CD-ROM features video presentations from the Chern symposium in geometry sponsored jointly by the University of CA (Berkeley) and MSRI. The symposium presented developments in differential geometry over the past few decades. Recent progress and new directions in the field were also covered. Invited speakers gave the following addresses: *Introductory remarks*, *Configuration space invariants of knots and 3-manifolds*, *Finsler manifolds of constant flag curvature*, *Extremal metrics in Riemann surfaces and the uniformization theorem*, *Projective geometry*, *Why do I like Chern classes?*, *Algebraic cycles and the classical groups*, *Mirror principle*, *Duistermaat-Heckman formulas for group valued moment maps*, *Backlund transformations and loop ground actions* and *From Riemann geometry to Poisson geometry and back again*.

The CD requires Real™Video Player, which can be downloaded for free from the RealNetworks Internet home page. RealVideo Player is available for Windows95/Windows NT, Windows 3.1, MacOS, IRIX 6.2/6.3, Solaris 2.5 and Linux 2.0.

®RealVideo is a registered trademark and RealNetworks is a trademark of RealNetworks, Inc.

Distributed worldwide by the American Mathematical Society.

1998; CD-ROM; List $15; Order code MSRICD/2NT92

All prices subject to change. Charges for delivery are $3.00 per order. For optional air delivery outside of the continental U. S., please include $6.50 per item. *Prepayment required.* Order from: **American Mathematical Society**, P. O. Box 5904, Boston, MA 02206-5904, USA. For credit card orders, fax 1-401-455-4046 or call toll free 1-800-321-4AMS (4267) in the U. S. and Canada, 1-401-455-4000 worldwide. Or place your order through the AMS bookstore at www.ams.org/bookstore/. Residents of Canada, please include 7% GST.

AMS
AMERICAN MATHEMATICAL SOCIETY

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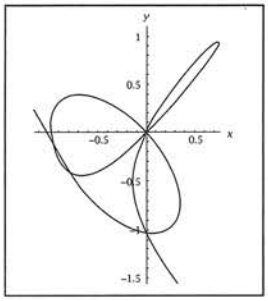

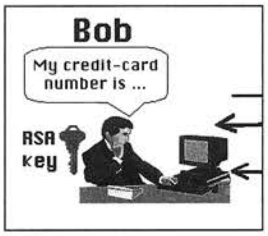

Memorial Article

Communications

From the AMS

Departments

Notices

of the American Mathematical Society

SUBSCRIPTION INFORMATION: Subscription prices for Volume 46 (1999) are \$309 list; \$247 institutional member; \$185 individual member. (The subscription price for members is included in the annual dues.) A late charge of 10% of the subscription price will be imposed upon orders received from nonmembers after January 1 of the subscription year. Add for postage: Surface delivery outside the United States and India—\$15; in India—\$36; expedited delivery to destinations in North America—\$35; elsewhere—\$70. Subscriptions and orders for AMS publications should be addressed to the American Mathematical Society, P.O. Box 5904, Boston, MA 02206-5904. All orders must be prepaid.

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`http://www.ams.org/notices/`

Those with VT100-type terminals or without WWW browsing software can connect to e-MATH via Telnet (`telnet e-math.ams.org`; login and password are "e-math") and use the Lynx option from the main menu.

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Editorial

Small Steps

The *Notices* is taking some small steps to make the information it contains better organized and more useful to readers.

Some of the changes affect the three monthly news columns "Mathematics People", "Mathematics Opportunities", and "For Your Information". Years ago the *Notices* had a column of personal items that reported promotions, new jobs, certain honors, and miscellaneous other information about its members. As the AMS membership grew larger, the reporting of this information became an unwieldy task, and eventually that kind of reporting was abandoned. In its place eventually was the column "Mathematics People", which has evolved to the point that it reports on national and international awards and honors in mathematics and certain other awards and honors that extend outside mathematics. This column also includes a list of death notices of AMS members, continuing a long tradition. "Mathematics Opportunities" lists information about fellowships, grants, competitions, and the like, while "For Your Information" includes news about other kinds of things—events, activities, the AMS, and related organizations. Announcements of conferences generally appear in the "Mathematics Calendar" rather than in "For Your Information". News of any kind that is proposed for inclusion may be sent to the managing editor, e-mail: `notices@ams.org`.

Apart from the evolution toward the current roles of the three news columns, one more change has occurred with these columns. Starting in 1999, seventeen selected mathematics institutes around the world will be offered space within "Mathematics Opportunities" throughout each year to describe their future programs and application procedures.

Annually the *Notices* has published certain lists of information prepared by the AMS staff. These include the lists of doctorates, of foreign visitors, of backlogs of research journals, and of a few other items. These lists will now be organized so they appear right after the three news columns.

The department "Reference" will continue to tell where to find the latest version of certain kinds of slowly varying information, such as lists of AMS officials and the list of current program directors in mathematics at the NSF. Changes for this section include the addition of a book list and changing the name of the section to "Reference and Book List".

In the recent past the *Notices* has published book reviews at the rate of approximately one per issue. The books that are reviewed represent a selection of the books that come to the attention of the editorial board and meet certain criteria, including the following: (i) The book must have mathematical themes and must hold appeal for a wide audience, including mathematicians and students. (ii) The book must normally be neither a textbook nor an advanced book of the kind that is reviewed by the *Bulletin.* (iii) In addition, except in unusual circumstances, the book must be less than two years old at the time of publication of the review.

The book list is intended to include for an interval of time any book that the editorial board knows about and is of the kind that the *Notices* reviews. Readers who learn of books that they think ought to be included on the book list are invited to bring these books to the attention of the managing editor.

One last change worth mentioning is in the way the bibliography is listed at the end of articles. Anyone who has ever written an article for an AMS journal knows that the AMS has its own conventions for what fonts to use in references. Article titles have been in italics, journal titles in roman, and so on. Most non-AMS journals, by contrast, put article titles in roman, journal titles in italics, and so on. The *Notices* has been faced with the problem that its articles do not contain just text and bibliographies, but they can contain annotated bibliographies, footnotes with references, footnotes with references and text, and references that are given in the text. The handling of references in the *Notices* thus has to be made consistent with the handling of titles in the text, and therefore the *Notices* departed from the AMS tradition with the January 1999 issue. Henceforth, references in the *Notices* will be in a form closer to that of most non-AMS journals throughout the part of the world that uses the Latin alphabet.

—*Anthony W. Knapp*

Commentary

In My Opinion

Compute and Conjecture

When I was a mathematical child, abstraction was king. In algebra (my field, and one I will concentrate on here) I was taught commutative algebra before I knew what a number field was. Galois theory was abstract structure; actual groups and fields did not appear until after the proof of the fundamental theorem.

It was as if examples were the detritus, and proof and theorem the real thing. Computation was for those who could not think abstractly—and we all knew that mathematics was abstraction. (This was most obvious in the differential equations course, where existence proofs formed the basis of the math department's offering. Learning to solve them was relegated to engineering.) Examples served to illustrate results and were not a way of doing mathematics. They did not guide research, or its direction, or lead to conjectures.

Before this century mathematicians computed aplenty. From Pythagoras to Archimedes, the Greeks calculated. Astronomical reckonings drove much of Newton's, Euler's, Gauss's, and Poincaré's work. Euler computed his way to quadratic reciprocity. Gauss's extensive calculations led him to the prime number theorem.[1] Based on computational work, Dedekind and Frobenius conjectured many results concerning group representations. Ramanujan used calculations to guide his many conjectures. But after Hilbert demonstrated the power of abstract methods in the basis and syzygy theorems and the Nullstellensatz, computation fell out of favor. Noether's work furthered the ascendancy of abstract methods. Abstraction replaced computation, and mathematics grew richer—but poorer too.

Abstract understanding is like viewing terrain through a satellite map, while examples show what the land is really like under your feet. Research benefits from both approaches. Knowing the terra firma often demonstrates why and where the theorem is true. Computation can help uncover surprising connections, and it can uncover fruitful areas for study.

Knowledge of the individual examples has always been crucial to group theory. It led, for example, to Burnside's conjecture (now the Feit-Thompson theorem) that every simple nonabelian group is of even order. More recently Tits's theory of buildings was derived from an intimate understanding of the structure of many groups. Birch and Swinnerton-Dyer used their knowledge of many elliptic curves obtained by extensive calculations to hone their famous conjecture. And people found questions to ask about the Mandlebrot set by looking at the pictures—then they went and proved theorems.

If for most of this century computation was held in low esteem, now the pendulum appears to be swinging back. It is doing so at a propitious time. Although mathematics has grown more complex than a century ago, we have more computational machinery than our predecessors did.

Symbolic computation packages such as AXIOM, Derive, GAP, Grobner, Macaulay, MAGMA, Maple, Mathematica, Pari/GP, and Singular[2] have made many calculations far easier to perform. Systems developed by mathematical computer scientists and computational mathematicians enable us to easily factor polynomials, solve systems of polynomial equations, compute Galois groups, build groups out of smaller ones (e.g., compute wreath products), calculate the primary decomposition of an ideal, perform arithmetic in rational function fields, compute algebraic varieties, enumerate the partitions of a set, construct Goppa and Reed-Muller codes, build graphs out of smaller ones, do symbol splitting in symbolic dynamics, compute limits, Taylor series, and Laplace transforms, and exactly solve ODEs and PDEs. One can check whether a polynomial is irreducible over $\mathbb{Q}$, compute its Galois group, find subgroups of the Galois group, then compute the corresponding subfields of the splitting fields. In the finite case, one can construct a group from a set of generators and determine its commutator subgroup and its Sylow subgroups. One can construct a graph, determine its automorphism group, and then construct the composition factors of the automorphism group. All of this can be done easily using various symbolic computation programs. (In a satisfying cross-fertilization, the work in symbolic computation has led to new mathematical results in algebra, analysis, combinatorics, and logic.)

In Hilbert's time multivariate computations grew too quickly to be computed by hand; now many of these problems can be easily done by computer. We can solve harder problems, in extensions of higher degree, with more variables than we could handle a decade ago.

Computation and examples enrich and guide research as much as they do teaching. At a time when mathematicians are returning to computation, computers and symbolic computation programs are giving mathematicians an exciting opportunity to expand their research capabilities.

—Susan Landau
Associate Editor

[1] *Gauss had a very modern view of computational complexity. In Art. 329 of* Disquisitiones, *which is about factorization, he carefully distinguishes primality testing from factorization and says things like "It is in the nature of the problem that* any *method will become more prolix as the numbers get larger. Nevertheless, in the following methods, the difficulties increase rather slowly, and numbers with 7, 8, or even more digits have been handled with success and speed beyond expectation … ."*

[2] *See* `http://symbolicnet.mcs.kent.edu/www-sites.html#A1.1` *for a partial listing of symbolic computation systems.*

Letters to the Editor

Impostures Intellectuelles and Faris's Review

I was very interested in the book review article by William G. Faris of *Impostures Intellectuelles* (Editions Odile Jacob, Paris, 1997) by Alan Sokal and Jean Bricmont in the August 1998 issue of the *Notices* (Vol. 45 pp. 874–876). The reason for my interest is the following point:

"The major gap in the Sokal-Bricmont book is that it avoids dealing with...the confusion over the foundations of quantum mechanics. This confusion is a major weak point in modern physical science. Numerous popular writings about science exploit this obscurity, but the book does not address this issue."

To the best of my knowledge, no other reviewer made this important point, and I suggest that this is a grave omission by both the Sokal-Bricmont book and its numerous reviews.

It is generally believed that postmodernism was originated by culture studiers in the revolutionary ambience of 1960s' France. But from which prior paradigms might the French postmodernists have derived their (now rightly recognised as) daft ideas? Might they have been influenced by the philosophical utterances of earlier eminent mathematicians and scientists (mostly quantum physicists)? I have argued that this is indeed the case. The following passages are conveniently taken from a single source, Alan L. Mackay's *A Dictionary of Scientific Quotations* (Adam Hilger, Bristol, 1991):

Niels Bohr: "...two sorts of truth: trivialities, where opposites are obviously absurd, and profound truths, recognised by the fact that the opposite is also a profound truth."

J. B. S. Haldane: "The universe is not only queerer than we suppose, but queerer than we can suppose."

David Bohm: "There are no things, only processes."

Hermann Bondi: "[Science doesn't deal with facts; indeed] fact is an emotion-loaded word for which there is little place in scientific debate."

Bertrand Russell: "Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true."

G. H. Hardy: "Beauty is the first test; there is no permanent place in the world for ugly mathematics."

Paul Dirac: "It is more important to have beauty in one's equations than to have them fit experiment."

Arthur Eddington: "It is also a good rule not to have overmuch confidence on the observational results that are put forward until they are confirmed by theory."

Albert Einstein: "Imagination is more important than knowledge."

Freeman Dyson: "Most of the papers which are submitted to the *Physical Review* are rejected, not because it is impossible to understand them, but because it is possible. Those which are impossible to understand are usually published."

Fred Hoyle: "[We must] recognise ourselves for what we are—the priests of a not very popular religion."

Before any mathematicians and scientists (and especially quantum physicists) dare to accuse any others of the very serious charge of intellectual imposture, they first ought to put their own houses in order.

—*Theo Theocharis*
London, England

(Received September 22, 1998
Revised October 7, 1998)

More History of the Chowla-Selberg Formula

Although the authors of the Chowla memorial article (*Notices*, May 1998) did not want to pursue the history of the Chowla-Selberg formula, there is more to it than is indicated in the exchange of letters in the September *Notices*. The relevant information can be found in section 3.2 of N. Schappacher's book *Periods of Hecke Characters* (Lecture Notes in Mathematics, vol. 1301, Springer-Verlag).

It seems that historically there were two lines of investigation connected with the formula. One involves examples due to Legendre and Eisenstein, and Chowla and Selberg were aware of this part of the history. But the formula itself was discovered about fifty years before the first article of Chowla and Selberg. Building on work of Berger and Kronecker, M. Lerch proved the Chowla-Selberg formula in an article "Sur quelques formules relatives au nombre des classes" (*Bull. Sci. Math.* (2) **21** (1897), prem. partie, 290–304). In a 1903 paper Landau proved a formula that implies the Lerch result, and then Schappacher is able to find no reference to the Lerch or Landau result in the literature between 1903 and the first paper of Chowla and Selberg in 1949. This historical information came to light when R. Sczech pointed out the Landau paper to Schappacher.

Schappacher goes on to describe how Weil looked, with only partial success, for a geometric proof of the formula, at least up to a rational factor, and then how B. H. Gross found the result mentioned in the September letter by McGuinness. More precisely, the method of Gross recovers the formula only up to a rational factor. This factor was determined by P. Colmez ("Périodes des variétés abéliennes à multiplication complexe", *Ann. of Math.* **138** (1993), 625–683), using the theory of p-adic periods.

—*Jan Nekovář*
University of Cambridge

(Received October 16, 1998)

Consider Price When Adopting Textbooks

I would like to comment on Edwin Beschler's November article, "The Pricing of Scientific Publications", and the increasing trend of textbook prices in general. One aspect of commercial publishing which is avoided in Beschler's article is lower-division undergraduate textbook prices. His essay doesn't account for why a student pays $100 for a "best-selling" calculus text. Although these books usually contain more colors and pictures than the lower-selling advanced texts, they can be printed in much higher quantities and shouldn't have the same long-term storage costs. Moreover, since they are popular texts, it seems that the risk is much lower. In short, it appears that the total unit cost, etc., doesn't account for the price, and it seems to follow that publishers are indeed price gouging.

Notice that most of these popular texts are in multiple editions. Although it speaks well of the authors for writing books that stand the test of time, it appears that many of these texts undergo revision every two to three years. It follows that with every new edition, the bookstores' used inventories are wiped out, forcing students to purchase new books. Hence it is in the publisher's best interest to be in the process of constant revision and to urge departments to switch texts. I fear that much of the contention in recent years regarding reformed pedagogy and technology-based learning has been promoted, even fueled by publishers. Authors are perhaps pressured to write specialized variations of their textbooks to accommodate specific calculators, classical and reformed teaching styles, single-semester and tracked courses, etc., thus again hampering and complicating the used-book market and passing a further expense on to the students.

I would like to urge teachers and book search committees in general to be more mindful of the extra expense their students incur when they switch either texts or editions and perhaps to factor into their choice the expected duration that a book, as is, will remain in print. We shouldn't be anti-publisher, but contrary to the tone of Beschler's article, they need us as much as we need them, and we shouldn't think that our book reps are doing us any favors. As teachers we have the opportunity and obligation to respond as consumers even though we aren't the ones consuming.

—*Jeffrey Humpherys*
Indiana University, Bloomington

(Received November 5, 1998)

Beschler Replies

As a parent currently putting his third child through college, I cannot help but share Jeffrey Humpherys's consternation at $100 textbooks. In the limited space available to me, I did indeed skirt that issue in favor of an emphasis on short-run, research-level books, which share some dynamics with journals.

My main objection to Humpherys's letter is that it again places all the blame on publishers, as though authors and the educational establishment had nothing to do with the requirements that have been put on textbooks to make them acceptable, as though the publishers create these "products" and the captive market has no choice but to pay the bill for them. There is something fundamentally wrong with this picture. There is no doubt that some publishers some of the time reap excessive profits on some of their products. Others settle for less. I should also mention that, since textbooks at the calculus level are not usually published by university presses, the comparison between profit and nonprofit organizations does not apply here. But the principle of attempting to profit on investment, as any business must, remains intact.

Some of the investment that goes into a textbook includes: extensive reviews to determine that the book has all the qualities of the market leader and surpasses them; supplemental material that accompanies the book gratis (answer manuals, teachers' manuals, tapes, CDs, videos, etc.); competitive royalties to attract the author in the first place; copious numbers of free copies to potential adopters; extensive sales forces to bring the wonders of this new "product" to the ears of adoption committees already deluged by similar presentations; marketing "gimmicks" to further increase visibility; and so on. In addition there are such items as checking to ensure that no words in the text exceed a certain presumed reading level, all concepts included are "politically correct", and other excesses at the extreme end of what is happening in textbook publishing. All of these activities are aimed to penetrate a market that has been shaped by the educational establishment and its perceived needs. They are in answer to what the market continually demonstrates that it wants.

A great deal of this investment must be recouped during the first year of a textbook's expected life, since the used-book marketers have greatly developed their ability to collect used copies and direct them to the most likely re-users. In addition, the same investment must be made for a textbook that fails to capture a significant part of the market and whose costs must therefore be subsumed within the economics of the successful ones. The fact that most books lose money and are subsidized by the few that succeed is well known in all areas of market-driven publishing.

If the educational establishment wishes to change the rules of the game, it will follow as the night the day that publishers will adapt. Pressure on authors and urgent arguments to adopting committees are part of the dynamics, but without willing cooperation of these partners in the enterprise, publishers would be powerless. In the end, I agree with Humpherys that the teachers, albeit not being the consumers themselves, ought to be the primary voice in determining what tools they want in the teaching of our children. How they can best exercise their "responsibility and obligation" in this process ought to be the subject of ongoing debate within the educational establishment and should involve the publishers. To paraphrase a comment from my article, "If commercial publishers are part of the problem, they CAN also be part of the solution."

—*Edwin F. Beschler*
Boston, MA

(Received November 8, 1998)

Linear Systems of Plane Curves

Rick Miranda

Introduction

Interpolation with polynomials is a subject that has occupied mathematicians' minds for millenia. The general problem can be informally phrased as: Given a set of points $\{(x_i, y_i)\}$ in the plane, find a polynomial $f(x, y)$ with these points as roots. (The one-variable version of this problem is easy and crops up in the high school and undergraduate curriculum on occasion.) Sometimes one asks for a polynomial of minimal degree that works. The condition to pass through a point is a linear one, and so a more sophisticated version of the interpolation problem asks for the vector space of *all* interpolating polynomials whose degree is bounded by a particular integer.

In this article I want to draw the reader's attention to the *dimension* of such a space. It turns out that if the points are in very special positions, the interpolation conditions may be dependent, which complicates the problem, of course. We then make the blanket assumption that the points are in *general* position, which insures that the interpolation conditions are independent; but then, as one realizes immediately, the dimension question is trivial: the codimension of the space of interpolating polynomials is equal to the number of points being imposed.

We therefore recomplicate the problem by requiring a more subtle form of interpolation: for each point p we fix an integer m (depending on p) and require that the polynomial not only vanish at p, but vanish "to order m": it and all of its derivatives up through order $m-1$ also vanish at p. We often say that the polynomial has *multiplicity* m at p if it vanishes to order m.

Rick Miranda is professor of mathematics at Colorado State University. His e-mail address is `miranda@math.colostate.edu`.

This more general problem, even for points in general position, turns out to be surprisingly complicated. The number of conditions imposed by asking a polynomial $f(x, y)$ to vanish to order m at p is $m(m+1)/2$: this is just the number of terms in the Taylor expansion of f at p up through order $m-1$, and all of these coefficients must vanish. So the naive conjecture would be that the codimension of the space of interpolating polynomials vanishing to order m_i at p_i is equal to $\sum_i m_i(m_i+1)/2$ (unless, of course, the interpolating space is empty); this gives the "expected" dimension, assuming that all the linear conditions being imposed are independent.

This naive conjecture is false, as some easy examples show. The simplest is to consider the space of conics having multiplicity two at each of two points p and q. The vector space dimension of conics is six, and each multiplicity-two point gives three conditions, so one expects there to be *no* nonzero conics double at the two points. However, if $e(x, y)$ is the linear polynomial defining the line through p and q, then $e(x, y)^2$ is a nonzero conic double at p and q.

The real conjecture, due to Harbourne and Hirschowitz in the mid-1980s, states that if the space of interpolating polynomials does not have the expected dimension, then there is a polynomial $e(x, y)$ such that every interpolating polynomial is divisible by $e(x, y)^2$. Moreover, the polynomial $e(x, y)$ has a special form, which will be exposed later.

Although the conjecture is rather recent, the general problem goes back to the last century, more or less to the origins of algebraic geometry. Bézout in the 1700s; Plücker, Bertini, and M. Noether in the 1800s; and Terracini, Castelnuovo, Segre, and Severi in this century all made contributions, among many others. Coolidge's treatise [Co] makes for interesting reading even today.

My purpose in writing this article is to pique the interest of *Notices* readers in this curious situation and to explain some of the methods leading to the conjecture. Along the way I shall discuss some of the variations and applications of the conjecture (in particular, the higher-dimensional analogue of the problem and its relationship to Waring's problem for forms) and give an impression of some recent results.

Basic Definitions

The Projective Space of Plane Curves

We regard the underlying field as the complex numbers. Informally, an algebraic curve in the plane is given by the vanishing of a nonzero polynomial $f(x, y) = 0$. This is a bit dangerous if we want to focus on the polynomials themselves, since the set of zeroes of the polynomial does not determine the polynomial: for example, f and f^2 have the same zeroes. The only ambiguity not affecting later computations is multiplication of the polynomial by a nonzero constant. We therefore define an algebraic plane curve (of degree d) to be an equivalence class of nonzero polynomials of degree at most d, two being identified if they are scalar multiples of one another. Such polynomials, including the zero polynomial, form a vector space of dimension $(d^2 + 3d + 2)/2$, which is the number of monomials in x and y of degree at most d.

With this definition, we see that the space of plane curves is naturally a *projective space*, that is, the space of 1-dimensional subspaces of the vector space of polynomials of degree at most d. The dimension of a projective space is always one less than that of the corresponding vector space. A single point has dimension 0 and the empty set, projectively, has dimension -1. The projective space of 1-dimensional subspaces of $\mathbb{C}^{r+1}$ is denoted by $\mathbb{P}^r$.

Therefore the projective space $\mathcal{L}_d$ of plane curves of degree d has dimension $d(d+3)/2$.

A *component* of a curve C, with defining polynomial f, is the curve associated to any nonconstant factor of f; a curve is *irreducible* if its defining polynomial cannot be factored. Geometrically every curve is the union of its irreducible components.

Plane Curves Interpolating Points with Multiplicity

Fix a point p in the plane, and denote by $\mathcal{L}_d(-mp)$ the set of plane curves of degree d which have multiplicity at least m at p. Having multiplicity at least one at p is equivalent to the curve passing through p.

As noted above, for a curve C defined by $f(x, y) = 0$ to have multiplicity at least m at p is exactly $m(m+1)/2$ independent linear conditions on the coefficients of f, as long as the degree of f is at least $m - 1$. Therefore the set $\mathcal{L}_d(-mp) \subset \mathcal{L}_d$ is either empty (if $d \le m-1$) or has codimension $m(m+1)/2$.

Suppose now that $p_1, \ldots, p_n$ are distinct points in the plane and that $m_1, \ldots, m_n$ are nonnegative integers. Define

$$\mathcal{L}_d\left(-\sum_{i=1}^n m_i p_i\right) = \{C \in \mathcal{L}_d(-m_i p_i) \text{ for every } i\} = \bigcap_{i=1}^n \mathcal{L}_d(-m_i p_i)$$

to be the space of plane curves of degree d having multiplicity at least m_i at p_i for each i. This is a linear subspace of $\mathcal{L}_d$, called a *linear system* of plane curves. The problem we have set ourselves to investigate is, What is the dimension of the linear system $\mathcal{L}_d(-\sum_{i=1}^n m_i p_i)$?

The Virtual and Expected Dimension

As noted above, one knows that for each point p the $m(m+1)/2$ conditions imposed by asking the curve to have multiplicity at least m are independent. However, if there is more than one point, it is not at all clear whether the totality of all these conditions at every point is independent.

If so, we have an easy formula for the dimension: if there are n points, define the *virtual dimension* of $\mathcal{L} = \mathcal{L}_d(-\sum_{i=1}^n m_i p_i)$ by

$$(1) \qquad v = v_d\left(-\sum_{i=1}^n m_i p_i\right) = \frac{d(d+3)}{2} - \sum_{i=1}^n m_i(m_i+1)/2.$$

Note that if this number is negative, then we really expect the space $\mathcal{L}$ to be empty; hence we define the *expected dimension* of $\mathcal{L}$ to be

$$(2) \qquad e = e_d\left(-\sum_{i=1}^n m_i p_i\right) = \max\{-1, v\}.$$

We note that

$$\dim \mathcal{L}_d\left(-\sum_{i=1}^n m_i p_i\right) \ge e_d\left(-\sum_{i=1}^n m_i p_i\right) \ge v_d\left(-\sum_{i=1}^n m_i p_i\right),$$

since the failure of the conditions to be independent can only raise the dimension of the interpolating space. Notice that the second and third quantities are equal if either is at least -1.

Whether this space of curves has the expected dimension depends on the positions of the points, even if all of the multiplicities are one.

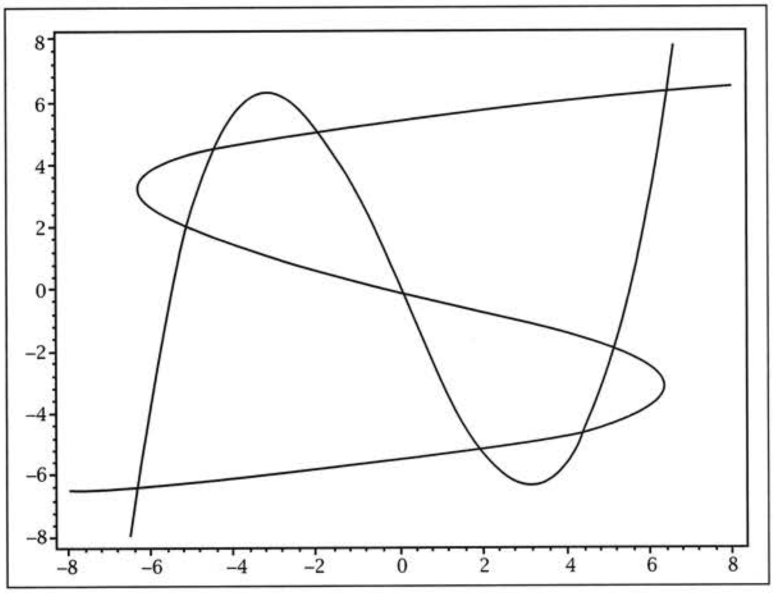

Figure 1. The nine intersections of two cubic curves, namely, $x = .1(y^3 - 30y)$ and $y = .1(x^3 - 30x)$. Only points with real coordinates are plotted, and all nine intersections are of this kind. For these cubics, there are no intersections at the points at infinity in the projective plane, and the intersection numbers of the two curves are 1 at each point of intersection.

Example 1. Suppose $d+2 \leq n \leq d(d+3)/2$ and all the points p_i, $1 \leq i \leq n$, lie on a line ℓ. We can change coordinates and assume that the line is the x-axis, given by $y = 0$, and hence the points p_i have the form $p_i = (x_i, 0)$. Suppose that C is a plane curve of degree d containing $d+1$ of the points, say $p_1, \dots, p_{d+1}$. If $f(x,y) = 0$ defines C, then this means that $f(x_i, 0) = 0$ for $1 \leq i \leq d+1$, and therefore the polynomial $f(x,0)$ has $d+1$ roots. Since it is a polynomial of degree at most d in x, it must be identically zero. The only way $f(x,0)$ can be identically zero is if every term of $f(x,y)$ contains y, which is equivalent to having y divide f. If this happens, then the curve C contains the line ℓ as a component.

What we have shown is that any curve $C \in \mathcal{L}_d(-\sum_{i=1}^{d+1} p_i)$ must, in this case, contain the line ℓ through all of the n points. Therefore, any curve of degree d containing the first $d+1$ points automatically contains the remaining $n-d-1$ points. Hence $\mathcal{L}_d(-\sum_{i=1}^{n} p_i) = \mathcal{L}_d(-\sum_{i=1}^{d+1} p_i)$, so that

$$\begin{aligned} \dim \mathcal{L}_d\left(-\sum_{i=1}^{n} p_i\right) \\ &= \dim \mathcal{L}_d\left(-\sum_{i=1}^{d+1} p_i\right) \geq \nu_d\left(-\sum_{i=1}^{d+1} p_i\right) \\ &= \frac{d(d+3)}{2} - (d+1) > \frac{d(d+3)}{2} - n \\ &= e_d\left(-\sum_{i=1}^{n} p_i\right), \end{aligned}$$

the final equality holding because $n \leq d(d+3)/2$. Hence we see in this case that the actual dimension is strictly greater than the expected dimension.

Example 2. Let C and D be two plane cubic curves which intersect nine times (this is forced by Bézout's theorem, which we shall discuss below). Suppose in fact they intersect transversally (crossing each other with distinct tangents) at nine distinct points $p_1, \dots, p_9$ (which happens generically, in fact). Consider the linear system $\mathcal{L} = \mathcal{L}_3(-\sum_{i=1}^{9} p_i)$ of cubics through the nine points. Since we have by construction two such cubics, this linear space contains two elements and so must have dimension at least one. But $\nu = 9 - 9 = 0$, so that the expected dimension e is also zero. Hence, we again have the situation where the actual dimension is greater than the expected dimension. See Figure 1.

Choosing Points Generically

The previous examples have dimension greater than the expected dimension because the positions of the points are special in some way. To understand this phenomenon, it is useful to consider the linear system $\mathcal{L}_d(-\sum_i m_i p_i)$, as a vector space of polynomials, to be the kernel of a linear map ϕ. This map ϕ simply takes a polynomial f to a t-tuple (where $t = \sum_i m_i(m_i+1)/2$) by evaluating f and all relevant derivatives at the points p_i. The map ϕ has a matrix when we use the basis of monomials $\{x^r y^s\}$ for the vector space of all polynomials of degree at most d. In this basis, if $p_i = (x_i, y_i)$, then the matrix for ϕ has entries equal to the derivatives of the monomials $x_i^a y_i^b$.

Let $\mathcal{R}_k$ be the set of all n-tuples of points $(p_1, \dots, p_n)$ where the above matrix has rank at most k. We clearly have $\mathcal{R}_{k-1} \subseteq \mathcal{R}_k$ for every k; moreover, for large k we see that $\mathcal{R}_k = (\mathbb{P}^2)^n$, since as soon as k is larger than the size of the matrix, there is no condition on the points p_i. Therefore, there is a maximum number r such that $\mathcal{R}_r \neq (\mathbb{P}^2)^n$, but $\mathcal{R}_{r+1} = (\mathbb{P}^2)^n$.

Suppose that the points $\{p_i\}$ are chosen so that $(p_1, \dots, p_n\}$ does *not* lie in $\mathcal{R}_r$. Then the matrix for ϕ has the maximum possible rank (namely, $r+1$) so that the dimension of the kernel has minimum possible dimension. The locus $\mathcal{R}_r$ is a closed subset of $(\mathbb{P}^2)^n$, defined by the vanishing of all $(r+1) \times (r+1)$ minors of the matrix for ϕ, and has dimension strictly smaller than $2n$, which is the dimension of $(\mathbb{P}^2)^n$. Therefore, we see that if we choose the n-tuple of points off this closed subset of lower dimension, the space $\mathcal{L}_d(-\sum_i p_i)$ achieves its minimum possible dimension, which we call the *generic dimension* for curves of degree d having the required multiplicities at the n points. For this problem, n-tuples of points off this closed subset will be said to be *in general position.*

The Multiplicity One Theorem

We can now address the situation that arose first in the introduction: the simple interpolation of polynomials, without higher multiplicities. In this case there are no surprises; all such systems have the expected dimension.

Multiplicity One Theorem. If the points $\{p_i\}$ are in general position, then the dimension of $\mathcal{L}_d(-\sum_i p_i)$ is equal to the expected dimension.

Proof: We prove this by induction on the number of points n. For $n = 0$ it is clear, and for $n = 1$ we are claiming that we can choose the point p_1 so that it does not lie on every curve of degree d, which is obvious. For the general induction step, since each additional point contributes exactly one linear condition, all that is required is to show that this condition is not dependent on the previous conditions. This is equivalent to having each additional point not lie on every curve passing through the previous points. Of course, if the points are in general position, it will not: simply take any curve passing through the previous points and take as the additional point any point not on that curve. □

First Examples of Special Systems

We say that a linear system $\mathcal{L}_d(-\sum_i m_i p_i)$ is *special* if it does not have the expected dimension; otherwise it is *nonspecial*. The Multiplicity One Theorem says that if all m_i are equal to one, then the system is nonspecial. A naive conjecture would be the analogue of the Multiplicity One Theorem: For generic choices of the points, the dimension of the system is equal to the expected dimension. As noted in the introduction, this is false, as the example of conics double at two points shows: $\dim \mathcal{L}_2(-2p-2q) = 0$, but the expected dimension is -1.

Let us offer another example of a case where no matter how general the choice of the points is, the linear system is special.

Example 3. Choose five points $p_1, \dots, p_5$ in the plane generically. Then $\dim \mathcal{L}_2(-\sum_i p_i) = 0$ by the Multiplicity One Theorem, since the virtual dimension is $5 - 5 = 0$: there is a unique conic through the five points. Let e be the quadratic equation defining this conic, and let $f = e^2$. Then f is a quartic, and as above the multiplicity of f is 2 at all points of the conic, in particular at each of the original five points. Hence $\mathcal{L}_4(-\sum_i 2p_i)$ is not empty. However, its virtual dimension is $v = 14 - 5 \cdot 3 = -1$, and so the system is expected to be empty.

(-1)-Curves

Intersection Multiplicities

To begin to understand the phenomenon of special systems, it is necessary to introduce the notion of intersection multiplicities between two curves. Briefly speaking, if two curves C_1 and C_2 meet at a point p, we want to carefully count *how many times* they meet there. This is nothing more than a generalization of the multiplicity of a root of a single equation in one variable; here we have two equations in two variables. I do not want to enter into the technicalities in this article. One can consult [F] for an elementary treatment; suffice it to say that if the curves C_1 and C_2 do not have a common component passing through a point p, then a nonnegative integer $I_p(C_1, C_2)$ is defined that measures the "intersection multiplicity" we need. It satisfies the following properties:

- $I_p(-,-)$ is bilinear over the integers,
- $I_p(C_1, C_2) \geq 1 \iff p \in C_1$ and $p \in C_2$,
- $I_p(C_1, C_2) \geq \mathrm{mult}_p(C_1) \cdot \mathrm{mult}_p(C_2)$, and
- $\sum_p I_p(C_1, C_2) = \deg(C_1) \cdot \deg(C_2)$.

The first three of these properties are not hard to understand. The first is quite natural: it says that if C meets D a total of r times at p and meets E a total of s times at p, then it meets the union $D + E$ a total of $r + s$ times at p. (Here the "sum" of two curves is given by the product of their defining functions.) The second simply indicates that $I_p = 0$ when p is not a root of both equations. The third generalizes the second: a curve C having multiplicity m at p is, generically, m branches, or separate smooth arcs, through p. If C_i has multiplicity m_i at p, then $I_p(C_1, C_2)$ gets a contribution of at least one from each branch of C_1 meeting each branch of C_2.

The final property is more subtle and is *Bézout's Theorem*: the number of intersections is the product of the degrees, "counted properly". Here counting properly means using the intersection multiplicity, and the sum is taken over all points in the *projective plane*, including, of course, whatever points at infinity are involved in the intersection. Bézout's Theorem holds only when the curves do not share a common component. It is the generalization to two variables of the fact that a polynomial in one variable of degree d has exactly d roots, counting roots according to their order.

Extra Intersections

Fix once and for all points $p_1, \dots, p_n$ in the plane. Consider a curve $D \in \mathcal{L}_d(-\sum m_i p_i)$ and another curve $E \in \mathcal{L}_e(-\sum k_i p_i)$: where do D and E meet? At one of the chosen points p_i, D has multiplicity at least m_i and E has multiplicity at least k_i, so that the third property of intersection numbers says that $I_{p_i}(D, E) \geq m_i k_i$. Therefore we have at least $\sum_i m_i k_i$ intersections all accounted for at the chosen points. The total number of intersections is, by Bézout's Theorem, the product de of the degrees. Therefore it is natural to consider the number of "extra intersections" $de - \sum_i m_i n_i$.

This quantity has several advantages, the primary one being that it is *bilinear* (over the integers) in the given data (of degrees and multiplicities); in-

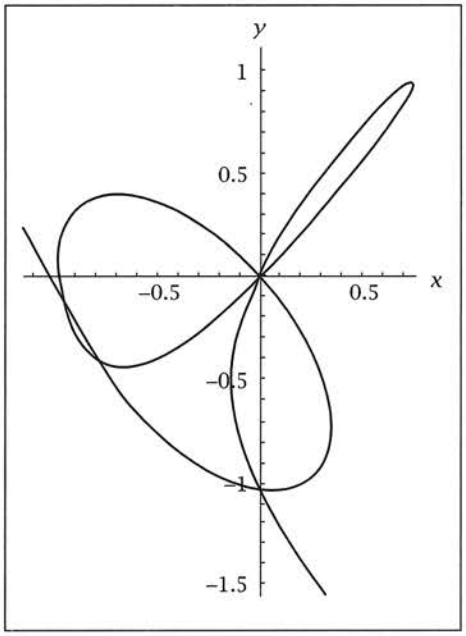

Figure 2. A quintic with one triple point and three other double points. The equation is: $18x^5+5x^4y-9x^3y^2-17x^2y^3+2xy^4$ $+9y^5+36x^4-4x^3y-29x^2y^2-16xy^3$ $+18y^4+18x^3-9x^2y-18xy^2+9y^3=0$. **The curve has a triple point at (0,0) and double points at (−1,0), (0,−1), and (−18/23, −9/23).**

deed, it depends only on these data. We are inexorably led to giving these data lives of their own: let us define a *curve class* to be an $(n+1)$-tuple of integers $(d; m_1, m_2, \dots, m_n)$; these form a group under addition. If C is an actual curve in the plane, we say that C belongs to the curve class $(d; m_1, m_2, \dots, m_n)$ if $\deg(C) = d$ and the multiplicity of C at p_i is at least m_i for each i.

Curve classes have associated linear systems (the space of curves $\mathcal{L}_d(-\sum_i m_i p_i)$), and derived from this they have virtual, expected, and actual dimensions. The first two of these are defined by (1) and (2) as earlier. The third is the generic dimension of $\mathcal{L}_d(-\sum_i m_i p_i)$ determined when the points are in general enough position.

Given two curve classes, we may define their *extra-intersection number*, motivated by the discussion above: if $\mathbf{d} = (d; m_1, \dots, m_n)$ and $\mathbf{e} = (e; n_1, \dots, n_n)$ are two curve classes, define $\langle \mathbf{d}, \mathbf{e} \rangle = de - \sum_i m_i n_i$. This is a bilinear function of curve classes.

One immediate result is that if C and D are curves belonging to curve classes $\mathbf{c}$ and $\mathbf{d}$ respectively, and $\langle \mathbf{c}, \mathbf{d} \rangle < 0$, then C and D must share a common component, since Bézout's Theorem is failing to hold. If, for example, C is an irreducible curve, then in this case C must be a component of D. We will often abuse the notation for the extra-intersection number slightly by applying it to actual curves instead of the curve classes; in this way we would write $\langle C, D \rangle$ for $\langle \mathbf{c}, \mathbf{d} \rangle$. We occasionally abuse the notation further and apply it to the linear systems $\mathcal{L}_d(-\sum_i m_i p_i)$ also.

The Genus Formula

Define the "canonical curve class" $\mathbf{k} = (-3; -1, -1, \dots, -1)$; this has all negative data, but the opposite curve class $-\mathbf{k} = (3, 1, 1, \dots, 1)$ is more easily understood: its linear system consists of cubic curves passing through all the points. There may not be any such curves, but the algebra of extra intersections does not really care.

With this class in hand, we have a formula for the virtual dimension of a curve class $\mathbf{c} = (d; m_1, \dots, m_n)$, expressed entirely in terms of extra-intersection numbers:

$$
\begin{aligned}
\nu(\mathbf{c}) &= \nu_d\Big(-\sum_i m_i p_i\Big) \\
&= \frac{d(d+3)}{2} - \sum_i \frac{m_i(m_i+1)}{2} \qquad (3)\\
&= \langle \mathbf{c}, \mathbf{c} - \mathbf{k} \rangle / 2.
\end{aligned}
$$

Here the difference $\mathbf{c} - \mathbf{k}$ is the class with the difference of the data: $\mathbf{c} - \mathbf{k} = (d+3; m_1+1, \dots, m_n+1)$. This formula happens to be a special case of the celebrated Riemann-Roch Theorem, but this fact will not concern us.

So far this extra-intersection number has not been useful in telling us anything we did not know already; let us remedy this. Recall that a smooth complex curve is a *Riemann surface*, i.e., a closed one-dimensional complex manifold; as such it is a closed orientable real two-manifold, and topologically it may be described by its *genus*.

A sphere has genus zero: examples are lines and conics in the plane. A torus has genus one: a smooth plane cubic curve is the prototype. If a curve C belonging to a curve class $\mathbf{c}$ is smooth and irreducible after resolving the singularities that are forced at the chosen points p_i with $m_i \geq 2$, then it will also have a genus g. The Genus Formula in the case that all of the singularities are ordinary (that is, each point of multiplicity m consists of m branches with distinct tangents) is

$$
g(C) = 1 + \langle C, C + \mathbf{k} \rangle / 2, \qquad (4)
$$

which expresses the genus of C in terms of an extra-intersection number. The formula actually decomposes into

$$
g(C) = (d-1)(d-2)/2 - \sum m_i(m_i - 1)/2,
$$

which some readers may recognize as a generalization of the famous Plücker formula, one of the cornerstones of surface theory.

For an irreducible curve C, the genus must be nonnegative. If a class is encountered with negative genus (which is numerically possible), its linear system cannot contain irreducible curves.

(-1)-Curves

The *self-intersection* of a class $\mathbf{c}$ is the integer obtained by extra-intersecting $\mathbf{c}$ with itself: $\langle \mathbf{c}^2 \rangle = \langle \mathbf{c}, \mathbf{c} \rangle$. If $\mathbf{c} = (d; m_1, \dots, m_n)$, then $\langle \mathbf{c}^2 \rangle = d^2 - \sum m_i^2$. It can well happen that a curve class $\mathbf{c}$ has negative self-intersection, even if it is a curve class of a real curve! This may initially be disturbing, but if one thinks for a moment, there is no contradiction to Bézout's Theorem. A simple example is a line through two chosen points, i.e., the curve class $(1; 1, 1)$. Another is a conic through five points; both these examples have $\langle C^2 \rangle = -1$.

These two examples are also extremal in the sense that they are both irreducible curves with zero genus, the minimum possible. Note from (4) that when $\langle C^2\rangle = -1$ and $\langle C, \mathbf{k}\rangle = -1$, then we have a genus zero curve. The condition that $g(C) = 0$ is equivalent to $\langle C, \mathbf{k}\rangle = -1$ if $\langle C^2\rangle = -1$. Such curves, which are simple spheres after resolving the singularities, are called (-1)-*curves*; every interesting extra-intersection number is -1.

Some other interesting (-1)-curves are cubics with one double point, passing through six other points. In general curves of degree e with one point of multiplicity $e-1$ and $2e$ points of multiplicity one are (-1)-curves. These are not the only types: sextics with one triple point and seven double points start another whole family. In general there are infinitely many sets of numerical data giving (-1)-curves, although only finitely many with eight or fewer chosen points. There are already infinitely many with nine points alone.

The Main Conjecture

Generating Special Systems with (–1)-Curves

Recalling two of our first examples of special systems, namely, conics double at two points and quartics double at five points, we see that each of these involve (-1)-curves in an essential way: these systems are expected to be empty, but in fact each contains as its unique element the double of a (-1)-curve. (The *double* of a curve is the curve defined by the square of the defining polynomial.) This turns out to be a critical observation and leads to the systematic generation of other special systems.

Indeed, suppose one wants to explore the generality of this type of example. We seek a curve E that exists whose double $2E$ is not expected to exist. We obtain the following system of inequalities for the relevant extra-intersection numbers:

$$\langle E^2\rangle - \langle E, \mathbf{k}\rangle \geq 0 \qquad (E \text{ is expected to exist, by (3)})$$

$$\langle E^2\rangle + \langle E, \mathbf{k}\rangle \geq -2 \qquad (E \text{ has a nonnegative genus, by the Genus Formula})$$

$$4\langle E^2\rangle - 2\langle E, \mathbf{k}\rangle \leq -1 \qquad (2E \text{ is not expected to exist, by (3)}).$$

The only solution to these inequalities is $\langle E^2\rangle = \langle E, \mathbf{k}\rangle = -1$, forcing E to be a (-1)-curve!

This little back-of-the-envelope calculation is not definitive but at least serves the purpose of focusing our attention on (-1)-curves and the way they prevent linear systems from having the expected dimension. In the above example it is the linear system of the double class $2E$ that visibly exists but is not expected to. It is not only the numerology of the (-1)-curve, but also the fact that it occurs *doubly* in the unexpected system that is important.

To see why this is true, suppose that a curve class $\mathbf{c}$ with linear system $\mathcal{L}$ has a negative extra-intersection number with a (-1)-curve E, say $\langle \mathcal{L}, E\rangle = -N$ with $N \geq 1$. Since E is an irreducible curve, by Bézout's Theorem every member of the system $\mathcal{L}$ must contain E as a component. We can therefore remove E (subtracting the data of the degree and multiplicity of E from $\mathcal{L}$) and obtain a residual class $\mathcal{L}' = \mathcal{L} - E$. If $N \geq 2$, the residual class also has $\langle \mathcal{L}', E\rangle < 0$, and so E will be removable again. Iterating the analysis implies that a total of N copies of E can be removed from $\mathcal{L}$; algebraically, this means that if the equation of E is $f(x, y) = 0$, then f^N divides the equation of every member of $\mathcal{L}$.

Denote by $\mathcal{M} = \mathcal{L} - NE$ the total residual system, obtained from $\mathcal{L}$ by removing all N copies of E from every member; then $\langle \mathcal{M}, E\rangle = 0$. A straightforward computation using the bilinearity of the extra-intersection number and (3) shows that

$$v(\mathcal{M}) = v(\mathcal{L}) + N(N-1)/2.$$

Notice that the actual dimensions of the two systems are the same: the elements of $\mathcal{L}$ differ from the elements of $\mathcal{M}$ only by the inclusion of NE as a component, which sets up an isomorphism between the two systems. Therefore, if $N \geq 2$ and the system $\mathcal{M}$ has positive virtual dimension, we see that

$$\begin{aligned}\dim(\mathcal{L}) = \dim(\mathcal{M}) &\geq v(\mathcal{M}) \\ &= v(\mathcal{L}) + N(N-1)/2 > v(\mathcal{L})\end{aligned}$$

and $\mathcal{L}$ is a special system, having dimension strictly greater than its virtual (and hence its expected) dimension.

Example 4. We can reverse this procedure and generate special systems more or less at will by adding in multiple (-1)-curves. Take any nonempty linear system $\mathcal{M}$ and a (-1)-curve E such that the extra-intersection number $\langle \mathcal{M}, E\rangle = 0$. Then the system $\mathcal{L} = \mathcal{M} + NE$ is special for every $N \geq 2$.

The special case when $\mathcal{M}$ is the trivial system gives the examples $\mathcal{L} = NE$, the special systems of multiple (-1)-curves all by themselves.

One can iterate this and continue to add in multiple (-1)-curves as long as one can find disjoint ones (disjoint in the sense of having extra-intersection number zero). A particularly spectacular example is afforded by considering the system $\mathcal{L}_{93}(-57p_0 - \sum_{i=1}^{7} 28p_i)$ of curves of degree 93 with one point of multiplicity 57 and seven points of multiplicity 28. The virtual dimension of this system is $93(96)/2 - 57(58)/2 - 7(28)(29)/2 = -31$, so that this is expected to be quite empty. However, as noted above, through seven general points there is always a cubic that is double at one and passes through the six others; and through eight general points there is always a sextic that is triple at one and passes through the seven others. Consider the seven cubics C_j, $1 \le j \le 7$, with a double point at p_0 and passing through all of the other seven points p_i except for p_j. Let S be the sextic triple at p_0 and double at the other seven p_i's. Then the given system contains as a member the curve $5S + 3\sum_{j=1}^{7} C_j$, and so is not empty at all! These eight curves $S, C_1, \dots, C_7$ are all disjoint (-1)-curves (disjoint in the sense of having extra-intersection number zero).

For those readers who like this sort of thing, one might also consider the linear system $\mathcal{L}_{96}(-\sum_{i=1}^{8} 34p_i)$ of curves of degree 96 with eight points of multiplicity 34. This system has $\nu = -8$, but there is a curve in the system! If one takes the eight sextics which are triple at one of the eight points and double at the other seven, adds them up, and doubles the result, the desired curve emerges.

The Main Conjecture

It is currently the case that the construction described above affords all known examples of special linear systems. Specifically, we have the following formulation:

Main Conjecture. If $\mathcal{L} = \mathcal{L}_d(-\sum m_i p_i)$ is a special linear system for generic points p_i, then there is a (-1)-curve E such that $(\mathcal{L} \cdot E) \le -2$.

More precise versions of the Main Conjecture have been formulated by Hirschowitz in [Hi] and Harbourne in [Ha1] (see also [Ha2]).

Before proceeding to discuss what is known about the conjecture, let us consider some variations to put the problem in a broader context.

Variations and Applications

The Generalization to Higher Dimension

The general problem of computing the dimension of a space of polynomials satisfying certain multiplicity conditions at a set of general points can be formulated in any dimension, not just in the plane. Define $\mathcal{L}_d^{(r)}$ to be the projective space of polynomials (modulo scalars) of degree at most d in r variables; this is a projective space of dimension $\binom{r+d}{d} - 1$. For a polynomial to have multiplicity at least m at a point p, one has $\binom{m-1+r}{r}$ conditions imposed (the number of Taylor coefficients of degree at most $m-1$). If we denote by $\mathcal{L}_d^{(r)}(-\sum_{i=1}^{n} m_i p_i)$ the space of polynomials of degree at most d in r variables having multiplicity at least m_i at n chosen points $\{p_i\}$, the problem is to compute the dimension of this space when the points are chosen generically. As the above discussion indicates, we have a *virtual dimension*

$$\nu = \nu_d^{(r)}\Big(-\sum_{i=1}^{n} m_i p_i\Big) = \binom{r+d}{d} - 1 - \sum_i \binom{m_i - 1 + r}{r}$$

and an *expected dimension* $e = \max\{-1, \nu\}$.

The reader can check that all this generalizes what we have discussed above in the case $r = 2$ and also gives the familiar formulas in the case $r = 1$.

The Alexander-Hirschowitz Theorem

In this general form, the problem of computing the dimension of $\mathcal{L}_d^{(r)}(-\sum_{i=1}^{n} m_i p_i)$ for n general points p_i is unsolved; there is not even a precise conjecture about which of these systems should be "special", in the sense of having dimension higher than expected. However, the analogue of the Multiplicity One Theorem is still true, with practically the same proof.

The only other statement known in higher dimension involves the multiplicity *two* case, which was settled by J. Alexander and A. Hirschowitz about 1988. Here the number of conditions imposed by a point of multiplicity at least two is $r+1$, so that the expected dimension is

$$\max\{-1, \binom{r+d}{d} - 1 - n(r+1)\}.$$

For a hypersurface to have multiplicity at least two at a point is equivalent to saying that it is singular at the point.

Alexander-Hirschowitz Theorem. Fix $r \ge 2$ and $d \ge 2$, and consider the linear system $\mathcal{L} = \mathcal{L}_d^{(r)}(-\sum_{i=1}^{n} 2p_i)$ consisting of hypersurfaces of degree at most d in r variables that are singular at n general points $\{p_i\}$.

(a) For $d = 2$, the linear system $\mathcal{L}$ is special if and only if $2 \le n \le r$.
(b) For $d \ge 3$, the linear system $\mathcal{L}$ is special if and only if the triple (r, d, n) is one of the following: $(2,4,5), (3,4,9), (4,4,14), (4,3,7)$.

Most of these special systems are rather easily understood. First, let us take up the case of the quadrics, where $d = 2$. Any quadric hypersurface is defined by a quadratic polynomial, which, if we homogenize, can be considered as a quadratic form in $r+1$ variables. This in turn can be considered as a symmetric square matrix Q of size $r+1$. We can choose coordinates so that the first $r+1$ of the points (if there are that many) occur at the "coordinate points" whose homogeneous coordinates correspond to the standard basis vectors; these are the points $[1:0:0:\cdots:0]$, $[0:1:0:\cdots:0]$, etc. For the quadric hypersurface to have multiplicity at least two at $[1:0:0:\cdots:0]$, the first row (and column) of the matrix Q must be zero. This is clearly $r+1$ linear conditions, as it should be. However, for the quadric to have multiplicity at least two at the second point $[0:1:0:\cdots:0]$, the second row and column of Q must be zero. If the first row and column are already zero, the first entry of the second row and column are automatically zero, so there are only r additional entries that must be zero. Hence the second point imposes only r conditions, not $r+1$, and the actual dimension is one larger than expected. This phenomenon continues until there are $r+1$ points, in which case the matrix Q is all zero, and there are no nontrivial quadratic polynomials satisfying the condition: $\mathcal{L}$ is empty and its actual dimension is -1, which is at this point quite expected.

We saw this example in the plane as the special system $\mathcal{L}_2(-2p-2q)$ of conics double at two points; this exists (as the double line) but is unexpected. Here $d=n=r=2$.

For the special systems with $d=4$, the philosophy is quite similar to that of the (-1)-curves in the plane: in every case the system is expected to be empty, but in fact a double quadric exists. To see the numerology of it all, first note that the space of quadrics in r-space has projective dimension $r(r+3)/2$. Let this be n, so that there exists a unique quadric passing through the n points. Then the double quadric will be a quartic with multiplicity two at the n points. For this to be unexpected, we want $v \le -1$, or

$$\binom{r+4}{4} - 1 - (r(r+3)/2)(r+1) \le -1,$$

which happens exactly for $r=2,3,4$. This explains the first three cases of (b) in the theorem.

The fourth one, the linear systems of cubics in 4-space with multiplicity at least 2 at seven general points, is a different animal altogether. Again the system is expected to be empty. However, there is a cubic with a fascinating construction in the system.

A *rational normal curve* in r-space is a curve that has, after a possible linear change of coordinates, the parametric description

$$t \mapsto (t, t^2, t^3, \dots, t^r).$$

These curves have a long history and enjoy many properties, causing them to attract more than their share of attention. For example, they have the smallest possible degree (namely r) among all curves spanning r-space. It is an exercise in linear algebra that through $r+3$ general points of r-space there passes a rational normal curve; in particular, through our seven general points of 4-space there passes a rational normal curve C. Let X be the union of all secant lines to C; since C is a curve and a point of a secant line is determined by choosing a first point x on C, choosing a second point y of C, and then choosing a third point on the line $\overline{xy}$, we see that X is a 3-dimensional object in 4-space. It therefore is defined by the vanishing of a single equation F, which is in fact of degree 3: there are exactly three secants to C meeting a general line of 4-space.

This cubic hypersurface X is the unexpected member of the linear system $\mathcal{L}_3^{(4)}(-\sum_1^7 2p_i)$. It clearly passes through the original seven points, since C does; therefore the multiplicity is at least one. If it were only one, say at p_1, then X would be smooth at p_1, not singular. Therefore X would have a tangent space at p_1, which would necessarily have dimension 3 and would contain every secant line of X which contained p_1. But since C spans the 4-space, there are secant lines to C through p_1 in four independent directions! This contradiction shows that X is singular all along C in fact, and in particular at the original seven points.

The reader who is interested in learning a bit more about rational normal curves may consult [Har].

The Waring Problem

The Waring problem for integers is the following: Given an integer N, write it as a sum of d^{th} powers. Of course, one can always do this by using 1^d N times, but the problem begins to have some meat to it when one asks how many d^{th} powers are necessary. For example, the famous Four Squares Theorem says that every positive integer can be written as a sum of four squares; this is sharp, since, for example, 7 is not a sum of three squares.

The Waring problem generalizes to polynomials as follows: Given a homogeneous polynomial ("form") F of degree d, write F as a sum of d^{th} powers of linear forms:

$$F = \sum_i L_i^d.$$

How many powers are necessary for a given F? For every F? For the general F?

It turns out that there is a surprising relationship between Waring's problem for forms and the Alexander-Hirschowitz Theorem on the dimension of linear systems of hypersurfaces with imposed singularities. This relationship exploits the duality between polynomials and partial differential operators.

Since we are discussing forms, it is convenient to work projectively. So fix homogeneous coordinates $[z_0 : z_1 : \cdots : z_r]$ in $\mathbb{P}^r$. Define dual variables $x_0, \dots, x_r$, that act on the z's as partial derivative operations: $x_i = \partial/\partial z_i$. In this way the dual polynomial ring $\mathbb{C}[x_0, \dots, x_r]$ acts on the original polynomial ring $\mathbb{C}[z_0, \dots, z_r]$ so that the homogeneous differential operators in $\underline{x}$ of degree d are perfectly paired with the homogeneous polynomials in $\underline{z}$ of degree d.

Now fix n points $p_1, \dots, p_n$ in $\mathbb{P}^r$ and a degree d. There are two constructions we can make with these n points. First, we can take the vector space of forms in the z's of degree d that are singular at the p_i's: this is the vector space associated to the space $\mathcal{L}_d^{(r)}(-\sum_i 2p_i)$ discussed above and is the subject of the Alexander-Hirschowitz Theorem.

Second, to any point $q = [q_0 : \cdots : q_r] \in \mathbb{P}^r$ we can associate the linear differential operator $\Delta = \sum_i q_i x_i$, which is well defined up to constant factor. In particular, to a set of n points $\{p_i\}$ in $\mathbb{P}^r$ we obtain a set of n linear differential operators $\Delta_1, \dots, \Delta_n$ in the dual polynomial ring $\mathbb{C}[x_0, \dots, x_r]$. Define

$$A_d^{(r)}\Big(\sum_i p_i\Big) = \Big\{\sum_i M_i(\underline{x})\Delta_i^{d-1} \mid \deg(M_i) = 1\Big\};$$

note that this is a subspace of the space of differential operators of degree d.

Recall that the differential operators in $\underline{x}$ of degree d are perfectly paired with the polynomials in $\underline{z}$ of degree d. In fact, under this pairing, the two spaces $\mathcal{L}_d^{(r)}(-\sum_i 2p_i)$ and $A_d^{(r)}(\sum_i p_i)$ exactly annihilate each other: this is Terracini's Lemma, dating back to 1915 or so.

The proof is not even too hard, once one organizes things and uses all of the algebraic tools at hand. The only real computation to make is to check that it is true for one point, say $p_1 = [1:0:0:\cdots:0]$. Then $\Delta_1 = x_0$, so $A_d^{(r)}(p_1)$ is spanned by the monomials $\{x_i x_0^{d-1} \mid 0 \le i \le r\}$.

Now $\mathcal{L}_d^{(r)}(-2p_1)$ is the space of polynomials of degree d that are singular at p_1, and this implies that such a polynomial cannot contain the monomial z_0^d (else it would not even vanish at p_1) nor any of the monomials $z_i z_0^{d-1}$ (else it would have multiplicity one at p_1).

Visibly these two spaces are dual to each other. This proves the statement for this one special point; it follows for any point by noticing that the duality is equivariant under linear transformations and any two points of $\mathbb{P}^r$ are in the same orbit of $\mathrm{GL}(r+1)$.

Now the statement for more than one point follows from the perfection of the pairing if one uses the equalities $A_d^{(r)}(\sum_i p_i) = \sum_i A_d^{(r)}(p_i)$ and $\mathcal{L}_d^{(r)}(-\sum_i 2p_i) = \bigcap_i \mathcal{L}_d^{(r)}(-2p_i)$.

The purpose of noticing this duality is to arrive at a determination of the dimension of $A_d^{(r)}(\sum_i p_i)$:

Corollary. Fix general points $\{p_i\}$. Then

$$\dim A_d^{(r)}\Big(\sum_i p_i\Big) = \binom{d+r}{r} - 1 - \dim \mathcal{L}_d^{(r)}(-\sum_i 2p_i).$$

If $d \ge 3$, then

$$\dim A_d^{(r)}\Big(\sum_i p_i\Big) = \min\Big\{n(r+1), \binom{d+r}{r}\Big\}$$

unless (r,d,n) is one of the four triples $(2,4,5), (3,4,9), (4,4,14), (4,3,7)$, in which case it is one less.

The first statement is simply an application of the duality, and the second uses the Alexander-Hirschowitz Theorem to identify the "unexpected" situations.

Now comes the connection to the Waring problem. Let W be the manifold of all forms of degree d in the x_i's that can be written as a sum of n d^{th} powers of linear forms. Fixing the points p_i as above and the corresponding linear forms Δ_i, we have that

$$A_d^{(r)}\Big(\sum_i p_i\Big) \text{ is the tangent space to } W \text{ at the point } w = \sum_i \Delta_i^d.$$

This is a simple calculation: the tangent space is given by the first-order terms of the variation

$$\sum_i (\Delta_i + M_i)^d = \sum_i \Delta_i^d + \sum_i d M_i \Delta_i^{d-1} + \dots,$$

which from the above expansion we see is exactly $A_d^{(r)}(\sum_i p_i)$.

At the general point of W, the dimension of the tangent space is equal to the dimension of W. If we want the general form to be written as a sum of n d^{th} powers, we need W to be the entire space of all forms of degree d, which is equivalent to having $\dim(W) = \binom{d+r}{r}$. Using the above computation, we then need $n(r+1) \ge \binom{d+r}{r}$, unless we are in one of the exceptional cases. This leads to the following.

Waring Problem for General Forms

Fix $d \ge 3$. Then the minimum n such that the general form of degree d in $r+1$ variables can be written as a sum of n d^{th} powers is $\lceil \frac{1}{r+1}\binom{d+r}{r} \rceil$, unless (r,d) is equal to $(2,4)$, $(3,4)$, $(4,4)$, or $(4,3)$, where it requires one more d^{th} power.

The exceptions were known in the last century; Clebsch, Reye, and Sylvester among others had noted them. For the experts, the manifold W introduced above is the "n-secant variety to the d-fold Veronese". Thinking in these terms, Lazarsfeld, Mukai, and others realized the connection between Alexander-Hirschowitz and Waring. The approach above is that taken by J. Emsalem and A. Iarrobino [I].

Recent Work on the Main Conjecture

The Main Conjecture concerning the dimensions of the linear systems of curves in the plane with general multiple base points, i.e., the spaces $\mathcal{L}_d(-\sum_i m_i p_i)$, is still open. Recent work has focused on the special case where all of the multiplicities are equal, say to m; this is the system

$\mathcal{L}_d(-\sum_{i=1}^{n} mp_i)$ of curves of degree d having multiplicity m at n general points. The $m = 2$ case has been treated by B. Segre, by E. Arbarello and M. Cornalba, and by A. Hirschowitz, and is now settled. Hirschowitz also handled the $m = 3$ case in 1985. The $m = 4$ case has recently been addressed by L. Evain and by T. Mignon (who also treats the general case with all $m_i \leq 4$). The Main Conjecture is also true in all of these cases.

In the last ten years there has been a flurry of activity in the area, by those mentioned above, and by L. Caporaso, J. Harris, A. Geramita, A. Gimigliano, Y. Pitteloud, and G. Xu; some of this builds on work of M. Nagata.

Recently the author, in joint work with C. Ciliberto of the University of Rome II, has been investigating a degeneration technique that applies to the problem at hand. The main idea is the following. We are studying systems of curves in the plane $\mathbb{P}^2$, with multiplicity at least m at n general points. If we put the points in special position, the dimension of the space can only rise, by semicontinuity. On the other hand, the special position of the points may allow us to compute the dimension more easily. If we are able to find a special position for the points such that the resulting system has the expected dimension, then it will certainly have the expected dimension for general positions of the points.

This "degeneration" approach, namely, to degenerate the positions of the points, is fundamentally the approach of the previous authors, in one form or another. The problem is that the computation of the dimension for the case when the points are in special position is, by its very nature, a somewhat special computation, and therefore it is difficult to arrange the analysis to take advantage of any possible recursions that may present themselves.

Ciliberto and the author have studied the possibility of degenerating the entire plane itself to two surfaces, each of which is more or less a plane. The corresponding degeneration in one dimension can be described as follows. Take the line with affine coordinate t. Embed the line in the plane using the coordinatization of the rational normal curve of degree 2: $t \mapsto (t, t^2)$. This realizes the line as a conic (a parabola, in fact) in the (x, y) plane, given by $y = x^2$. Now degenerate the conic to two lines by introducing a degeneration parameter u and considering $(1 - u)y^2 + uy = x^2$. For $u = 1$ we have the original parabola; for u near zero but not zero, we have hyperbolas; for $u = 0$ we have the two lines $y = \pm x$.

This trick, of degenerating one line to two, can be executed with the plane also using similar methods. One re-embeds the plane into 5-space (by sending (x, y) to (x, y, x^2, xy, y^2)); the result is a quartic surface, which then degenerates to a union of two surfaces, one a plane and one a cubic surface that is itself a re-embedded plane. This has the effect of degenerating the plane into two planes. A degeneration of this type was first exploited by Z. Ran for enumerative purposes in [R].

One now studies the degeneration of the plane curves, passing through n general points with multiplicity at least m. The advantage of this approach is that the n points also degenerate to points on the two surfaces, and one can arrange to degenerate a of the points on the one plane and $b = n - a$ of the points on the other plane. The plane curves then degenerate to plane curves of known degree having multiplicity at least m at a points (respectively b points) in the limit. The reader can now appreciate the possibility of a recursion being performed, which is in fact what we are able to execute in many cases.

The story gets technical rather quickly, but the bottom line is that using this method we have been able to verify that the Main Conjecture is true whenever the multiplicities are all constant and at most 12; these results are described in [CM1] and [CM2]. Unfortunately, we have found examples of parameters d, m, and n for which not one of these degenerations works, in the sense that the dimension of the limit system is always greater than the expected dimension: hence no conclusion can be drawn from the semicontinuity argument. So more thought is required!

I hope that I have piqued the reader's interest in some of these questions and given a small glimpse into the theoretical world of polynomial interpolation and its ramifications. In summary, here is a great classical problem, easily stated and understood, which is stubbornly resisting attempts to finish it off.

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Twenty Years of Attacks on the RSA Cryptosystem

Dan Boneh

Introduction

The RSA cryptosystem, invented by Ron Rivest, Adi Shamir, and Len Adleman [18], was first publicized in the August 1977 issue of *Scientific American*. The cryptosystem is most commonly used for providing privacy and ensuring authenticity of digital data. These days RSA is deployed in many commercial systems. It is used by Web servers and browsers to secure Web traffic, it is used to ensure privacy and authenticity of e-mail, it is used to secure remote login sessions, and it is at the heart of electronic credit card payment systems. In short, RSA is frequently used in applications where security of digital data is a concern.

Since its initial publication, the RSA system has been analyzed for vulnerability by many researchers. Although twenty years of research have led to a number of fascinating attacks, none of them is devastating. They mostly illustrate the dangers of improper use of RSA. Indeed, securely implementing RSA is a nontrivial task. Our goal is to survey some of these attacks and describe the underlying mathematical tools they use. Throughout the survey we follow standard naming conventions and use "Alice" and "Bob" to denote two generic parties wishing to communicate with each other. We use "Marvin" to denote a malicious attacker wishing to eavesdrop or tamper with the communication between Alice and Bob.

We begin by describing a simplified version of RSA encryption. Let $N = pq$ be the product of two large primes of the same size ($n/2$ bits each). A typical size for N is $n = 1024$ bits, i.e., 309 decimal digits. Each of the factors is 512 bits. Let e, d be two integers satisfying $ed = 1 \bmod \varphi(N)$ where $\varphi(N) = (p-1)(q-1)$ is the order of the multiplicative group $\mathbb{Z}_N^*$. We call N the *RSA modulus*, e the *encryption exponent*, and d the *decryption exponent*. The pair $\langle N, e\rangle$ is the *public key*. As its name suggests, it is public and is used to encrypt messages. The pair $\langle N, d\rangle$ is called the *secret key* or *private key* and is known only to the recipient of encrypted messages. The secret key enables decryption of ciphertexts.

A *message* is an integer $M \in \mathbb{Z}_N^*$. To encrypt M, one computes $C = M^e \bmod N$. To decrypt the ciphertext, the legitimate receiver computes $C^d \bmod N$. Indeed,

$$C^d = M^{ed} = M \mod N,$$

where the last equality follows by Euler's theorem.[1] One defines the RSA function as $x \longmapsto x^e \bmod N$. If d is given, the function can be easily inverted using the above equality. We refer to d as a *trapdoor* enabling one to invert the function. In this survey we study the difficulty of inverting the RSA function *without* the trapdoor. We refer to this as *breaking RSA*. More precisely, given the triple $\langle N, e, C\rangle$, we ask how *hard* is it to compute the e^{th} root of C modulo $N = pq$ when the factorization of N is unknown. Since $\mathbb{Z}_N^*$ is a finite set, one may enumerate all elements of $\mathbb{Z}_N^*$ until the correct M is found. Unfortunately, this results in an algorithm with running time of order N,

Dan Boneh is an assistant professor of computer science at Stanford University. His e-mail address is `dabo@cs.stanford.edu`.

[1] *Our description slightly oversimplifies RSA encryption. In practice, messages are padded prior to encryption using some randomness [1]. For instance, a simple (but insufficient) padding algorithm may pad a plaintext M by appending a few random bits to one of the ends prior to encryption. Adding randomness to the encryption process is necessary for proper security.*

namely, *exponential* in the size of its input, which is of the order $\log_2 N$. We are interested mostly in algorithms with a substantially lower running time, namely, on the order of n^c where $n = \log_2 N$ and c is some small constant (less than 5, say). Such algorithms often perform well in practice on the inputs in question. Throughout the paper we refer to such algorithms as *efficient*.

In this survey we mainly study the RSA *function* as opposed to the RSA *cryptosystem*. Loosely speaking, the difficulty of inverting the RSA function on random inputs implies that given $\langle N, e, C \rangle$, an attacker cannot recover the plaintext M. However, a cryptosystem must resist more subtle attacks. If $\langle N, e, C \rangle$ is given, it should be intractable to recover *any* information about M. This is known as *semantic security*.[2] We do not discuss these subtle attacks, but point out that RSA as described above is not semantically secure: given $\langle N, e, C \rangle$, one can easily deduce some information about the plaintext M (for instance, the Jacobi symbol of M over N can be easily deduced from C). RSA can be made semantically secure by adding randomness to the encryption process [1].

The RSA function $x \longmapsto x^e \bmod N$ is an example of a *trapdoor one-way function*. It can be easily computed, but (as far as we know) cannot be efficiently inverted without the trapdoor d except in special circumstances. Trapdoor one-way functions can be used for *digital signatures* [16]. Digital signatures provide authenticity and nonrepudiation of electronic legal documents. For instance, they are used for signing digital checks or electronic purchase orders. To sign a message $M \in \mathbb{Z}_N^*$ using RSA, Alice applies her private key $\langle N, d \rangle$ to M and obtains a signature $S = M^d \bmod N$. Given $\langle M, S \rangle$, anyone can verify Alice's signature on M by checking that $S^e = M \bmod N$. Since only Alice can generate S, one may suspect that an adversary cannot forge Alice's signature. Unfortunately, things are not so simple; extra measures are needed for proper security. Digital signatures are an important application of RSA. Some of the attacks we survey specifically target RSA digital signatures.

An RSA key pair is generated by picking two random $\frac{n}{2}$-bit primes and multiplying them to obtain N. Then, for a given encryption exponent $e < \varphi(N)$, one computes $d = e^{-1} \bmod \varphi(N)$ using the extended Euclidean algorithm. Since the set of primes is sufficiently dense, a random $\frac{n}{2}$-bit prime can be quickly generated by repeatedly picking random $\frac{n}{2}$-bit integers and testing each one for primality using a probabilistic primality test [16].

Factoring Large Integers

The first attack on an RSA public key $\langle N, e \rangle$ to consider is factoring the modulus N. Given the factorization of N, an attacker can easily construct $\varphi(N)$, from which the decryption exponent $d = e^{-1} \bmod \varphi(N)$ can be found. We refer to factoring the modulus as a *brute-force attack* on RSA. Although factoring algorithms have been steadily improving, the current state of the art is still far from posing a threat to the security of RSA when RSA is used properly. Factoring large integers is one of the most beautiful problems of computational mathematics [14, 17], but it is not the topic of this article. For completeness we note that the current fastest factoring algorithm is the General Number Field Sieve. Its running time on n-bit integers is $\exp\left((c + o(1))n^{1/3} \log^{2/3} n\right)$ for some $c < 2$. Attacks on RSA that take longer than this time bound are not interesting. These include attacks such as an exhaustive search for M and some older attacks published right after the initial publication of RSA.

Our objective is to survey attacks on RSA that decrypt messages without directly factoring the RSA modulus N. Nevertheless, it is worth noting that some sparse sets of RSA moduli, $N = pq$, can be easily factored. For instance, if $p - 1$ is a product of prime factors less than B, then N can be factored in time less than B^3. Some implementations explicitly reject primes p for which $p - 1$ is a product of small primes.

As noted above, if an efficient factoring algorithm exists, then RSA is insecure. The converse is a long-standing open problem: must one factor N in order to efficiently compute e^{th} roots modulo N? Is breaking RSA as hard as factoring? We state the concrete open problem below.

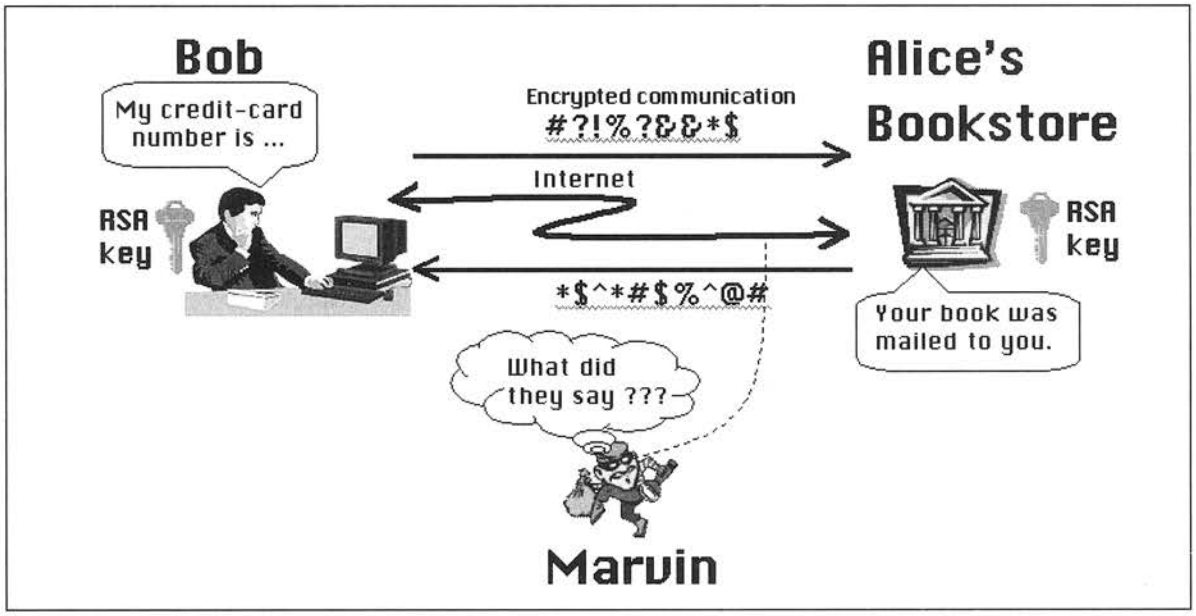
Open Problem 1. Given integers N and e satisfying $\gcd(e, \varphi(N)) = 1$, define the function $f_{e,N} : \mathbb{Z}_N^* \to \mathbb{Z}_N^*$ by $f_{e,N}(x) = x^{1/e} \bmod N$. Is there a polynomial-time algorithm $\mathcal{A}$ that computes the factorization of N given N and access to an "oracle" $f_{e,N}(x)$ for some e?

An *oracle* for $f(x)$ evaluates the function on any input x in unit time. Recently Boneh and Venkatesan [6] provided evidence that for small e the answer to the above problem may be no. In other words, for small e there may not exist a polynomial-time reduction from factoring to breaking RSA. They do so by showing that in a certain model, a positive answer to the problem for small e yields an efficient factoring algorithm. We note that a positive answer to Open Problem 1 gives rise to a "chosen ciphertext attack"[3] on RSA. Therefore, a negative answer may be welcome.

Next we show that exposing the private key d and factoring N are equivalent. Hence there is no

[2] *A source that explains semantic security and gives examples of semantically secure ciphers is [9].*

[3] *In this context, "chosen ciphertext attack" refers to an attacker, Marvin, who is given a public key $\langle N, e \rangle$ and access to a black box that decrypts messages of his choice. Marvin succeeds in mounting the chosen ciphertext attack if by using the black box he can recover the private key $\langle N, d \rangle$.*



point in hiding the factorization of N from any party who knows d.

Fact 1. Let $\langle N, e\rangle$ be an RSA public key. Given the private key d, one can efficiently factor the modulus $N = pq$. Conversely, given the factorization of N, one can efficiently recover d.

Proof. A factorization of N yields $\varphi(N)$. Since e is known, one can recover d. This proves the converse statement. We now show that given d, one can factor N. Given d, compute $k = de - 1$. By definition of d and e we know that k is a multiple of $\varphi(N)$. Since $\varphi(N)$ is even, $k = 2^t r$ with r odd and $t \geq 1$. We have $g^k = 1$ for every $g \in Z_N^*$, and therefore $g^{k/2}$ is a square root of unity modulo N. By the Chinese Remainder Theorem, 1 has four square roots modulo $N = pq$. Two of these square roots are ± 1. The other two are $\pm x$ where x satisfies $x = 1 \bmod p$ and $x = -1 \bmod q$. Using either one of these last two square roots, one can reveal the factorization of N by computing $\gcd(x-1, N)$. A straightforward argument shows that if g is chosen at random from $\mathbb{Z}_N^*$, then with probability at least $1/2$ (over the choice of g) one of the elements in the sequence $g^{k/2}, g^{k/4}, \dots, g^{k/2^t} \bmod N$ is a square root of unity that reveals the factorization of N. All elements in the sequence can be efficiently computed in time $O(n^3)$ where $n = \log_2 N$. □

Elementary Attacks

We begin by describing some old elementary attacks. These attacks illustrate blatant misuse of RSA. Although many such attacks exist, we give only two examples.

Common Modulus

To avoid generating a different modulus $N = pq$ for each user, one may wish to fix N once and for all. The same N is used by all users. A trusted central authority could provide user i with a unique pair e_i, d_i from which user i forms a public key $\langle N, e_i\rangle$ and a secret key $\langle N, d_i\rangle$.

At first glance this may seem to work: a ciphertext $C = M^{e_a} \bmod N$ intended for Alice cannot be decrypted by Bob, since Bob does not possess d_a. However, this is incorrect, and the resulting system is insecure. By Fact 1 Bob can use his own exponents e_b, d_b to factor the modulus N. Once N is factored Bob can recover Alice's private key d_a from her public key e_a. This observation, due to Simmons, shows that an RSA modulus should *never* be used by more than one entity.

Blinding

Let $\langle N, d\rangle$ be Bob's private key and $\langle N, e\rangle$ his corresponding public key. Suppose Marvin wants Bob's signature on a message $M \in \mathbb{Z}_N^*$. Being no fool, Bob refuses to sign M. Marvin can try the following: he picks a random $r \in \mathbb{Z}_N^*$ and sets $M' = r^e M \bmod N$. He then asks Bob to sign the random message M'. Bob may be willing to provide his signature S' on the innocent-looking M'. But recall that $S' = (M')^d \bmod N$. Marvin now simply computes $S = S'/r \bmod N$ and obtains Bob's signature S on the original M. Indeed,

$$S^e = (S')^e/r^e = (M')^{ed}/r^e \equiv M'/r^e = M \pmod N.$$

This technique, called *blinding*, enables Marvin to obtain a valid signature on a message of his choice by asking Bob to sign a random "blinded" message. Bob has no information as to what message he is actually signing. Since most signature schemes apply a "one-way hash" to the message M prior to signing [16], the attack is not a serious concern. Although we presented blinding as an attack, it is actually a useful property of RSA needed for implementing anonymous digital cash (cash that can be used to purchase goods, but does not reveal the identity of the person making the purchase).

Low Private Exponent

To reduce decryption time (or signature-generation time), one may wish to use a small value of d rather than a random d. Since modular exponentiation takes time linear in $\log_2 d$, a small d can improve performance by at least a factor of 10 (for a 1024-bit modulus). Unfortunately, a clever attack due to M. Wiener [19] shows that a small d results in a total break of the cryptosystem.

Theorem 2 (M. Wiener). Let $N = pq$ with $q < p < 2q$. Let $d < \frac{1}{3}N^{1/4}$. Given $\langle N, e\rangle$ with $ed = 1 \bmod \varphi(N)$, Marvin can efficiently recover d.

Proof. The proof is based on approximations using continued fractions. Since $ed = 1 \bmod \varphi(N)$, there exists a k such that $ed - k\varphi(N) = 1$. Therefore,

$$\left|\frac{e}{\varphi(N)} - \frac{k}{d}\right| = \frac{1}{d\varphi(N)}.$$

Hence, $\frac{k}{d}$ is an approximation of $\frac{e}{\varphi(N)}$. Although Marvin does not know $\varphi(N)$, he may use N to approximate it. Indeed, since $\varphi(N) = N - p - q + 1$ and $p + q - 1 < 3\sqrt{N}$, we have $|N - \varphi(N)| < 3\sqrt{N}$. Using N in place of $\varphi(N)$, we obtain:

$$\begin{aligned}\left|\frac{e}{N} - \frac{k}{d}\right| &= \left|\frac{ed - k\varphi(N) - kN + k\varphi(N)}{Nd}\right| \\ &= \left|\frac{1 - k(N - \varphi(N))}{Nd}\right| \le \left|\frac{3k\sqrt{N}}{Nd}\right| \\ &= \frac{3k}{d\sqrt{N}}.\end{aligned}$$

Now, $k\varphi(N) = ed - 1 < ed$. Since $e < \varphi(N)$, we see that $k < d < \frac{1}{3}N^{1/4}$. Hence we obtain:

$$\left|\frac{e}{N} - \frac{k}{d}\right| \le \frac{1}{d\sqrt[4]{N}} < \frac{1}{2d^2}.$$

This is a classic approximation relation. The number of fractions $\frac{k}{d}$ with $d < N$ approximating $\frac{e}{N}$ so closely is bounded by $\log_2 N$. In fact, all such fractions are obtained as convergents of the continued fraction expansion of $\frac{e}{N}$ [10, Th. 177]. All one has to do is compute the $\log N$ convergents of the continued fraction for $\frac{e}{N}$. One of these will equal $\frac{k}{d}$. Since $ed - k\varphi(N) = 1$, we have $\gcd(k, d) = 1$, and hence $\frac{k}{d}$ is a reduced fraction. This is a linear-time algorithm for recovering the secret key d. □

Since typically N is 1024 bits, it follows that d must be at least 256 bits long in order to avoid this attack. This is unfortunate for low-power devices such as "smartcards", where a small d would result in big savings. All is not lost however. Wiener describes a number of techniques that enable fast decryption and are not susceptible to his attack:

Large e: Suppose instead of reducing e modulo $\varphi(N)$, one uses $\langle N, e'\rangle$ for the public key, where $e' = e + t \cdot \varphi(N)$ for some large t. Clearly e' can be used in place of e for message encryption. However, when a large value of e is used, the k in the above proof is no longer small. A simple calculation shows that if $e' > N^{1.5}$, then no matter how small d is, the above attack cannot be mounted. Unfortunately, large values of e result in increased encryption time.

Using CRT: An alternate approach is to use the Chinese Remainder Theorem (CRT). Suppose one chooses d such that both $d_p = d \bmod (p-1)$ and $d_q = d \bmod (q-1)$ are small, say, 128 bits each. Then fast decryption of a ciphertext C can be carried out as follows: first compute $M_p = C^{d_p} \bmod p$ and $M_q = C^{d_q} \bmod q$. Then use the CRT to compute the unique value $M \in \mathbb{Z}_N$ satisfying $M = M_p \bmod p$ and $M = M_q \bmod q$. The resulting M satisfies $M = C^d \bmod N$ as required. The point is that although d_p and d_q are small, the value of $d \bmod \varphi(N)$ can be large, i.e., on the order of $\varphi(N)$. As a result, the attack of Theorem 2 does not apply. We note that if $\langle N, e\rangle$ is given, there exists an attack enabling an adversary to factor N in time $O\left(\min(\sqrt{d_p}, \sqrt{d_q})\right)$. Hence, d_p and d_q cannot be made too small.

We do not know whether either of these methods is secure. All we know is that Wiener's attack is ineffective against them. Theorem 2 was recently improved by Boneh and Durfee [4], who show that as long as $d < N^{0.292}$, an adversary can efficiently recover d from $\langle N, e\rangle$. These results show that Wiener's bound is not tight. It is likely that the correct bound is $d < N^{0.5}$. At the time of this writing, this is an open problem.

Open Problem 2. Let $N = pq$ and $d < N^{0.5}$. If Marvin is given $\langle N, e\rangle$ with $ed = 1 \bmod \varphi(N)$ and $e < \varphi(N)$, can he efficiently recover d?

Low Public Exponent

To reduce encryption or signature-verification time, it is customary to use a small public exponent e. The smallest possible value for e is 3, but to defeat certain attacks the value $e = 2^{16} + 1 = 65537$ is recommended. When the value $2^{16} + 1$ is used, signature verification requires 17 multiplications, as opposed to roughly 1,000 when a random $e \le \varphi(N)$ is used. Unlike the attack of the previous section, attacks that apply when a small e is used are far from a total break.

Coppersmith's Theorem

The most powerful attacks on low public exponent RSA are based on a theorem due to Coppersmith [7]. Coppersmith's theorem has many applications, only some of which will be covered here. The proof uses the LLL lattice basis reduction algorithm [15], as explained below.

Theorem 3 (Coppersmith). Let N be an integer and $f \in \mathbb{Z}[x]$ be a monic polynomial of degree d. Set $X = N^{\frac{1}{d}-\epsilon}$ for some $\epsilon \geq 0$. Then, given $\langle N, f \rangle$, Marvin can efficiently find all integers $|x_0| < X$ satisfying $f(x_0) = 0 \bmod N$. The running time is dominated by the time it takes to run the LLL algorithm on a lattice of dimension $O(w)$ with $w = \min(1/\epsilon, \log_2 N)$.

The theorem provides an algorithm for efficiently finding all roots of f modulo N that are less than $X = N^{1/d}$. As X gets smaller, the algorithm's running time decreases. The theorem's strength is its ability to find small roots of polynomials modulo a composite N. When working modulo a prime, there is no reason to use Coppersmith's theorem, since other, far better root-finding algorithms exist.

We sketch the main ideas behind the proof of Coppersmith's theorem. We follow a simplified approach due to Howgrave-Graham [12]. Given a polynomial $h(x) = \sum a_i x^i \in \mathbb{Z}[x]$, define $\|h\|^2 = \sum_i |a_i|^2$. The proof relies on the following observation.

Lemma 4. Let $h(x) \in \mathbb{Z}[x]$ be a polynomial of degree d, and let X be a positive integer. Suppose $\|h(xX)\| < N/\sqrt{d}$. If $|x_0| < X$ satisfies $h(x_0) = 0 \bmod N$, then $h(x_0) = 0$ holds over the integers.

Proof. Observe from the Schwarz inequality that

$$\begin{aligned} |h(x_0)| &= \left| \sum a_i x_0^i \right| \\ &= \left| \sum a_i X^i \left(\frac{x_0}{X}\right)^i \right| \leq \sum \left| a_i X^i \left(\frac{x_0}{X}\right)^i \right| \\ &\leq \sum \left| a_i X^i \right| \leq \sqrt{d}\, \|h(xX)\| < N. \end{aligned}$$

Since $h(x_0) = 0 \bmod N$, we conclude that $h(x_0) = 0$. □

The lemma states that if h is a polynomial with low norm, then all small roots of $h \bmod N$ are also roots of h over the integers. The lemma suggests that to find a small root x_0 of $f(x) \bmod N$, we should look for another polynomial $h \in \mathbb{Z}[x]$ with small norm having the same roots as f modulo N. Then x_0 will be a root of h over the integers and can be easily found. To do so, we may search for a polynomial $g \in \mathbb{Z}[x]$ such that $h = gf$ has low norm, i.e., norm less than N. This amounts to searching for an *integer linear combination* of the polynomials $f, xf, x^2f, \ldots, x^rf$ with low norm. Unfortunately, most often there is no nontrivial linear combination with sufficiently small norm.

Coppersmith found a trick to solve the problem: if $f(x_0) = 0 \bmod N$, then $f(x_0)^k = 0 \bmod N^k$ for any k. More generally, define the following polynomials:

$$g_{u,v}(x) = N^{m-v} x^u f(x)^v$$

for some predefined m. Then x_0 is a root of $g_{u,v}(x)$ modulo N^m for any $u \geq 0$ and $0 \leq v \leq m$. To use Lemma 4 we must find an integer linear combination $h(x)$ of the polynomials $g_{u,v}(x)$ such that $h(xX)$ has norm less than N^m (recall that X is an upper bound on x_0 satisfying $X \leq N^{1/d}$). Thanks to the relaxed upper bound on the norm (N^m rather than N), one can show that for sufficiently large m there always exists a linear combination $h(x)$ satisfying the required bound. Once $h(x)$ is found, Lemma 4 implies that it has x_0 as a root over the integers. Consequently x_0 can be easily found.

It remains to show how to find $h(x)$ efficiently. To do so, we must first state a few basic facts about lattices in $\mathbb{Z}^w$. We refer to [15] for a concise introduction to the topic. Let $u_1, \ldots, u_w \in \mathbb{Z}^w$ be linearly independent vectors. A (full-rank) lattice L spanned by $\langle u_1, \ldots, u_w \rangle$ is the set of all *integer* linear combinations of $u_1, \ldots, u_w$. The determinant of L is defined as the determinant of the $w \times w$ square matrix whose rows are the vectors $u_1, \ldots, u_w$.

In our case, we view the polynomials $g_{u,v}(xX)$ as vectors and study the lattice L spanned by them. We let $v = 0, \ldots, m$ and $u = 0, \ldots, d-1$, and hence the lattice has dimension $w = d(m+1)$. For example, when f is a quadratic monic polynomial and $m = 3$, the resulting lattice is spanned by the rows of the following matrix:

$$\begin{array}{r} \\ g_{0,0}(xX) \\ g_{1,0}(xX) \\ g_{0,1}(xX) \\ g_{1,1}(xX) \\ g_{0,2}(xX) \\ g_{1,2}(xX) \\ g_{0,3}(xX) \\ g_{1,3}(xX) \end{array} \begin{array}{c} \begin{array}{cccccccc} 1 & x & x^2 & x^3 & x^4 & x^5 & x^6 & x^7 \end{array} \\ \begin{bmatrix} N^3 & & & & & & & \\ & XN^3 & & & & & & \\ * & * & X^2N^2 & & & & & \\ & * & * & X^3N^2 & & & & \\ * & * & * & * & X^4N & & & \\ & * & * & * & * & X^5N & & \\ * & * & * & * & * & * & X^6 & \\ & * & * & * & * & * & * & X^7 \end{bmatrix} \end{array}$$

The entries $*$ correspond to coefficients of the polynomials whose value we ignore. All empty entries are zero. Since the matrix is triangular, its determinant is the product of the elements on the diagonal (which are explicitly given above). Our objective is to find short vectors in this lattice.

A classic result of Hermite states that any lattice L of dimension w contains a nonzero point $v \in L$ whose L_2 norm satisfies $\|v\| \leq \gamma_w \det(L)^{1/w}$, where γ_w is a constant depending only on w. Hermite's bound can be used to show that for large enough m our lattice contains vectors of norm less than N^m, as required. The question is whether we can efficiently construct a short vector in L whose length is not much larger than the Hermite bound. The LLL algorithm is an efficient algorithm that does precisely that.

Fact 5 (LLL). Let L be a lattice spanned by $\langle u_1, \ldots, u_w \rangle$. When $\langle u_1, \ldots, u_w \rangle$ are given as input, then the LLL algorithm outputs a point $v \in L$ satisfying

$$\|v\| \le 2^{w/4} \det(L)^{1/w}.$$

The running time for LLL is quartic in the length of the input.

The LLL algorithm (named after its inventors L. Lovasz, A. Lenstra, and H. Lenstra Jr.) has many applications in both computational number theory and cryptography. Its discovery in 1982 provided an efficient algorithm for factoring polynomials over the integers and, more generally, over number rings. LLL is frequently used to attack various cryptosystems. For instance, many cryptosystems based on the "knapsack problem" have been broken using LLL.

Using LLL, we can complete the proof of Coppersmith's theorem. To ensure that the vector produced by LLL satisfies the bound of Lemma 4, we need

$$2^{w/4}\det(L)^{1/w} < N^m/\sqrt{w},$$

where $w = d(m+1)$ is the dimension of L. A routine calculation shows that for large enough m the bound is satisfied. Indeed, when $X = N^{\frac{1}{d}-\epsilon}$, it suffices to take $m = O(k/d)$ with $k = \min(\frac{1}{\epsilon}, \log N)$. Consequently, the running time is dominated by running LLL on a lattice of dimension $O(k)$, as required.

A natural question is whether Coppersmith's theorem can be applied to bivariate and multivariate polynomials. If $f(x, y) \in \mathbb{Z}_N[x, y]$ is given for which there exists a root (x_0, y_0) with $|x_0 y_0|$ suitably bounded, can Marvin efficiently find (x_0, y_0)? Although the same technique appears to work for some bivariate polynomials, it is currently an open problem to prove it. As an increasing number of results depend on a bivariate extension of Coppersmith's theorem, a rigorous algorithm will be very useful.

Open Problem 3. Find general conditions under which Coppersmith's theorem can be generalized to bivariate polynomials.

Hastad's Broadcast Attack

As a first application of Coppersmith's theorem, we present an improvement to an old attack due to Hastad [11]. Suppose Bob wishes to send an encrypted message M to a number of parties $P_1, P_2, \ldots, P_k$. Each party has its own RSA key $\langle N_i, e_i \rangle$. We assume M is less than all the N_i's. Naively, to send M, Bob encrypts it using each of the public keys and sends out the i^{th} ciphertext to P_i. Marvin can eavesdrop on the connection out of Bob's sight and collect the k transmitted ciphertexts.

For simplicity, suppose all public exponents e_i are equal to 3. A simple argument shows that Marvin can recover M if $k \ge 3$. Indeed, Marvin obtains C_1, C_2, C_3, where

$$C_1 = M^3 \bmod N_1, \qquad C_2 = M^3 \bmod N_2, \qquad C_3 = M^3 \bmod N_3.$$

We may assume that $\gcd(N_i, N_j) = 1$ for all $i \neq j$, since otherwise Marvin can factor some of the N_i's. Hence, applying the Chinese Remainder Theorem (CRT) to C_1, C_2, C_3 gives a $C' \in \mathbb{Z}_{N_1 N_2 N_3}$ satisfying $C' = M^3 \bmod N_1 N_2 N_3$. Since M is less than all the N_i's, we have $M^3 < N_1 N_2 N_3$. Then $C' = M^3$ holds over the integers. Thus, Marvin may recover M by computing the real cube root of C'. More generally, if all public exponents are equal to e, Marvin can recover M as soon as $k \ge e$. The attack is feasible only when a small e is used.

Hastad [11] describes a far stronger attack. To motivate Hastad's result, consider a naive defense against the above attack. Rather than broadcasting the encryption of M, Bob could "pad" the message prior to encryption. For instance, if M is m bits long, Bob could send $M_i = i2^m + M$ to party P_i. Since Marvin obtains encryptions of different messages, he cannot mount the attack. Unfortunately, Hastad showed that this linear padding is insecure. In fact, he proved that applying any fixed polynomial to the message prior to encryption does not prevent the attack.

Suppose that for each of the participants $P_1, \ldots, P_k$, Bob has a fixed public polynomial $f_i \in \mathbb{Z}_{N_i}[x]$. To broadcast a message M, Bob sends the encryption of $f_i(M)$ to party P_i. By eavesdropping, Marvin learns $C_i = f_i(M)^{e_i} \bmod N_i$ for $i = 1, \ldots, k$. Hastad showed that if enough parties are involved, Marvin can recover the plaintext M from all the ciphertexts. The following theorem is a stronger version of Hastad's original result.

Theorem 6 (Hastad). Let $N_1, \ldots N_k$ be pairwise relatively prime integers, and set $N_{min} = \min_i(N_i)$. Let $g_i \in \mathbb{Z}_{N_i}[x]$ be k polynomials of maximum degree d. Suppose there exists a unique $M < N_{min}$ satisfying

$$g_i(M) = 0 \bmod N_i \qquad \text{for all } i = 1, \ldots, k.$$

Under the assumption that $k > d$, one can efficiently find M given $\langle N_i, g_i \rangle_{i=1}^k$.

Proof. Let $\overline{N} = N_1 \cdots N_k$. We may assume that all g_i's are monic. (Indeed, if for some i the leading coefficient of g_i is not invertible in $\mathbb{Z}_{N_i}^*$, then the factorization of N_i is exposed.) By multiplying each g_i by the appropriate power of x, we may assume they all have degree d. Construct the polynomial

$$g(x) = \sum_{i=1}^{k} T_i g_i(x),$$

$$\text{where } T_i = \begin{cases} 1 \bmod N_j & \text{if } i = j \\ 0 \bmod N_j & \text{if } i \neq j. \end{cases}$$

The T_i's are integers known as the Chinese Remainder Coefficients. Then $g(x)$ must be monic, since it is monic modulo all the N_i. Its degree is d. Furthermore, we know that $g(M) = 0 \bmod \overline{N}$. Theorem 6 now follows from Theorem 3, since $M < N_{min} \le \overline{N}^{1/k} < \overline{N}^{1/d}$. □

The theorem shows that a system of univariate equations modulo relatively prime composites can be efficiently solved, assuming sufficiently many equations are provided. By setting $g_i = f_i^{e_i} - C_i \bmod N_i$, we see that Marvin can recover M from the given ciphertexts whenever the number of parties is at least d, where d is the maximum of $e_i \deg(f_i)$ over all $i = 1, \dots, k$. In particular, if all e_i's are equal to e and Bob sends out *linearly* related messages, then Marvin can recover the plaintext as soon as $k > e$.

Hastad's original theorem is weaker than the one stated above. Rather than d polynomials, Hastad required $d(d+1)/2$ polynomials. Hastad's proof is similar to the proof of Coppersmith's theorem described in the previous section. However, Hastad does not use powers of g in the lattice and consequently obtains a weaker bound.

To conclude this section, we note that to properly defend against the broadcast attack above, one must use a *randomized* pad [1] rather than a fixed one.

Franklin-Reiter Related Message Attack

Franklin and Reiter [8] found a clever attack when Bob sends Alice related encrypted messages using the same modulus. Let $\langle N, e \rangle$ be Alice's public key. Suppose $M_1, M_2 \in \mathbb{Z}_N^*$ are two distinct messages satisfying $M_1 = f(M_2) \bmod N$ for some publicly known polynomial $f \in \mathbb{Z}_N[x]$. To send M_1 and M_2 to Alice, Bob may naively encrypt the messages and transmit the resulting ciphertexts C_1, C_2. We show that given C_1, C_2, Marvin can easily recover M_1, M_2. Although the attack works for any small e, we state the following lemma for $e = 3$ in order to simplify the proof.

Lemma 7 (FR). Set $e = 3$, and let $\langle N, e \rangle$ be an RSA public key. Let $M_1 \neq M_2 \in Z_N^*$ satisfy $M_1 = f(M_2) \bmod N$ for some linear polynomial $f = ax + b \in \mathbb{Z}_N[x]$ with $b \neq 0$. Then, given $\langle N, e, C_1, C_2, f \rangle$, Marvin can recover M_1, M_2 in time quadratic in $\log N$.

Proof. To keep this part of the proof general, we state it using an arbitrary e (rather than restricting to $e = 3$). Since $C_1 = M_1^e \bmod N$, we know that M_2 is a root of the polynomial $g_1(x) = f(x)^e - C_1 \in \mathbb{Z}_N[x]$. Similarly, M_2 is a root of $g_2(x) = x^e - C_2 \in \mathbb{Z}_N[x]$. The linear factor $x - M_2$ divides both polynomials. Therefore, Marvin may use the Euclidean algorithm[4] to compute the gcd of g_1 and g_2. If the gcd turns out to be linear, M_2 is found. The gcd can be computed in quadratic time in e and $\log N$.

We show that when $e = 3$, the gcd must be linear. The polynomial $x^3 - C_2$ factors modulo both p and q into a linear factor and an irreducible quadratic factor (recall that $\gcd(e, \varphi(N)) = 1$, hence $x^3 - C_2$ has only one root in $\mathbb{Z}_N$). Since g_2 cannot divide g_1, the gcd must be linear. For $e > 3$ the gcd is almost always linear. However, for some rare M_1, M_2, and f, it is possible to obtain a nonlinear gcd, in which case the attack fails. □

For $e > 3$ the attack takes time quadratic in e. Consequently, it can be applied only when a small public exponent e is used. For large e the work in computing the gcd is prohibitive. It is an interesting question (though likely to be difficult) to devise such an attack for arbitrary e. In particular, can the gcd of g_1 and g_2 above be found in time polynomial in $\log e$?

Coppersmith's Short Pad Attack

The Franklin-Reiter attack might seem a bit artificial. After all, why should Bob send Alice the encryption of related messages? Coppersmith strengthened the attack and proved an important result on padding [7].

A naive random padding algorithm might pad a plaintext M by appending a few random bits to one of the ends. The following attack points out the danger of such simplistic padding. Suppose Bob sends a properly padded encryption of M to Alice. Marvin intercepts the ciphertext and prevents it from reaching its destination. Bob notices that Alice did not respond to his message and decides to resend M to Alice. He randomly pads M and transmits the resulting ciphertext. Marvin now has two ciphertexts corresponding to two encryptions of the same message using two different random pads. The following theorem shows that although he does not know the pads used, Marvin is able to recover the plaintext.

Theorem 8. Let $\langle N, e \rangle$ be a public RSA key where N is n-bits long. Set $m = [n/e^2]$. Let $M \in \mathbb{Z}_N^*$ be a message of length at most $n - m$ bits. Define $M_1 = 2^m M + r_1$ and $M_2 = 2^m M + r_2$, where r_1 and r_2 are distinct integers with $0 \le r_1, r_2 < 2^m$. If Marvin is given $\langle N, e \rangle$ and the encryptions C_1, C_2 of M_1, M_2 (but is not given r_1 or r_2), he can efficiently recover M.

Proof. Define $g_1(x, y) = x^e - C_1$ and $g_2(x, y) = (x + y)^e - C_2$. We know that when $y = r_2 - r_1$, these polynomials have M_1 as a common root. In other words, $\Delta = r_2 - r_1$ is a root of the "resultant" $h(y) = \text{res}_x(g_1, g_2) \in \mathbb{Z}_N[y]$. The degree of h is at most e^2. Furthermore, $|\Delta| < 2^m < N^{1/e^2}$. Hence, Δ is a small root of h modulo N, and Marvin can efficiently find it using Coppersmith's theorem (The-

[4] *Although $\mathbb{Z}_N[x]$ is not a Euclidean ring, the standard Euclidean algorithm can still be applied to polynomials in $\mathbb{Z}_N[x]$. One can show that if the algorithm "breaks" in any way, then the factorization of N is exposed.*

orem 3). Once Δ is known, the Franklin-Reiter attack of the previous section can be used to recover M_2 and consequently M. □

When $e = 3$, the attack can be mounted as long as the pad length is less than 1/9 the message length. This is an important result. Note that for the recommended value of $e = 65537$, the attack is useless against standard moduli sizes.

Partial Key Exposure Attack

Let $\langle N, d \rangle$ be a private RSA key. Suppose by some means Marvin is able to expose a fraction of the bits of d, say, a quarter of them. Can he reconstruct the rest of d? Surprisingly, the answer is positive when the corresponding public key is small. Recently Boneh, Durfee, and Frankel [5] showed that as long as $e < \sqrt{N}$, it is possible to reconstruct all of d from just a fraction of its bits. These results illustrate the importance of safeguarding the *entire* private RSA key.

Theorem 9 (BDF). Let $\langle N, d \rangle$ be a private RSA key in which N is n bits long. Given the $\lceil n/4 \rceil$ least significant bits of d, Marvin can reconstruct all of d in time linear in $e \log_2 e$.

The proof relies on yet another beautiful theorem due to Coppersmith [7].

Theorem 10 (Coppersmith). Let $N = pq$ be an n-bit RSA modulus. Then given the $n/4$ least significant bits of p or the $n/4$ most significant bits of p, one can efficiently factor N.

Theorem 9 readily follows from Theorem 10. In fact, by definition of e and d, there exists an integer k such that

$$ed - k(N - p - q + 1) = 1.$$

Since $d < \varphi(N)$, we must have $0 < k \le e$. Reducing the equation modulo $2^{n/4}$ and setting $q = N/p$, we obtain

$$(ed)p - kp(N - p + 1) + kN = p \mod 2^{n/4}.$$

Since Marvin is given the $n/4$ least significant bits of d, he knows the value of $ed \bmod 2^{n/4}$. Consequently, he obtains an equation in k and p. For each of the e possible values of k, Marvin solves the quadratic equation in p and obtains a number of candidate values for $p \bmod 2^{n/4}$. For each of these candidate values, he runs the algorithm of Theorem 10 to attempt to factor N. One can show that the total number of candidate values for $p \bmod 2^{n/4}$ is at most $e \log_2 e$. Hence, after at most $e \log_2 e$ attempts, N will be factored. □

Theorem 9 is known as a *partial key-exposure* attack. Similar attacks exist for larger values of e as long as $e < \sqrt{N}$. However, the techniques are a bit more complex [5]. It is interesting that discrete log-based cryptosystems, such as the El-Gamal public key system, do not seem susceptible to partial key exposure. Indeed, if $g^x \bmod p$ and a constant fraction of the bits of x are given, there is no known polynomial-time algorithm to compute the rest of x.

To conclude the section, we show that when the encryption exponent e is small, the RSA system leaks *half* the most significant bits of the corresponding private key d. To see this, consider once again the equation $ed - k(N - p - q + 1) = 1$ for an integer $0 < k \le e$. Given k, Marvin may easily compute

$$\hat{d} = \lfloor (kN + 1)/e \rfloor.$$

Then

$$|\hat{d} - d| \le k(p + q)/e \le 3k\sqrt{N}/e < 3\sqrt{N}.$$

Hence, $\hat{d}$ is a good approximation for d. The bound shows that, for most d, half the most significant bits of $\hat{d}$ are equal to those of d. Since there are only e possible values for k, Marvin can construct a small set of size e such that one of the elements in the set is equal to half the most significant bits of d. The case $e = 3$ is especially interesting. In this case one can show that always $k = 2$ and hence the system completely leaks half the most significant bits of d.

Implementation Attacks

We turn our attention to an entirely different class of attacks. Rather than attacking the underlying structure of the RSA function, these attacks focus on the implementation of RSA.

Timing Attacks

Consider a smartcard that stores a private RSA key. Since the card is tamper resistant, Marvin may not be able to examine its contents and expose the key. However, a clever attack due to Kocher [13] shows that by precisely measuring the *time* it takes the smartcard to perform an RSA decryption (or signature), Marvin can quickly discover the private decryption exponent d.

We explain how to mount the attack against a simple implementation of RSA using the "repeated squaring algorithm". Let $d = d_n d_{n-1} \dots d_0$ be the binary representation of d (i.e., $d = \sum_{i=0}^{n} 2^i d_i$ with $d_i \in \{0, 1\}$). The *repeated squaring algorithm* computes $C = M^d \bmod N$, using at most $2n$ modular multiplications. It is based on the observation that $C = \prod_{i=0}^{n} M^{2^i d_i} \bmod N$. The algorithm works as follows:

> Set z equal to M and C equal to 1. For $i = 0, \dots, n$, do these steps:
>
> 1. If $d_i = 1$, set C equal to $Cz \bmod N$.
> 2. Set z equal to $z^2 \bmod N$.
>
> At the end, C has the value $M^d \bmod N$.

The variable z runs through the set of values $M^{2^i} \bmod N$ for $i = 0, \ldots, n$. The variable C "collects" the appropriate powers in the set to obtain $M^d \bmod N$.

To mount the attack, Marvin asks the smartcard to generate signatures on a large number of random messages $M_1, \ldots, M_k \in \mathbb{Z}_N^*$ and measures the time T_i it takes the card to generate each of the signatures.

The attack recovers bits of d one at a time, beginning with the least significant bit. We know d is odd. Thus $d_0 = 1$. Consider the second iteration. Initially $z = M^2 \bmod N$ and $C = M$. If $d_1 = 1$, the smartcard computes the product $Cz = M \cdot M^2 \bmod N$. Otherwise, it does not. Let t_i be the time it takes the smartcard to compute $M_i \cdot M_i^2 \bmod N$. The t_i's differ from each other, since the time to compute $M_i \cdot M_i^2 \bmod N$ depends on the value of M_i (simple modular reduction algorithms take a different amount of time depending on the value being reduced). Marvin measures the t_i's offline (prior to mounting the attack) once he obtains the physical specifications of the card.

Kocher observed that when $d_1 = 1$, the two ensembles $\{t_i\}$ and $\{T_i\}$ are correlated. For instance, if for some i, t_i is much larger than its expectation, then T_i is also likely to be larger than its expectation. On the other hand, if $d_1 = 0$, the two ensembles $\{t_i\}$ and $\{T_i\}$ behave as independent random variables. By measuring the correlation, Marvin can determine whether d_1 is 0 or 1. Continuing in this way, he can recover d_2, d_3, and so on. Note that when a low public exponent e is used, the partial key exposure attack of the previous section shows that Kocher's timing attack need only be employed until a quarter of the bits of d are discovered.

There are two ways to defend against the attack. The simplest is to add appropriate delay so that modular exponentiation always takes a fixed amount of time. The second approach, due to Rivest, is based on *blinding*. Prior to decryption of M the smartcard picks a random $r \in \mathbb{Z}_N^*$ and computes $M' = M \cdot r^e \bmod N$. It then applies d to M' and obtains $C' = (M')^d \bmod N$. Finally, the smartcard sets $C = C'/r \bmod N$. With this approach, the smartcard is applying d to a random message M' unknown to Marvin. As a result, Marvin cannot mount the attack.

Kocher recently discovered another attack along these lines called *power cryptanalysis*. Kocher showed that by precisely measuring the smartcard's *power consumption* during signature generation, Marvin can often easily discover the secret key. As it turns out, during a multiprecision multiplication the card's power consumption is higher than normal. By measuring the length of high consumption periods, Marvin can easily determine if in a given iteration the card performs one or two multiplications, thus exposing the bits of d.

Random Faults

Implementations of RSA decryption and signatures frequently use the Chinese Remainder Theorem to speed up the computation of $M^d \bmod N$. Instead of working modulo N, Bob first computes the signatures modulo p and q and then combines the results using the Chinese Remainder Theorem. More precisely, Bob first computes

$$C_p = M^{d_p} \bmod p \quad \text{and} \quad C_q = M^{d_q} \bmod q,$$

where $d_p = d \bmod (p-1)$ and $d_q = d \bmod (q-1)$. He then obtains the signature C by setting

$$C = T_1 C_p + T_2 C_q \qquad \bmod N,$$

where

$$T_1 = \begin{Bmatrix} 1 \bmod p \\ 0 \bmod q \end{Bmatrix} \quad \text{and} \quad T_2 = \begin{Bmatrix} 0 \bmod p \\ 1 \bmod q \end{Bmatrix}.$$

The running time of the last CRT step is negligible compared to the two exponentiations. Note that p and q are half the length of N. Since simple implementations of multiplication take quadratic time, multiplication modulo p is four times faster than modulo N. Furthermore, d_p is half the length of d, and consequently computing $M^{d_p} \bmod p$ is eight times faster than computing $M^d \bmod N$. Overall signature time is thus reduced by a factor of four. Many implementations use this method to improve performance.

Boneh, DeMillo, and Lipton [3] observed that there is an inherent danger in using the CRT method. Suppose that while generating a signature, a glitch on Bob's computer causes it to miscalculate in a single instruction. For instance, while copying a register from one location to another, one of the bits is flipped. (A glitch may be caused by ambient electromagnetic interference or perhaps by a rare hardware bug, like the one found in an early version of the Pentium chip.) Given an invalid signature, Marvin can easily factor Bob's modulus N.

We present a version of the attack as described by A. K. Lenstra. Suppose a single error occurs while Bob is generating a signature. As a result, exactly one of C_p or C_q will be computed incorrectly. Say C_p is correct, but $\hat{C}_q$ is not. The resulting signature is $\hat{C} = T_1 C_p + T_2 \hat{C}_q$. Once Marvin receives $\hat{C}$, he knows it is a false signature, since $\hat{C}^e \neq M \bmod N$. However, notice that

$$\hat{C}^e = M \bmod p \quad \text{while} \quad \hat{C}^e \neq M \bmod q.$$

As a result, $\gcd(N, \hat{C}^e - M)$ exposes a nontrivial factor of N.

For the attack to work, Marvin must have full knowledge of M; namely, we are assuming Bob does not use any random padding procedure. Random padding prior to signing defeats the attack. A simpler defense is for Bob to check the generated signature before sending it out to the world. Checking is especially important when using the CRT speedup method. Random faults are hazardous to many cryptographic systems. Many systems, including a non-CRT implementation of RSA, can be attacked using random faults [3]. However, these results are far more theoretical.

Bleichenbacher's Attack on PKCS 1

Let N be an n-bit RSA modulus and M be an m-bit message with $m < n$. Before applying RSA encryption it is natural to pad the message M to n bits by appending random bits to it. An old version of a standard known as Public Key Cryptography Standard 1 (PKCS 1) uses this approach. After padding, the message looks as follows:

02	Random	00	M

The resulting message is n bits long and is directly encrypted using RSA. The initial block containing "02" is 16 bits long and is there to indicate that a random pad has been added to the message.

When a PKCS 1 message is received by Bob's machine, an application (e.g., a Web browser) decrypts it, checks the initial block, and strips off the random pad. However, some applications check for the "02" initial block, and if it is not present, they send back an error message saying "invalid ciphertext". Bleichenbacher [2] showed that this error message can lead to disastrous consequences: using the error message, Marvin can decrypt ciphertexts of his choice.

Suppose Marvin intercepts a ciphertext C intended for Bob and wants to decrypt it. To mount the attack, Marvin picks a random $r \in \mathbb{Z}_N^*$, computes $C' = rC \bmod N$, and sends C' to Bob's machine. An application running on Bob's machine receives C' and attempts to decrypt it. It either responds with an error message or does not respond at all (if C' happens to be properly formatted). Hence, Marvin learns whether the most significant 16 bits of the decryption of C' are equal to 02. In effect, Marvin has an *oracle* that tests for him whether the 16 most significant bits of the decryption of $rC \bmod N$ are equal to 02, for any r of his choice. Bleichenbacher showed that such an oracle is sufficient for decrypting C.

Conclusions

Two decades of research into inverting the RSA function produced some insightful attacks, but no devastating attack has ever been found. The attacks discovered so far mainly illustrate the pitfalls to be avoided when implementing RSA. At the moment it appears that proper implementations can be trusted to provide security in the digital world.

We categorized known attacks on RSA into four categories: (1) elementary attacks that exploit blatant misuse of the system, (2) low private exponent attacks serious enough that a low private exponent should never be used, (3) low public exponent attacks, (4) and attacks on the implementation. These last attacks illustrate that a study of the underlying mathematical structure is insufficient. Throughout the paper we observed that many attacks can be defeated by properly padding the message prior to encryption or signing.

The first twenty years of RSA have led to a number of fascinating algorithms. My hope is the next twenty will prove to be equally exciting.

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Mary Cartwright (1900–1998)

Shawnee McMurran and James Tattersall

Dame Mary Cartwright, 1950.

Mary Cartwright died in Cambridge, England, on April 3, 1998, at the age of ninety-seven. Cartwright led a distinguished career in mathematics and university administration. During her career Cartwright authored over ninety articles, making important contributions to the theory of functions and differential equations. Her early work led to significant results concerning Dirichlet series, Abel summation, directions of Borel spreads, analytic functions regular on the unit disk, the zeros of integral functions, maximum and minimum moduli, and functions of finite order in an angle. She is particularly well known for her work with J. E. Littlewood on van der Pol's equation, nonlinear oscillators, and the development of topological techniques to prove existence theorems. Her later work includes contributions to the theory of cluster sets in collaboration with Edward Collingwood.

Cartwright and Littlewood were among the first mathematicians to recognize that topological and analytical methods could be combined to efficiently obtain results for various problems in differential equations, and their results helped inspire the construction of Smale's horseshoe diffeomorphism. Their names can be included with those mathematicians, including Levinson, Minorsky, Liapounov, Kryloff, Bogolieuboff, Denjoy, Birkhoff, and Poincaré, whose work provided an impetus to the development of modern dynamical theory.

In addition to her research, Cartwright took a keen interest in mathematical education at all levels. She was an effective administrator at Cambridge University and ambassador for several mathematical and scientific organizations. She is remembered as a person who had a gift for going to the heart of a matter and for seeing the important point, both in mathematics and human affairs.

Cartwright received many honors. In particular, she was elected a Fellow of the Royal Society of London in 1947. Until Dusa McDuff was elected in 1994, Cartwright remained the only woman mathematician in the Royal Society. She received honorary doctorates from the universities of Edinburgh, Leeds, Hull, Wales, and Oxford. In 1969 Queen Elizabeth II elevated her to Dame Commander of the British Empire.

Mary Cartwright was born in Aynho, Northamptonshire, England, on December 17, 1900, into a family with a tradition of public service. She matriculated at St. Hugh's, Oxford, in the fall of 1919 and decided to pursue the honors mathematics program instead of her long-time favorite subject, history. Lectures were difficult to get into due to the flood of men recently released from the army. Cartwright went to the lectures she could and obtained notes from the others. After two years she received a second class on the Mathematical Moderations Examination. Although very few firsts were given that year, Cartwright was disappointed and seriously considered changing her focus to his-

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Shawnee McMurran teaches at the Claremont Colleges. Her e-mail address is `smcmurran@pomona.edu`.

James Tattersall is professor of mathematics at Providence College. His e-mail address is `tat@providence.edu`.

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All photographs in this article are courtesy of the Mistress and Fellows, Girton College, Cambridge.

tory. After considerable deliberation she concluded that she was hooked on the theory of residues. She joked that history would entail longer hours of work anyway. Her decision to remain in mathematics did not diminish her interest in history. Many of her mathematical papers include historical perspectives that add an interesting dimension to her work. She also wrote several biographical memoirs that portray her exceptional sense of history.

Near the end of Cartwright's third year at Oxford, an important event in her mathematical career occurred at a well-chaperoned party. She was introduced to V. C. Morton, who told her that if she was really serious about mathematics she should read Whittaker and Watson's *Modern Analysis* and attend the evening classes of G. H. Hardy, then Savilian Professor of Geometry. Taking Morton's advice, she read *Modern Analysis* that summer and received special permission to attend Hardy's class. She found Hardy's lectures inspiring. With Hardy serving as an examiner, she received a first class on the Final Honours School Examination in Mathematics, obtaining her degree from Oxford in 1923.

During the next four years, Cartwright taught mathematics, first at the Alice Ottley School in Worcester and then at the Wycombe Abbey School in Buckinghamshire, where she also served as assistant mistress. Cartwright began to feel sidetracked by her mounting administrative duties. In addition, teaching and method content were strictly dictated at the school. Having no room to experiment led Cartwright to feel discontent with her career. She felt she had to return to mathematics research, and in January 1928 she arranged to join Hardy's group of research students at Oxford. Hardy's class consisted of an hour lecture followed by tea, biscuits, and talk about mathematics and mathematicians.

Cartwright's mathematical talent blossomed in the seminar. One evening Hardy gave a list of problems in his seminar, one of which referred to an application of Abel's method of summation to Dirichlet series. Hardy was amazed when Cartwright completely solved the problem by contour integration. Her work on generalized Abel summability with applications to Fourier series was published that year and also appears in the index of Hardy's book on divergent series.

E. C. Titchmarsh, who succeeded Hardy as Savilian Professor at Oxford, became Cartwright's supervisor while Hardy was at Princeton during the 1928–29 academic year. During an interview in 1990, Cartwright recalled that Titchmarsh was a good supervisor and his suggestions suited her well. Both Hardy and Titchmarsh inspired Cartwright's interest in the theory of functions of complex variables. Cartwright completed her D.Phil. when Hardy returned to Oxford. Fortuitously, J. E. Littlewood served as an external examiner. Littlewood recalled that the first question by the other examiner was so silly and unreal as to make her blush, but he thought he helped to restore her nerve with a wink. Her thesis on the zeros of integral functions generated a series of papers and eventually led to her book on integral functions.

In October of 1930, financed by a Yarrow Research Fellowship, Cartwright continued her work in the theory of functions at Girton College, Cambridge. During this time she attended several of Littlewood's courses and seminars. She drew Littlewood's attention when she obtained the right order of magnitude for the maximum modulus of multivalent functions, a problem that Littlewood had presented in his theory of functions class. Her result is:

Cartwright's Theorem. Suppose $w(z) = \sum_{n=0}^{\infty} a_n z^n$ is regular for $|z| < 1$. Let $r < 1$. If $w(z)$ takes no value more than p times in $|z| < 1$, then $|w(z)| < A(p)\mu(1-r)^{-2p}$ for all $|z| \le r$, where $\mu = \max(|a_0|, |a_1|, |a_2|, \dots, |a_p|)$ and $A(p)$ is a constant depending only on p.

Cartwright was the first to obtain significant results for p-valent functions, and she did so using some rather unconventional methods. She used the conformal mapping technique pioneered by Ahlfors to prove the theorem and show that an entire function of order ρ has at most 2ρ asymptotic values. She had learned about the technique in her lectures from E. F. Collingwood. W. K. Hayman described the technique in a talk given on the occasion of Cartwright's ninetieth birthday. According to Hayman, Ahlfors mapped a strip-like domain S onto a strip $R = \{|\eta| < \frac{\pi}{2}\}$ in the $\zeta = \xi + i\eta$ plane. If S meets the line $\sigma = t$ in one or more segments of length at most $\theta(t)$ and if $s = \sigma + it$ corresponds to $\zeta = \xi + i\eta$, then Ahlfors showed that the map grows at least as fast as in the case when S is itself a strip. Suppose now that $f(z)$ is p-valent in the unit disk $\Delta = \{|z| < 1\}$, and assume for simplicity that $f(z) \neq 0$. Those who have had dealings with the zeta function may recall that zeros can give rise to problems. However, in this case the damage can be limited, since $f(z)$ can have at most p zeros. Map Δ onto the strip R by $\zeta = \log(\frac{1+z}{1-z})$, and consider $s = \log f(z(\zeta))$ as a function of ζ. Unfortunately this is not a 1-1 map if $p > 1$. However, if we consider a level curve $\sigma = t$, then the variation of the argument τ on such a curve cannot be more than $2\pi p$. Thus $\theta(t) \le 2\pi p$.

Cartwright was able to adapt Ahlfors's technique to her situation and deduce that

$$\sigma = \log|f| \le 2p\xi + O(1) \le 2p\log\left(\frac{1}{1-|z|}\right) + O(1),$$

which yields her theorem.

Littlewood was impressed with Cartwright's creativity in adapting Ahlfors's Distortion Theorem to such a different situation. Her polished proof was published in *Mathematische Annalen* in 1935, and her results are referred to in Littlewood's *Lectures on the Theory of Functions.* Her paper inspired a great deal of work and was later improved by D. C. Spencer. Cartwright's Theorem is still frequently quoted and applied in signal processing and is perhaps her most important work in the theory of functions.

Cartwright's mathematics flourished during the 1930s, and she published several papers on integral functions, meromorphic functions, and analytic functions with essential singularities. Cartwright's work included descriptions of the subtle phenomena that can appear near fractal boundaries and has found some new applications in this field. Collingwood provided a great deal of assistance with her work on entire integral functions and refereed nearly all of her papers published in the *Proceedings of the London Mathematical Society.* Her work on directions of Borel spreads in *Comptes Rendus* was noted by G. Valiron in his lectures at the Zürich International Congress in 1932. Both Valiron and Cartwright are known for some of the earliest results concerning meromorphic functions sharing a level curve or tract. She collaborated with L. S. Bosanquet in the early 1930s, and they coauthored two papers, the first on the Hölder and Cesàro means of an analytic function and the second on Tauberian theorems. In the former paper the authors obtain results on the limiting behavior of Cesàro means $C^{(k)}(z)$ as $z \to 0$ and show that the results still hold when the $C^{(k)}(z)$ are replaced by Hölder means. The authors also obtain results of the type of Montel's theorem for bounded means. Two typical results of their work on Tauberian theorems are the following. In both, let $f(z) = \sum_{n=0}^{\infty} a_n z^n$.

Theorem. Fix $\alpha \geq -1$ and a positive integer λ, and let $f_\lambda(z) = (1-z)^{-1} \int_z^1 f_{\lambda-1}(u)\,du$. If the (C, α) sums of $\sum_0^\infty a_n$ are bounded and if $f_\lambda(z) \to A$ as $z \to 1$ along some arc $\arg(1-z) = \gamma$ with $0 \leq |\gamma| < \pi/2$, then the series $\sum a_n$ is $(C, \alpha + \delta)$ summable for every $\delta > 0$.

Theorem. Fix α with $0 < \alpha < \pi/2$ and γ with $0 \leq |\gamma| < \alpha$. Suppose all a_n are real and $f(z) = O(\exp|(1-|z|)|^{-\pi/(2\alpha)})$ as $z \to 1$ in $|z| < 1$. If $f(z) \to A$ as $z \to 1$ along the arc $\arg(1-z) = \gamma$, then $f(z) \to A$ when $z \to 1$ within the set $|\arg(1-z)| \leq \gamma$.

Cartwright's work prompted Hardy, who had moved to Cambridge in 1931, and Littlewood to recommend her for an Assistant Lectureship in Mathematics. In 1934 she was appointed to a College Lectureship in Mathematics and a Staff Fellowship. Cartwright became a part-time University Lecturer in Mathematics in 1935. At Girton, Cartwright also came under the influence of the director of studies, Frances E. Cave-Brown-Cave, who had finished just behind Hardy on the 1898 Cambridge Mathematical Tripos. In 1936 she succeeded Cave-Brown-Cave as director of studies in mathematics. She served as director until 1949.

In January of 1938 the Radio Research Board of the Department of Scientific and Industrial Research issued a memorandum requesting the expert guidance of pure mathematicians with nonlinear differential equations used in the modeling of radio and radar technology. Some of the problems presented in the literature intrigued Cartwright. At the time it seemed curious that such problems would appeal to her, since her interests lay with complex analysis and not dynamics. In hindsight, she believed that she intuitively recognized the topological implications of the problems.

Cartwright sought Littlewood's assistance in helping her understand the dynamical aspects of radio research, and in so doing they embarked on a ten-year collaboration. Their work was influenced by the mathematics of Poincaré, Birkhoff, and Bendixon, among others. Cartwright considered the area of nonlinear oscillations "a curious branch of mathematics developed by different people from different standpoints—straight mechanics, radio oscillations, pure mathematics and servo-mechanisms of automatic control theory." At the time, much of the nonlinear theory was concerned with equations of the form

$$\ddot{x} + f(x)\dot{x} + g(x) = p(t), \tag{1}$$

where $p(t)$ has period $2\pi/\lambda$, $g(x)$ behaves in a somewhat similar manner to a restoring force, and the damping $f(x)$, sometimes $f(x, \dot{x})$, is usually positive for large $|x|$. For such equations the principle of superposition does not hold. One of the most famous of such equations is that introduced by van der Pol in 1920:

$$\ddot{x} - k(1 - x^2)\dot{x} + x = bk\lambda \cos \lambda t. \tag{2}$$

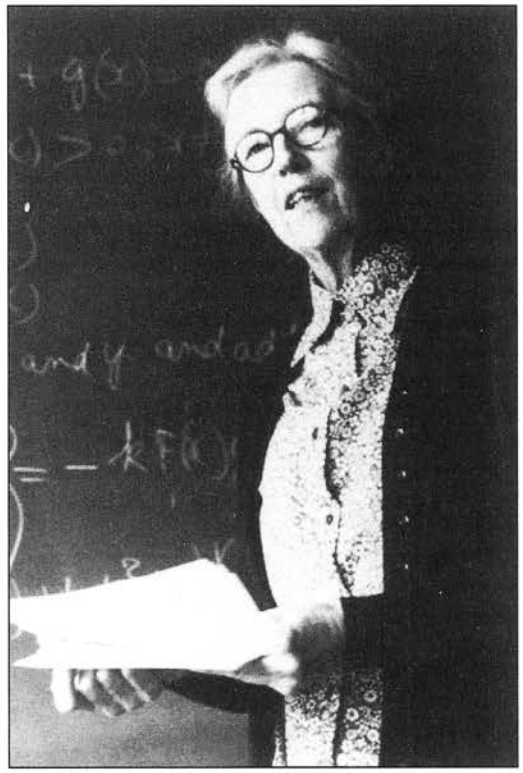
Even when the forcing term $bk\lambda \cos \lambda t$ is zero, the general solution to van der Pol's equation cannot be obtained by the combination of two linearly independent solutions.

The first big problem studied by Cartwright and Littlewood concerned the amplitude of the stable periodic solution of van der Pol's equation without forcing term. Van der Pol used this equation as the basic model for a triode oscillator, since it retained the essential features of the situation being experimented with by radio engineers. Van der Pol's research seemed to imply convergence to a periodic solution with amplitude 2. Cartwright and Littlewood proved that when k is large, all nontrivial solutions converge to a periodic solution whose amplitude tends to 2 as $k \to \infty$.

When the nonlinear term of equation (2) is large—that is, when k is large—van der Pol's equation represents a relaxation oscillator. The next problem considered by Cartwright and Littlewood was whether this equation could have two stable periodic solutions with different periods in this situation. Such a phenomenon had been suggested by experiments. During their investigations Cartwright and Littlewood were considerably influenced by Levinson's 1944 paper "Transformation theory of nonlinear differential equations of the second order". This paper laid the foundations of a general topological approach to nonautonomous periodic second-order differential equations. Cartwright and Littlewood expanded their research on equation (2) to the generalized form of van der Pol's equation, equation (1), and showed the existence of two stable sets of subharmonics of different orders. Their results led to some rather interesting mappings, and their topological approach to the problem led to several unsolved problems in topology. The inner and outer edges of the boundary between the domains of attraction of the two sets had different rotation numbers under the diffeomorphism corresponding to advancing the solutions of (2) through one period, leading to the conclusion that the boundary could not be a Jordan curve and was most likely to be an indecomposable continuum. Cartwright and Littlewood's fine structures are recognized by contemporary mathematics as typical manifestations of the "butterfly effect".

In their work Cartwright and Littlewood made use of an analytic transformation, developed by Birkhoff, of the plane into itself with complicated invariant curves. They were among the earliest mathematicians to associate such transformations with a simple differential equation. The diffeomorphism indicated that the nonstable periodic solutions and subharmonics of the equation corresponded to fixed points of the set. This led Cartwright and Littlewood to develop some original fixed-point theorems for continua invariant under a diffeomorphism of the plane. In particular, they needed a fixed-point theorem that would apply to a bounded invariant continuum whose complement is a single simply connected domain that may not have a Jordan curve tending to it. The theorem they developed is stated below. This theorem is more general than Brouwer's fixed-point theorem, since I need not be locally connected; however, the conditions on T are more restrictive. One application of their theorem is to an area-preserving twist homeomorphism of the annulus.

Cartwright & Littlewood Fixed-Point Theorem. If T is a 1-1 continuous and orientation-preserving transformation of the whole plane into itself that leaves a bounded continuum I invariant and if $T(I)$ is a single simply connected domain, then I contains a fixed point.

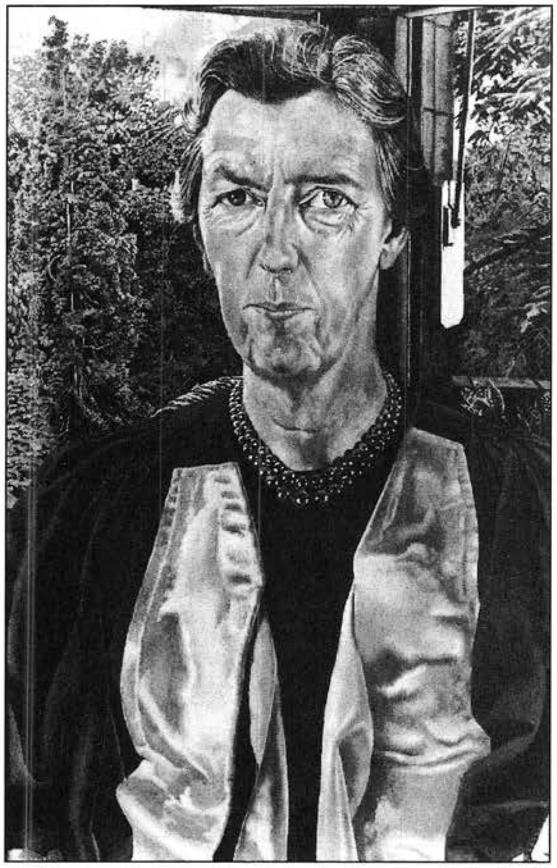


Dame Mary teaching, around 1970.

It eventually became evident that the van der Pol oscillator provided an example of a stable chaotic system. Dissipation in the van der Pol oscillator meant that the system's shape in phase space would contract. A complex combination of transformations was necessary to fully represent the system in phase space, inspiring Smale's construction of the horseshoe diffeomorphism, the cornerstone of the modern theory of chaos.

Cartwright and Littlewood's collaboration produced some of the earliest fully rigorous work in relaxation oscillations. According to J. Guckenheimer, none of Levinson, Cartwright, and Littlewood carried through an analysis of the strange asymptotic behavior exhibited by some solutions, since adequate tools to do so were not then available. However, the results they obtained on the periodicity and stability of solutions of nonlinear differential equations influenced the development of the modern theory of dynamical systems, and there has been an enormous expansion of the subject since their work was completed. Modern techniques have enabled contemporary mathematicians to carry through a more thorough analysis of the exotic behavior of solutions to the forced van der Pol equation. For example, N. G. Lloyd proved the Cartwright-Littlewood conjecture that there is only one stable oscillation for $b > 2/3$. Also, Guckenheimer and Levi have each used modern methods from dynamical systems to give a more complete analysis of the phenomena that appear in the forced van der Pol equation.

The bulk of Cartwright and Littlewood's collaborative work was completed in the mid-1940s and contributed to her election as a Fellow of the Royal Society of London in 1947. When asked if she felt there was any prejudice toward women at Cambridge or within the Royal Society, Cartwright responded that during her time she never felt as if there was. She even felt favored and preferred to men available on many occasions, for example, when representing the London Mathematical Society, the Cambridge Philosophical Society, and



Stanley Spencer's portrait of Cartwright in 1958 conveys her as a scholar and administrator, but misses the warm sense of humor and sympathy that her friends, colleagues, and students knew.

Cambridge University at the Centenary of Henri Poincaré. She explained that although very few women had been elected to the Royal Society, there were also few women combining research and teaching. In addition, she noted that "hordes of men are put up for election and never get in."

In the years during and following the Second World War, Cartwright carried out a very full program of teaching and research at Girton. She collaborated with Littlewood, she was commandant of the college's Red Cross detachment from 1940 to 1944, and she worked with Copson and Greig to publish a thorough expository article on nonlinear vibrations. Her Girton students were at first apt to find her rather frail and timid. Closer acquaintance quickly dispelled that impression. Cartwright was a no-nonsense person with a wry sense of humor. It was said that even Hardy ducked when she threw her hardball.

In July of 1948 Cartwright was preelected mistress of Girton. Before taking up office, she spent the early part of 1949 lecturing on nonlinear differential equations in the United States at the invitation of John Curtis, Solomon Lefschetz, and Mina Rees. She spent three weeks at Stanford and one week at UCLA as a visiting professor. She spent several more weeks lecturing at Princeton as a consultant under the Office of Naval Research, since Princeton did not allow for women faculty. Lecture notes from her Princeton seminar appear in a 1950 volume in the series Annals of Mathematics Studies.

Upon her return to Cambridge, Cartwright's life changed dramatically when she took up the responsibilities of mistress of Girton. The women's colleges had just become full members of the University during the previous year. Cartwright's quiet, unassuming, and clear-headed leadership helped the college to adapt and take its place in the University. However, becoming mistress did put many administrative duties on her agenda. Demands from various University committees were very heavy. Her commitments included service as chairman of the Cambridge University Women's Appointments Board, service on the Education Syndicate, and two terms on the Board Council of the Cambridge University Senate.

Although Cartwright found it impossible to refuse to be elected mistress of Girton, she did refuse to take on all but a few research students and "those for some special reason." She believed that perhaps being head of a college and trying to avoid too many research students stopped her promotion to full professor. Her research students included Sheila Scott (Macintyre); Hilary Shuard, who did not take a D.Phil. but did become a prominent figure in the Teaching Training World; Barbara Maitland, who became a Lecturer at Liverpool; Marc Noble, who became a professor of mathematics at the University of Canterbury; James Ejeilo, who became a professor, and vice-chancellor for a time, at Nsukka University of Nigeria; Carl Lindon, who taught at the University College of Swansea; W. K. Hayman, who is a Fellow of the Royal Society and was awarded the Berwick Prize from the London Mathematical Society; and Chike Obi, a self-taught Nigerian, who was taken over by Littlewood and became a professor at Layos University. Cartwright was reportedly an excellent supervisor who gave due encouragement and took great care in reading and criticizing her students' work, both in content and form. Hayman recalls that Cartwright was a marvelous supervisor who was never discouraging. She corrected, but did not put down. Her advice was always available and pointed, and her conversation interesting and varied. She was noted for being meticulous about English grammar and syntax. In addition, Hayman says, "Mary taught me that proofs must be supplied by the writer and not the reader and that we had to refer to previous authors and what they had done."

After completing her collaborative work with Littlewood and becoming mistress of Girton, Cartwright claimed that her burden of administrative duties prevented her from devoting herself wholeheartedly to mathematics. However, in the years between 1950 and 1989 she still managed to publish several papers in differential equations, most using topological methods, as well as some research in theory of functions, some expository articles, memorial articles, and papers with historical and biographical interest, including historical research on the Hardy-Littlewood-Paley-Riesz circle from the 1920s and 1930s. Her book *Integral Functions* was published in 1956 and exceeded in depth and precision anything that had gone before. The book was heavily based on work that she had almost finished when the war began in 1939. In 1960 she proved some interesting results about solutions to a third-order differential equation using Lyapunov functions. In the mid-1960s she wrote papers that addressed the importance of linking topological results more closely with the theory of differential equations. Even though she was not a topologist by training, she believed that mathematicians ought to make fuller use of the topological way of thinking in formulating problems. In the 1970s she collaborated with H. P. F. Swinnerton-Dyer, cowriting three papers on boundedness theorems for second-order differential equations. And as late as 1987, with G. E. H. Reuter she coauthored a paper on periodic solutions of van der Pol's equation with large parameters. However, regarding her research after 1950, she is probably best known for her work with Collingwood in the theory of cluster sets.

Cartwright and Collingwood had worked together before the war. They resumed their collaboration around 1950 when Collingwood pointed out that in her 1936 paper "On the behaviour of an analytic function in the neighborhood of its essential singularities" she had not taken into account the possibility that a function analytic in the unit disk might tend to a limit along a spiral touching the boundary or along an oscillating curve. Recognition of the too-strong hypothesis led them to redevelop the theory from a more general point of view, culminating in the famous Collingwood-Cartwright theory of cluster sets, in which they developed boundary uniqueness theorems for meromorphic functions on $|z| < 1$. Results in the first part of the paper belonged to what they called boundary theory in the large. In the second part of their paper they establish a system of boundary theorems in the small corresponding to their previously proved boundary theorems in the large. Here they study the behavior of $f(z)$ near a selected point $z = e^{i\theta}$ of the boundary. In their introduction they say that the central idea of their method was derived from Iversen's theory of the inverse function. It consists in the continuation of an ordinary or algebraic element of the inverse function along an appropriate path free from nonalgebraic singularities. They define the expressions $C(f)$, $R(f)$, and $\Gamma(f)$ as follows:

1. $C(f)$ denotes the set of cluster values of f. A point a is a cluster value of $f(z)$ if there is a point z_0 of the boundary $|z| = 1$ and a sequence $\{z_n\}$, $|z_n| < 1$, such that $\lim_{n\to\infty} z_n = z_0$ and $\lim_{n\to\infty} f(z_n) = a$.

2. $R(f)$ denotes the range of values of f. A point a is an element of $R(f)$ if there is a sequence $\{z_n\}$, $|z_n| < 1$, such that $\lim_{n\to\infty} |z_n| = 1$ and $f(z_n) = a$ for all values of n.

3. $\Gamma(f)$ denotes the set of asymptotic values of f. A point a is an asymptotic value of $f(z)$ if there is a continuous simple path $z = z(t)$, $\alpha < t < 1$, such that $|z(t)| < 1$, $\lim_{t\to 1} |z(t)| = 1$, and $\lim_{t\to 1} f(z(t)) = a$.

With these definitions, the main theorem of Cartwright and Collingwood is as follows.

Theorem. If $f(z)$ is meromorphic in $|z| < 1$, then the following relations are satisfied:

(i) If $\Gamma(f)$ is unrestricted, then the union of the frontiers of $C(f)$ and $R(f)$ is equal to the intersection of $C(f)$ and the closure of the complement of $R(f)$. In addition, this set is contained in the closure of $\Gamma(f)$.

(ii) If $\Gamma(f)$ is of linear measure zero, then it contains the complement of $R(f)$.

In each of the above, the complement is with respect to the closed complex plane.

Cartwright and Collingwood's work on cluster sets led to some of Collingwood's best work, culminating in his presidency of the London Mathematical Society. Their other paper was published in 1961 and contains an extension of various results on asymptotic values and ranges of values to the derivatives of the function considered.

Cartwright's colleagues recall that she never seemed harried. During her entire tenure as mistress of Girton she exhibited a readiness to look ahead and to respond to new needs by adopting new practices. It meant a great deal to the College that their mistress contributed to the advance of knowledge in her own field as well as devoting time and energy to the College's concerns. Cartwright served as president of the Mathematical Association from 1951 to 1952. In 1956 she was appointed a member of the Royal Society's delegation to the Soviet Union and Poland. Cartwright attended conferences, and she visited Moscow University and the Polish Academy of Sciences at Warsaw. In 1959 she was promoted to Reader in the Theory of Functions at Cambridge. She served as president of the London Mathematical Society from 1961 to 1963. After her retirement from Girton in 1968 she held visiting professorships at universities in England, America, and Poland before returning to Cambridge, where she was one of the editors of *The Collected Papers of G. H. Hardy.*

Cartwright fondly remembered her academic travels to the United States and Europe, and in later years she enjoyed telling stories of her travels over lunch at Girton. She spent the academic year 1968–69 as a resident fellow at Brown University. During her stay, she was particularly impressed by the students at Brown who were putting a great deal of pressure on the administration to change the curriculum. She spent the next academic year as a visiting professor at the Claremont Graduate College, Professor of the Royal Society to Poland, and Visiting Professorial Fellow at the University of Wales. Both she and some of her colleagues at the Claremont Colleges clearly remembered that she broke her hip in a bicycle accident. The following academic year she was a visiting professor at Case Western Reserve. She was elected an honorary member of the Institute of Mathematics and received a medal from the University of Finland.

Cartwright was a pioneer in many senses. She was the first woman to achieve a first class on the Oxford Finals, one of the first women to be elected to the Royal Society, the first woman to sit on its Council, and the first woman to receive its Sylvester Medal (1964)—for her "distinguished contributions to analysis and the theory of functions of a real and complex variable." She was, as of this writing, the only woman elected president of the London Mathematical Society (1961–63) and the only woman to receive its De Morgan Medal (1968).

Cartwright obtained immense satisfaction from doing mathematics. She believed that a number of major developments in pure mathematics were first thought out in terms of real-world situations. When asked what her favorite paper was, she gave the ultimate mathematician's reply: "...the one I was working on at the moment."

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Interview with AMS President Arthur Jaffe

On January 31, 1999, Arthur Jaffe will complete his term as president of the AMS. In this interview with *Notices* deputy editor and senior writer Allyn Jackson, Jaffe reflects on his time as president and describes some of the main issues on which he worked. An interview with president-elect Felix Browder is planned for the March issue of the *Notices*.

***Notices:** What were your main accomplishments as AMS president?*

Jaffe: During my term I have strived to increase the visibility of mathematicians in the realm of public science policy. This global goal subsumes many particular issues on which we have made some progress.

Someone wanting to know details about these questions should read my semiannual reports to the AMS Executive Committee and Board of Trustees. Briefly, my three years as an officer fall into three periods. During each year I focused on one major theme, aside from my normal AMS duties. The year as president-elect plunged the AMS into the problems of the mathematics department at the University of Rochester. This experience taught me the importance of working together with other science disciplines to achieve a common goal. The second year led to forming the ad-hoc coalition of science society presidents, with the goal in 1997 to begin to reverse a steady, five-year decline in federal science funding. (Science funding in every federal agency declined during that period, except for the National Institutes of Health.) This effort began at a fortuitous time. In the background of predictions by the American Association for the Advancement of Science of dramatic future declines in science funding by the year 2002, we saw the federal budget come into balance. This has allowed the start of a national pro-science movement in Congress itself, a movement we have helped along, encouraged, and worked with. Eventually it also spread to the executive branch of the government. During my third year we have focused on advocating investigator-initiated basic research. I believe this is the most important question for the future. We need to come to grips with how mathematics funds are spent. Above all, in the future we need to focus more and more on our most valuable resource, people. We need to repeat this point of view whenever we can, both to the agencies and to our representatives.

The starting point of this argument is that mathematics is important for the future of our society. We can base this case on history, but we need to make this point over and over. Mathematics has been the enabling subject for science, engineering, and also for business. It will remain that way in the future. But we need to have a coherent explanation why. The man in the street needs to appreciate mathematics before we get a lasting commitment from the members of Congress and the president. Once we make the case that our scientific future rests on preserving our mathematical strength, we are not finished. We need to ensure our ability to attract the brightest young people into mathematics, and we need to retain them. This means that we should support mathematicians, not just when they begin their studies, but as long as they remain innovative at the forefront of research developments.

In recent years we have seen more and more government funding going into directed programs. For the health of mathematics, we need to refocus attention on people. In order to do this we need a vision that transcends the short-term goals of the funding agencies; we should play a greater role in the formulation of these goals by the agencies.

As a candidate for president I wrote about the importance of advocacy for mathematics. I still believe in this, but I have also learned that it is important not just to advocate mathematics but to advocate science as a whole. This is why I started to work with organizations like the American Chemical Society and the American Physical Society. Starting with their presidents as partners, we put together the ad-hoc coalition as a way to achieve common goals. We spent about a year working on this, and now it has grown to encompass 110 presidents of organizations with 3.5 mil-

Outgoing AMS President Arthur Jaffe.

lion members. These presidents signed statements in support of scientific research. But statements are not enough. We also met with key people in Washington to explain our point of view and to help shape the future.

Just one direct conversation with a member of Congress or with a senator can have a big impact. Members are even busier people than we are, so they do not get to talk to lots of others about science. When you do get to meet a member in person, it is a memorable experience on both sides. Ultimately the future success in funding science and mathematics depends upon mathematicians and scientists in the community making sure that the public realizes that research is important.

Notices: *How in a practical way do you see mathematicians and scientists doing this?*

Jaffe: There are only 535 congressmen and senators. Therefore, if just a couple of people make personal contact with each of these 535 representatives, the problem would be solved by the action of only .05% of the members alluded to above. This is a realistic goal, and it would begin a national grass-roots movement for science. By mathematicians' being a major player in this way, mathematicians will also be at the table when research policies are designed; mathematicians will frame them along with other scientists.

As a small example, look at some events of quite diverse character organized by the Society. First, our two successful congressional briefings (one on data analysis and the other on encryption) drew extraordinarily large audiences exceeding all expectations. Furthermore, they were well received. We should build on these successes.

A second type of event were the Town Meetings organized by the AMS, one at the headquarters office in Providence and one at the office of *Mathematical Reviews* in Ann Arbor. These events brought mathematicians together with other local scientists and with legislators at the national level to discuss the importance of supporting research in science and mathematics. If individuals were to organize such events with other members of their local universities, it could really have a big impact. The AMS is working on developing materials to assist those who would like to do so.

Here is another example. In June of last year, three scientists and three mathematicians went to Washington to talk about the role of basic research with Representative John Porter [R-IL] and Senator Bill Frist [R-TN]. The scientists I took were David Mumford, Edward Witten, and William Lipscomb, a Nobel Prize winner in chemistry. The meeting was set up by the AMS and organized by Sam Rankin, director of the AMS Washington Office. We had a very good meeting with Representative Porter, and we saw him for half an hour as scheduled. We also had a half-hour appointment to speak with Senator Frist, but he ended up spending two or two and a half hours with us. In the end we had an opportunity to help Frist in rewriting parts of an important bill pertaining to science funding. This bill, the Federal Research Investment Act, is cosponsored by Senator John D. Rockefeller [D-WV]. It passed the Senate unanimously on a voice vote in October 1998, and it will be considered in the House of Representatives in 1999.

Part of this bill pertains to the Government Performance and Results Act [GPRA]. GPRA mandates that all federal departments and agencies must set forth specific goals, together with time lines for achieving them and ways of measuring whether the goals have been achieved. While justification of performance mandated by this bill across all of government has many virtues, its application to basic research poses many difficulties, because it has the potential to drive all agencies toward quite short-term goals. Senator Frist is very concerned about this. One part of his bill directed the Office of Management and Budget and the Office of Science and Technology Policy to commission a study by the National Academy of Sciences to come up with a way to devise metrics to decide whether research is successful. Now this study has become part of the appropriations bill for the National Science Foundation. This study must be performed extraordinarily thoughtfully and well. I believe that different metrics need to be developed for long-term research in order to judge its success differently from the way we view more immediate, directed projects. We have to think this through carefully, for if the scientific community puts its stamp of approval on an ill-devised plan, then we will be in a worse situation than before. This brings the responsibility for the framing of metrics back from the government and places it in the scientific community, where the process belongs.

Notices: *Could you describe what serendipity went into being able to meet with someone like Senator Frist?*

Jaffe: This is an excellent example of how apparently unrelated incidents led to our contributing to key legislation. Our June meeting culminated a year during which we worked together with members of Frist's staff on other questions. We first met these staff members, Tom Wood and Elizabeth Prostic, through staff members of Senator Joseph Lieberman [D-CT]. In helping one senator's office to set up a roundtable on education, we became acquainted with staff in the other office; both senators are members of the science caucus. Eventually, after some other meetings, Elizabeth Prostic helped us to ensure a private meeting with Frist. This is just one example of many things that we have done in Washington where chance meetings of one sort led to unexpected contacts of another sort.

Notices: *Will you continue these kinds of activities in Washington after your term as AMS president ends?*

Jaffe: The next president will have his own agenda. But Felix Browder and I see eye to eye on many matters, so I expect to remain active through the Committee on Science Policy.

Notices: *Are there some matters that you feel are important that you were not able to address during your presidency?*

Jaffe: There are many things. No AMS president can focus on more than a couple of important issues, and there are many such issues throughout mathematics. One example is the future of electronic publishing. It is extremely important for the future of mathematics to ensure that the transition to electronic publishing is handled well. Of course, the AMS is at the present time a leading player in electronic publishing, especially with MathSciNet and the electronic journals it publishes. We would like to stay at the forefront.

Another central issue is how mathematics is funded—not just how big the budgets are, but how mathematics is viewed by agencies. The relation between research and education is also a key issue. These things will be discussed and framed for years to come.

Mathematics has to attract the brightest young people in the country, as should being a mathematician. We need to address the job problem. A small step to simplify procedures is under discussion at the moment, to attempt to agree on a common initial date of acceptance of first job offers[1]. Another problem in the job market is the lack of long-range consistency in supporting good research. Having consistency and tradition is extremely important in ensuring that there is a flow of excellent people who decide that they are going to spend their lives in mathematics.

Another important and unresolved question revolves around discussions on how to make Society membership more meaningful to the community. I have appointed a Task Force on Membership, chaired by Salah Baouendi, to look into this question and to make recommendations. The Task Force is collecting data and will work together with the AMS staff. Persons with ideas can transmit them directly to Salah or to Jim Maxwell at the Providence headquarters. The Task Force is only beginning to work, so its recommendations will probably wait for their discussion and implementation until Felix is president.

Notices: *As president you have devoted a lot of time to making individual personal contacts. And yet the structure of the AMS, with its large number of committees and with the Council comprising about forty members, does not facilitate that kind of approach. Do you think a change is needed in the structure of the AMS?*

Jaffe: It's important that there are different ways for members to be involved in the AMS. However, I do think the AMS has too many committees; we have over one hundred. I am responsible for many of these appointments, and by virtue of being president I serve on something like fourteen committees and chair six. I find this structure unwieldy, and it certainly wastes time. But there were two reasons that I made a conscious decision not to try to make any changes in this realm. The committee structure of the AMS had just been reformed by the Council, so it was too soon to look at it again. Also, dealing with the committee structure would be another full-time project, and that wasn't where I wanted to put my energy.

The major change in the structure of the AMS in recent years was the formation of the five policy committees: the Committee on Science Policy, the Committee on Education, the Committee on Publications, the Committee on Meetings and Conferences, and the Committee on the Profession. There are some problems with the policy committees, but I think they are working much better now than when I began as president—they've had some time to understand how to work and what their roles are. Clearly, on certain policy committees there is tension between the committee's charge and what decisions are made in Providence by the AMS staff. These are complicated questions, and I am not sure they were thought through with sufficient care when the policy committees were set up.

Notices: *Do you have any advice for your successor, Felix Browder?*

Jaffe: My only advice for Felix is to focus on a few issues. I was preceded by a distinguished president, Cathleen Morawetz, and I will be followed by another. He will ensure that the AMS continues to play a meaningful role for the mathematics community.

[1] *See the item "Departments Coordinate Job Offer Deadlines" in the "For Your Information" section of this issue of the* Notices.

1998 Annual Survey of the Mathematical Sciences

(First Report)

Report on the 1998 Survey of New Doctoral Recipients
Faculty Salary Survey

Paul W. Davis, James W. Maxwell, and Kinda M. Remick

This first report on the 1998 Survey includes information about the employment of 1997–98 new doctoral recipients and salary data on faculty members in four-year colleges and universities. The report is based on information collected from questionnaires distributed in May to departments in the mathematical sciences in colleges and universities in the United States. A further questionnaire concerned with data on fall enrollments, majors, and departmental size was distributed in September. These data will appear in the Second Report of the 1998 Annual Survey in a summer 1999 issue of the *Notices*.

The 1998 Annual Survey represents the forty-second in an annual series begun in 1957 by the Society. The 1998 Survey is under the direction of the Annual Survey Data Committee, whose members are Paul W. Davis (chair), Lorraine Denby, Malay Ghosh, Mary W. Gray, Alfred W. Hales, Don O. Loftsgaarden, James W. Maxwell (ex officio), M. Beth Ruskai, Ann K. Stehney, and Ann E. Watkins. The committee is assisted by AMS Survey Specialist Kinda Remick. Comments or suggestions regarding this Survey Report may be directed to the Committee.

Report on the 1998 Survey of New Doctoral Recipients

This report presents a statistical profile of recipients of doctoral degrees awarded by departments in the mathematical sciences at universities in the United States during the period July 1, 1997, through June 30, 1998. It includes a preliminary analysis of the employment market for 1997–98 doctoral recipients and a demographic profile summarizing characteristics of citizenship status, gender, and racial/ethnic group. Table 1 provides the response rates for the 1998 Survey of New Doctoral Recipients. Please see page 231 for a description of the groups, newly defined for the 1996 Survey.

Table 1: Response Rates

Group I	48 of 48
Group II	54 of 56 including 2 with 0 degrees
Group III	67 of 73 including 19 with 0 degrees
Group IV	59 of 82 including 5 with 0 degrees
Group Va	13 of 18
Group Vb	12 of 31

Revised Procedure for Survey of Employment Status

In the years prior to 1997, the Data Committee determined the employment status of doctoral recipients in two stages: departments were asked in May about the employment status of that year's doctoral recipients (using the Doctorates Granted form), and the individual recipients themselves were polled during the summer (using the Salaries and Professional Experience or SAPE form). Obviously, the employment information obtained from individuals is more accurate than the preliminary data obtained from departments, and it is the department data updated by the SAPE form that has been presented in previous First Reports from the Committee.

Beginning with last year, the summer sampling of individual degree recipients using the SAPE form was replaced by a fall mailing using an instrument known as Employment Experiences of New Doctoral Recipients. This new procedure gathers additional information and permit comparisons with employment patterns in other disciplines, but its timing prevents having the more accurate employment data from individuals available for the Committee's First Report.

The employment data contained in this report is comparable to last year's data but not to data presented in reports prior to 1997. The Committee's Second Report, which will appear in a future issue of *Notices*, will present employment data comparable with those prior reports by virtue of its incorporation of responses from individual degree recipients.

Since sex, race/ethnicity, and citizenship reported by departments are not changed significantly by the individual SAPE forms, those data in this report can reasonably be compared with past reports from the Committee.

Doctoral Degrees Granted

The number of new doctoral recipients reported in 1997-98 by U.S. mathematical sciences departments is 1,216. Table 2A gives the fall and final counts for the past four Annual Surveys together with the current fall count. This year's fall count will be updated in the Second Report of the 1998 Annual Survey, to appear in a summer 1999 issue of *Notices.*

The 1998 fall count of the total number of new doctoral recipients of 1,216 represents an increase from the 1997 fall count of 1,158, and it is the highest number in three years.

Table 2A: U.S. New Doctoral Recipients, Fall and Final Counts

Year	Fall	Final
1993-1994	1059	1076
1994-1995	1226	1237
1995-1996	1153	1154
1996-1997	1158	1174
1997-1998	1216	*

*To appear in a summer 1999 issue of *Notices.*

Table 2B records the annual number of new doctoral recipients in the mathematical sciences in the U.S. from the year 1993-94, exclusive of Group Vb. The response rate for Group Vb, which includes some departments in engineering and management science, is the lowest of all groups.

Table 2B: New Doctoral Degrees Awarded by Groups I-Va, Fall Count

Year	93-94	94-95	95-96	96-97	97-98
I-Va	1025	1148	1098	1123	1163

The columns in Table 3B indicate how the count of 1,216 new doctoral recipients was spread over the mathematical sciences departments in Groups I-V. For mathematics departments (Groups I, II, and III combined), there was an increase of 2.2% in the fall count of new doctoral recipients over the previous year.

Employment Status of U.S. New Doctoral Recipients, 1997-98

The Annual Survey of New Doctoral Recipients provides a view of the employment market for new Ph.D.s in the mathematical sciences from the perspective of job applicants. Additional information about recruitment by four-year colleges and universities is reported in the Second Report of the Annual Survey; see the 1997 Second Report, *Notices*, October 1998, pages 1158-1171, for data on the numbers of positions departments attempted to fill and characteristics of the people hired for fall 1997.

As described in "Revised Procedure of Survey of Employment Status" at the beginning of this report, the employment information provided by departments on their doctoral recipients is updated and expanded by questionnaires sent to each doctoral recipient. In years prior to 1997 these forms were mailed out at the beginning of June, and early returns of these questionnaires were incorporated into the data that was ana-

Highlights

Based on responses from departments alone (see Revised Employment Status Survey Procedure), the preliminary unemployment rate among the 1,216 new doctoral recipients from the 1997-98 academic year has dropped to 7.2%, slightly higher than last year's 6.8% but still significantly better than the 1995-1996 figure of 10.1%. Of the 1997-1998 doctoral recipients, 1.7% hold part-time positions and 5.7% are employed at the same institution that awarded their degree, though not necessarily in the same department.

Of those doctoral recipients employed in the U.S., 30.0% hold jobs in business and industry, only slightly down from last year's fraction of 31.7% but larger in total number than last year by 3.4%. The number of recipients employed in U.S. academic positions increased in doctoral-degree granting departments by 5.7% and in master's and bachelor's departments by 11.3%.

Unemployment rates varied considerably by type of degree-granting department, ranging from 1.7% in Group V to 15.1% in Group III.

Women account for 24.4% of 1,216 new doctoral recipients, down slightly from 24.8% in 1996-97. The proportion varies with the type of department; for example, 22.3% of the recipeints from Groups I-III are women while 34.3% from statistics departments are women.

The proportion of women hired by doctoral-degree granting departments is merely 18.5%, well below their representation in the overall population of new doctoral recipients. The 163 women recipients who are U.S. citizens is the highest number ever reported by the Annual Survey. They represent 27.8% of the U.S. citizen pool, a slight reduction from last year's 28.7% share of the smaller number of graduates.

Among U.S. citizen doctoral recipients, Black or African Americans increased from 9 last year to 11 this year, while Hispanic or Latino remained constant at 14.

Of the 1,216 new doctoral recipients, 586 were awarded to U.S. citizens, an increase of 13.6% from last year's fall count of 516; 630 non-U.S. citizens received doctorates, down slightly from 642 in 1996-1997.

Paul W. Davis is professor of mathematics at Worcester Polytechnic Institute. James (Jim) W. Maxwell is AMS associate executive director for Professional Programs and Services. Kinda M. Remick is AMS survey specialist.

Table 3A: Employment Status of 1997–1998 U.S. New Doctoral Recipients in the Mathematical Sciences

TYPE OF EMPLOYER	FIELD OF THESIS: Algebra Number Theory	Real or Complex Analysis	Geometry/ Topology	Discr. Math./ Combin./ Logic/ Comp. Sci.	Probability/ Statistics	Applied Math.	Numerical Analysis Approxi- mations	Functional Analysis	Linear Nonlinear Optim./ Control	Differential Integral and Difference Equations	Harmonic Analysis and Topological Groups	Other/ Unknown	TOTAL
Group I (Public)	19	2	13	5	4	4	3	3	0	5	4	1	63
Group I (Private)	12	1	8	2	2	6	3	0	0	7	1	0	42
Group II	15	2	7	1	6	2	3	4	0	7	1	1	49
Group III	3	1	6	1	2	3	4	2	0	0	1	1	24
Group IV	1	2	0	0	32	0	0	0	0	0	0	0	35
Group V	0	0	1	2	2	3	2	0	0	0	0	0	10
Master's	9	2	6	8	15	4	7	4	2	6	1	1	65
Bachelor's	23	9	20	14	8	4	7	7	0	13	4	4	113
Two-Year College	0	0	2	0	0	1	1	0	0	0	0	0	4
Other Academic Dept.	3	0	6	7	29	16	7	1	5	3	2	3	82
Research Institute/ Other Nonprofit	6	1	2	0	9	5	0	0	0	2	3	2	30
Government	4	2	1	3	11	4	9	3	4	2	1	0	44
Business and Industry	17	8	7	15	93	33	20	4	12	21	7	3	240
Foreign, Academic	25	3	22	6	16	13	6	8	1	10	5	4	119
Foreign, Nonacademic	1	1	1	1	5	4	2	0	1	1	3	0	20
Not seeking employment	2	1	2	1	3	0	0	0	0	2	0	0	11
Still seeking employment	13	4	9	12	9	4	5	6	3	4	4	1	74
Unknown (U.S.)	15	5	15	10	32	12	4	0	4	7	3	5	112
Unknown (non-U.S.)*	13	4	12	5	16	4	3	1	3	7	5	6	79
Column Total	**181**	**48**	**140**	**93**	**294**	**122**	**86**	**43**	**35**	**97**	**45**	**32**	**1216**
Column Subtotals Male	146	40	111	72	200	95	73	35	27	70	32	18	**919**
Column Subtotals Female	35	8	29	21	94	27	13	8	8	27	13	14	**297**

*Non-U.S. citizens who return to their country of citizenship and whose status is reported as "unknown" or "still seeking employment".

Table 3B: Employment Status of 1997–1998 U.S. New Doctoral Recipients by Type of Granting Department

TYPE OF EMPLOYER	TYPE OF DOCTORAL DEGREE-GRANTING DEPARTMENT: Group I (Public) Math	Group I (Private) Math	Group II Math	Group III Math	Group IV Statistics	Group V Applied Math/OR	ROW TOTAL	ROW SUBTOTAL Male	ROW SUBTOTAL Female
Group I (Public)	26	24	9	1	0	3	63	49	14
Group I (Private)	10	23	5	1	0	3	42	39	3
Group II	17	10	17	1	2	2	49	39	10
Group III	7	3	5	6	2	1	24	18	6
Group IV	0	0	2	2	30	1	35	25	10
Group V	1	1	0	2	2	4	10	7	3
Master's	11	6	24	11	11	2	65	48	17
Bachelor's	32	11	45	18	6	1	113	76	37
Two-Year College	0	0	3	1	0	0	4	2	2
Other Academic Dept.	7	10	11	5	23	26	82	53	29
Research Institute/ Other Nonprofit	6	9	1	1	8	5	30	23	7
Government	14	1	11	5	8	5	44	31	13
Business and Industry	29	27	41	27	70	46	240	180	60
Foreign, Academic	49	19	19	7	14	11	119	99	20
Foreign, Nonacademic	6	5	0	1	2	6	20	17	3
Not seeking employment	4	3	1	1	2	0	11	8	3
Still seeking employment	18	8	24	16	6	2	74	56	18
Unknown (U.S.)	40	4	28	12	18	10	112	85	27
Unknown (non-U.S.)*	29	10	18	11	9	2	79	64	15
Column Total	**306**	**174**	**264**	**129**	**213**	**130**	**1216**	**919**	**297**
Column Subtotals Male	239	139	210	90	140	101	**919**		
Column Subtotals Female	67	35	54	39	73	29	**297**		

*Non-U.S. citizens who return to their country of citizenship and whose status is reported as "unknown" or "still seeking employment".

lyzed and reported in the First Report. Starting with the 1997 Annual Survey, the mailing to individual doctoral recipients took place in October. Hence, the 1998 figures on employment reported here do not reflect updated information from individuals, and they may not be strictly comparable with those of Annual Surveys prior to 1997.

Table 3A shows the employment status, by type of employer and field of degree, of the 1,216 recipients of doctoral degrees conferred by mathematical sciences departments in the U.S. between July 1, 1997, and June 30, 1998. The names of the individuals are listed with their thesis titles in this issue of *Notices* (pages 246–265).

Table 3A shows that among those whose employment status is known, 7.2% are unemployed. The corresponding rate of unemployment from 1996–97 is approximately 6.8%. After adjustment for comparability with current statistics, the unemployment rate for 1995–96, the last year of the old survey scheme, is approximately 10.1%. An update of Table 3A, incorporating the results of the follow-up questionnaire to individual recipients, will appear in the 1998 Second Report in a summer 1999 issue of *Notices*.

Beyond the unemployment statistics that are explicitly reported in Tables 3A, 3B, and 3C, the 1998 Survey provides other indicators about the job market. For example, 17 (1.7%) new doctoral recipients are reported to hold part-time positions, and 58 (5.7%) new doctoral recipients hold employment at the same institution that awarded their degree, although not necessarily in the same department in which the degree was earned. To compare with the corresponding statistics in 1997, 31 positions (3.3%) were part-time and 71 (7.5%) were held by doctoral recipients in the same institutions where they earned their doctoral degrees.

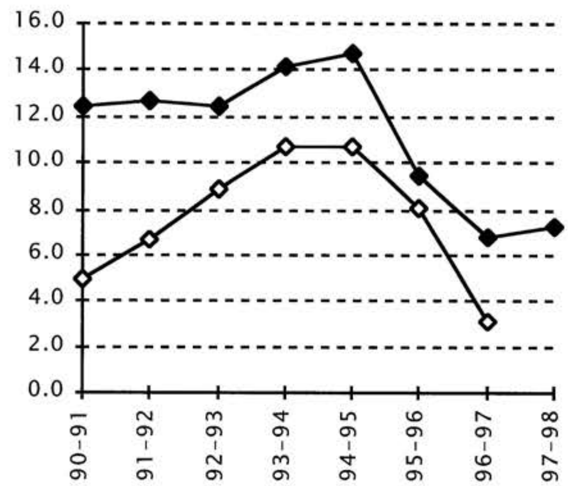
Most new doctoral recipients seek and accept academic positions. Of the 801 new doctoral recipients employed in the U.S., a total of 517 (64.5%) hold jobs in academia (including research institutes). For comparison, last year's data showed 731 new doctoral recipients employed in the U.S., including 467 (63.9%) in academic positions. Thus, total U.S. employment of new doctoral recipients has increased by 9.6%, and the percentage of positions in academia increased by 10.7%. Concomitantly, the fraction of nonacademic positions in the U.S. taken by new doctoral recipients decreased only slightly from 36.1% to 35.5% of those employed in the U.S, and the total number rose from 264 in 1996–97 to 284 this year.

The 517 U.S. academic positions this year include a total of 223 in U.S. doctoral degree-granting departments (Groups I–V). This number is 5.7% higher than last year's count (211 positions in Groups I–V). The number of new doctoral recipients employed by master's and bachelor's degree-granting colleges and universities (Groups M and B) increased by 18 (11.3%) from the number reported last year. The number of new doctoral recipients hired by research institutes increased by 50.0%, government increased by 37.5%, and business and industry increased by 3.4% from last year. Employment of the new doctoral recipients by business and industry constitutes 30.0% of all U.S. employment of these new doctoral recipients. Last year 31.7% were hired by business and industry.

Table 3C: Percentage of New Doctoral Recipients Unemployed (as reported in the respective Annual Survey Reports 1991–1998)

Year	Fall	Final
1990–1991	12.4	5.0
1991–1992	12.7	6.7
1992–1993	12.4	8.9
1993–1994	14.2	10.7
1994–1995	14.7	10.7
1995–1996	9.4	8.1
1996–1997	6.8	3.1
1997–1998	7.2	*

*To appear in a summer 1999 issue of *Notices.*



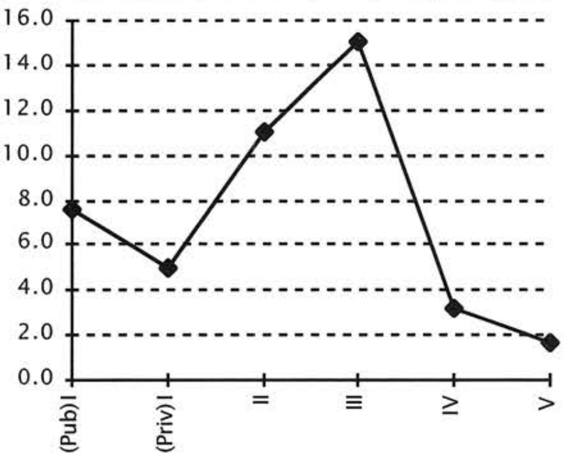
Caution: See Revised Procedure for Survey of Employment Status.

Table 3B reveals the dependence of employment patterns on the type of department from which the doctoral degree is received. New doctoral recipients hired for positions in doctoral degree-granting mathematics departments (Groups I, II, III) are drawn predominantly from these same departments: 92.7% of the positions filled in Groups I, II, and III are held by those who received their degrees from Group I, II, or III departments. Similarly, 85.7% of the Group IV jobs held by new doctoral recipients went to Group IV degree recipients. These percentages compare with 95.3% and 93.9% respectively from the 1997 figures.

Women represent 24.4% of the population of new doctoral recipients, down slightly from 24.8% in 1996–97, but the proportion is not uniform across different types of departments. For example, 22.3% of the new doctoral recipients in mathematics (Groups I+II+III) are women (up from 21.9% last year), and 34.3% of the new doctoral recipients from statistics departments are women (down from 37.6% last year). The proportion of women among new doctoral recipients hired by doctoral degree-granting mathematics departments (18.5%) is considerably less than

Table 3D: Percentage of Unemployed New Doctoral Recipients by Granting Department

Group	I (Public)	I (Private)	II	III	IV	V
%	7.6	5.0	11.0	15.1	3.2	1.7



their proportion among mathematics doctoral recipients. The rate of unemployment for the female new doctoral recipients (7.1%) is slightly lower than the rate for the male new doctoral recipients (7.3%).

Table 3D shows different rates of unemployment for doctoral recipients based on the group of their granting department. The percentages unemployed is based on those whose employment status is known. The rates for groups I, II, and IV are roughly comparable with last year. Groups III and V are significantly different, being 4.2% and 12.3%, respectively, in fall 1997.

Table 3E shows the pattern of employment within broad job categories broken down by the citizenship status of the new doctoral recipients. The citizenship status is known for all of the 1,216 new doctoral recipients. For those whose job status is known, the rate of unemployment for non-U.S. citizens is 1.4 percentage points lower than that for U.S. citizens (6.5% for noncitizens and 7.9% for citizens). Nevertheless, the unemployment rate for U.S. citizens is 0.5 percentage points below the level of last year's data. The percentage of U.S. citizens in U.S. nonacademic jobs is higher than the percentage of noncitizens in the same category (29.6% of citizens versus 25.8% of noncitizens). While the former figure went up by 6.6 percentage points, the latter figure dropped by 6.8 percentage points. The percentage of U.S. citizen degree recipients holding positions in U.S. doctoral degree-granting departments (19.5%) is lower than the percentage for non-U.S. citizens (24.0%). U.S. citizen graduates hold positions in nondoctoral-degree granting U.S. departments in substantially higher proportion than do noncitizens (35.4% of citizens compared to 15.9% of noncitizens). All percentages exclude new doctoral recipients whose job status is unknown.

Of the temporary residents who received doctorates this year, 50.6% obtained U.S. employment, while 77.6% of the permanent residents found U.S. employment, compared with 49.9% and 64.0% respectively last year.

Sex, Ethnicity, and Citizenship of U.S. New Doctoral Recipients, 1997–1998

Table 4 presents a breakdown according to gender, ethnic group, and citizenship of the new doctoral recipients. The information reported in this table was obtained in summary form from the departments granting the degrees.

The citizenship status is known for all of the 1,216 new doctoral recipients, including 586 U.S. citizens. The number of U.S. citizen new doctoral recipients is 13.6% more than the 1996–97 figure of 516. Table 5 shows the changes from year to year in the numbers and proportions of U.S. citizens.

The percentage of U.S. citizens among the new doctoral recipients is 48.2%, an increase from last year's percentage of 44.5%. A total of 630 noncitizens were awarded doctoral degrees by U.S. institutions in 1997–98. This represents a decrease of 12 individuals (1.9%) from last year's count of 642. The 1997–98 count is 73.6% greater than the number awarded by U.S. institutions ten years ago (363 in 1987–88).

Among the U.S. citizens receiving doctoral degrees in the mathematical sciences, 11 are Black or African American (6 men and 5 women) and 14 are Hispanic or Latino (8 men and 6

Table 3E: Employment Status of 1997–1998 U.S. New Doctoral Recipients by Citizenship Status

	CITIZENSHIP								TOTAL DOCTORAL RECIPIENTS WHOSE CITIZENSHIP IS KNOWN*	
			NON-U.S. CITIZENS							
	U.S. CITIZENS		Permanent Visa		Temporary Visa		Unknown Visa			
TYPE OF EMPLOYER	Number	%	Number	%	Number	%	Number	%	Number	%
U.S. Academic, Ph.D. Department	101	17.2	27	23.3	81	18.2	14	20.3	223	18.3
U.S. Academic, Non-Ph.D. Department	183	31.3	26	22.4	49	11.0	6	8.7	264	21.7
U.S. Research Institute/Other Nonprofit	11	1.9	2	1.7	14	3.2	3	4.4	30	2.5
U.S. Nonacademic	153	26.1	35	30.2	81	18.2	15	21.7	284	23.3
Foreign Academic	20	3.4	5	4.3	83	18.7	11	15.9	119	9.8
Foreign Nonacademic	3	0.5	0	0.0	16	3.6	1	1.5	20	1.6
Not Seeking Employment	5	0.9	1	0.9	5	1.1	0	0.0	11	0.9
Still Seeking Employment	41	7.0	5	4.3	28	6.3	0	0.0	74	6.1
Unknown (U.S. address given)	65	11.1	14	12.1	24	5.4	9	13.0	112	9.2
Unknown (foreign address given)	4	0.7	1	0.9	64	14.4	10	14.5	79	6.5
TOTAL	586	100.0*	116	100.0*	445	100.0*	69	100.0*	1216	100.0*

* Column totals are rounded to the nearest whole percent.

women). The former increased by 2 individuals from last year, while the latter remained the same.

Women account for 27.8% of the U.S. citizens receiving doctoral degrees in the mathematical sciences from U.S. universities. This is only slightly lower than last year's figure of 28.7, the highest percentage ever reported. In addition, the total number of U.S. citizen women who were 1997-98 doctoral recipients (163) increased by 10.1% from last year's reported 148 and is now the highest number ever reported by the Annual Survey (see Table 6).

Note that in Tables 5 and 6 all years prior to 1982-83 include doctoral recipients from computer science departments.

Acknowledgments

The Annual Survey attempts to provide an accurate appraisal and analysis of various aspects of the academic mathematical sciences scene for the use and benefit of the community and for filling the information needs of the professional organizations. Every year, college and university departments in the United States are invited to respond. The Annual Survey relies heavily on the conscientious efforts of the dedicated staff members of these departments for the quality of its information. On behalf of the Annual Survey Data Committee and the Annual Survey staff, we thank the many secretarial and administrative staff members in the mathematical sciences departments for their cooperation and assistance in responding to the survey questionnaires.

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Table 4: Sex, Race/Ethnicity, and Citizenship of 1997-1998 U.S. New Doctoral Recipients

	MEN					WOMEN					
		NON-U.S. CITIZEN					NON-U.S. CITIZEN				
RACIAL/ETHNIC GROUP	U.S. CITIZEN	Permanent Visa	Temporary Visa	Unknown Visa	Total Men	U.S. CITIZEN	Permanent Visa	Temporary Visa	Unknown Visa	Total Women	TOTAL
American Indian or Alaska Native	2	0	3	0	5	2	0	0	0	2	7
Asian	15	36	191	32	274	12	22	42	6	82	356
Black or African American	6	4	4	0	14	5	0	1	0	6	20
Hispanic or Latino	8	2	32	5	47	6	1	10	0	17	64
Native Hawaiian or Other Pacific Islander	0	1	1	0	2	0	0	0	2	2	4
White	392	38	126	19	575	138	12	33	5	188	763
Unknown	0	0	2	0	2	0	0	0	0	0	2
TOTAL	423	81	359	56	919	163	35	86	13	297	1216

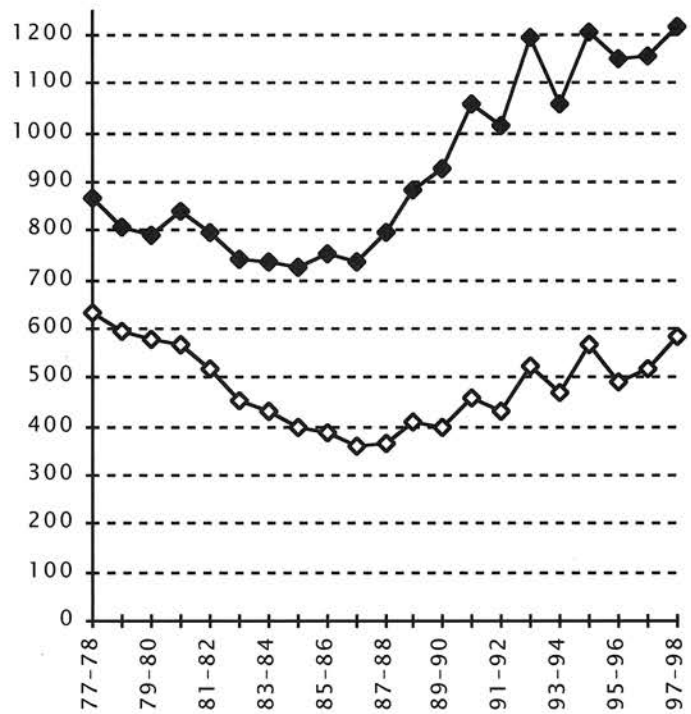
Table 5: U.S. Citizen Doctoral Recipients

	Adjusted Total* Doctorates Granted by U.S. Institutions	Total U.S. Citizen Doctoral Recipients	%
77–78	868	634	73
78–79	806	596	74
79–80	791	578	73
80–81	839	567	68
81–82	798	519	65
82–83	744	455	61
83–84	738	433	59
84–85	726	396	55
85–86	755	386	51
86–87	739	362	49
87–88	798	363	45
88–89	884	411	46
89–90	929	401	43
90–91	1061	461	43
91–92	1016	430	42
92–93	1197	526	44
93–94	1059	469	44
94–95	1207	567	47
95–96	1150	493	43
96–97	1158	516	45
97–98	1216	586	48

*Number of doctoral recipients whose citizenship is known. Total may vary from Table 3E of the respective First Reports, as the data is gathered on different surveys.

Graph 5A: U.S. Citizen Doctoral Recipients

Upper Line: Adjusted Total Doctorates Granted by U. S. Institutions
Lower Line: Total U.S. Citizen Doctoral Recipients



Graph 5B: U.S. Citizen Doctoral Recipients by Percent

Upper Line: Total U.S. Citizen Doctoral Recipients as a Percent of Total Doctorates Granted
Lower Line: Female U.S. Citizen Doctoral Recipients as a Percent of Total U.S. Citizen Doctoral Recipients

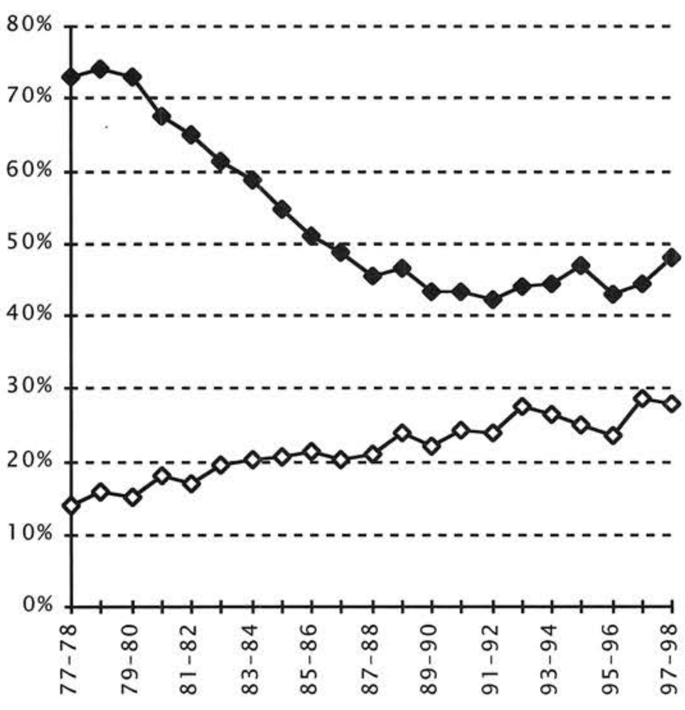


Table 6: U.S. Citizen Doctoral Recipients by Sex

	Total U.S. Citizen Doctoral Recipients	Male	Female	% Female
77–78	634	545	89	14
78–79	596	503	93	16
79–80	578	491	87	15
80–81	567	465	102	18
81–82	519	431	88	17
82–83	455	366	89	20
83–84	433	346	87	20
84–85	396	315	81	20
85–86	386	304	82	21
86–87	362	289	73	20
87–88	363	287	76	21
88–89	411	313	98	24
89–90	401	312	89	22
90–91	461	349	112	24
91–92	430	327	103	24
92–93	526	381	145	28
93–94	469	345	124	26
94–95	567	426	141	25
95–96	493	377	116	24
96–97	516	368	148	29
97–98	586	423	163	28

National Research Council, *Summary Report 1996, Doctorate Recipients from U. S. Universities*, National Academy Press, Washington, DC, 1998.

____, *Moving beyond Myths: Revitalizing Undergraduate Mathematics*, National Academy Press, Washington, DC, 1991.

____, *Everybody Counts: A Report to the Nation on the Future of Mathematics Education*, National Academy Press, Washington, DC, 1989.

____, *Renewing U.S. Mathematics: A Plan for the 1990s*, National Academy Press, Washington, DC, 1990.

National Science Board, Science and engineering indicators–1998, National Science Foundation, Arlington, VA, 1998 (NSB 98-1).

National Science Foundation, Science and technology pocket data book, NSF 96-324, Arlington, VA, 1996.

____, Science and engineering degrees: 1966–95, NSF 97-335, Arlington, VA, 1997.

____, Science and engineering doctorate awards: 1996, NSF 97-329, Detailed Statistical Tables, Arlington, VA, 1997.

____, Academic science and engineering: Graduate enrollment and support, 1991, NSF 93-309, Detailed Statistical Tables, Washington, DC, 1993.

____, Selected data on graduate students and postdoctorates in science and engineering, Fall 1993, NSF 95-316; Selected Pamphlet No. 11: Institutional listings, NSF 90-324-11; Selected Pamphlet No. 12: Postdoctorates and other nonfaculty research staff, NSF 90-324-12; Washington, DC, 1990.

____, Survey of mathematics and statistics departments at higher education institutions, Higher Education Surveys Report, Survey Number 5, Washington, DC, December 1990.

____, Foreign participation in U.S. academic science and engineering: 1991, NSF 93-302, Washington, DC, 1993.

Salary Survey for Faculty

The charts on the following pages display faculty salary data for Groups I Public, I Private, II, III, IV, Va, M, and B: faculty salary distribution by rank, mean salaries by rank, information on quartiles by rank, and the number of usable returns for the group. Since groupings used for the mathematics departments in this year's report differ from years prior to 1995–96, comparisons are possible only to the last two years' data. In addition, Group Va is reported separately this year. Group Vb departments have been dropped from the salary survey due to extremely low response rates. Departments were asked to report the number of tenured and tenure-track faculty whose 1998–99 academic-year salaries fell within given salary intervals. Reporting salary data in this fashion eliminates some of the concerns about confidentiality but does not permit determination of actual quartiles. What can be determined is the salary interval in which the quartiles occur; the salary intervals containing the quartiles are denoted by <n, n+5>.

Reclassification of Departments

As has been the case for a number of years, much of the data in these reports is presented for departments divided into groups according to several characteristics, the principal one being the highest degree offered in the mathematical sciences. Doctorate-granting departments of mathematics are further subdivided according to their ranking of "scholarly quality of program faculty" as reported in the 1995 publication *Research-Doctorate Programs in the United States: Continuity and Change.*[1] These rankings update those reported in a previous study published in 1982.[2] Consequently, the departments which now comprise Groups I, II, and III differ significantly from those used prior to the 1996 Survey.

The subdivision of the Group I institutions into Group I Public and Group I Private was new for the 1996 survey. With the increase in number of the Group I departments from 39 to 48, the Annual Survey Data Committee judged that a further subdivision of public and private would provide more meaningful reporting of the data for these departments.

Brief descriptions of the groupings used for reporting purposes are as follows:

Group I is composed of 48 departments with scores in the 3.00–5.00 range.

Group I Public and Group I Private are Group I departments at public institutions and private institutions respectively.

Group II is composed of 56 departments with scores in the 2.00–2.99 range.

Group III contains the remaining U.S. departments reporting a doctoral program, including a number of departments not included in the 1995 ranking of program faculty.

Group IV contains U.S. departments (or programs) of statistics, biostatistics, and biometrics reporting a doctoral program.

Group V contains U.S. departments (or programs) in applied mathematics/applied science, operations research, and management science which report a doctoral program.

Group Va is applied mathematics/applied science; Group Vb is operations research and management science.

Group M contains U.S. departments granting a master's degree as the highest graduate degree.

Group B contains U.S. departments granting a baccalaureate degree only.

Listings of the actual departments which comprise these groups are available on the AMS Web site at www.ams.org/employment/.

[1] Research-Doctorate Programs in the United States: Continuity and Change, *edited by Marvin L. Goldberger, Brendan A. Maher, and Pamela Ebert Flattau; National Academy Press; Washington, D; 1995.*

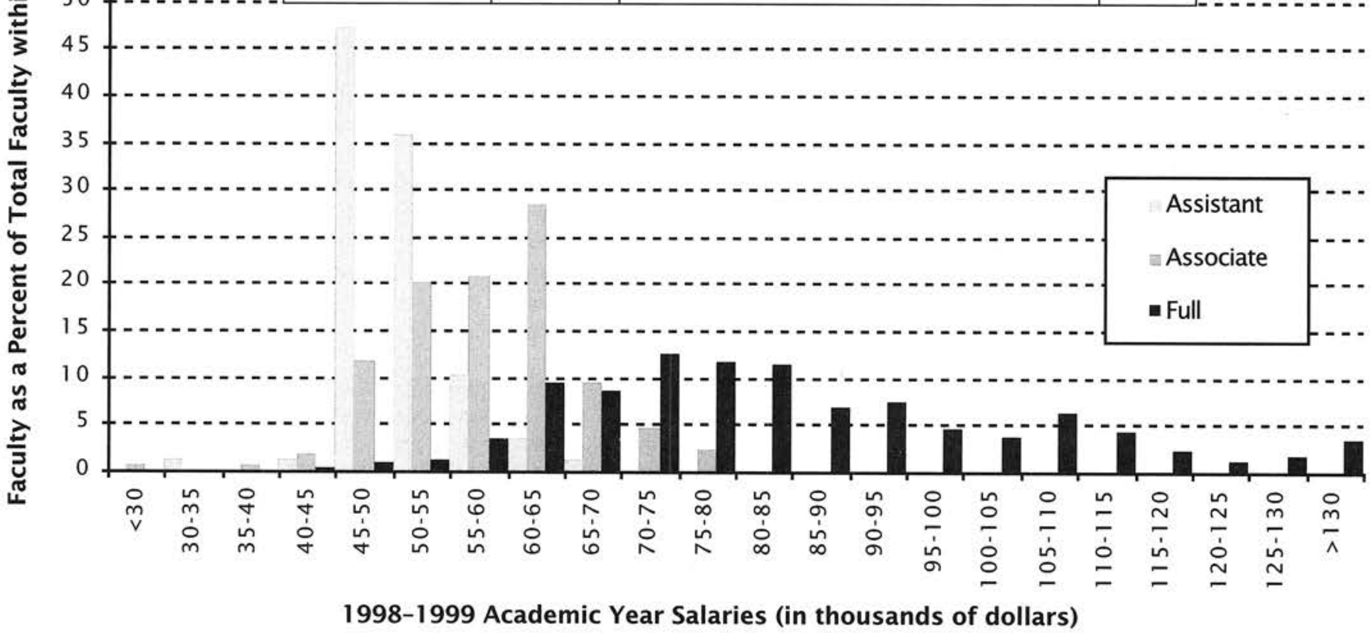
[2] *These findings were published in* An Assessment of Research-Doctorate Programs in the United States: Mathematical and Physical Sciences, *edited by Lyle V. Jones, Gardner Lindzey, and Porter E. Coggeshall; National Academy Press; Washington, DC; 1982. The information on mathematics, statistics, and computer science was presented in digest form in the April 1983 issue of the* Notices, *pages 257–67, and an analysis of the classifications was given in the June 1983* Notices, *pages 392–3.*

Group I Public Faculty Salaries

Doctoral degree-granting departments of mathematics (25)

21 usable responses (84%)

Rank	No. Reported	1998-1999 Q1	1998-1999 Median	1998-1999 Q3	1998-1999 Mean	1997-1998 Mean
Assistant Professor	87	<40,45>	<45,50>	<50,55>	50,424	47,451
Associate Professor	173	<50,55>	<55,60>	<60,65>	58,166	55,087
Full Professor	810	<70,75>	<80,85>	<95,100>	85,571	80,370

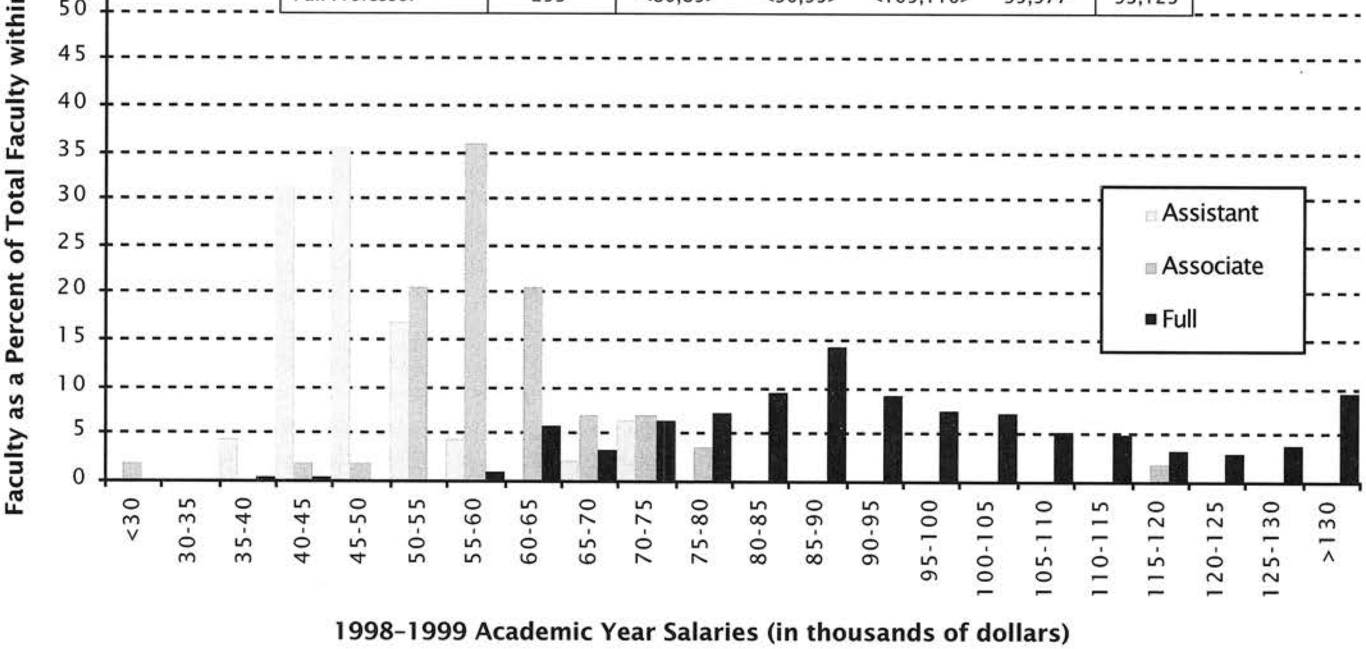


Group I Private Faculty Salaries

Doctoral degree-granting departments of mathematics (23)

14 usable responses (61%)

Rank	No. Reported	1998-1999 Q1	1998-1999 Median	1998-1999 Q3	1998-1999 Mean	1997-1998 Mean
Assistant Professor	48	<40,45>	<45,50>	<45,50>	48,722	47,561
Associate Professor	59	<50,55>	<55,60>	<60,65>	59,744	62,657
Full Professor	253	<80,85>	<90,95>	<105,110>	95,977	93,123

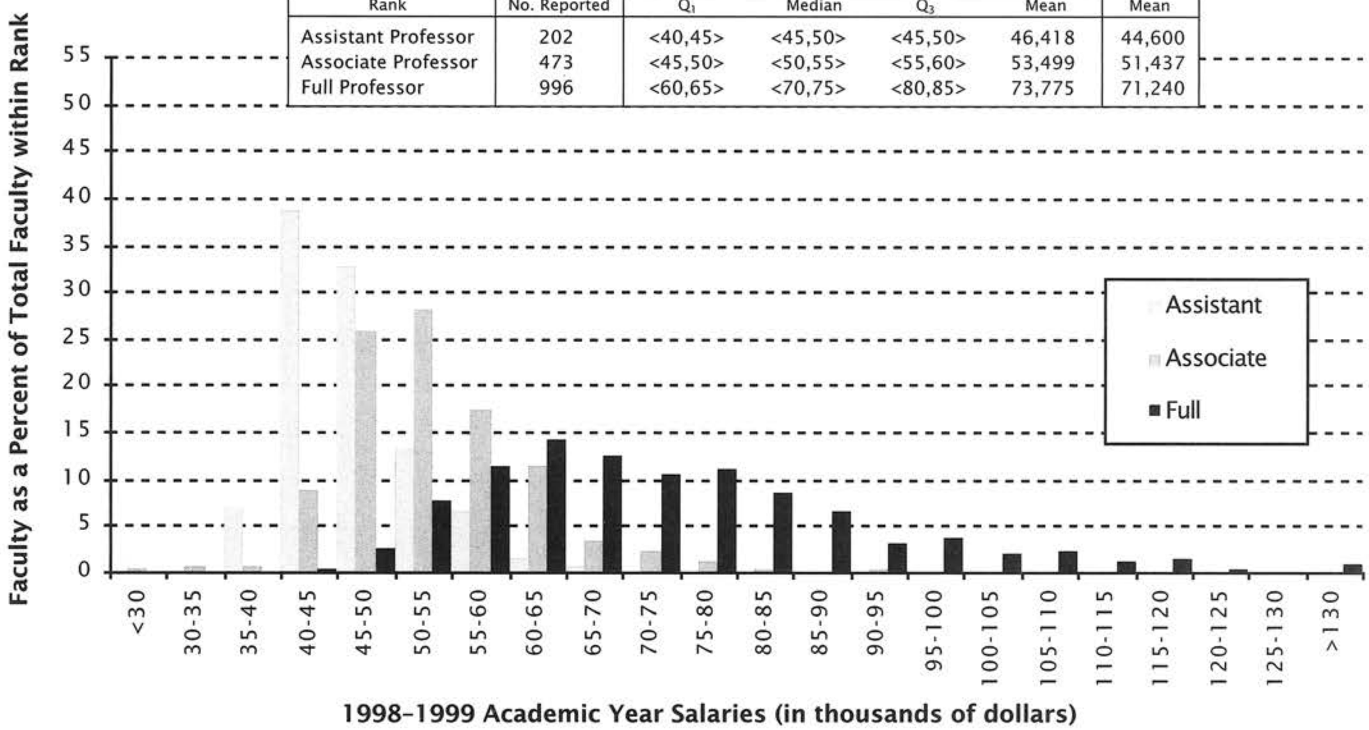


Group II Faculty Salaries

Doctoral degree-granting departments of mathematics (56)

50 usable responses (89%)

Rank	1998-1999 No. Reported	1998-1999 Q_1	1998-1999 Median	1998-1999 Q_3	1998-1999 Mean	1997-1998 Mean
Assistant Professor	202	<40,45>	<45,50>	<45,50>	46,418	44,600
Associate Professor	473	<45,50>	<50,55>	<55,60>	53,499	51,437
Full Professor	996	<60,65>	<70,75>	<80,85>	73,775	71,240

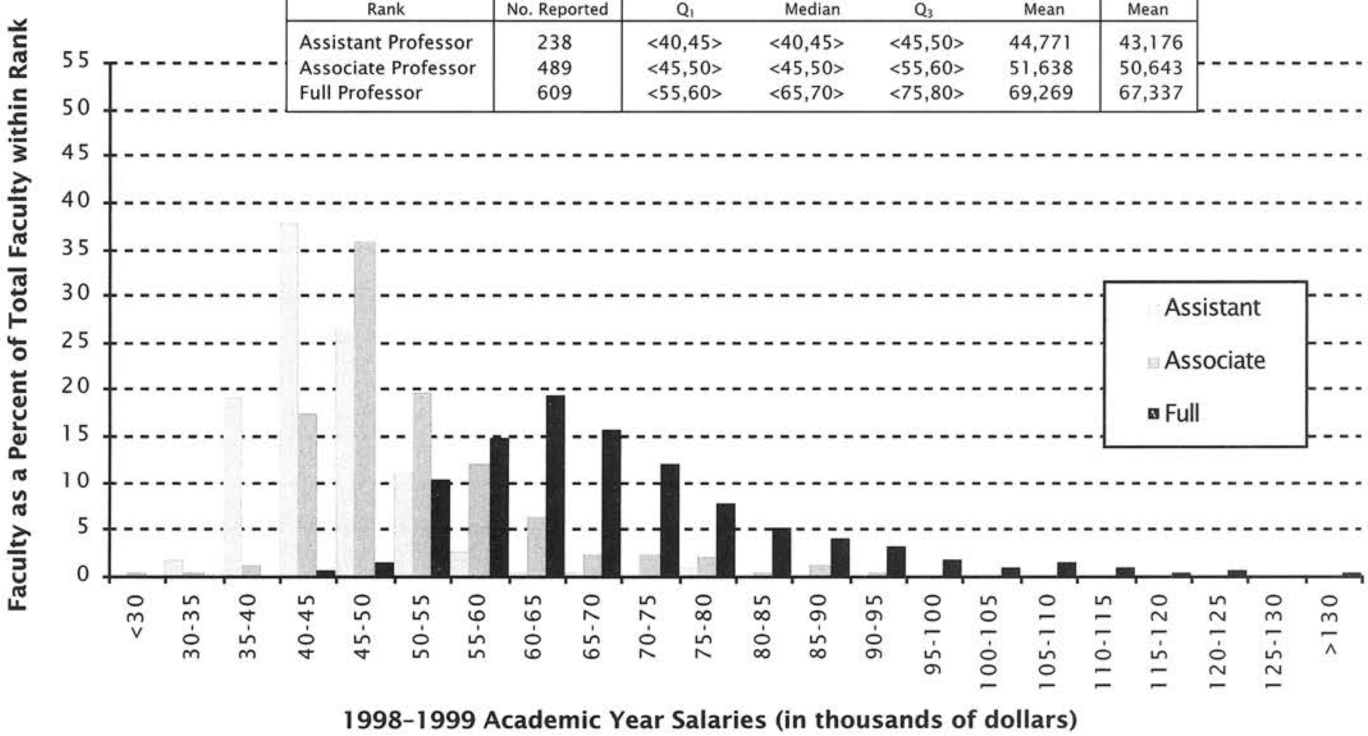


Group III Faculty Salaries

Doctoral degree-granting departments of mathematics (73)

60 usable responses (82%)

Rank	1998-1999 No. Reported	1998-1999 Q_1	1998-1999 Median	1998-1999 Q_3	1998-1999 Mean	1997-1998 Mean
Assistant Professor	238	<40,45>	<40,45>	<45,50>	44,771	43,176
Associate Professor	489	<45,50>	<45,50>	<55,60>	51,638	50,643
Full Professor	609	<55,60>	<65,70>	<75,80>	69,269	67,337

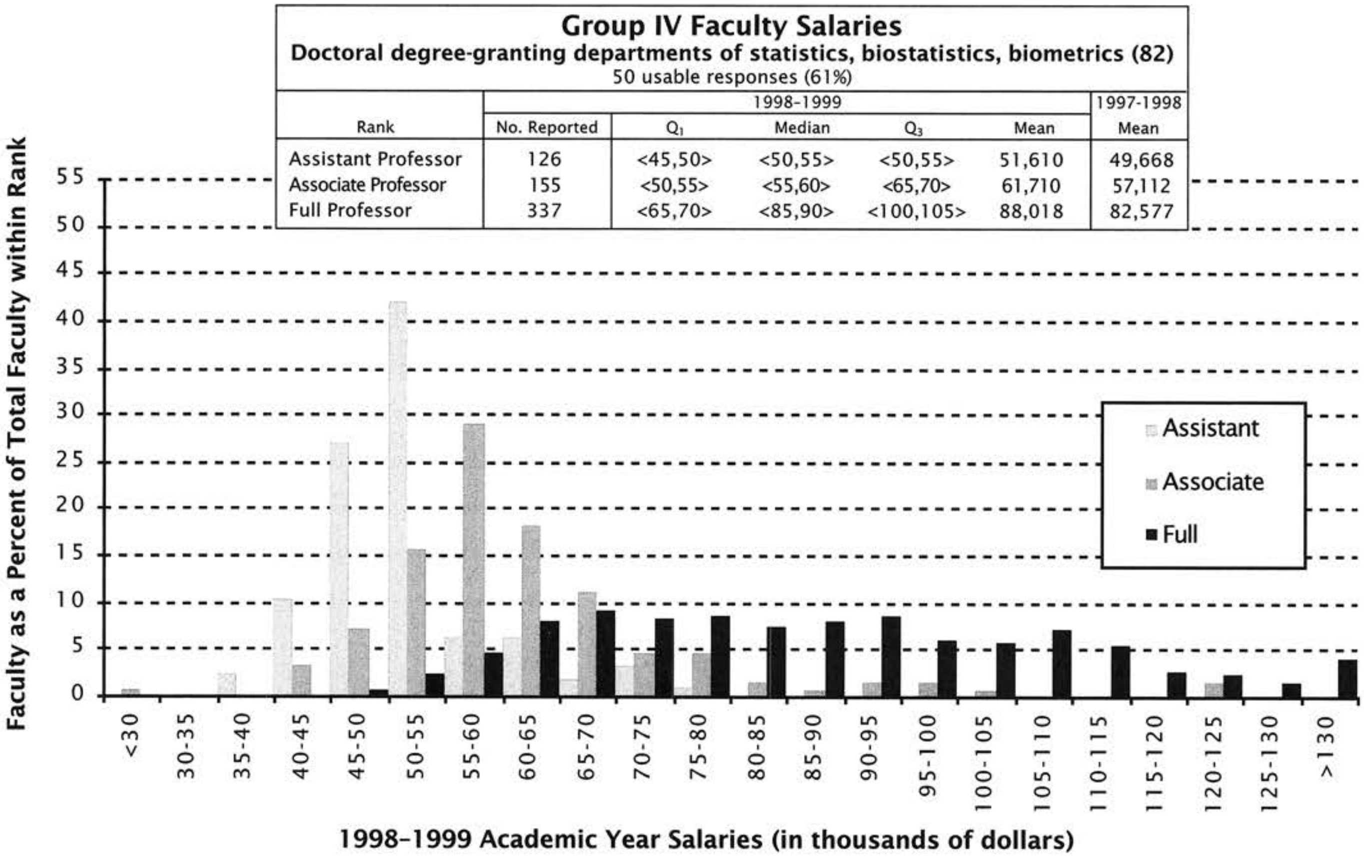


Group IV Faculty Salaries

Doctoral degree-granting departments of statistics, biostatistics, biometrics (82)

50 usable responses (61%)

Rank	1998-1999 No. Reported	Q_1	Median	Q_3	Mean	1997-1998 Mean
Assistant Professor	126	<45,50>	<50,55>	<50,55>	51,610	49,668
Associate Professor	155	<50,55>	<55,60>	<65,70>	61,710	57,112
Full Professor	337	<65,70>	<85,90>	<100,105>	88,018	82,577

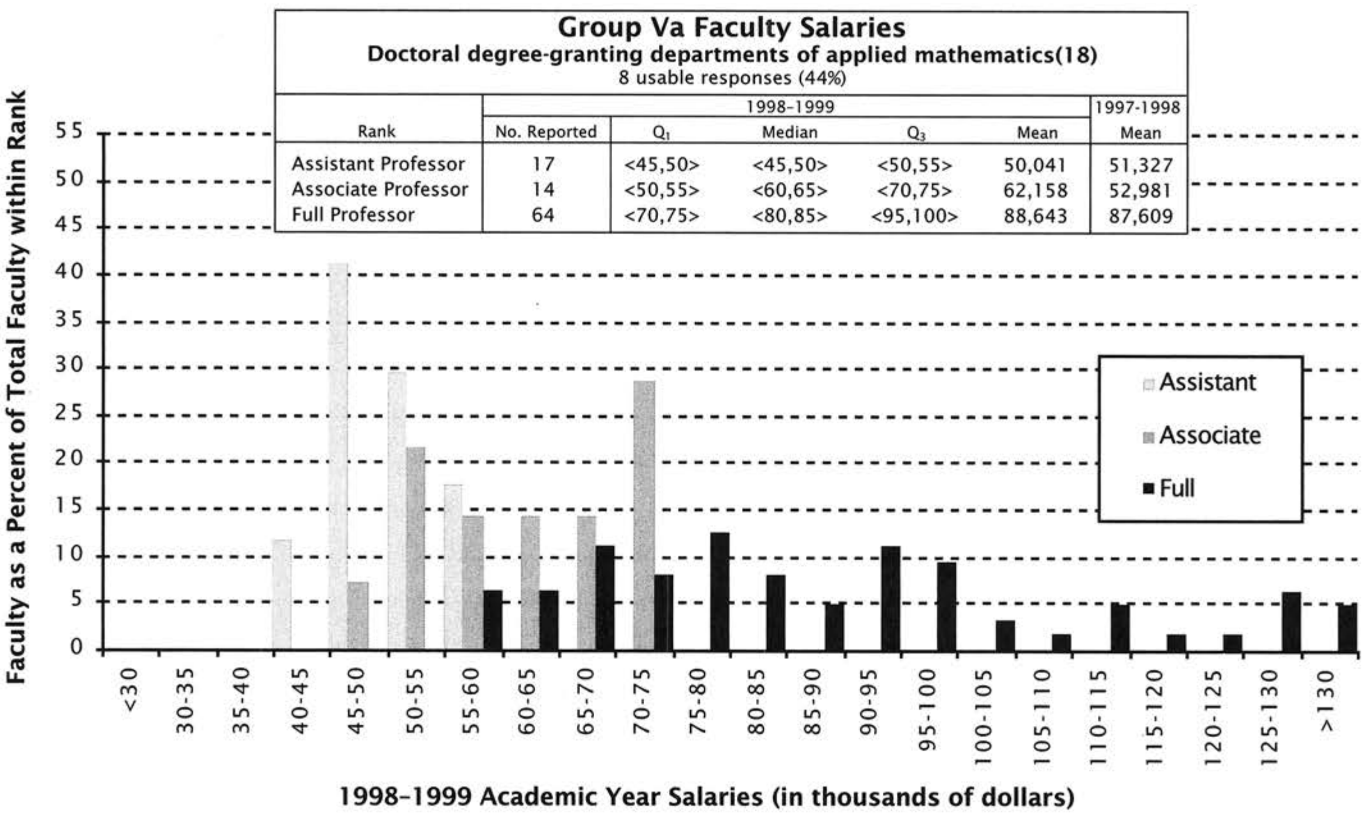


Group Va Faculty Salaries

Doctoral degree-granting departments of applied mathematics(18)

8 usable responses (44%)

Rank	1998-1999 No. Reported	Q_1	Median	Q_3	Mean	1997-1998 Mean
Assistant Professor	17	<45,50>	<45,50>	<50,55>	50,041	51,327
Associate Professor	14	<50,55>	<60,65>	<70,75>	62,158	52,981
Full Professor	64	<70,75>	<80,85>	<95,100>	88,643	87,609

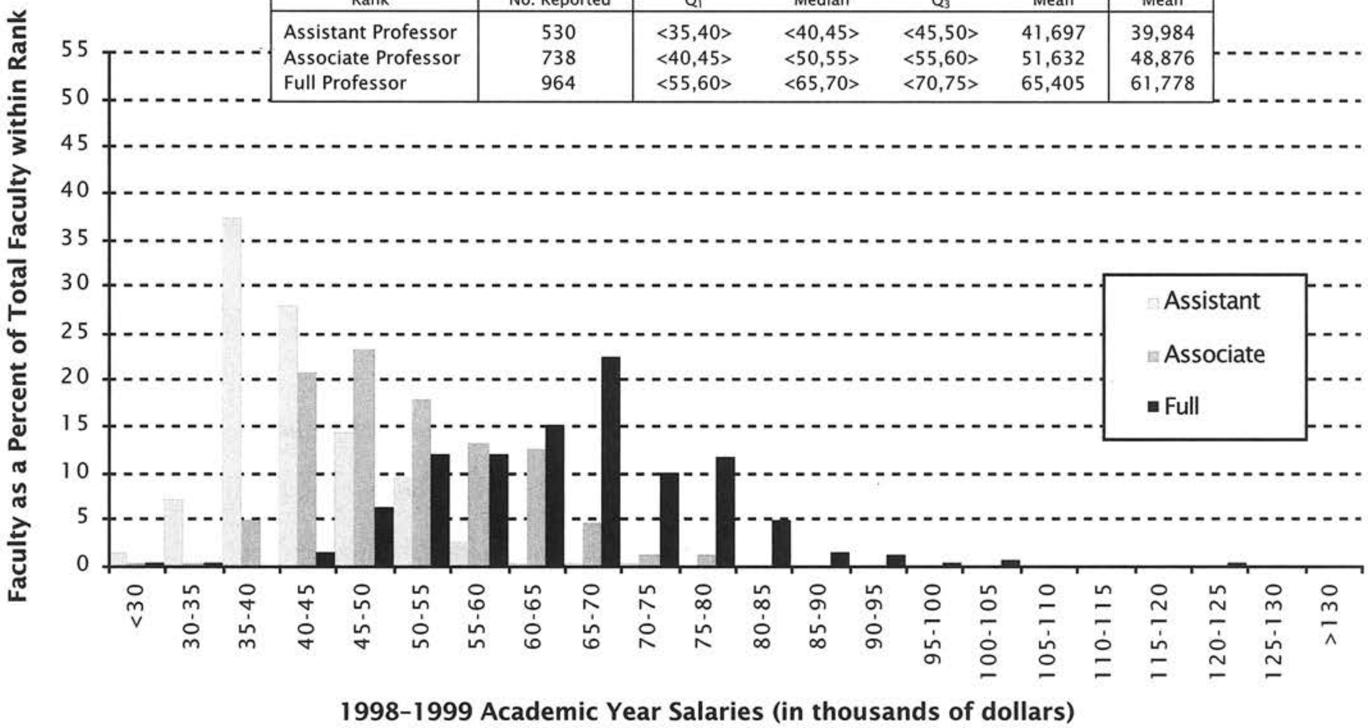


Group M Faculty Salaries

Master's degree-granting departments of mathematics (231)

124 usable responses (54%)

Rank	1998–1999 No. Reported	1998–1999 Q_1	1998–1999 Median	1998–1999 Q_3	1998–1999 Mean	1997-1998 Mean
Assistant Professor	530	<35,40>	<40,45>	<45,50>	41,697	39,984
Associate Professor	738	<40,45>	<50,55>	<55,60>	51,632	48,876
Full Professor	964	<55,60>	<65,70>	<70,75>	65,405	61,778

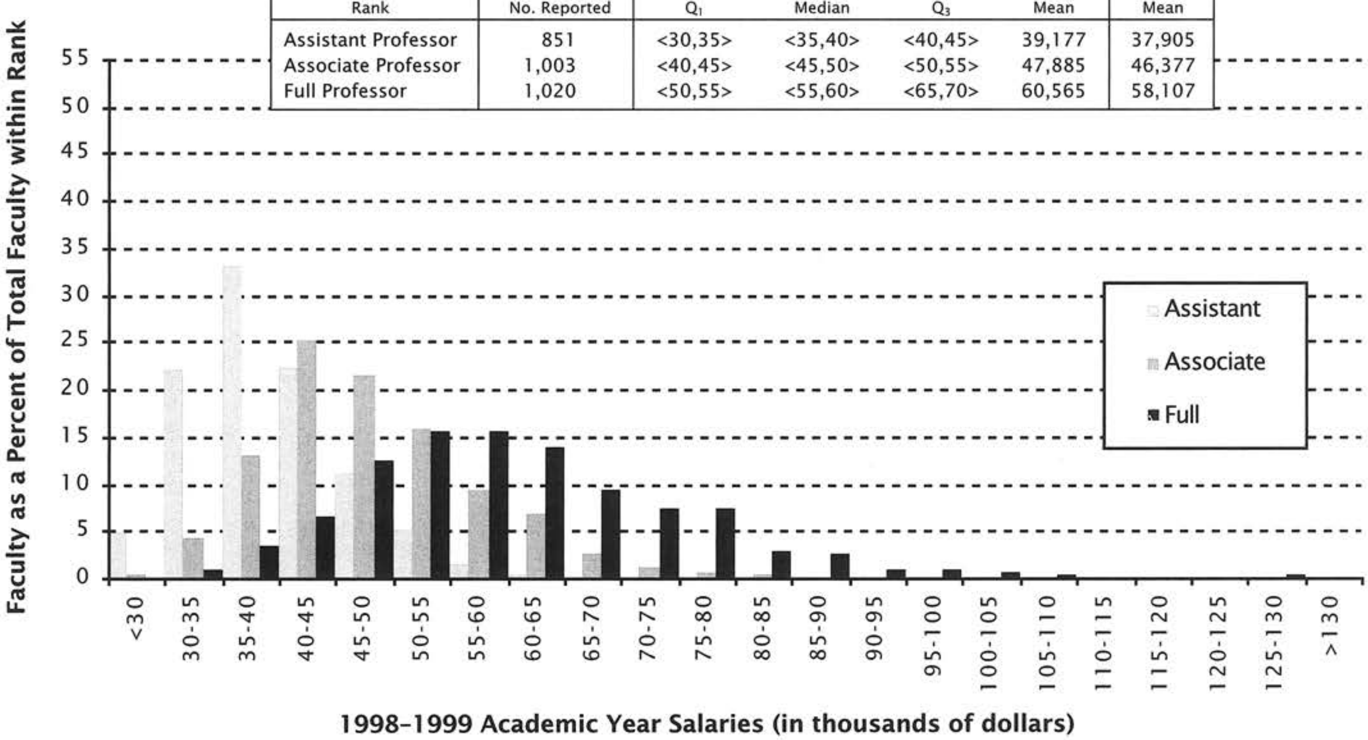


Group B Faculty Salaries

Bachelor's degree-granting departments of mathematics (1,012)

383 usable responses (38%)

Rank	1998–1999 No. Reported	1998–1999 Q_1	1998–1999 Median	1998–1999 Q_3	1998–1999 Mean	1997-1998 Mean
Assistant Professor	851	<30,35>	<35,40>	<40,45>	39,177	37,905
Associate Professor	1,003	<40,45>	<45,50>	<50,55>	47,885	46,377
Full Professor	1,020	<50,55>	<55,60>	<65,70>	60,565	58,107



Mathematics People

AAAS Fellows Elected

Four mathematicians have been elected as Fellows of Section A, the mathematics section, of the American Association for the Advancement of Science. The new fellows are JERRY L. BONA, University of Texas, Austin; KEITH DEVLIN, St. Mary's College; DEBORAH HUGHES HALLETT, Harvard University; and JAMES A. YORKE, University of Maryland.

—From an AAAS announcement

Putnam Prizes Awarded

The winners of the 58th William Lowell Putnam Competition have been announced. The Putnam Competition is administered by the Mathematical Association of America and consists of an examination containing mathematical problems that are designed to test both originality and technical competence. Prizes are awarded to both individuals and teams.

The six highest ranking individuals, listed in alphabetical order, were PATRICK K. CORN, Harvard University; MIKE L. DEVELIN, Harvard University; SAMUEL GRUSHEVSKY, Harvard University; CIPRIAN MANOLESCU, Harvard University; OVIDIU SAVIN, University of Pittsburgh; and DANIEL K. SCHEPLER, Washington University, St. Louis.

IOANA DUMITRIU of New York University was awarded the Elizabeth Lowell Putnam Prize, which is given to the woman who turns in the most outstanding performance in the Competition. Dumitriu also won the Elizabeth Lowell Putnam Prize in the 57th Competition, in which she was the first woman ever to place among the six highest-scoring individuals. The Elizabeth Lowell Putnam Prize carries a cash award of $1,000.

Institutions with at least three registered participants obtain a team ranking in the Competition based on the rankings of three designated individual participants. The five top-ranked teams (with team members listed in alphabetical order) were: Harvard University (Samuel Grushevsky, Dragos N. Oprea, Stephen S. Wang), Duke University (Jonathan G. Curtis, Andrew O. Dittmer, Noam M. Shazeer), Princeton University (Craig R. Helfgott, Michael R. Korn, Alexandru-Anton A. M. Popa), Massachusetts Institute of Technology (Federico Ardila, Constantin S. Chiscanu, Amit Khetan), and Washington University, St. Louis (Daniel B. Johnston, Daniel K. Schepler, Arun K. Sharma).

The top five individuals in the Competition received cash awards of $2,500; the next ten received $1,000. The first-place team was awarded $25,000, with each team member receiving $1,000. The team awards for second place were $20,000 and $800; for third place, $15,000 and $600; for fourth place, $10,000 and $400; and for fifth place, $5,000 and $200.

—Elaine Kehoe

Pi Mu Epsilon Awards Student Prizes

The AMS sponsors an annual prize that is awarded by Pi Mu Epsilon, the national honorary mathematics society. The prize was initiated in 1989 in honor of PME's seventy-fifth anniversary. PME administers the prize and uses it to recognize the best student papers presented at a PME student paper session. Each recipient of the AMS Award for Outstanding Pi Mu Epsilon Student Paper Presentation receives a check for $150. Following is a list of the recipients of the awards that were made at the 1998 Pi Mu Epsilon meeting, held last July in Toronto, Canada.

The winning speakers were STEPHEN BOCHANSKI, St. Joseph's University; JOE FERGUSON, Youngstown State University; NATHAN L. GIBSON, Worcester Polytechnic Institute; STEPHEN HARTKE, University of Dayton; KIMBALL MARTIN, University of Maryland, Baltimore County; TING FAI NG, University of Pennsylvania; JOHN SLANINA, Youngstown State University; and HARRY SMITH, St. Joseph's University.

The winners each received a prize of $150. Bochanski and Smith, who coauthored their paper, shared the $150 award.

—From a Pi Mu Epsilon announcement

NRC-Ford Foundation Minority Fellowships Awarded

Four mathematicians have been awarded Ford Foundation Minority Fellowships for 1998. The fellowship programs are administered by the National Research Council for the purpose of increasing the presence of underrepresented groups among faculty members in colleges and universities.

The recipients of 1998 Predoctoral Fellowships are Sharon Angela Newman-Gomez, University of California, Riverside; John Anthony Pérez, Brown University; and Francisco Ramon Rios, University of California, Berkeley. The Predoctoral Fellowship program provides students of demonstrated ability with the opportunity to engage in advanced study leading to the Ph.D. or Sc.D. degree in research-based doctoral programs.

David Vicente Cruz-Uribe of Trinity College was chosen as a 1998 Postdoctoral Fellow. This fellowship allows teacher-scholars the opportunity for research and scholarship free from the interference of their professional duties.

The award winners were selected from a field of about 1,000 applicants, based on merit and promise of future achievement. More information about the fellowship programs is available on the World Wide Web at `http://fellowships.nas.edu/`.

—From a National Research Council announcement

Deaths

Walter Bernard, of Providence, RI, died on August 31, 1998. He was a member of the Society for 7 years.

Gabriel Fontrier, professor emeritus at Queens College, CUNY, died on August 5, 1998. Born on November 21, 1918, he was a member of the Society for 6 years.

Jean Leray, professor emeritus at the Collège de France, died on November 10, 1998. Born on November 7, 1906, he was a member of the Society for 47 years.

Ralph S. Phillips, Robert Grimmett Professor Emeritus at Stanford University, died on November 23, 1998. Born on June 23, 1913, he was a member of the Society for 61 years.

Thomas H. Slook, professor emeritus at Temple University, died on October 9, 1998. Born on October 6, 1919, he was a member of the Society for 50 years.

Mathematics Opportunities

Conference Announcement

The Summer Mathematics Experience: A Working Conference on Summer Mathematics Programs for Undergraduates, organized by the AMS and funded by the National Security Agency, will take place Thursday, September 30, 1999–Sunday, October 3, 1999, in the Washington, DC, area.

The goals of the conference include: identifying best practices in summer programs for undergraduates, building a network of faculty who work on such programs, using these programs to increase the number of mathematicians from historically underrepresented groups, and identifying successful assessment techniques for such programs. The AMS will publish a conference proceedings.

The majority of conference participants will be invited by the AMS because of their experience in designing and running undergraduate summer programs. In addition to these participants, the conference organizing committee invites faculty who have an interest in and history of working with undergraduates in summer mathematics programs or who have worked with undergraduates on research projects outside the classroom to apply to participate in the conference.

To apply, please submit:

1. A statement of interest (200–500 words) that describes your experience with undergraduate summer mathematics programs and how you might contribute to the success of the conference.

2. A curriculum vitae.

Applications should be sent to: Dr. James Maxwell, Professional Programs and Services, American Mathematical Society, P. O. Box 6248, Providence, RI 02940-6248.

Applications must be postmarked by **March 15, 1999**. Applicants will be notified of acceptance or not by April 15, 1999. For more information please contact the conference organizing committee: Joseph A. Gallian (jgallian@d.umn.edu, 218-726-7576), Herbert A. Medina (hmedina@popmail.lmu.edu, 310-338-5113), and Deborah Nolan (nolan@stat.berkeley.edu, 510-643-7097).

—From James Maxwell

1999 NSF-CBMS Regional Conferences

With funding from the National Science Foundation (NSF), the Conference Board of the Mathematical Sciences (CBMS) will hold five NSF-CBMS Regional Research Conferences during the summer of 1999. These conferences are intended to stimulate interest and activity in mathematical research.

Each five-day conference features a distinguished lecturer who will deliver ten lectures on a topic of importance in current research. Support for about thirty participants will be provided for each conference. Established researchers and interested newcomers, including postdoctoral fellows and graduate students, are invited to attend.

The title of each conference follows, along with the name of the principal speaker, the date and location of the conference, and the names of the organizers, as well as contact information. More information about the conferences can also be found at the Web site http://www.maa.org/cbms/nsf/99nsf.html or by contacting the Conference Board of the Mathematical Sciences, 1529 18th St., NW, Washington, DC 20036-1385; telephone 202-293-1170; fax 202-265-2384; e-mail: kolbe@math.georgetown.edu or rosier@math.georgetown.edu.

Combinatorial Optimization: Packing and Covering, Gérard P. Cornuéjols, May 24–28, University of Kentucky. Organizers: Jon Lee, Michael Jacobson, Carl Lee, Kristina Vuskovic, Andre Kezdy, Jeno Lehel. Telephone: 606-257-3336; e-mail: kristina@ms.uky.edu; World Wide Web: http://www.ms.uky.edu/~jlee/cbms.html.

Generalized Linear Mixed Models and Related Topics, Charles E. McCulloch, June 8–12, University of Florida. Organizer: James G. Booth. Telephone: 352-392-1941; e-mail:

jbooth@stat.ufl.edu; World Wide Web: http://www.stat.ufl.edu/.

Mathematical Analysis of Viscoelastic Flows, Michael Renardy, June 19–23, University of Delaware. Organizers: David O. Olagunju, Yuriko Renardy. Telephone: 302-831-1875; e-mail: Olagunju@math.udel.edu or renardy@math.vt.edu; World Wide Web: http://www.math.udel.edu/.

Statistical Inference from Genetic Data on Pedigrees, Elizabeth A. Thompson, July 19–23, Michigan Technological University. Organizers: Jianping Dong, Anant Godbole. Telephone: 906-487-2928; e-mail: jdong@mtu.edu or anant@mtu.edu; World Wide Web: http://www.math.mtu.edu/~jdong/CBMS.html.

Mathematical Control Theory of Coupled Systems of Partial Differential Equations, Irena Lasiecka, August 5–9, University of Nebraska. Organizer: Richard Rebarber. Telephone: 402-472-7235; e-mail: rrebarbe@math.unl.edu; World Wide Web: http://www.math.unl.edu/Dept/Conferences/CBMS/.

—From a CBMS announcement

IAS/Park City Mathematics Institute

The Institute for Advanced Study (IAS)/Park City Mathematics Institute (PCMI) will hold its 1999 summer session from June 20–July 10, 1999. The topic is arithmetic algebraic geometry, and the organizers are Karl Rubin (Stanford University) and Brian Conrad (Harvard University).

The IAS/PCMI began in 1991 at the University of Utah as a National Science Foundation Regional Geometry Institute. In 1993 the Institute for Advanced Study assumed sponsorship of the program. Each summer the Institute offers an integrated set of programs for researchers, postdoctorates, graduate and undergraduate students, and teachers. The Institute also sponsors a Mentoring Program for Women in Mathematics, organized by Karen Uhlenbeck (University of Texas, Austin) and Chuu-Lian Terng (Northeastern University).

Further information on the Institute and the Mentoring Program for Women, as well as on application procedures, is available at the Web site http://www.admin.ias.edu/ma/park.htm.

—From an IAS/PCMI announcement

Special Minisymposium at ICIAM 99

A minisymposium for women postdoctoral researchers will be held at the Fourth International Congress on Industrial and Applied Mathematics (ICIAM 99), July 5–9, 1999, in Edinburgh, Scotland. The symposium is being sponsored jointly by the Association for Women in Mathematics (AWM), European Women in Mathematics (EWM), and the Society for Industrial and Applied Mathematics (SIAM).

Four speakers are being sought for the symposium. Each selected speaker will present a 30-minute talk on her research in applied mathematics. The speakers will be chosen from women mathematicians working in the United States, Europe, and throughout the world. All applicants must have a doctoral degree awarded no earlier than July 1989. The National Science Foundation and the Office of Naval Research have provided funds for travel support for up to two speakers from the United States who must be U.S. citizens or noncitizens working in the United States. Limited funding for European speakers may be available from EWM.

The deadline for application is **February 28, 1999.** Further information and instructions for applying may be obtained at the AWM Web site, http://www.awm-math.org/workshops.html or by contacting the AWM at 301-405-7892 or by e-mail at awm@math.umd.edu.

—From an AWM announcement

Travel Grants for Women in Mathematics

The Association for Women in Mathematics (AWM) is offering grants for women mathematicians to travel to professional conferences in their fields and also to the Olga Taussky Todd Celebration of Careers in Mathematics for Women.

The AWM travel grants program, which is sponsored by the National Science Foundation (NSF), allows women mathematicians to attend research conferences in fields that are supported by the Division of Mathematical Sciences of the NSF. The grants provide full or partial support for travel and subsistence up to a maximum of $1,000 for domestic and $2,000 for foreign travel.

Applicants must be women who have a doctorate or equivalent experience and have a work (or home, if unemployed) address in the United States. The deadline for receipt of applications is **February 1, 1999**.

Travel grants are also available for women graduate students and recent Ph.D.'s (not yet tenured) to attend the Olga Taussky Todd Celebration, July 16–18, 1999, at the Mathematical Sciences Research Institute (MSRI) in Berkeley, California. Funding is being provided by the National Security Agency (NSA), MSRI, the Office of Naval Research (ONR), and AWM.

The celebration will feature lectures showcasing the research of outstanding women in mathematics and talks by established mathematicians working in government, business, industry, and academia. Applicants who receive travel funds will present their work in a poster session or a talk and will receive reimbursement for travel costs (up to $600) and 2.5 days' subsistence at $150 per diem for meals and lodging. The deadline to apply for these travel funds is **February 18, 1999**.

Further information about the Todd Celebration and about travel grants in general, as well as about application procedures, can be obtained on the AWM Web site, http://www.awm-math.org/, by telephone at 301-405-7892, or by e-mail at awm@math.umd.edu.

—*From the AWM*

Prize for Achievement in Information-Based Complexity

This annual prize, given by a group of people interested in the area of information-based complexity, is for outstanding achievement in information-based complexity. It will consist of three thousand dollars ($3,000) and a certificate and will be awarded at a suitable location. The initial prize committee will consist of Joseph F. Traub and Henryk Wozniakowski. Anyone other than current members of the prize committee is eligible. The members of the prize committee would appreciate nominations for the prize. However, a person does not have to be nominated to win the award.

The deadline for the first award is **March 31, 1999**. The achievement can be based on work done in a single year, over a number of years, or over a lifetime. It can be published in any journal, or number of journals, or monographs.

Nominations can be sent to Joseph F. Traub, Computer Science Department, Columbia University, 1214 Amsterdam Avenue, MC0401, New York, NY 10027; e-mail traub@cs.columbia.edu.

—*From Joseph F. Traub*

For Your Information

Departments Coordinate Job Offer Deadlines

Over sixty Ph.D.-granting mathematics departments in the U.S. have adopted an agreement to coordinate deadlines for responding to postdoctoral job offers.

The agreement attempts to address the problem that sometimes faces candidates for postdoctoral positions when they are asked to respond to a job offer by a certain date and this date is before the date of announcement of the National Science Foundation (NSF) Mathematical Sciences Postdoctoral Fellowships. In order to avoid this problem, the NSF has agreed to announce the names of fellowship recipients earlier, on Friday, January 29, 1999. The departments have agreed not to require responses to job offers before Monday, February 8, 1999.

For further information about the agreement, see the "For Your Information" section of the January 1999 issue of the *Notices*. As of December 4, sixty-seven departments had signed the agreement. An earlier plan to list in the *Notices* the departments adhering to the agreement was dropped because the list was continuing to change, and instead an up-to-date list may be found on the AMS Web site at `http://www.ams.org/employment/postdoc-offers.html`.

—*Allyn Jackson*

NSF to Sponsor Conference on Doctoral Programs

The National Science Foundation, in conjunction with the University of Missouri, will sponsor a National Conference on Issues Related to Doctoral Programs in Mathematics Education to be held in the fall of 1999. Faculty at institutions offering doctoral programs are invited to contribute information about their programs.

To provide background information for the conference, a survey of faculty at institutions that offer doctoral degrees in mathematics education or an emphasis on mathematics education at any level—elementary, secondary, or collegiate—will be conducted. For those who would like to participate in this survey, a questionnaire will be posted after January 1 at `www.showmecenter.missouri.edu/doctoralprograms/`.

For further information about the conference, please contact Robert Reys, University of Missouri, 104 Stewart Hall, Columbia, MO 65211; telephone 573-882-3740; e-mail: `reysr@missouri.edu`; fax 573-882-4481.

—*Robert E. Reys,*
University of Missouri

Reference and Book List

*The **Reference** section of the* Notices *is intended to provide the reader with frequently sought information in an easily accessible manner. New information is printed as it becomes available and is referenced after the first printing. As soon as information is updated or otherwise changed, it will be noted in this section.*

Upcoming Deadlines

February 1, 1999: Deadline for applications for AWM travel grants. For more information, see "Mathematics Opportunities" in this issue.

February 5, 1999: Deadline for receipt of proposals for MAA Grants for Women and Mathematics Projects. For more information, consult the Web site http://www.maa.org/projects/solic_99.html or contact Bernice Kastner, Mathematical Association of America, 1529 Eighteenth Street, NW, Washington, DC 20036; telephone 800-741-9415; e-mail: bkastner@maa.org.

February 16, 1999: Deadline for proposals for the first VIGRE Grant competition. For more information, consult the NSF Web site at http://www.nsf.gov/cgi-bin/getpub?nsf9916/.

February 18, 1999: Deadline for application for AWM travel grants for the Olga Taussky Todd Celebration of Careers in Mathematics for Women. For details, see "Mathematics Opportunities" in this issue.

February 28, 1999: Deadline for applications for the special minisymposium at the Fourth International Congress on Industrial and Applied Mathematics (ICIAM 99). For more information, see "Mathematics Opportunities" in this issue.

February 28, 1999: Deadline for proposals for the 2001-02 scientific program of the Mittag-Leffler Institute. For more information, consult the Web site http://www.ml.kva.se/proposals.html or contact the director of the Institute, Kjell-Ove Widman, at widman@ml.kva.se.

March 1, 1999: Deadline for applications for Enhancing Diversity in Graduate Education (EDGE), the Bryn Mawr College summer program for women. For details, consult the Web site http://www.brynmawr.edu/Acads/Math/edge.html or contact EDGE Program, Box 270, Spelman College, Atlanta, GA 30314.

March 31, 1999: Deadline for applications for the Mittag-Leffler Insti-

Where to Find It

A brief index to information that appears in this and previous issues of the *Notices.*

tute postdoctoral fellowships. For details, consult the World Wide Web at `http://www.ml.kva.se/`.

July 19, 1999: Deadline for proposals for the second VIGRE Grant competition. For more information, consult the NSF Web site at `http://www.nsf.gov/cgi-bin/getpub?nsf9916/`.

NSF Mathematics Education Staff

The Directorate for Education and Human Resources (EHR) of the National Science Foundation (NSF) sponsors a range of programs that support educational projects in mathematics, science, and engineering. Listed below are the names, telephone numbers, and e-mail addresses of those EHR program officers whose field is in the mathematical sciences or mathematics education. These individuals can provide information about the programs they oversee, as well as information about other EHR programs of interest to mathematicians. The mailing address is: Directorate for Education and Human Resources, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230. The World Wide Web address is `http://www.nsf.gov/ehr/`.

Division of Elementary, Secondary, and Informal Education
Teacher Enhancement Program
Francis (Skip) Fennel
`ffennel@nsf.gov`

John Luedeman
`jluedema@nsf.gov`

Diane Spresser
`dspresser@nsf.gov`

Anna Suarez
`asuarez@nsf.gov`
703-306-1620

Instructional Materials Development Program
John (Spud) Bradley, Acting Deputy Division Director
`jbradley@nsf.gov`
703-306-1620

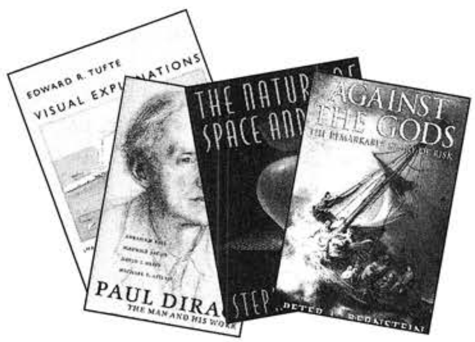
Division of Research, Evaluation, and Dissemination
Larry Suter, Deputy Division Director
`lsuter@nsf.gov`
703-306-1650

Division of Undergraduate Education
James Lightbourne
`jhlightb@nsf.gov`

Elizabeth Teles
`eteles@nsf.gov`

Frank Wattenberg
`fwattenb@nsf.gov`
703-306-1670

Division of Educational System Reform
Eric Hamilton
`ehamilto@nsf.gov`
703-306-1690



Book List

Readers will find listed here books that have mathematical themes and hold appeal for a wide audience, including mathematicians, students, and a significant portion of the general public. In cases where a book has been reviewed in the Notices, *a reference is given to the review. Generally the list will contain only books published within the last two years, though exceptions may be made in cases where current events (e.g., the death of a prominent mathematician, coverage of a certain piece of mathematics in the news) warrant drawing readers' attention to older books. While efforts are made to include as many books as possible, the list is necessarily limited to those books that have come to the attention of the* Notices *editors and that are deemed appropriate for inclusion in the list. Suggestions for books to include on the list may be sent to the managing editor,* e-mail: `notices@ams.org`.

Against the Gods: The Remarkable Story of Risk, by Peter L. Bernstein, John Wiley & Sons, 1996. ISBN 0-471-12104-5. (Reviewed January 1998)

The Apprenticeship of a Mathematician, by André Weil (translation by Jennifer Gage), Birkhäuser Boston, 1992. ISBN 0-817-62650-6.

A Beautiful Mind: A Biography of John Forbes Nash Jr., by Sylvia Nasar, Simon & Schuster, 1998. ISBN 0-684-81906-6. (Reviewed November 1998)

Challenges, by Serge Lang, Springer-Verlag, 1998. ISBN 0-387-94861-9.

e: The Story of a Number, by Eli Maor, paperback edition, Princeton University Press, 1998. ISBN 0-691-05854-7.

Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science, by Alan Sokal and Jean Bricmont, English version of *Impostures Intellectuelles* (reviewed August 1998), St. Martin's Press, 1998. ISBN 0-312-19545-1.

Fermat's Enigma: The Epic Quest to Solve the World's Greatest Mathematical Problem, by Simon Singh, paperback edition, Bantam Books, 1998. ISBN 0-385-49362-2. (Reviewed November 1997)

Fermat's Last Theorem: Unlocking the Secret of an Ancient Mathematical Problem, by Amir D. Aczel, paperback edition, Delacorte Trade Paper, 1997. ISBN 0-385-31946-0.

The Feynman Processor, by Gerard J. Milburn and Paul Davies, Helix Books, Perseus, 1998. ISBN 0-738-20016-6.

Goodbye, Descartes: The End of Logic and the Search for a New Cosmology of the Mind, by Keith Devlin, John Wiley & Sons, 1998. ISBN 0-471-14216-6.

An Imaginary Tale: The Story of $\sqrt{-1}$, by Paul J. Nahin, Princeton University Press, 1998. ISBN 0-691-02795-1.

The Jungles of Randomness: A Mathematical Safari, by Ivars Peterson, paperback edition, John Wiley & Sons, 1998. ISBN 0-471-29587-6.

Life by the Numbers, by Keith Devlin, John Wiley & Sons, 1998. ISBN 0-471-24044-3.

Logical Dilemmas: The Life and Work of Kurt Gödel, by John W. Dawson Jr., AK Peters, 1997. ISBN 1-568881025-3.

The Man Who Loved Only Numbers: The Story of Paul Erdős and the Search for Mathematical Truth, by Paul Hoffman, Hyperion, 1998. ISBN 0-786-86362-5. (Reviewed October 1998)

Mathematics: From the Birth of Numbers, by Jan Gullberg, Peter Hilton, W.W. Norton, 1997. ISBN 0-393-04002-X.

Modern Mathematics in the Light of the Fields Medals, by Michael Monastyrsky, AK Peters, 1997. ISBN 1-56881-065-2.

Moral Calculations: Game Theory, Logic, and Human Frailty, by László Mérö, Copernicus-Springer-Verlag, 1998. ISBN 0-387-98419-4.

My Brain Is Open: The Mathematical Journeys of Paul Erdős, by Bruce Schecter, Simon & Schuster, 1998. ISBN 0-684-84635-7.

The Nature of Space and Time, by Stephen Hawking and Roger Penrose, Princeton University Press, 1996. ISBN 0-691-03791-4. (Reviewed December 1998)

The Number Devil, by Hans Magnus Enzensberger, Metropolitan Books, 1998. ISBN 0-805-05770-6.

Paul Dirac: The Man and His Work, by Abraham Pais, Maurice Jacob, David Olive, and Michael Atiyah, Cambridge University Press, 1998. ISBN 0-521-58382-9. (Reviewed October 1998)

The Pleasures of Counting, by T. W. Körner, Cambridge University Press, 1996. ISBN 0-521-56087-X; 0-521-56823-4. (Reviewed March 1998)

Polyhedra, by Peter Cromwell, Cambridge University Press, 1997. ISBN 0-521-55432-2. (Reviewed September 1998)

Privacy on the Line: The Politics of Wiretapping and Encryption, by Whitfield Diffie and Susan Landau, MIT Press, 1997. ISBN 0-262-04167-7. (Reviewed June/July 1998)

Randomness, Deborah Bennett, Harvard University Press, 1998. ISBN 0-674-10745-4.

Strength in Numbers, by Sherman Stein, John Wiley & Sons, 1996. ISBN 0-471-152528-8.

The Universe and the Teacup: The Mathematics of Truth and Beauty, by K. C. Cole, Harcourt Brace, 1998. ISBN 0-151-00323-8.

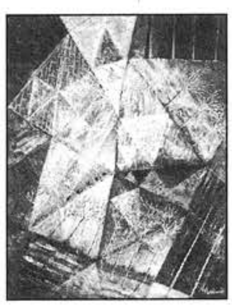
Visual Explanations—Images and Quantities, Evidence and Narrative, by Edward R. Tufte, Graphics Press, Cheshire, CT, 1997. ISBN 0-961-39212-6. (Reviewed January 1998)

Women in Mathematics: The Addition of Difference, by Claudia Henrion, Indiana University Press, 1997. ISBN 0-253-33279-6. (Reviewed May 1998)

About the Cover

A photograph of "Sierpinski Garden", a painting by Khaldoun Khashanah, research assistant professor at Stevens Institute of Technology (`http://attila.stevens-tech.edu/~kkhashan`).

The artist writes, "This painting was inspired by the study and teaching of fractals in early 1997 and the beautiful landscapes of Narrowsburg, NY, on the Delaware River. The painting was completely spontaneous, with no intention of articificially invoking fractals. However, when the painting was completed, it looked to me like the construction of the Sierpinski gasket, or carpet; hence the painting is named "Sierpinski Garden". It seems appropriate to dedicate the painting to some of the creators of the 'mathematical monsters', Cantor, Sierpinski, von Koch, and Peano."



The painting itself is oil on canvas, 38" x 48".

Doctoral Degrees Conferred

1997–1998

ALABAMA

Auburn University, Auburn (9)

DISCRETE AND STATISTICAL SCIENCES

Grant, Carrie, An $_n$ to 2_n embedding of incomplete idempotent latin squares for small value of n.

Parker, Carol, Complete bipartite graph path decompositions.

Wehrung, Lloyd B., Maximum packings of K_n with fish.

MATHEMATICS

Choi, Jongsool, Cohomological properties of compacta.

Clark, Alex, Linear flows on solenoids, exponents and denjoids.

Kornman, Paul, ARI and refinable maps on CANR spaces.

Lamar, Tuwaner, Analysis of a 2n-th order differential equations with Lidstone boundary.

Larsen, Eric, Large intersection of continuous nowhere monotone functions with smooth functions.

Weathers, Tony, Weak solutions to a system of equations arising from MHD theory.

University of Alabama, Birmingham (4)

BIOSTATISTICS

Fox, Liesl M., An exploration of the pseudo-binomial distribution with applications to survival curve confidence intervals.

Peschell, Kenneth J., Likelihood-ratio-based asymptotic fiducial and Bayesian methods for therapeutic equivalence assessment (TEA) using survival distributions.

Zaidi, Akbar A., A family of confluent hypergeometric distributions.

MATHEMATICS

Yung, Joyce, Mathematical applications of diffusion equations in cancer tumor growth.

University of Alabama, Huntsville (2)

MATHEMATICAL SCIENCES

Lampert, Douglas, Independence related graph theory parameters.

Youree, Roger, Convergence of discrete-time European option problems with hereditary price structures to continuous time versions.

University of Alabama, Tuscaloosa (6)

MANAGEMENT SCIENCE AND STATISTICS

Bauskar, Milind E., Special models for a multi-item, multi-location, multi-echelon, multi-period inventory system with centralized replenishments and restricted transshipment.

Dale, Cheryl, Sequence dependent production scheduling using the p-media integer linear programming model and hierarchical clustering techniques: an empirical study.

Dyer, John N., Evaluation of control charting techniques for monitoring autocorrected processes.

Jones, Lady Allison (L. Allison), Topics on data intensive and computationally intensive control charting methods.

Raina, Sidhartha, Multi-criteria decision analysis approach to evaluation of inter-organizational systems.

Solis, Adriano, Evaluation of the negative binomial approximation and stochastic leadtimes in a multi-echelon inventory model.

ARIZONA

Arizona State University (9)

MATHEMATICS

Diaz-Rivera, Ivonne, The dynamics of queues of re-entrant manufacturing systems.

Ding, Xiaohong, Theoretical and numerical evaluation of convergence acceleration for the Stokes problem.

Hong, Kang, Robust multivariate analysis: principal components analysis and discriminant analysis.

Le, Dung, Nonlinear parabolic systems and attractors.

Little, Leigh, A finite element Navier-Stokes solver using an adaptive BICGSTAB algorithm.

Sieben, Nandor, Actions of inverse semigroups on C^*-algebras.

Siefker, Andrew, Characteristics of non-uniformly spaced discrete-time signals from their Fourier phase.

Van Wieren, Jack, Using diagonally implicit multistage integration methods for solving ordinary differential equations.

Yan, Lirong, On part decompositions of graphs.

University of Arizona (7)

APPLIED MATHEMATICS

Abbey, Craig, Assessment of reconstructed images.

Brazier, Richard, Seismic wave propagation stitching: matching local and global techniques.

Ghamasaee, Rahman, A neural network approach for the solution of traveling salesman and basic vehicle routing problems.

Gifford, Howard, Theory and application of Fourier crosstalk: an evaluator for digital-system design.

Horsch, Karla, Attractors for Lyapunov cases of the complex-Ginsburg Landau equation.

MATHEMATICS

Gillis, Gregory, Design considerations in composite conductors: an exposition of percolation theory.

Simek, Olga, Hear trace asymptotics for domains with singular boundaries.

The above list contains the names and thesis titles of recipients of doctoral degrees in the mathematical sciences (July 1, 1997, to June 30, 1998) reported in the 1998 Annual Survey of the Mathematical Sciences by 227 departments in 153 universities in the United States. Each entry contains the name of the recipient and the thesis title. The number in parentheses following the name of the university is the number of degrees listed for that university. A supplementary list, containing names received since compilation of this list, will appear in a summer 1999 issue of the *Notices*.

ARKANSAS

University of Arkansas, Fayetteville (1)

MATHEMATICAL SCIENCES

Alhami, Kifah, Cyclic vectors for the shift on Bergman spaces.

CALIFORNIA

California Institute of Technology (8)

APPLIED MATHEMATICS

Hill, David J., Part I: Vortex dynamics in wake models; Part II: Wave generation.

Meloon, Mark R., Models of Richtmyer-Meskhov instability in continuously stratified fluids.

Rudnon, Mikhail K., Exponentially small splicing of separatrices and the Arnold's diffusion problem.

Sgoureva-Philippakos, Russina, Nonlinear effects in elastic Raleigh waves.

MATHEMATICS

Ajoodani-Namini, Shahin, Large sets of tau-designs.

Blaom, Anthony, The perturbation of Hamiltonian systems with a non-Abelian symmetry.

Choi, Yanglim, (3, 1)-Surfaces via branched surfaces.

Mitsis, Themistokus, On a problem in geometric measure theory related to sphere and circle packing.

Claremont Graduate University (3)

MATHEMATICS

Besnard, Eric, Prediction of high lift flows with separation.

Elshihabi, Azzam, Disturbance decoupling with stability for nonlinear systems using static/output feedback: a geometric approach.

Giray, Okten, Contributions to the theory of Monte Carlo and quasi-Monte Carlo methods.

Naval Postgraduate School (1)

MATHEMATICS

Beaver, Philip F., On the quasimonotonicity of a square linear operator with respect to a nonnegative cone.

Stanford University (8)

MATHEMATICS

Bray, Hubert Lewis, The Penrose inequality in general relativity and volume comparison theorems involving scalar curvature.

Entov, Mikhail, Surgery on Lagrangian and Legendrian singularities.

Iga, Kevin Mitsuo, Moduli spaces of Seiberg-Witten flows.

Kurlberg, Par Martin, A local Riemann hypothesis.

Lien, Wen-Ching, Hyperbolic conservation laws with a moving source.

Pezzoli, Elena, Complexity of type-two functionals and of logical games on finite structures.

Ryzhik, Leonid V., High frequency waves and transport in a random medium.

Tsalenko, Anna M., Stochastic stability of Bernoulli flows.

University of California, Berkeley (29)

BIOSTATISTICS

Hubbard, Alan Edward, Applications of locally efficient estimation to censored data models.

Peterson, Derick Randall, Missing data models and the selection of explanatory variables in regression.

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Chitchachornvanich, Thawee, Optimizing semiconductor fabrication scheduling in the face of uncertainties.

Jang, Wooseung, Markovian quality control for multiple processes under capacity constraints.

Kuo, William, Adaptive sampling strategies for semiconductor manufacturing.

Liu, Ting-Yun, Equipment acquisition planning in the semiconductor industry—considering learning effects in equipment efficiency.

Shen, Youxun, Stochastic water fabrication scheduling.

MATHEMATICS

Alvarez, Catherine, Inverse nodal problems with mixed boundary conditions.

Badoian, Leslie, Flow equivalence of shifts of finite type and flow K-theory.

Bhattacharyya, Bina, Krishnan-Sunder subfactors and a new countable family of subfactors related to trees.

Bromberg, Kenneth, Rigidity of hyperbolic 3-manifolds with geometrically finite ends.

Burlakov, Yuri, The phase space of a focusing cubic Schroedinger equation: a numerical study.

Dreier, Roland, On p-adic properties of families of curves.

Jones, David, Results on modular representations of GAL $(\overline{Q}/Q)$ in characteristic 3.

Kathotia, Vinay, Universal formulae for deformation quantization and the Campbell-Baker-Hausdorff formula.

Kleber, Michael, Finite-dimensional representations of quantum affine algebras.

Krapp, Donald, The applicability of certain Monte Carlo methods of the analysis of interacting polymers.

Larson, Paul, Variations of $P_{\max}$ forcing.

Magidin, Arturo, Dominions in varieties of groups.

Mitchell, Julie, Hodge decomposition and expanding maps on flat tori.

Shlyakhtenko, Dimitri, Free quasi-free states.

Staddon, Jessica, A combinatorial study of communication storage and traceability in broadcast encryption systems.

Steinberg, Benjamin, Decidability and hyperdecidability of joins of pseudovarieties.

Takahashi, Shuzo, Degrees of parametrizations of elliptic curves by modular curves and Shimura curves.

Terr, David, The distribution of shapes of cubic orders.

Tucker, Thomas, Some diophantine properties of points on curves.

Tvedt, Brian, Global existence of solutions and propagation of regularity of quasilinear viscoelastic systems of differential type.

Wilkerson, Daniel, Communication on networks of finite automata: three instances of wormhole routing.

Xaba, Enoch, Robust iterative solvers for linear and nonlinear finite element equations.

University of California, Davis (6)

MATHEMATICS

Rutaganira, Thomas, Numerical simulation of blood flow in arteries: effect of elastic walls.

Zaboronsky, Oleg, Localization and supergeometry.

STATISTICS

Chiou, Jeng-Min, Nonparametric quasi-likelihood and curve data modelling.

Vestrup, Eric, A comparison of Bayesian and frequentist shrinkage.

Wood, Matthew, Analysis of the effects of missing data in the *NAS* data set.

Yee, Julie, Large and small sample Bayesian inference and diagnostics for models with latent variables.

University of California, Irvine (1)

MATHEMATICS

Ni, Lei, Vanishing theorems on complete Kahler manifolds and their applications.

University of California, Los Angeles (21)

MATHEMATICS

Afshartous, David, Prediction in multilevel models.

Blomgren, Peter, Total variation methods for restoration of vector valued images.

Carrero, Jesus, Lie theoretical aspects of self gravitating Riemann ellipsoids.

Cowden Vassilev, Janet, Test ideals in Gorenstein isolated singularities and F-finite reduced rings.

Gao, Su, The isomorphism relation between countable models and definable equivalence relations.

Go, Susie, Multilevel methods on unstructured grids.

Graber, Thomas, Enumerative geometry of hyperelliptic plane curves.

Grassi, Michele, Characteristic cohomology of smooth manifolds.

Guerrini, Luca, Construction and deformation of infinite dimensional Lie algebras.

Hacon, Christopher, Divisors on principally polarized Abelian varieties. Seshadri constants of ample vector bundles.

Hui, Unkit, Cocycle conjugacy of one parameter automorphism of AFD factors of type III.

Lin, Chi-Tien, On approximate solutions for hyperbolic conservation laws and Hamilton-Jacobi equations.

Matheos, Peter, Failure of compactness for the d-bar Neumann problem for two complex dimensional Hartogs domains with no analytic disks in the boundary.

Miller, Brian, Improvements in multiple phase flow computations.

Puha, Amber, A reversible interacting particle system on homogeneous tree.

Sharapov, Ilya, Multilevel subspace correction for large scale optimization problems.

Strong, David, Adaptive total variation minimizing image restoration.

Wald, Linda, Minimal inherently nonfinitely based varieties of groupoids.

Wan, Wing-Lok, Scalable and multilevel iterative methods.

Wang, Caitlin, Calderon-Zygmund inequality for differential forms on a compact Riemannian manifold.

Yeung, Man-Chung, Probability and symmetry in computional linear algebra.

University of California, Riverside (9)

MATHEMATICS

Dimitrov, Ivan, Weight modules of infinite-dimensional Lie algebras and Lie superalgebras.

Fisher-Vasta, Tammy, Presentations of Z-forms for the universal enveloping algebras of affine Lie algebras.

Guu, Ching, The circular wirelength of cubes.

Hanley, William, On the Lorenz zonoid representation of distributional variability.

Mohanty, Sara, Invariants of degree 1 of almost generic plane curves.

Vasta, Joseph, Orthogonal product of simplices.

Wallace, Laura, Graded Mori rings.

STATISTICS

Fairchild, Lisa, Testing interactions between treatments and subgroups within groups in a two-period crossover trial.

Liu, Thomas, Optimal mixture designs in orthogonal blocks.

University of California, San Diego (10)

MATHEMATICS

Agol, Ian, Topology of hyperbolic 3-manifolds.

Brockman, William Bennett, The atomic decomposition of the q-Kostka polynomials in combinatorics and geometry.

Carlson, Stephen John, Normal bases in class fields over real Abelian number fields.

Chang, Carol Haekyung, Geometric interpretations of the Macdonald polynomials and the n! conjecture.

Gamst, Anthony Collins, Stochastic Burgers flow.

Garibaldi, Ryan Lee, Trialitarian algebraic groups.

Hunziker, Markus, Harish-Chandra systems on a reductive Lie algebra and the Zuckerman functor.

Lucia, Ned F., A center of mass method with applications to the solution of the two-dimensional Stokes equations in a channel.

Miller, Wendy L., Counting points on certain *CM* elliptic curves modulo primes.

Zabrocki, Michael Alan, On the action of the Hall-Littlewood vertex operator.

University of California, Santa Barbara (12)

MATHEMATICS

Bart, Anneke, Some results concerning surface groups in surgered manifolds.

Calvo, Jorge, Geometric knot theory: the classification of spatial polygons with small number of edges.

Ebert, Todd, Applications of recursive operators to randomness and complexity.

Gaulter, Mark, Characteristic vectors of unimodular lattices over the integers.

Shell, Glenn, Locally nonconical convex sets.

Sola, Dino, Essential surfaces with nonmeridian boundry in the complement of an alternating link.

Woodward, Scot, The global dimension of a q-skew polynomial ring.

STATISTICS AND APPLIED PROBABILITY

Gallagher, Colin, Fitting ARMA models to heavy-tailed data.

Ghosh, Kaushik, Some contributions to inference using spacings.

Haynatzka, Vera, An application of probability metrics in epidemiology.

Lund, Ulric, Regression and goodness of FIT for circular data.

Schumacher, Norbert, Option pricing with definitely divisible returns.

University of California, Santa Cruz (2)

MATHEMATICS

Hoyle, Mark, Perfect Morse functions on the moduli space of parabolic bundles.

Ortega, Juan-Pablo, Symmetry reduction and stability in Hamiltonian systems.

University of Southern California (5)

MATHEMATICS

Bodine, Sigrun, A dynamical systems approach to asymptotic diagonalization and integration of linear differential systems.

Hoffman, Corneliu, On some problems in representation theory of finite Chevalley groups.

Kojima, Tetsuro, Positive definite unimodular forms as trace forms.

Ouyang, Min, Actions of Hopf algebras.

Pappacena, Christopher, Some problems in the representation theory of associative algebras.

COLORADO

Colorado School of Mines, Golden (2)

MATHEMATICS AND COMPUTER SCIENCES

Goktas, Unal, Algorithmic computation of symmetries, invariants and recursion operators for systems of nonlinear evolution and differential-difference equations.

Knudson, David, A piecewise Hermite bicubic finite element Galerkin method for the biharmonic Dirichlet problem.

Colorado State University (7)

MATHEMATICS

Adair, Ronnie Jr., Simulations of Taylor-Couette flow.

Marak, Tyrel, A filtration for K_0 of the inverse limit of a diagram of rings.

STATISTICS

Al-Karni, Said H. M., On the distribution of quadratic forms and of their ratios.

Chu, Jui-Yuan, Model identification in factorial experiment.

Delgado-Saldivar, Jaime, Optimal design of experiments in nested variance components models.

Smith, David, Adjusting for publication bias and quality effects in Bayesian random effects meta-analysis.

Ueng, Chang-Yue, Confidence intervals for variance components in two components mixed models.

University of Colorado, Boulder (8)

APPLIED MATHEMATICS

Bernard, Deconinck, The initial-value problem for multiphase solutions of the Kadomtsev-Petviashvili equation.

Teng, Chi-Hse, Two-stage genome search design in affected-sib-pair method.

Yin, Ming, Noninformative priors with applications.

Zheng, Beiyao, Summarizing the predictive power of a generalized linear model.

University of Miami (1)

Mathematics and Computer Science

Fernandez, Higinio, Span and real functional diameter of metric continua.

University of South Florida (3)

Mathematics

Dragnev, Peter, Constrained energy problems for logarithmic potentials.

Markov, Lubomir, An L^2 approach to second order functional evolutions in Banach spaces.

Simeonov, Plamen, Weighted polynomial and rational approximation with varying weights.

GEORGIA

Emory University (5)

Biostatistics

Golm, Gregory, Semiparametric methods for mismeasured exposure information in HIV vaccine trials.

Stiger, Thomas, Small-sample performance and validation of the proportional odds model for correlated ordinal data fitted with GEE.

Mathematics and Computer Science

Krzastek, Kathleen, Describing convex sets in R^2.

Lu, Xiaowu, Symplectic integration for Hamiltonian systems and applications.

Nardo, John, Equilateral random polygons are globally knotted.

Georgia Institute of Technology (12)

Mathematics

Belogay, Eugene, Construction of smooth orthogonal wavelets with compact support.

Bin, Tan, Invariant manifolds, invariant foliations and linearization theorems in Banach spaces.

Carbinatto, Maria do Carmo, The Conley index and chaos.

Keeve, Michael, Study and implementation of Gauss Runge-Kutta schemes and application to Riccati equations.

Kuhn, Wolfgang, Rigorous and reasonable error bounds for the numerical solution of dynamical systems.

Kuhn, Zuzana, Ranges of vector measures and valuations.

Lara, Teodoro, Controllability of cellular neural networks.

Liu, Weishi, Center manifold theory for smooth invariant manifolds.

O'Connell, W. Richard Jr., Estimates for the St. Petersburg game.

Pederson, Steven, Homoclinic tangencies and families of interval maps with non-constant topological entropy.

Salazar-Gonzalez, Jose Domingo, Boundary and internal layers in a semilinear parabolic problem.

Yang, Xue-Feng, Extensions of Sturm-Liouville theory: nodal sets in both ordinary and partial differential equations.

University of Georgia (9)

Mathematics

Fox, Glenn, A P-adic l-function of two variables.

James, Kevin, On congruences for the coefficients on modular forms and some applications.

Park, Mu Yeol, Classification of stable cut loci of surfaces.

Penniston, David, The unipotent part of the generalized Jacobian of a curve.

Rushton, Joseph, On exact finite dimensional filters in mixed time.

Statistics

Allen, Michael, Bootstrap and inference for some linear time series models.

Day, Bann-Mo, Bayes and empirical Bayes estimation with application to small area estimation.

Kim, Sahmyeong, Inference for nonlinear time series models via estimating functions.

Srivastava, Anjali, Parameter estimation and saddlepoint distributions for models in plant disease epidemics.

HAWAII

University of Hawaii (1)

Mathematics

Hanson, Jason, Algebraic realization of smooth group actions.

IDAHO

Idaho State University (2)

Mathematics

Darrow, Jeffrey, Revitalizing the curriculum: using original sources, history, and writing in undergraduate mathematics.

Thornburg, Mark, Order intervals of matrices and linear transformations.

University of Idaho (1)

Mathematics

Johnson, Kathrine, Sufficiency and maximum likelihood estimation for a class of population genetic models.

ILLINOIS

Illinois State University (2)

Mathematics

Hassani, Sarah, Calculus students knowledge of the composition of functions and the chain rule.

Kersaint, Gladis, Preservice elementary teachers ability to generalize functional relationships.

Northern Illinois University (2)

Mathematical Sciences

Manning, Gregory, The $m(4)$ problem of Erdős and Hajnal.

Ran, Shiaohong, Choosing smoothing parameters in nonparametric curve fitting using kernel contrasts.

Northwestern University (13)

Industrial Engineering and Management Science

Abeysinghe, Rasika, External effects on firm technology strategy in Sri Lanka: an analysis of firm technology strategy in local and global context.

Berger, Rosemary, Location-routing models for distribution systems design.

Creticos, Peter, Task and skill based job matching.

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Florida State University (7)

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University of Notre Dame (4)

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Iowa State University (14)

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Kansas State University (6)

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Louisiana State University, Baton Rouge (5)

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MARYLAND

Johns Hopkins University (9)

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University of Maryland, Baltimore (4)

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Lurie, Anna, Change-point problems in auto-correlated data.

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MASSACHUSETTS

Boston University (2)

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Brandeis University (5)

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Michigan State University (14)

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MISSOURI

University of Missouri, Columbia (11)

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University of Nebraska, Lincoln (11)

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Dartmouth College (1)

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University of New Hampshire (3)

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Cransac, Adriana, Perfect matchings: modified Aztec diamonds, covering graphs, and n-matchings.

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New Jersey Institute of Technology (2)

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Duke University (7)

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NORTH DAKOTA

North Dakota State University, Fargo (3)

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OHIO

Air Force Institute of Technology (3)

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Kent State University (9)

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Baglama, James, Krylov subspace methods with applications in liquid crystal modeling.

Bernardes, Nilson Da Costa Jr., Some problems on iteration theory and on polynomials.

Bes, Juan, Three problems on hypercyclic operators.

Choi, Hong-In, Fault tolerance in bitonic sorting networks and static shuffle-exchange networks.

Fernandez, Cecilia, Some problems concerning multilinear and holomorphic maps on Banach spaces.

Goonatilake, Rohitha, On probabilistic aspects of summability theory.

Osikiewicz, Jeffrey, Summability of matrix submethods and spliced sequences.

Patterson, Richard, Some theorems in the theory of divergent double sequences.

Pawlowski, Piotr, The location of the zeros of a polynomial and a generalized Jensen's inequality.

Ohio State University (13)

MATHEMATICS

Balteanu, Cornel, Coherence for iterated mononoidal categories and homological obstructions to delooping.

Chen, Yuqing, Farrell cohomology of automorphism groups of free groups of finite rank.

Golds, Jeffrey, Estimation of the fractal dimensions of selected classes of Julia sets using spectral radius calculations.

Hlavacek, Jan, Norms of powers of absolutely convergent Fourier series of modulus 1.

Larick, Paul, Results in polynomial recurrence.

Makarov, Mihail, On the second Poisson structure for the Korteweg-DeVries equation.

Stadler, Jonathan, Schur functions, juggling and statistics on shuffled permutations.

Vompe, Dmitry, Numerical modeling of crystal growth in Bridgman device.

Wayand, Lee, Identifying communication obstacles that arise when translating the modern mathematics classroom to distance.

Weishaar, Robert, An asymptotic study of several models of sparse graphs.

Yao, Lihua, Topics in measure-valued processes.

Ye, Jian, The generalized toda lattices and the Whitham averaged systems for the defocusing nonlinear Schrödinger equations.

Zenkov, Dmitry, Integrability and stability of nonholonomic systems.

Ohio University (3)

MATHEMATICS

Barthwal, Savita, Semiperfect CS-rings.

Schaler, Elena, Admissibility and asymptotic behavior of first and second order differential equations in Banach spaces.

Tannan, Sujal Jhingan, Weakly self-injective matrix rings.

University of Cincinnati (1)

QUANTITATIVE ANALYSIS AND OPERATIONS MANAGEMENT

Cochran, James, Statistical properties of optimal solutions to coverage problems over sample data.

OKLAHOMA

Oklahoma State University (4)

STATISTICS

Kim, Chansoo, Robust tests using weighted likelihood estimation.

Masters, Brenda, Grade density estimation.

Richter, Scott, Exact and estimated exact tests for designs involving interactions using the rank transform.

Wilson, Craig, An approach to modelling the coefficient of variation in factorial experiments.

University of Oklahoma (1)

MATHEMATICS

Bhatia, Kavita, Pleating coordinates for a slice of the deformation space of a hyperbolic 3-manifold with compressible boundary.

OREGON

Oregon State University (4)

MATHEMATICS

Fischer, James, A new look at the Ashtekar-Magnon energy condition.

STATISTICS

Kincaid, Thomas, Estimating absence.

Lyons, Benjamin, Applying higher order asymptotics to mixed linear models.

Purdy, Kathleen, confidence intervals for variance components.

Portland State University (2)

MATHEMATICAL SCIENCES

Cresap, David, Contributions in survival analysis: estimation of location and scale using Cramer-von Mises methods on randomly censored data.

Roxana, Costinescu, On the transversal geometry of Poisson manifolds.

University of Oregon (3)

MATHEMATICS

Brewer, Joseph (Patrick), Complex subgroups of real reflection groups.

Heo, Sangwoo, Constructing cubature formulae on the disk, the triangle, and the sphere.

Herman, Edwin (Jed), Totally disconnected topological groups.

PENNSYLVANIA

Carnegie Mellon University (8)

MATHEMATICAL SCIENCES

Christopher, George, Structure and applications of totally decomposable metrics.

Doytchinov, Bogdan, Heavy-traffic analysis of queueing systems with due dates.

Kangro, Raul, Analysis of artificial boundary conditions for Black-Scholes equations.

Kangro, Urve, Spurious fields in computational electromagnetics.

Perera, Priyantha, Liquid diffusion couple in a microgravity environment.

Simonetti, Neil, A dynamic programming approach to the traveling salesman problem.

Watson, Stephen, Unique global solvability for initial-boundary value problems in one-dimensional nonlinear thermoviscoelasticity with phase transitions.

Wystup, Uwe, Valuation of exotic options under shortselling constraints as a singular stochastic control problem.

Lehigh University (4)

MATHEMATICS

Friedman, Theresa, Relating embedding properties with certain operator-theoretic properties.

McElroy, Kuntal, Stochastic analysis of Euclidean functionals.

McGivney, Katherine, Probabilistic limit theorems for combinatorial optimization problems.

Zelov, Vitaly, Immersions and embeddings of real projective spaces.

Pennsylvania State University (9)

MATHEMATICS

Chen, Jinghong, Hydrodynamic coupling between a viscoelastic gas/liquid interface and a swirling vortex flow.

Guysinsky, Moisey, Normal forms of extensions.

Payne, Garth H., Multivariate hypergeometric terms.

Suciv, Liviv C., The $SU(3)$ wire model.

Wang, Feng, Efficient block interactive methods for convection-dominated problems and multigrid for long-thin elements.

STATISTICS

Cooper, William, Inferential techniques for landmark data.

Gaydos, Brenda, The semiparametric likelihood method and its extensions with application to errors-in-variables.

Pilla, Ramani, Improving the rate of convergence of EM in high-dimensional finite-mixtures.

Tipa, Eleanor, An evaluation of the usefulness of weights in the presence of nonignorable dropout.

University of Pennsylvania (13)

MATHEMATICS

Achter, Jeffrey, Stratifications on moduli spaces of Abelian varieties in positive characteristic.

Burstein, Alexander, Enumeration of words with forbidden patterns.

Greenwald, Sarah, Diameters of spherical Alexandrov spaces and constant curvature one orbifolds.

Hu, Shubin, On Eisenstein cocycles.

Lazarev, Andrey, Spectral sheaves in stable homotopy.

Mihailovs, Aleksandrs, A combinatorial approach to representations of Lie groups and algebras.

Pauls, Scott, On quasi isometric invariants rigidity and related phenomena.

Selinger, Peter, Functionality, polymorphism, and concurrency: a mathematical investigation of programming paradigms.

STATISTICS

Craig (Kostritshaya), Ksenia, On edge estimation in image reconstruction problems.

Lin, Yi, Tensor product space ANOVA models.

Olsen, Stephanie, Multivariate matching with non-normal covariates in observational studies.

Wang, Yichun, Asymptotic equivalence for nonparametric location models.

Zhang, Jing, Model selection and some extensions of Markov switching models.

University of Pittsburgh (8)

MATHEMATICS

Chen, Zhixiong, Wave propagation in neuronal models.

Fairag, Faisal, A two-level discretization method for the streamfunction form of the Navier-Stokes equations.

Pinto, David, Computational, experimental, and analytic explorations of neuronal circuits in the cerebral cortex.

Wang, Chie Bing, Asymptotics for Painlevé III by isomonodromic deformation method.

Wang, Xiaolin, Numerical solutions of two-phase flow in networks.

Wang, Xiyou, On positive definiteness reproducing spaces.

STATISTICS

Jong, Yi-Kuan (Joey), Burn-in and bathtub distributions.

Shen, Sa, A bootstrap confidence procedure for a pulse detection model for hormone secretion data.

RHODE ISLAND

Brown University (18)

APPLIED MATHEMATICS

Boue, Michelle, Representations, asymptotics and approximations for large deviations and risk-sensitive problems.

Chi, Zhiyi, Probability models for complex systems.

Ferry, James, Thermal convection: a numerical simulation and modal analysis.

Gottlieb, Sigal, Convergence to steady state of weighted ENO schemes, norm preserving Runge-Kutta methods and a modified conjugate gradient method.

Kochanek, Kevin, Dynamic programming algorithms for maximum likelihood decoding.

Nicholls, David, Traveling gravity water waves in two and three dimensions.

Ramanan, Kavita, Construction and large deviations analysis of constrained processes with applications to communication networks.

Robertson, Christopher, Tracking of objects from image sequences using Lagrangian dynamics and nonlinear filtering.

Stephens, Monica, A one-dimensional mixed-layer ocean model for use in 3-D climate simulations.

Su, Hsuan-Wen, Periodic solution of finite regularity for the nonlinear Klein-Gordon equation.

Tufo III, Henry Michael, Algorithms for large scale parallel simulation of unsteady incompressible plans with three-dimensional complex geometrics.

Yang, Baolin, Spectral methods and absorbing boundary conditions.

MATHEMATICS

Benedetto, Robert, Fatou components in p-adic dynamics.

Chin, Bing, Stabilization of a sequence of images.

Dreibelbis, Daniel, A bitangency thoerem for surfaces in Euclidean four-space.

Holden, Joshua, On the Fontaine-Mazur conjecture for number fields and an analogue for function fields.

Hukovic, Sanja, Singular integral operators in weighted spaces and Bellman functions.

Papanikolas, Matthew, Canonical heights in characteristic p.

University of Rhode Island (3)

MATHEMATICS

Al-Amleh, Amal, Boundedness, periodicity, and stability of some difference equations.

Feuer, Jeffrey, Lyness-type difference equations.

Kent, Candace, Stability and periodicity of some difference equations and applications.

SOUTH CAROLINA

Clemson University (2)

MATHEMATICAL SCIENCES

Chen, Shehchong, Estimation and hypothesis testing for a mixture of two univariate normal distribution.

Wang, Jian, Some issues on nonparametric regression.

University of South Carolina (10)

MATHEMATICS

Al-Lawatia, Mohammed, Algorithm development and numerical analysis of transport equations.

Cornea, Emil, Multiresolution analysis of nonlinear phenomenon arising in surface modeling.

Ho, Chih-Chang, The cycling of partitions and compositions under repeated shifts.

Nagy, Marton, Expandably finitely based algorithms.

Pan, Chunliang, Insertion properties of monotonically defined spaces.

Szarvas, Tibor, Uniform $Lp(w)$ spaces.

STATISTICS

Merchant, Aparna, Improved multiple comparisons in response surface methodology.

Owen, William Jason, Accelerated test models using the Birnbaum-Saunders distribution.

Street, Walter Scott, IV, B-splines and nonlinear mixed models for environmental time series.

Tu, Wanzhu, Empirical Bayes analysis of count data.

TENNESSEE

University of Memphis (3)

MATHEMATICAL SCIENCES

Linderman, William, Edge extremal graphs with Hamiltonian properties.

Song, Hongjun, Control structures for software agents.

Xiang, Zhihua, The HIV epidemic: I. Bayesian estimation of the HIV infection and incubation distribution through backcalculation; II. The state space model of the HIV epidemic with variable infection in a homosexual population.

University of Tennessee (4)

MANAGEMENT SCIENCE

Flanagan, Debra, Optimal monitoring systems using statistical experimental design.

MATHEMATICS

Collier Melescue, Suzanne, A theory on pertubations of the Dirac operator.

Kim, Hwankoo, Factorization in monoid domains.

Kim, Yongkuk, Codimension two submanifold decompositions that induce approximate fibrations.

Vanderbilt University (10)

MATHEMATICS

Assaf, IV, David, Sensitivity of spline functions on triangulation to vertex perturbation.

Burton, David, On hyponormal tuples of commuting operators with finite rank self-commutators.

Dishman, Laurie Gail Plunk, Interassociativity and strong interassociativity.

Hota, Sanjukta, Mathematical models of respiratory function.

Johnson, Michael Eugene, Resonances in periodic chemotherapy scheduling: age structured models.

Kessler, Walter Bruce, Construction of orthogonal compactly-supported scaling functions and multiwavelets on arbitrary meshes.

Lee, Hoseung, Recognizable elements of quantales: a result of Myhill revisted.

Menser, David, Lower bounds on the circumference of graphs in terms of girth and degree conditions.

Talbert, Robert, Stratified and equivariant homology via homotopy colimits.

Vandergriff, Jim, Contributions to the class number problem for real quadratic number fields.

TEXAS

Rice University (7)

COMPUTATIONAL AND APPLIED MATHEMATICS

Martinez, Monica, A priori error estimates of finite element models of systems of shallow water equations.

Williams, Pamela, Effective finite termination procedures in interior point methods for linear programming.

Yang, Chao, Accelerating the Arnoldi iteration-theory and practice.

MATHEMATICS

Cunningham, Nancy, A variational approach to local uniqueness of immersed minimal surfaces in R^3.

Hawking, Christopher, A minimization of a curvature functional on fiber bundles.

Ledbetter, Ashley, Energy minimizers, gradient flow solutions, and computational investigation in the theory of biharmonic maps.

McIlwain, Mary, Can you hear the size of vertices? An inverse spectral problem of Laplacians on weighted graphs.

Southern Methodist University (4)

MATHEMATICS

Gonzalez Santos, J. German, A numerical study of simple shearing flow of foams.

Kamm, Julie, Singular value decomposition-based methods for signal and image processing.

STATISTICAL SCIENCE

Hartfield, Molly Isbell, Characterizing changes in time across geographical regions.

Vergara, Stephen Wiechecki, Semiparametric estimation for long memory parameters via wavelet packet.

Texas A&M University (21)

MATHEMATICS

Bobby, Daniel, Concerning the Hahn-Mazurkiewicz theorem in monotonically normal spaces.

Chiu, Wang, Hypercontractivity of order statistics and increments of fractional Brownian motion.

Gu, Qing, The wavelets and wavelet sets.

Han, Deguang, Irrational rotation unitary systems and extensions of triangular operators.

Hanisch, Jorg, Computational aspects of spline-wavelets.

Ionascu, Eugen, On the structure of operators and wavelets.

Kamat, Vishnu, Operator algebras, wandering subspaces and wavelet theory.

Lau, Wai Wah, Reflexive sheaves on Pc and the dimension of spaces of multivariate splines.

Lauric, Vasile, Some results on invariant subspaces.

Lu, Shijin, Wavelets associated with a multi-resolution analysis (MRA) and infinite matricially normed spaces.

Mashat, Daoud, Fast algorithms and thier application to numerical quasiconformal mappings of doubly connected domains onto annuli.

Sun, Tong, Locking-free finite element methods for thin plates and shells.

Zheng, Yan, Multi-scale parameter estimation for the steady state diffusion equation.

STATISTICS

Crown, John, On the theory and practice of fitting distributions to data.

Galindo, Christian, Topics in nonparametric regression: mean functional estimation and bootstrap confidence intervals for local estimating equations.

Iturria, Stephen, Applications and methodology in genetic epidemiology.

Li, Chin-Shang, Testing lack of heteroscedastic regression models.

Liaw, Andy I-Hsuen, A diagnostic test of heteroscedasticity based on nonparametric smoothing.

Maca, Jeffrey Dean, Nonparametric regression and measurement error.

Newman, Richard, Testing parallelism among the profiles after a certain time period.

Park, Eun Sug, Multivariate receptor modeling from a statistical science viewpoint.

Texas Tech University (6)

MATHEMATICS AND STATISTICS

Chandrawansa, Kumari, Statistical inverse estimation of irregular input signals.

DeWoody, Yssa, The role of musculoskeletal dynamics and neuromuscular control in stress development in bone.

Gilliam, Xiaoning, Wavelet detection of coherent structures in wind fields.

Hodges, Lucille, Quadrature, interpolation and observability.

Tomlinson, John, Functional techniques for data analysis.

Wheeler, William, On properties of the zeros of the Cesaro approximants to outer functions.

University of Houston (3)

MATHEMATICS

Khoury, Raja, Closest points to the space of stochastic matrices.

Reiff, Andrea, Existence of weak solutions for a class of conservation laws with multiple characteristics.

Zhang, Zhuangzhi, The existence and decay of solution of a class of nonstrictly hyperbolic systems of conservation laws.

University of North Texas (3)

MATHEMATICS

Baciu, Dragos, Spaces of measures and an introduction to functional analysis.

Hayes, Diana, Minimality of the special linear groups.

Opalecky, Robert, A topological uniqueness result for special linear groups.

University of Texas, Arlington (3)

MATHEMATICS

Anabtawi, Mahmoud, A study of stochastic partial differential equations.

Corley, Herbert W., Jr., Maximization with respect to cones.

Potter, Andrew Jay, A generalization of the Shapley value for games in partition function form: axioms, formula and potential.

University of Texas, Austin (13)

MATHEMATICS

Abramson, Daniel, On an integral related to Vinogradov's integral.

Chiu, Wan-Yi, Optimal fractional factorial designs.

Dresden, Gregory, Spectra of heights over certain finite groups.

Fogel, Karrolyne, Stark's conjecture for octahedral extensions.

Handfield, Francis, Adiabatic limits of the anti-self-dual equation.

Harper, Shinko, Segre class of almost complete intersections.

Judd, Robert, On Bourgain's index and Schreier sets.

Lane, David, Exceptional surfaces for resolution of isolated threefold singularities.

Osoinach, John, Manifolds obtained by Dehn surgery on infinitely many distinct knots in s^3.

Paul, Randall, Normal form techniques in degenerate Hamiltonian systems.

Sedgwick, Eric, On the classification and stabilization problems for Heegaard splittings of three-manifolds.

Shults, Benjamin, Discoveries and experiments in the automation of mathematics.

Yoav, Rieck, Heegaard surfaces and Dehn fillings: $G(M) - 1 \leq T(X) \leq G(M)$.

University of Texas, Dallas (1)

MATHEMATICAL SCIENCES

Zuo, Yijun, Contributions to the theory and applications of statistical depth functions.

UTAH

Brigham Young University (3)

MATHEMATICS

Goodsell, Troy, Projections of compacta in R^n.

Omran, Mohammad, The real positive semi-definite completion problem for two unspecified entries.

Zeng, Chongchun, Normally hyperbolic invariant manifolds and invariant foliations for semiflow in Banach spaces.

University of Utah (6)

MATHEMATICS

Chan, Hsungrow, Nonexistence of isometric immersions of noncompact surfaces with nonpositive curvature.

Chen, Chi-kan, Non-local thermo elastic phase field models.

Fletcher, Jeffrey, Homological group invariants.

Macura, Natasa, Quasi-isometries and mapping Tori.

Mineyev, Igor, Exotic homology theories and negative curvature in groups.

Xie, Min, Theoretical studies of forced excitable systems.

Utah State University (1)

MATHEMATICS AND STATISTICS

Gobena, Ermias, Bootstrapping regression quantiles.

VERMONT

University of Vermont (2)

MATHEMATICS AND STATISTICS

Brill, Stephen, The solution of two-dimensional partial differential equations via hermite collocation with block red-black Gauss-Seidel preconditioner.

Herrera, Graciela, Cost effective groundwater quality sampling network design.

VIRGINIA

College of William and Mary (1)

MATHEMATICS

Glen, Andrew, A probability programming language: development and applications.

George Mason University (2)

APPLIED AND ENGINEERING STATISTICS

Ahn, Sung, A maximum likelihood method for density estimation.

Levine, Jonathan, Choosing strata weights in two group fixed effect analysis of variance with multiple strata when interaction may be present: a problem in analyzing multicenter clinical trials.

University of Virginia (4)

MATHEMATICS

Roycroft, Denise, A quantum mechanical manifold and its integral geometric transfer to classical phase space.

Saiers, Nelson, Involutions fixing products of projective spaces.

Terry, Christopher, Normal subgroups of $GL(2, A)$.

STATISTICS

McFarland, Harry, The exact distributions of "Plug-in" discriminant functions in multivariate analysis.

Virginia Commonwealth University (4)

BIOSTATISTICS

Farina, Dianne, The development of D-optimal designs for exponential survival models.

Kuhn, Andrew, Incorporating noise and dispersion effects into medical experiments involving failure time data.

London, Wendy, Application of within-cluster correlations in a generalized estimating equations approach (GEE): implications for inference in survival analysis.

Tesfaye, Fisseha, Modeling onset times in twins based on multivariate frailty model.

Virginia Polytechnic Institute and State University (13)

INDUSTRIAL AND SYSTEMS ENGINEERING

Al-Loughani, Intesar, Algorithmic approaches for solving Euclidean distance location and location-allocation problems.

Suharko, Arief, Tactical network flow and discrete optimization models and algorithms for the empty railcar transportation problem.

MATHEMATICS

Kang, Jinghong, The computational Kleinman-Newton method in solving nonlinear nonquadratic control problems.

Mackin, Gail, On an order-parameter model of solid-solid phase transitions.

Ramirez-Gomez, Edgaurdo, Finite element methods for parameter estimation in steady-state diffusion equation.

Ranalli, Ramona, The structure of the 2-Sylow subgroups of the ideal class groups of imaginary bicyclic biquadratic fields.

Repp, Andrew, Discrete Riemann maps and the parabolicity of tilings.

Taylor, Frank, Abelian quintic fields.

Yu, Tom, On-line traffic signalization using robust feedback control.

STATISTICS

Beaghen, Michael, Canonical variate analysis and related methods with longitudinal data.

Kim, Ki-Ho, Construction and analysis of linear trend-free factorial designs under a general cost structure.

Kitchin, Patty, A new method for comparing experiments and measuring information.

Wang, Shin-Cheng (David), Analysis of zero heavy data using a mixture model approach.

WASHINGTON

University of Washington (20)

APPLIED MATHEMATICS

Jackson, Trachette, Mathematical models in two-step chemotherapy.

Nelson, Patrick, Mathematical models of HIV pathogenesis and immunology.

Stollnitz, Eric, Reproducing color images with custom inks.

Thompson, Christopher, A stochastic, linear, dynamic model El Nino/southern oscillation.

BIOSTATISTICS

Kulich, Michal, Additive hazards model with imcomplete covariate data.

Lumley, Thomas, Marginal regression modelling of weakly dependent data.

Nunn, Martha, Influence diagnostics for correlated data.

Pecková, Monika, Adaptive testing for difference in survival distributions.

Xie, Sharon, Covariate measurement error methods in failure time regression.

MATHEMATICS

Burton, Cynthia, Hopf algebras and Dieudonné modules.

Jay, Jon, Recovering a layered viscoacoustic medium from its response to a point source.

Martinez-Morales, José Luis, Geometric data fitting.

Wang, Jenn-Nan, Inverse backscattering for acoustic and Maxwell's equations.

Wiegmann, Andreas, The explicit jump immersed interface method and interface problems for differential equations.

STATISTICS

Catlin, Sandra, Statistical inference for partially observed Markov population processes.

Hu, Hui-lin, Large sample theory for pseudo maximum likelihood estimates in semiparametric models.

Keim, Michelle, Bayesian information retrieval.

Sardy, Sylvain, Regularization techniques for linear regression with a large set of carriers.

Schaffner, Andrew, Tools for the advancement of undergraduate statistics education.

Zhang, Ying, Estimation for counting processes with incomplete data.

Washington State University (4)

PURE AND APPLIED MATHEMATICS

Begashaw, Negash, Optimization algorithms based on conic approximations and collinear scalings.

Hakim, Sara, Generalized Andre planes with rank three collineation.

Jiang, Pelei, Interior point methods for stochastic programming and related problems.

Zhu, Min, Techniques for large-scale nonlinear optimization- principals and practice.

WEST VIRGINIA

West Virginia University, Morgantown (4)

MATHEMATICS

Buchanan, II, Hollie, Graph factors and Hamiltonian decompositions.

Cropper, Matthew, Hall's condition and list coloring.

Jordan, Francis, Cardinal numbers connected with adding Darboux-like functions.

Zhu, Chen, Asymptotics behaviors of solutions to some hydrodynamics models of semiconductors.

WISCONSIN

University of Wisconsin, Madison (35)

MATHEMATICS

Alrefaei, Mahmoud H., Discrete stochastic optimization using random search.

Andersson, Carl D., Bow and stern flows with gravity and surface tension.

Catoiu, Stefan, Ideals of enveloping algebras.

Caughman, John S., Bipartite P- and Q-polynomial association schemes.

Eisen, Nicolas L., Holomorphic sections of an orientable vector bundle.

Flores, Manuel T., L^2-theory for some rigid generalizations of the Heisenberg group.

Folch-Gabayet, Magali L., Boundedness of certain convolution operators.

Griffiths, Evan J., Completely mitotic Turing degrees, jump classes, and enumeration degrees.

Hermann, Paul D., Symmetric and unsymmetric buckling of circular arches.

Kim, Joonil, Hilbert transform and maximal function along curves in the Heisenberg group.

Lewis, Heather Ames, Homotopy and distance-regular graphs.

Lindhurst, Scott C., Computing roots in finite fields and groups, with a jaunt through sums of digits.

Logan, Mark J., Homology and invariants of reflection groups and Lie algebras.

Montgomery, Aaron G., Lusternik-Schnirelmann category and simplicial sets.

Moon, Dongho, Schur-Weyl duality for Lie super algebra and Lie color algebras.

Nam, Ki-Bong, Generalized Witt algebras over a field of characteristic zero.

Parker, Darren B., Hopf Galois extensions and forms of coalgebras and Hopf algebras.

Shaw, May Shu-Mei, Solution to the coagulation and fragmentation and partial differential equation.

Sneyd, Elizabeth S., Tolerance graphs and pseudo-interval graphs.

Strom, Jeffrey A., Category weight and essential category weight.

Torres-Gallardo, Evelyn, A FOSLS method for the overlapping grid problem.

Tsai, Tsung-Hsi, The uniform CLT and LIL for Markov chains.

Uen, Wuu-Nan, A descriptive study of mathematical teaching styles of junior high mathematics teachers in Taiwan.

Westlund, Eric R., The boundary manifold of an arrangement.

Yeh, Chien-ning, o-minimal expansions of ordered sets with unary functions.

Yeh, Nai-Sher, Contributions to forced capillary-gravity waves under Hocking's edge condition.

STATISTICS

Borghi, Elaine, Methods of inference in Strauss disc processes.

Chen, Yinzhong, Inference with complex survey data under random hot deck imputation.

Hsiao, Chin-Fu, Are sequential trial designs Bayes?.

Ladd, William, Two-dimensional self-modeling.

Martin, Sandra, Profiling methods in nonlinear models inverse prediction, and calibration.

Pan, Wei, Nonparametric and semiparametric survival analysis with left truncated and internal censored data.

Tao, Huageng, Estimation methods of statistical models for longitudinal data.

Yeo, In-Kwon, On alternative power transformation to handle skewness.

Zhang, Yunlei, Two new algorithms for nonparametric analysis given incomplete data.

University of Wisconsin, Milwaukee (9)

MATHEMATICAL SCIENCES

Abroell, Sigrid, Asymptotic behavior and design of a sieve estimator for a Gaussian mean function.

Balser, Tobias, New approximations for avoiding Gibbs phenomenon in wavelet subspaces.

Chen, Daning, Multipliers on certain function spaces.

Diestelkamp, Wiebke, Projections, decompositions and parameter inequalities for orthogonal arrays.

Fischer, Hanspeter, Visual boundaries of right angled Coxeter groups and reflection manifolds.

Nabhan, Maha, The weighted continuous Galerkin method for initial value problems.

Petersen, Hans-Juergen, A spline estimate of the score function in Adaptive L-estimation for linear regression.

Price, Kenneth, Enveloping algebras of Lie color algebras.

Shen, Xiaoping, Wavelet based numerical methods.

WYOMING

University of Wyoming (6)

MATHEMATICS

Bornholdt, Bryan, On isometries of Frechet spaces.

Desai, Alpana, Homogenization analysis applied to biofilm growth in porous media.

Lister, Lisa, Graph decomposition.

Liu, Mingjun, Mathematical theory and numerical methods for the valuation of American options.

Wo, Shaochang, The mathematical modeling and numerical approaches for microbial permeability modification of enhanced oil recovery processes.

STATISTICS

Seier, Edith, A family of skewness and Kurtosis measures.

Doctoral Degrees Conferred 1996–1997

Supplementary List

The following list supplements the list of thesis titles published in the January 1998 *Notices*, pages 45–63.

COLORADO

University of Colorado, Boulder (1)

MATHEMATICS

Azmi, Fatima Mohammad, Computation of the equivariant cocycle of the Dirac operator.

From the AMS

1998 Election Results

In the elections of 1998 the Society elected a vice president, a trustee, five members at large of the Council, two members of the Editorial Boards Committee, and three members of the Nominating Committee. Terms for these positions are three years beginning on 01 February 1999 and ending on 31 January 2002, except for the trustee, whose term is for five years ending on 31 January 2004, and for members elected to the Nominating Committee, who begin serving immediately and whose terms end on 31 December 2001.

Vice President

Elected as the new vice president is **James G. Arthur** from the University of Toronto, Toronto, Canada.

Trustee

Elected as the new trustee is **Linda Keen** from Herbert H. Lehman College (CUNY), New York, NY.

Members at Large of the Council

Elected as new members at large of the Council of the Society are

Haim Brezis from Rutgers University
Robert Fefferman from the University of Chicago
Donald G. Saari from Northwestern University
Tatiana Toro from the University of Washington
Nolan R. Wallach from the University of California, San Diego

Editorial Boards Committee

Elected as new members of the Editorial Boards Committee are

George E. Andrews from Penn State University
Krystyna Kuperberg from Auburn University

Nominating Committee

Elected as new members of the Nominating Committee are

William Browder from Princeton University
Lisa Claire Jeffery from McGill University
Marc A. Rieffel from the University of California, Berkeley

Members approved two amendments to the bylaws. A few years ago the Society's agreement with the publisher of the *American Journal of Mathematics* was terminated. It was therefore necessary to remove mention of the editors of that journal in the governance structure of the Society.

In order to bring the titles of officers into conformance with standard English usage, an amendment was approved to change the way titles are mentioned in the bylaws. At the same time the title of ex-president was changed to immediate past president.

Suggestions for elections to be held in the fall of 1999 are solicited by the 1999 Nominating Committee. The Nominating Committee will be meeting during the Annual Meeting in San Antonio in January. Positions to be filled in the 1999 election are: president-elect, vice president, trustee, and five members at large of the Council.

Suggestions for nominations for election for two positions on the Editorial Boards Committee and three positions on the 2000 Nominating Committee are also welcome and can be sent to the secretary.

There will be a number of contested seats in the 1999 AMS Elections. Your suggestions are wanted by:

CALL FOR SUGGESTIONS

The Nominating Committee
for president-elect, vice president, trustee, and five members at large of the council

and by

The President
for three Nominating Committee members and two Editorial Boards Committee members.

In addition

The Editorial Boards Committee
requests suggestions for appointments to various editorial boards of Society publications.

Send your suggestions for any of the above to:

Robert J. Daverman
American Mathematical Society
Department of Mathematics
University of Tennessee
Knoxville, TN 37996
e-mail: daverman@novell.math.utk.edu

1999 AMS Election

Nominations by Petition

Vice President or Member at Large

One position of vice president and member of the Council *ex officio* for a term of three years is to be filled in the election of 1999. The Council intends to nominate at least two candidates, among whom may be candidates nominated by petition as described in the rules and procedures.

Five positions of member at large of the Council for a term of three years are to be filled in the same election. The Council intends to nominate at least ten candidates, among whom may be candidates nominated by petition in the manner described in the rules and procedures.

Petitions are presented to the Council, which, according to Section 2 of Article VII of the bylaws, makes the nominations. The Council of 23 January 1979 stated the intent of the Council of nominating all persons on whose behalf there were valid petitions.

Prior to presentation to the Council, petitions in support of a candidate for the position of vice president or of member at large of the Council must have at least fifty valid signatures and must conform to several rules and operational considerations, which are described below.

Editorial Boards Committee

Two places on the Editorial Boards Committee will be filled by election. There will be four continuing members of the Editorial Boards Committee.

The president will name at least four candidates for these two places, among whom may be candidates nominated by petition in the manner described in the rules and procedures.

The candidate's assent and petitions bearing at least 100 valid signatures are required for a name to be placed on the ballot. In addition, several other rules and operational considerations, described below, should be followed.

Nominating Committee

Three places on the Nominating Committee will be filled by election. There will be six continuing members of the Nominating Committee.

The president will name at least six candidates for these three places, among whom may be candidates nominated by petition in the manner described in the rules and procedures.

The candidate's assent and petitions bearing at least 100 valid signatures are required for a name to be placed on the ballot. In addition, several other rules and operational considerations, described below, should be followed.

Rules and Procedures

Use separate copies of the form for each candidate for vice president, member at large, or member of the Nominating and Editorial Boards Committees.

1. To be considered, petitions must be addressed to Robert J. Daverman, Secretary, P.O. Box 6248, Providence, Rhode Island 02940, and must arrive by 28 February 1999.
2. The name of the candidate must be given as it appears in the *Combined Membership List* (*CML*). If the name does not appear in the list, as in the case of a new member or by error, it must be as it appears in the mailing lists, for example on the mailing label of the *Notices*. If the name does not identify the candidate uniquely, append the member code, which may be obtained from the candidate's mailing label or the Providence office.
3. The petition for a single candidate may consist of several sheets each bearing the statement of the petition, including the name of the position, and signatures. The name of the candidate must be exactly the same on all sheets.
4. On the next page is a sample form for petitions. Copies may be obtained from the secretary; however, petitioners may make and use photocopies or reasonable facsimiles.
5. A signature is valid when it is clearly that of the member whose name and address is given in the left-hand column.
6. The signature may be in the style chosen by the signer. However, the printed name and address will be checked against the *Combined Membership List* and the mailing lists. No attempt will be made to match variants of names with the form of name in the *CML*. A name neither in the *CML* nor on the mailing lists is not that of a member. (Example: The name Robert M. Fossum is that of a member. The name R. Fossum appears not to be.)
7. When a petition meeting these various requirements appears, the secretary will ask the candidate to indicate willingness to be included on the ballot. Petitioners can facilitate the procedure by accompanying the petitions with a signed statement from the candidate giving consent.

Nomination Petition for 1999 Election

The undersigned members of the American Mathematical Society propose the name of

____

as a candidate for the position of (check one):

- ☐ **Vice President**
- ☐ **Member at Large of the Council**
- ☐ **Member of the Nominating Committee**
- ☐ **Member of the Editorial Boards Committee**

of the American Mathematical Society for a term beginning 1 February, 2000.

Name and address (printed or typed)	Signature
	Signature
	Signature
	Signature
	Signature
	Signature
	Signature

Add this Cover Sheet to all of your Academic Job Applications

How to use this form

1. Using the facing page or a photocopy, (or a TEX version which can be downloaded from the e-math "Employment Information" menu, `http://www.ams.org/employment/`), fill in the answers which apply to *all* of your academic applications. Make photocopies.

2. As you mail each application, fill in the remaining questions neatly on one cover sheet and include it *on top of* your application materials.

The Joint Committee on Employment Opportunities has adopted the cover sheet on the facing page as an aid to job applicants and prospective employers. The form is now available on e-math in a TEX format which can be downloaded and edited. The purpose of the cover form is to aid department staff in tracking and responding to each application.

Mathematics Departments in Bachelor's, Master's and Doctorate granting institutions have been contacted and are expecting to receive the form from each applicant, along with any other application materials they require. Obviously, not all departments will utilize the cover form information in the same manner. Please direct all general questions and comments about the form to: `emp-info@ams.org` or call the Professional Programs and Services Department, AMS, at 800-321-4267 extension 4105.

JCEO Recommendations for Professional Standards in Hiring Practices

The JCEO believes that every applicant is entitled to the courtesy of a prompt and accurate response that provides timely information about his/her status. Specifically, the JCEO urges all institutions to do the following after receiving an application:

(1) Acknowledge receipt of the application—immediately; and
(2) Provide information as to the current status of the application, as soon as possible.

The JCEO recommends a triage-based response, informing the applicant that he/she
(a) is not being considered further;
(b) is not among the top candidates; or
(c) is a strong match for the position.

Academic Employment in Mathematics

AMS STANDARD COVER SHEET

Last Name ______________________________

First Name ______________________________

Middle Names ______________________________

Address *through June 1999* ______________________________ **Home Phone**

______________________________ ______________

______________________________ **e-mail Address**

______________________________ ______________

Current Institutional Affiliation **Work Phone**

______________________________ ______________

Highest Degree and Source ______________________________

Year of Ph.D. (optional) ______________________________

Ph.D. Advisor ______________________________

If the Ph.D. is not presently held, date on which you expect to receive ______________

Indicate *the mathematical subject area(s) in which you have done research using, if applicable, the 1991 Mathematics Subject Classification printed on the back of this form. If listing more than one number, list first the one number which best describes your current primary interest.*

Primary Interest ______________________________

Secondary Interests *optional* ______________________________

Give a brief synopsis *of your current research interests (e.g. finite group actions on four-manifolds). Avoid special mathematical symbols and please do not write outside of the boxed area.*

____

____

Most recent, if any, position held *post Ph.D.*

University or Company ______________________________

Position Title ______________________________

Indicate the position for which you are applying and position posting code, if applicable

____

If unsuccessful for this position, would you like to be considered for a temporary position?

☐ Yes ☐ No If yes, please check the appropriate boxes.

☐ Postdoctoral Position ☐ 2+ Year Position ☐ 1 Year Position

List the names, affiliations, and e-mail addresses *of up to four individuals who will provide letters of recommendation if asked. Mark the box provided for each individual whom you have already asked to send a letter.*

☐ ______________________________

☐ ______________________________

☐ ______________________________

☐ ______________________________

This form is provided courtesy of the American Mathematical Society.

This cover sheet is provided as an aid to departments in processing job applications. It should be included with your application material.

Please print or type. Do not send this form to the AMS.

AMERICAN MATHEMATICAL SOCIETY · FOUNDED 1888 · ΤΡΙΤΟΣ ΜΙΙ · ΑΓΕΩΜΕ ΕΙΣΙΤΩ

1991 Mathematics Subject Classification

00 General
01 History and biography
03 Logic and foundations
04 Set theory
05 Combinatorics
06 Order, lattices, ordered algebraic structures
08 General mathematical systems
11 Number theory
12 Field theory and polynomials
13 Commutative rings and algebras
14 Algebraic geometry
15 Linear and multilinear algebra, matrix theory
16 Associative rings and algebras
17 Nonassociative rings and algebras
18 Category theory, homological algebra
19 K-theory
20 Group theory and generalizations
22 Topological groups, Lie groups
26 Real functions
28 Measure and integration
30 Functions of a complex variable
31 Potential theory
32 Several complex variables and analytic spaces
33 Special functions
34 Ordinary differential equations
35 Partial differential equations
39 Finite differences and functional equations
40 Sequences, series, summability
41 Approximations and expansions
42 Fourier analysis
43 Abstract harmonic analysis
44 Integral transforms, operational calculus
45 Integral equations
46 Functional analysis
47 Operator theory
49 Calculus of variations, optimal control
51 Geometry
52 Convex and discrete geometry
53 Differential geometry
54 General topology
55 Algebraic topology
57 Manifolds and cell complexes
58 Global analysis, analysis on manifolds
60 Probability theory and stochastic processes
62 Statistics
65 Numerical analysis
68 Computer science
70 Mechanics of particles and systems
73 Mechanics of solids
76 Fluid mechanics
78 Optics, electromagnetic theory
80 Classical thermodynamics, heat transfer
81 Quantum theory
82 Statistical mechanics, structure of matter
83 Relativity and gravitational theory
85 Astronomy and astrophysics
86 Geophysics
90 Economics, operations research, programming, games
92 Biology and other natural sciences, behavioral sciences
93 Systems theory, control
94 Information and communication, circuits

Leroy P. Steele Prizes

Call for Nominations

The selection committee for this prize requests nominations for consideration for the 2000 award. Further information about this prize can be found in the November 1997 Notices, pp. 1350-1353 (also available at http://www.ams.org/general/prizes.html).

Three Leroy P. Steele Prizes are awarded each year in the following categories: (1) the Steele Prize for Lifetime Achievement: for the cumulative influence of the total mathematical work of the recipient, high level of research over a period of time, particular influence on the development of a field, and influence on mathematics through Ph.D. students; (2) the Steele Prize for Mathematical Exposition: for a book or substantial survey or expository-research paper; and (3) the Steele Prize for Seminal Contributions to Research: for a paper, whether recent or not, that has proved to be of fundamental or lasting importance in its field, or a model of important research.

Nominations with supporting information should be submitted to the Secretary, Robert J. Daverman, Department of Mathematics, University of Tennessee, Knoxville, TN 37996. Include a short description on the work that is the basis of the nomination, including complete biographic citations. A curriculum vitae should be included. The nominations will be forwarded by the Secretary to the prize selection committee, which will, as in the past, make final decisions on the awarding of prizes.

Deadline for nominations is March 31, 1999.

1999 Frank and Brennie Morgan AMS-MAA-SIAM Prize for Outstanding Research in Mathematics by an Undergraduate Student

The prize is awarded each year to an undergraduate student (or students having submitted joint work) for outstanding research in mathematics. Any student who is an undergraduate in a college or university in the United States or its possessions, or Canada or Mexico, is eligible to be considered for this prize.

The prize recipient's research need not be confined to a single paper; it may be contained in several papers. However, the paper (or papers) to be considered for the prize must be submitted while the student is an undergraduate; they cannot be submitted after the student's graduation. The research paper (or papers) may be submitted for consideration by the student or a nominator. All submissions for the prize must include at least one letter of support from a person, usually a faculty member, familiar with the student's research. Publication of research is not required.

The recipients of the prize are to be selected by a standing joint committee of the AMS, MAA, and SIAM. The decisions of this committee are final. The 1999 prize will be awarded for papers submitted for consideration no later than **June 30, 1999,** by (or on behalf of) students who were undergraduates in December 1998.

Nominations and submissions should be sent to:

Morgan Prize Committee
c/o Robert J. Daverman, Secretary
American Mathematical Society
Department of Mathematics
University of Tennessee
Knoxville, TN 37996

Questions may be directed to the chairperson of the Morgan Prize Committee:

George Andrews
Department of Mathematics
Pennsylvania State University
University Park, PA 16802
telephone: 814-865-6642
e-mail: andrews@math.psu.edu

AMERICAN MATHEMATICAL SOCIETY

Mathematics Calendar

The most comprehensive and up-to-date Mathematics Calendar information is available on e-MATH at http://www.ams.org/mathcal/.

February 1999

* 25–27 **Second New Mexico Analysis Seminar**, University of New Mexico, Albuquerque, New Mexico.

Main Lecturer: G. Pisier (Texas A&M, Univ. Paris VI), Similarity problems and the generation of operator algebras with bounded length.

Aim: This is the second conference organized jointly by The University of New Mexico (UNM) and New Mexico State University (NMSU), to provide an opportunity for scientific exchange and cooperation among broadly defined analysts in the Southwest region. The conference centerpiece is a series of one-hour lectures given by a keynote speaker. There is also time allocated for shorter contributed talks. If you would like to attend and/or give a talk, please respond by January 31 so that arrangements can be made. We will try to cover accommodation for graduate students.

Organizers: J. Alvarez, jalvarez@nmsu.edu; J. Lakey, jlakey@nmsu.edu; V. Koltchinskii, vlad@math.unm.edu; C. Pereyra, crisp@math.unm.edu.

Information: Contact C. Pereyra, crisp@math.unm.edu.

March 1999

* 16–18 **German-American Academic Council Lectures on Prophet Theory**, Lehigh University, Bethlehem, Pennsylvania.
Information: B. K. Ghosh, Department of Mathematics, Lehigh Univ., 14 E. Packer Ave., Bethlehem, PA 18015; tel: 610-758-3722; e-mail: bkg0@lehigh.edu.

April 1999

* 15–17 **4th April Dialogue**, National Science Foundation and the Hilton Arlington & Towers, Arlington, Virginia.
Information: Contact: Council on Undergraduate Research, 734 15th Street, NW, Suite 550, Washington, DC 20005; tel: 202-783-4810; fax: 202-783-4811. For more information please visit our Web site: http://www.cur.org/.

* 17–18 **Riviere-Fabes Symposium on Analysis and PDE**, University of Minnesota, Minneapolis, Minnesota.
Organizers: M. Jodeit, N. Krylov, W. Littman, W. M. Ni.
Main Speakers: J. Bourgain (Institute for Advanced Study), C. Kenig (University of Chicago).
Support: A limited amount of financial support will be available to out-of-town graduate students who participate in the symposium.
Information: School of Mathematics, University of Minnesota, 206 Church Street S.E., 127 Vincent Hall, Minneapolis, MN 55455; tel: 612-625-5591, jodeit@math.umn.edu, or Web page: http://www.math.umn.edu/.

* 18–24 **Spring School on Functional Analysis**, Paseky nad Jizerou, Czech Republic.
Program Committee: J. Lukes, J. Kolar.
Organized By: Department of Mathematical Analysis, Charles University, Sokolovska 83, Prague, Czech Republic.
Speakers: J. M. F. Castillo (Universidad de Extremadura, Spain), V. Fonf (Ben-Gurion University, Negev, Israel), N. Kalton (Univ. of Missouri, Columbia), I. I. Namioka (Univ. of Washington, Seattle).
Participation: Graduate students and others beginning their mathematical careers are encouraged to participate.
Information: Phone/fax: +420-2-232-3390; e-mail: paseky@karlin.mff.cuni.cz; URL: http://www.karlin.mff.cuni.cz/katedry/kma/ss/.

May 1999

* 26–30 **Great Plains Operator Theory Symposium**, Iowa State University, Ames, Iowa.
Aim: To foster interaction of researchers in operator theory/operator algebras and ap-

This section contains announcements of meetings and conferences of interest to some segment of the mathematical public, including ad hoc, local, or regional meetings, and meetings and symposia devoted to specialized topics, as well as announcements of regularly scheduled meetings of national or international mathematical organizations. A complete list of meetings of the Society can be found on the last page of each issue.

An announcement will be published in the *Notices* if it contains a call for papers and specifies the place, date, subject (when applicable), and the speakers; a second announcement will be published only if there are changes or necessary additional information. Once an announcement has appeared, the event will be briefly noted in every third issue until it has been held and a reference will be given in parentheses to the month, year, and page of the issue in which the complete information appeared. Asterisks (*) mark those announcements containing new or revised information.

In general, announcements of meetings and conferences held in North America carry only the date, title of meeting, place of meeting, names of speakers (or sometimes a general statement on the program), deadlines for abstracts or contributed papers, and source of further information. Meetings held outside the North American area may carry more detailed information. In any case, if there is any application deadline with respect to participation in the meeting, this fact should be noted. All communications on meetings and conferences in the mathematical sciences should be sent to the Editor of the *Notices* in care of the American Mathematical Society in Providence or electronically to notices@ams.org or mathcal@ams.org.

In order to allow participants to arrange their travel plans, organizers of meetings are urged to submit information for these listings early enough to allow them to appear in more than one issue of the *Notices* prior to the meeting in question. To achieve this, listings should be received in Providence **six months** prior to the scheduled date of the meeting.

The complete listing of the Mathematics Calendar will be published only in the September issue of the *Notices*. The March, June, and December issues will include, along with new announcements, references to any previously announced meetings and conferences occurring within the twelve-month period following the month of those issues. New information about meetings and conferences that will occur later than the twelve-month period will be announced once in full and will not be repeated until the date of the conference or meeting falls within the twelve-month period.

The Mathematics Calendar, as well as Meetings and Conferences of the AMS, is now available electronically through e-MATH on the World Wide Web. To access e-MATH, use the URL: http://e-math.ams.org/ (or http://www.ams.org/). (For those with VT100-type terminals or for those without WWW browsing software, connect to e-MATH via Telnet (telnet e-math.ams.org; login and password e-math) and use the Lynx option from the main menu.)

plications. In addition to principal lecturers, participants are invited to give 20-minute talks. Graduate students are welcome.

Invited Speakers: W. Arveson (Univ. of California, Berkeley), M.-D. Choi (Univ. of Toronto), Y. Latushkin (Univ. of Missouri), H. Lin (Univ. of Oregon), S. Power (Univ. of Lancaster, U.K.), B. Solel (Technion-Israel Institute of Technology), V. S. Sunder (Institute of Mathematical Sciences, Madras, India).

Information: Contact J. R. Peters, Y. T. Poon or B. H. Wagner at gpots@iastate.edu. Also, see our Web page at http://www.math.iastate.edu/. Or write us at Department of Mathematics, Iowa State University, Ames, Iowa 50011.

June 1999

*6–19 **Second Summer School of Mathematical Biology**, Termoli, Italy.

Subject: The subject of the school will be mathematical methods applied to the study of cell and molecular biology.

Goal: The goal of the school is to offer doctoral students and young postdoctoral researchers a presentation of some mathematical techniques widely used in modelling problems in cell physiology and proliferation, together with a review of a selection of some such problems of contemporary relevance. The target audience is mainly composed of advanced graduate students and post-graduates in the life sciences and in mathematical disciplines (math, applied math, physics, engineering).

Classes: Duration of the school is two weeks, including 10 days of classes, Monday through Friday. Each day there will be 8 lecture units of 40 min. by the staff and by invited speakers, practice sessions and lectures contributed by participants.

Participation: The number of participants is limited to 60. Interested biological and mathematical researchers, Ph.D. students and postdoctoral fellows are encouraged to apply. While the registration fee is fixed, accommodation costs will be assessed on the basis of effective stay. The foreseen average cost of the school to participants, on the basis of the presently expected funding by institutional sponsors, is of the order of 800 Euro (double room, 15 days, full board and lodging, registration and social programme included). The organizing committee is actively seeking more funding in order to further substantially reduce the cost to participants.

Scientific Committee: Z. Agur (Israel), O. Arino (France, President), A. De Gaetano (Italy), M. B. Donati (Italy), A. Gandolfi (Italy), M. Kimmel (USA), M. Mackey (Canada), E. Sanchez (Spain), A. Swierniak (Poland), P. Ubezio (Italy).

Organizing Committee: O. Arino, A. De Gaetano (managing director), A. Gandolfi, M. Kimmel.

Main Topics: Cell biology; Haemopoiesis: Dynamics of haemopoiesis in normal and disease conditions; Structured cell populations; Cancer therapy and optimization; Cytometry and parameter estimation; Stochastic models in cell genetics.

Invited Speakers: (tentative) Z. Agur, O. Arino, J. Belair, E. Beretta, A. Bertuzzi, V. Capasso, R. Chakraborty, M. Chaplain, A. De Gaetano, A. Gandolfi, M. Kimmel, M. Mackey, J. Mahaffy, E. Sanchez, A. Swierniak, Z. Taib, S. Tavare, P. Ubezio, G. Webb. Other speakers are being contacted.

Information: An updated description of the school may be found at the Web page http://space.tin.it/scienza/hjcas/biomasch.htm. For all e-mail communications please use the address biomath@tin.it.

*7–11 **11th International Conference on Formal Power Series and Algebraic Combinatorics (FPSAC'99)**, Universitat Politecnica de Catalunya, Barcelona, Spain.

Topics: Algebraic and bijective combinatorics and their relations to other parts of mathematics, computer science and physics.

Invited Speakers: G. Andrews (USA), M. A. Fiol (Spain), C. Kenyion (France), V. Neumann-Lara (Mexico), C. Praeger (Australia), A. Ram (USA), D. Welsh (England), J. B. Zuber (France).

Organizers: J. M. Brunat, M. Delest, P. Esque, F. Hurtado, C. Martinez, M. Maureso, A. Montes, M. Mora, M. Noy (chair), J. L. Ruiz, C. Seara, O. Serra.

Information: http://www-ma2.upc.es/~fpsac99/.

*27–July 25 **Summer Mathematics Program for Undergraduate Women**, Carleton and St. Olaf Colleges, Northfield, Minnesota.

Eligibility: Eighteen students will be selected to participate in the program. Applicants must be female mathematics students who are finishing their first or second year of undergraduate work, are enrolled in an American college or university, and have completed linear algebra but not more than one year of mathematics beyond linear algebra. Students chosen for the program will recieve astipend of $1,300, room and board on campus, and a travel allowance.

Deadline: The deadline for applications to be postmarked is February 28, 1999.

Information: Further information about the program and instruction for applying can be found at the Web site http://turing.mathcs.carleton.edu/smp/information.html or by contacting D. Haunsperger, Summer Mathematics Program, Department of Mathematics and Computer Science, Carleton College, Northfield, MN 55057; tel: 507-646-4360; e-mail: dhaunspe@mathcs.carleton.edu.

July 1999

*8–9 **100 Years After Sophus Lie**, University of Leipzig, Leipzig, Germany.

Purpose: The purpose of this conference is to commemorate the great mathematician Sophus Lie, who was a Professor at Leipzig University during his most productive years 1886–1898 and who died at 1899. The conference is devoted to Sophus Lie's work and his impact on modern mathematics.

Organizing Committee: K. Beyer (Univ. of Leipzig), J. Jost (Max-Planck-Institute for Mathematics in the Sciences), K. Schmüdgen (Univ. of Leipzig).

Invited Speakers: A. Borel (Princeton), S. Helgason (MIT), B. Kostant (MIT), D. Rowe (Mainz), A. Weinstein (Berkeley), to be confirmed.

Program: In addition to the invited talks a limited number of talks related to Lie's work and his impact can be given by participants.

Information: Those interested please contact e-mail: Lie100@mathematik.uni-leipzig.de. See also the Web page at http://www.mathematik.uni-leipzig.de/Lie100.

*15–17 **Applications of Physics in Financial Analysis**, Trinity College, Dublin, Ireland.

Aim: The scientific aim of this conference is to provide an active forum for cross-disciplinary interaction between economists, financial experts, physicists, and mathematicians.

Focus: The conference will focus on analyses and models of financial markets by discussing topics such as market fluctuations, option pricing, risk assessment, and other phenomena of current interest in econophysics, finance, and mathematical and statistical finance. Experts from different field (economists, physicists and mathematicians) are invited.

Information: For further information please contact: C. Bastian, EPS Conferences, European Physical Society, BP 2136, 68060 Mulhouse Cedex, France; tel: +33-3-89-32-94-40; fax: +33-3-89-32-94-49; e-mail: eps.conf@univ-mulhouse.fr. Conference Web site: http://www.nbi.dk/APFA/.

*18–28 **Foundations of Computational Mathematics (FoCM)**, University of Oxford, Oxford, England.

Information: See http://www-sccm.stanford.edu/FoCM/for details.

August 1999

*8–14 **Second International Conference on Boundary Value Problems, Integral Equations and Related Problems**, Chengde, Hebei, and Beijing, China.

Topics: The conference will be about the following five subjects: 1) Various boundary value problems for partial differential equations including free and moving boundary problems; 2) The theory and methods of integral equations including singular integral equations; 3) Applications of boundary value problems and integral equations to mechanics and physics; 4) Numerical methods of integral equations and boundary value problems; 5) Some related problems with analysis and above subjects.

Organizing Committee: Z. Y. Hou (Fudan Univ.), W. Lin (Zhongshan Univ.), J. K. Lu

(Wuhan Univ.), G. C. Wen (Peking Univ.), G. W. Yang (Hebei Sci. & Tech. Univ.) and Z. Zhao (Beijing Normal Univ.).

Information: For more detailed information, please contact G. C. Wen, Dept. of Math., Peking Univ., Beijing 100871, China; tel: 008610-62755937; fax: 008610-62751801; e-mail: wengc@pku.edu.cn.

*16-21 **International Conference on Differential and Functional Differential Equations**, Moscow, Russia.

Organized By: Moscow State Aviation Institute with the cooperation of the Steklov Institute of Mathematics of the Russian Academy of Sciences and Moscow Mathematical Society.

Scientific Program: The scientific program will consist of invited 45-minute lectures and 20-minute communications.

Topics: The Conference will be devoted to classical topics of the theory of differential equations and different kinds of nonlocal interactions: the Galois theory of differential equations, multisummability of formal solutions to differential equations, limit cycles and bifurcation, spectral theory, partial differential equations in functional spaces, linear and nonlinear problems of mathematical physics, boundary value problems and nonlocal problems, functional differential equations, applications.

Program Committee: H. Amann, W. Balser, M. Bertsch, A. A. Bolibruch, J. Hale, V. A. Ilôin, W. Jager, L. D. Kudryavtsev, S. B. Kuksin, E. Mitidieri, A. D. Myshkis, S. M. Nikolô, O. A. Oleinik (chairman), S. I. Pohozaev, J. Serrin, M. Singer, A. L. Skubachevskii (vice chairman), V. G. Veretennikov.

Organizing Committee: E. I. Galakhov, V. A. Ilôin, A. K. Kalliopin, G. A. Kamenskii, E. B. Kuznetsov, S. I. Pohozaev, A. A. Puntus, L. E. Rossovskii, V. N. Seryogin, A. L. Skubachevskii (vice chairman), V. G. Veretenikov (chairman).

Information: Those who wish to attend the Conference are kindly requested to send the title of their talk, mailing address, e-mail and fax number to: A. L. Skubachevskii, Moscow State Aviation Institute, Russia, 125871, Moscow, Volokolamskoe shosse, 4; fax: (095) 158 2977; e-mail: skub@k803.mainet.msk.su.

*25-28 **XI International Workshop on Numerical Methods in Viscoelastic Flows**, Vaals, The Netherlands.

Topics: Over the past few years we have witnessed a strong development of numerical methods for viscoelastic flow simulations, and emphasis is shifting towards confrontation with experimental results, enhanced constitutive modelling, stochastic simulations, molecular modelling and multi-dimensional, time-dependent simulations. A continued evolution along these lines is expected and encouraged for the 1999 International Workshop on Numerical Methods in Viscoelastic Flows.

Registration and Fees: The meeting location is a historic castle in the south of the Netherlands: Hotel Vaalsbroek. Registration cost includes housing, all breakfasts, lunches and dinners (including conference dinner) and a visit to downtown Maastricht on Friday evening. Registration fees, due before April 1, 1999: single room: DfL. 1,200; double room: Dfl. 1,100; accompanying person: Dfl. 750. The number of participants is limited, therefore it is critical to respond early. Registration and submission of abstract will be via the Web site.

Information: Further information about the workshop can be found on the Web page: http://www.mate.tue.nl/ or direct http://www.mate.tue.nl/workshop/.

September 1999

*20-24 **The 10th Biennial Computational Techniques and Applications Conference and Workshops (CTAC99)**, Australian National University, Canberra, Australia.

Topics: A conference and workshops on aspects of computational mathematics; scientific, technical, and industrial applications; and high-performance computing.

Invited Speakers: M. Hegland (Australian National Univ.), S. Hirschman (Oak Ridge National Laboratory), J. Lewis (Boeing Corp.), T. Speed (Univ. of California, Berkeley), G. Steven (Univ. of Sydney), A. Watson (Univ. of Dundee).

Public Lecture: J. Dongarra (Univ. of Tennessee and Oak Ridge National Laboratory).

Workshops: Data mining, high performance computing, scientific visualisation and virtual environments.

Organizing Committee: B. Anderssen, H. Gardner, B. Gingold, L. Grosz, D. Harrar II, M. Hegland, M. Osborne, S. Roberts, T. Tran.

Information: Further information, including deadlines, registration information, contact information for workshop organizers, etc., is available from the conference Web site: http://www.maths.anu.edu.au/conferences/CTAC99/. This will be updated as further information becomes available.

October 1999

*6-9 **New Trends in the Calculus of Variations**, Lisbon, Portugal.

Topics: Variational methods in nonlinear elasticity; variational models for material behavior; homogenization and relaxation methods; nonconvex problems; shape optimization; free discontinuity problems.

Program: 30-minute presentations by invited speakers, 15-minute presentations by younger researchers.

Deadline: Applications for financial support of graduate students and postdoc fellows should be submitted before May 30, 1999.

Organizers: A. C. Barroso and L. Mascarenhas (FC, U. Lisboa), J. Matias and J. Matos (IST, Lisboa).

Information: http://www.math.ist.utl.pt/~ntcv99/.

The following new announcements will not be repeated until the criteria in the next to the last paragraph at the bottom of the first page of this section are met.

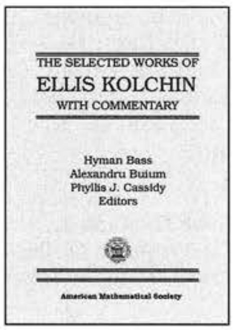
March 2000

*16-18 **Seminar on Stochastic Processes, 2000**, The University of Utah, Salt Lake City, Utah.

Information: For further information please contact D. Khoshnevisan, (davar@math.utah.edu) or visit the URL: http://www.math.utah.edu/~davar/ssp2000-2.html.

New Publications Offered by the AMS

Algebra and Algebraic Geometry



Selected Works of Ellis Kolchin with Commentary

Hyman Bass, *Columbia University, New York*, **Alexandru Buium**, *University of New Mexico, Albuquerque*, and **Phyllis J. Cassidy**, *Smith College, Northampton, MA*, Editors

The work of Joseph Fels Ritt and Ellis Kolchin in differential algebra paved the way for exciting new applications in constructive symbolic computation, differential Galois theory, the model theory of fields, and Diophantine geometry. This volume assembles Kolchin's mathematical papers, contributing solidly to the archive on construction of modern differential algebra. This collection of Kolchin's clear and comprehensive papers—in themselves constituting a history of the subject—is an invaluable aid to the student of differential algebra.

In 1910, Ritt created a theory of algebraic differential equations modeled not on the existing transcendental methods of Lie, but rather on the new algebra being developed by E. Noether and B. van der Waerden. Building on Ritt's foundation, and deeply influenced by Weil and Chevalley, Kolchin opened up Ritt theory to modern algebraic geometry. In so doing, he led differential geometry in a new direction. By creating differential algebraic geometry and the theory of differential algebraic groups, Kolchin provided the foundation for a "new geometry" that has led to both a striking and an original approach to arithmetic algebraic geometry. Intriguing possibilities were introduced for a new language for nonlinear differential equations theory.

The volume includes commentary by A. Borel, M. Singer, and B. Poizat. Also Buium and Cassidy trace the development of Kolchin's ideas, from his important early work on the differential Galois theory to his later groundbreaking results on the theory of differential algebraic geometry and differential algebraic groups. Commentaries are self-contained with numerous examples of various aspects of differential algebra and its applications. Central topics of Kolchin's work are discussed, presenting the history of differential algebra and exploring how his work grew from and transformed the work of Ritt. New directions of differential algebra are illustrated, outlining important current advances. Prerequisite to understanding the text is a background at the beginning graduate level in algebra, specifically commutative algebra, the theory of field extensions, and Galois theory.

This item will also be of interest to those working in differential equations.

Contents: Picard-Vessiot theory of partial differential fields; The notion of dimension in the theory of algebraic differential equations; *Part I. The Papers of Ellis Kolchin:* On certain ideals of differential polynomials; On the basis theorem for infinite systems of differential polynomials; On the exponents of differential ideals; On the basis theorem for differential systems; Extensions of differential fields. I; Extensions of differential fields. II; Algebraic matric groups; The Picard-Vessiot theory of homogeneous linear ordinary differential equations; Extensions of differential fields. III; Algebraic matric groups and the Picard-Vessiot theory of homogeneous linear ordinary differential equations; On certain concepts in the theory of algebraic matric groups; Existence theorems connected with the Picard-Vessiot theory of homogeneous linear ordinary differential equations; Algebraic groups and differential equations; Two proofs of a theorem on algebraic groups; Picard-Vessiot theory of partial differential fields; Galois theory of differential fields; Differential fields and group varieties (First lecture); Differential fields and group varieties (Second lecture); On the Galois theory of differential fields; Algebraic groups and the Galois theory of differential fields; Rational approximation to the solutions of algebraic differential equations; Existence of invariant bases; Abelian extensions of differential fields; Le théorème de la base finie pour les polynômes différentiels; The notion of dimension in the theory of algebraic differential equations; Singular solutions of algebraic differential equations and a lemma of Arnold Shapiro; Some problems in differential algebra; Algebraic groups and algebraic dependence; Differential polynomials and strongly normal extensions; Constrained extensions of differential fields; Differential equations in a projective space and linear dependence over a projective variety; Differential algebraic groups; Differential algebraic structures; On universal extensions of differential fields; Differential algebraic groups; A problem on differential polynomials; Painlevé transcendent; *Part II. Commentary:* **A. Borel**, Algebraic groups and Galois theory in the work of Ellis R. Kolchin; **M. F. Singer**, Direct and inverse problems in differential Galois theory; **B. Poizat**, Les corps différentiellement clos, compagnons de route de la théorie des modèles; **A. Buium** and **P. J. Cassidy**, Differential algebraic geometry and differential algebraic groups: From algebraic differential equations to Diophantine geometry.

Collected Works, Volume 12

March 1999, approximately 664 pages, Hardcover, ISBN 0-8218-0542-8, 1991 *Mathematics Subject Classification*: 00B60, 12H05; 03C60, 11D99, 12F12, 12H20, 12Y05, 13A35, 13N10, 14E20, 14G20, **Individual member $72**, List $120, Institutional member $96, Order code CWORKS/12N

Sur le Transfert des Intégrales Orbitales Pour les Groupes Linéaires (CAS *p*-adique)

François Courtès, *Université de Poitiers, France*

A publication of Société Mathématique de France.

In this memoir, the author considers the transfer problem for orbital integrals for the linear group $SL_n(F)$, where F is a non-Archimedean local field of characteristic zero and residual characteristic p with $p > n$. In particular, Courtès establishes the transfer of the orbitals integrals from $SL_n(F)$ to its endoscopic groups. In order to do this, he proves the following result: For $G = GL_n(F)$ and $H = GL_m(E)$, with E a tamely ramified extension of F of degree n/m and any p, the transfer from G to H holds on the set of semisimple regular elements, which generates an algebra in $M_n(F)$ that is the product of tamely ramified extensions of F.

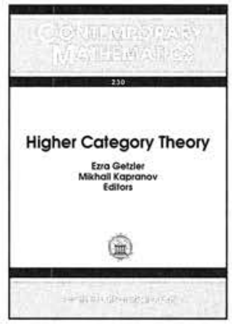
In a neighborhood of the identity, orbital integrals on G and H can be developed in Shalika germs; it is enough then to compare them for functions belonging to some well-chosen space. For these functions, one obtains another development in germs, related to twisted traces of induced Steinberg representations. The computation of such traces, combined with recurrence relations (on n) on the value of orbital integrals, yields recurrence relations on the values of these germs. One also obtains recurrence relations on the value of the transfer factors. All these relations allow one to compare the value of germs on G and H, and the result follows.

Distributed by the AMS in the United States, Canada, and Mexico. Orders from other countries should be sent to the SMF, Maison de la SMF, B.P. 67, 13274 Marseille cedex 09, France, or to Institut Henri Poincaré, 11 rue Pierre et Marie Curie, 75231 Paris cedex 05, France. Members of the SMF receive a 30% discount from list.

Contents: Introduction; Préliminaires; Fonctions utilisées; Calcul de traces; Calcul des germes par récurrence; Le transfert; Bibliographie.

Mémoires de la Société Mathématique de France, Number 69

March 1998, 140 pages, Softcover, ISBN 2-85629-062-0, 1991 *Mathematics Subject Classification*: 22E50; 11F70, **Individual member $23**, List $26, Order code SMFMEM/69N



Higher Category Theory

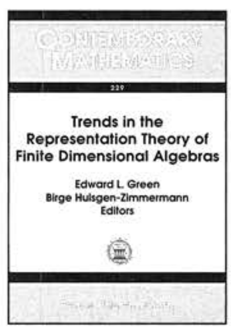
Ezra Getzler and **Mikhail Kapranov,** *Northwestern University, Evanston, IL,* Editors

This volume presents the proceedings of the workshop on higher category theory and mathematical physics held at Northwestern University. Exciting new developments were presented with the aim of making them better known outside the community of experts. In particular, presentations in the style, "Higher Categories for the Working Mathematician", were encouraged. The volume is the first to bring together developments in higher category theory with applications. This collection is a valuable introduction to this topic—one that holds great promise for future developments in mathematics.

Contents: J. C. Baez and **J. Dolan**, Categorification; **M. A. Batanin**, Computads for finitary monads on globular sets; **L. Breen**, Braided n-categories and Σ-structures; **J.-L. Brylinski**, Categories of vector bundles and Yang-Mills equations; **R. Street**, The role of Michael Batanin's monoidal globular categories; **D. N. Yetter**, Braided deformations of monoidal categories and Vassiliev invariants.

Contemporary Mathematics, Volume 230

February 1999, 134 pages, Softcover, ISBN 0-8218-1056-1, LC 98-32266, 1991 *Mathematics Subject Classification*: 18–06, 18D05, 18G50, **Individual member $20**, List $34, Institutional member $27, Order code CONM/230N



Trends in the Representation Theory of Finite Dimensional Algebras

Edward L. Green, *Virginia Polytechnic Institute and State University, Blacksburg,* and **Birge Huisgen-Zimmermann,** *University of California, Santa Barbara,* Editors

This refereed collection of research papers and survey articles reflects the interplay of finite-dimensional algebras with other areas (algebraic geometry, homological algebra, and the theory of quantum groups). Current trends are presented from the discussions at the AMS-IMS-SIAM Joint Summer Research Conference at the University of Washington (Seattle).

The volume features several excellent expository articles which will introduce the beginning researcher to cutting-edge topics in representation theory. The book will also provide inspiration to researchers in related areas, as it includes original papers spanning a broad spectrum of representation theory.

Features:

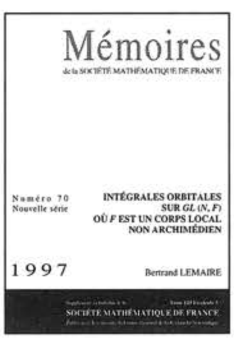
- Work outlining significant progress on long-standing open problems.

- Survey articles offering both overviews and introductions to various subfields of the topic.
- Expositions reflecting the interplay between the representation theory of algebras and other fields.

Contents: **I. Assem** and **F. U. Coelho**, Postprojective partitions for tilting torsion pairs; **M. Barot** and **H. Lenzing**, Derived canonical algebras as one-point extensions; **F. M. Bleher**, Special biserial algebras and their automorphisms; **S. Brenner** and **M. C. R. Butler**, Wild subquivers of the Auslander-Reiten quiver of a tame algebra; **K. A. Brown**, Representation theory of Noetherian Hopf algebras satisfying a polynomial identity; **R.-O. Buchweitz**, Finite representation type and periodic Hochschild (co-)homology; **M. C. R. Butler**, The syzygy theorem for monomial algebras; **J. A. de la Peña**, Algebras whose derived category is tame; **P. Dräxler**, Circular biextensions of tame concealed algebras; **R. Farnsteiner**, On the distribution of AR-components of restricted Lie algebras; **M. Gerstenhaber** and **A. Giaquinto**, Compatible deformations; **D. Happel** and **I. Reiten**, Directing objects in hereditary categories; **D. Happel** and **L. Unger**, On subcategories associated with tilting modules; **Y. Iwanaga** and **J. Miyachi**, Modules of the highest homological dimension over a Gorenstein ring; **M. Kauer**, Derived equivalence of graph algebras; **O. Kerner**, Basic results on wild hereditary algebras; **H. Krause** and **M. Saorín**, On minimal approximations of modules; **R. Martínez-Villa**, Serre duality for generalized Auslander regular algebras; **S. Montgomery**, Classifying finite-dimensional semisimple Hopf algebras; **C. Riedtmann**, Geometry of modules: Degenerations; **C. M. Ringel**, The preprojective algebra of a tame quiver: The irreducible components of the module varieties; **D. Simson**, Representation types, Tits reduced quadratic forms and orbit problems for lattices over orders; **A. Skowroński** and **G. Zwara**, Degenerations in module varieties with finitely many orbits.

Contemporary Mathematics, Volume 229

January 1999, 356 pages, Softcover, ISBN 0-8218-0928-8, LC 98-44526, 1991 *Mathematics Subject Classification*: 14D15, 14L30, 16D30, 16D60, 16E10, 16E30, 16E40, 16G10, 16G20, 16G30, 16G50, 16G60, 16G70, 16P10, 16P20, 16P40, 16S80, 16W30, 17B37, 81R50, **Individual member $45**, List $75, Institutional member $60, Order code CONM/229N



Intégrales Orbitales sur *GL(N, F)* Où *F* Est Un Corps Local Non Archimédien

Bertrand Lemaire, *Université de Paris-Sud, Orsay, France*

A publication of Société Mathématique de France.

This memoir gathers together the fundamental results about orbital integrals for $G = GL(N,F)$ for a non-Archimedean field F of characteristic $p \geq 0$, and $N \geq 2$. Many of the results were already known, but had not been published for the case $p > 0$: convergence, reduction formulas, germ expansion in a neighborhood of a point in a closed orbit and linear independence of the germs, characterization on the set of regular absolutely semi-simple elements, and the density of the regular absolutely semi-simple orbital integrals in the space of invariant distributions. The treatment of the inseparable elements requires the decomposition of the Dixmier strata of G into sub-strata and a normalization $J^G(f,x) (f \in C_c^\infty(G), x \in G)$ of the orbital integrals on G which induce, for all $f \in C_c^\infty(G)$, a map $x \mapsto J^G(f,x)$ that is locally constant on each of these sub-strata.

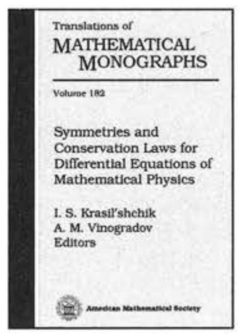
Distributed by the AMS in the United States, Canada, and Mexico. Orders from other countries should be sent to the SMF, Maison de la SMF, B.P. 67, 13274 Marseille cedex 09, France, or to Institut Henri Poincaré, 11 rue Pierre et Marie Curie, 75231 Paris cedex 05, France. Members of the SMF receive a 30% discount from list.

Contents: Introduction; Les classes de conjugaison de G; Intégrales orbitales sur G; Normalisation $\langle\langle J \rangle\rangle$ des intégrales orbitales sur G; Indépendance linéaire des germes; Caractérisation des intégrales orbitales sur G et théorème de densité; Bibliographie.

Mémoires de la Société Mathématique de France, Number 70

June 1998, 94 pages, Softcover, ISBN 2-85629-063-9, 1991 *Mathematics Subject Classification*: 22E50, **Individual member $23**, List $26, Order code SMFMEM/70N

Differential Equations



Symmetries and Conservation Laws for Differential Equations of Mathematical Physics

I. S. Krasil'shchik, *Moscow Institute for Municipal Economy, Russia*, and **A. M. Vinogradov**, *University of Salerno, Italy*, Editors

This book presents developments in the geometric approach to nonlinear partial differential equations (PDEs). The expositions discuss the main features of the approach, and the theory of symmetries and the conservation laws based on it. The book combines rigorous mathematics with concrete examples. Nontraditional topics, such as the theory of nonlocal symmetries and cohomological theory of conservation laws, are also included.

The volume is largely self-contained and includes detailed motivations, extensive examples and exercises, and careful proofs of all results. Readers interested in learning the basics of applications of symmetry methods to differential equations of mathematical physics will find the text useful. Experts will also find it useful as it gathers many results previously only available in journals.

Contents: Ordinary differential equations; First-order equations; The theory of classical symmetries; Higher symmetries; Conservation laws; Nonlocal symmetries; From symmetries of partial differential equations towards secondary ("quantized") calculus; Bibliography; Index.

Translations of Mathematical Monographs, Volume 182

February 1999, approximately 347 pages, Hardcover, ISBN 0-8218-0958-X, 1991 *Mathematics Subject Classification*: 35A30, 58F07; 58F05, 58G05, **Individual member $77**, List $129, Institutional member $103, Order code MMONO/182N

General and Interdisciplinary

Proceedings of the International Congress of Mathematicians, Berlin 1998

Gerd Fischer, *University of Dusseldorf, Germany*, and **Ulf Rehmann**, *University of Bielefeld, Germany*, Editors

***A publication of* DOCUMENTA MATHEMATICA.**

Each International Congress brings together mathematicians from all over the world to discuss recent developments in all areas of mathematics. It is one of the most exciting gatherings of mathematicians. The 1998 Congress in Berlin was no exception.

The invited speakers at the ICM have been recognized by their colleagues as important leaders in their fields, with their work representing some of the most significant recent research in mathematics. The twenty-one plenary speakers are asked to address the whole congress on recent results and trends that are shaping mathematics today. All plenary and invited lectures are published in these proceedings.

The announcement of the Fields Medalists and the Nevanlinna Prize Winner is a particular highlight of each International Congress. Volume I of the proceedings includes a short description of their work and the text of the lectures presented by the Medalists and Prize Winner at the Congress. This year, the Fields Medal Committee also paid special tribute to Andrew Wiles for his proof of Fermat's Last Theorem.

The *Proceedings of an International Congress of Mathematicians* provides a snapshot of mathematics at a given time. The articles for ICM '98 are guideposts to the significant developments in mathematical research at the end of the millenium.

Contents: *Volume I: Plenary One-Hour Invited Lectures:* **J.-M. Bismut**, Local index theory and higher analytic torsion; **C. Deninger**, Some analogies between number theory and dynamical systems; **P. Diaconis**, From shuffling cards to walking around the building: An introduction to modern Markov chain theory; **G. Gallavotti**, Chaotic hypothesis and universal large deviations properties; **W. Hackbusch**, From classical numerical mathematics to scientific computing; **H. H. W. Hofer**, Dynamics, topology and holomorphic curves; **E. Hrushovski**, Geometric model theory; **I. G. Macdonald**, Constant term identities, orthogonal polynomials and affine Hecke algebras; **S. Mallat**, Applied mathematics meets signal processing; **D. McDuff**, Fibrations in symplectic topology; **T. Miwa**, Solvable lattice models and representation theory of quantum affine algebras; **G. Papanicolaou**, Mathematical problems in geophysical wave propagation; **G. Pisier**, Operator spaces and similarity problems; **P. Sarnak**, L-functions; **P. W. Shor**, Quantum computing; **K. Sigmund**, The population dynamics of conflict and cooperation; **M. Talagrand**, Huge random structures and mean field models for spin glasses; **C. Vafa**, Geometric physics; **M. Viana**, Dynamics: A probabilistic and geometric perspective; **V. Voevodsky**, A^1-homotopy theory; *Appendix:* **M. Safonov**, Estimates near the boundary for solutions of second order parabolic equations; **A. J. Wilkie**, o-minimality; Appendix; *Volume II: Invited Forty-five Minute Lectures, Section 1–9:* Logic, see also Appendix Vol. I; Algebra; Number theory an arithmetic algebraic geometry; Algebraic geometry; Differential geometry and global analysis; Topology; Lie groups and Lie algebras; Analysis; Ordinary differential equations and dynamical systems; Author index for volumes II, III; *Volume III: Invited Forty-five Minute Lectures, Sections 10–19:* Partial differential equations, see also Appendix Vol. I; Mathematical physics; Probability and statistics; Combinatorics; Mathematical aspects of computer science; Numerical analysis and scientific computing; Applications; Control theory and optimization; Teaching and popularization of mathematics; History of mathematics; Appendix; Author index for volumes II, III.

December 1998, 2374 pages, Hardcover, 1991 *Mathematics Subject Classification*: 00, **Individual member $105**, List $140, Order code PICM/98N

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PUBLICATIONS *of* CONTINUING INTEREST

Bestselling Publications Distributed by the AMS

These publications are among the bestsellers distributed by the AMS. They are published by various academic publishers—International Press (Boston), Narosa Publishing House (New Delhi, India), Société Mathématique de France (Paris), and Vieweg Verlag (Wiesbaden, Germany). The AMS maintains distribution rights to the works within and outside the USA. Details are listed with the ordering information.

Recommended Text

Basic Partial Differential Equations

David Bleecker and **George Csordas**, *University of Hawaii, Honolulu*

A publication of International Press.

Distributed worldwide, except in Japan, by the American Mathematical Society.

International Press; 1996; ISBN 1-57146-036-5; 735 pages; Hardcover; **All AMS members $47**, List $59, Order Code INPR/23CI92

Inverse Problems in the Mathematical Sciences

Charles W. Groetsch, *University of Cincinnati, OH*

A publication of Vieweg Verlag.

The AMS is exclusive distributor in North America, and non-exclusive distributor worldwide except in Germany, Switzerland, Austria, and Japan.

Vieweg Monographs; 1993; ISBN 3-528-06545-1; 152 pages; Hardcover; **All AMS members $27**, List $30, Order Code VW/2CI92

A First Course in Differential Geometry

Chuan C. Hsiung, *Lehigh University, Bethlehem, PA*

A publication of International Press.

Distributed worldwide, except in Japan, by the American Mathematical Society.

International Press; 1997; ISBN 1-57146-046-2; 343 pages; Hardcover; **All AMS members $36**, List $45, Order Code INPR/24CI92

The Man Who Loved Only Numbers

The Story of Paul Erdős and the Search for Mathematical Truth

Paul Hoffman

A publication of Hyperion Press.

No mathematician is more legendary than Paul Erdős (1913–96) ... The Man Who Loved Only Numbers *is [Hoffman's] expanded homage to the man and his discipline ... Hoffman does not analyze the man but lets Erdős and his colleagues speak for themselves, and Erdős the person, and his intellectual interests, emerge ... We follow the trains of thought (and some of the personalities) that evolved from the attempts to comprehend the infinite sets lurking behind calculus. We visit Andrew Wiles' recent solution of the second-most famous theorem in mathematics, Fermat's last one. And we pursue the "Monty Hall" problem ... This book opens doors on a world and characters that are often invisible. It is interesting that Hoffman, Erdős and others in the book remember the mathematical tidbit that first intrigued them and bound them to this world. Possibly a future scientist or mathematician, or future scientific writer, will remember something in this book that way.*

—New York Times Book Review

Distributed worldwide by the American Mathematical Society.

1998; ISBN 0-7868-6362-5; 302 pages; Hardcover; **All AMS members $16**, List $23, Order Code MLONCI92

Quantum Groups and Knot Invariants

Christian Kassel, **Marc Rosso**, and **Vladimir Turaev**, *CNRS, Strasbourg, France*

A publication of Société Mathématique de France.

Distributed by the AMS in the United States, Canada, and Mexico. Orders from other countries should be sent to the SMF, Maison de la SMF, B.P. 67, 13274 Marseille cedex 09, France, or to Institut Henri Poincaré, 11 rue Pierre et Marie Curie, 75231 Paris cedex 05, France. Members of the SMF receive a 30% discount from list.

Panoramas et Synthèses, Number 5; 1997; ISBN 2-85629-055-8; 115 pages; Softcover; **Individual member $22**, List $24, Order Code PASY/5CI92

Supplementary Reading

An Introduction to Measure and Integration

Inder K. Rana, *Indian Institute of Technology, Pawai*

A publication of Narosa Publishing House.

A good addition to the standard texts on the subject ... the book is clearly a labour of love. The exuberance of detail, the wealth of examples and exercises and the evident delight in discussing variations and counter examples all attest to that ... highly recommended to serious and demanding students of mathematics.

—Resonance

Distributed by the AMS exclusively in North America and Europe and non-exclusively elsewhere.

1997; ISBN 81-7319-120-4; 380 pages; Hardcover; **All AMS members $39**, List $49, Order Code IMICI92

Supplementary Reading

Lectures on the Mordell-Weil Theorem

Third Edition

Jean-Pierre Serre, *Collège de France, Paris*

A publication of Vieweg Verlag.

The AMS is exclusive distributor in North America, and non-exclusive distributor worldwide except in Germany, Switzerland, Austria, and Japan.

Vieweg Aspects of Mathematics, Volume 15; 1997; ISBN 3-528-28968-6; 218 pages; Hardcover; **All AMS members $41**, List $45, Order Code VWAM/15CI92

Deformations of Galois Representations and Hecke Algebras

J. Tilouine, *Université de Paris Nord, Villetaneuse, France*

A publication of Narosa Publishing House.

Distributed by the AMS exclusively in North America and Europe and non-exclusively elsewhere.

1996; ISBN 81-7319-106-9; 108 pages; Softcover; **All AMS members $19**, List $24, Order Code DGRCI92

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Candidates must have expertise in modeling and computation encompassing research in materials science or materials engineering. Candidates should expect to participate fully in cross-disciplinary programs, research, teaching, and professional service and should have an established record of research funding.

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Applicants must send (i) their résumé, which identifies three people who will write letters of recommendation for them if contacted by the committee; (ii) a letter stating they wish to be considered for the position and addressing their research agenda; and (iii) a statement of teaching philosophy to:

Chair, Math/CBME Search Committee
P. O. Box 871804
Arizona State University
Tempe, AZ 85287-1804

Review of applications will begin December 15, 1998, and will continue weekly until the position is filled. AA/EOE.

ARIZONA STATE UNIVERSITY

Arizona State University invites applications for a joint senior position in the Departments of Mathematics and of Electrical Engineering commencing fall 1999. All candidates must have a Ph.D. in mathematics, electrical engineering, or a related area. Candidates must have an outstanding research record and a proven commitment to excellence and innovation in teaching, appropriate to rank.

Candidates must have expertise in the modeling and computation of complex dynamical systems encompassing applications from industry or the life sciences. Preferred research areas are in control and nonlinear dynamics (for example, neurodynamics, spatial and temporal signal processing and data analysis, complex systems). Candidates should expect to participate fully in cross-disciplinary programs, research, teaching, and professional service and should have an established record of research funding.

The main campus of Arizona State University has approximately 49,000 students and is located in the rapidly growing metropolitan Phoenix area, which provides a wide variety of recreational and cultural opportunities. The Department of Mathematics has 57 full-time faculty, and the Department of Electrical Engineering has 40 full-time faculty. Faculty from the Departments of Electrical Engineering and Mathematics are also members of the Systems Science and Engineering Research Center (SSERC). This center has associated with it approximately 100 faculty from various engineering, science, and mathematics disciplines. It sponsors many active collaborations with semiconductor,

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Upcoming deadlines for classified advertising are as follows: March issue–December 21, 1998; April issue–January 16, 1999; May issue–February 23, 1999; June/July issue–April 26, 1999; August issue–May 21, 1999; September issue–June 21, 1999.

U.S. laws prohibit discrimination in employment on the basis of color, age, sex, race, religion, or national origin. "Positions Available" advertisements from institutions outside the U.S. cannot be published unless they are accompanied by a statement that the institution does not discriminate on these grounds whether or not it is subject to U.S. laws. Details and specific wording may be found on page 1373 (vol. 44).

Situations wanted advertisements from involuntarily unemployed mathematicians are accepted under certain conditions for free publication. Call toll-free 800-321-4AMS (321-4267) in the U.S. and Canada, or 401-455-4084 worldwide, for further information.

Submission: Promotions Department, AMS, P.O. Box 6248, Providence, Rhode Island 02940, or via fax, 401-331-3842, or send e-mail to `classads@ams.org`. AMS location for express delivery packages is 201 Charles Street, Providence, Rhode Island 02904. Advertisers will be billed upon publication.

active collaborations with semiconductor, aerospace, biotechnology and chemical industries. Outstanding computing and visualization facilities are available. Further information about the Departments of Mathematics and of Electrical Engineering and the SSERC can be found on the World Wide Web at http://math.la.asu.edu/, http://www.eas.asu.edu/~eee/, and http://www.asu.edu/~sserc/.

Applicants must send (i) their résumé, which identifies three people who will write letters of recommendation for them if contacted by the committee; (ii) a letter stating they wish to be considered for the position and addressing their research agenda; and (iii) a statement of teaching philosophy to:

Chair, Math/EE Search Committee
P. O. Box 871804
Arizona State University
Tempe, AZ 85287-1804

Review of applications will begin December 15, 1998, and will continue weekly until the position is filled. AA/EOE.

CALIFORNIA

UNIVERSITY OF CALIFORNIA
Department of Mathematics
Riverside, CA

Applications are invited for possibly one or more visiting assistant professor positions beginning September 1999, contingent upon available funding. Applicants must show demonstrated or strong promise in research and teaching. The positions are open to applicants from all research areas in mathematics. The teaching load is six quarter-courses per year. Candidates must have received a Ph.D. degree by September 1999.

Applicants should send their curriculum vitae, including publications list, and at least three letters of recommendation to:

Temporary Faculty Search Committee
Department of Mathematics
University of California, Riverside
Riverside, CA 92521-0135

by Friday, February 26, 1999. The University of California, Riverside, is an Affirmative Action/Equal Opportunity Employer.

Inquiries (not applications) can be sent to linda@math.ucr.edu or lterry@ucrac1.ucr.edu.

COLORADO

THE COLORADO COLLEGE
Department of Mathematics
14 E. Cache La Poudre
Colorado Springs, CO 80903
e-mail:
msiddoway@coloradocollege.edu

The Department of Mathematics invites applications for one or more one-year non-tenure-track positions to begin in September 1999. The department will hire one person in applied mathematics. Applications from all fields are encouraged for any additional positions. Ph.D. in applied mathematics or mathematics required for all positions. In keeping with departmental tradition, all applicants are expected to be able to teach courses across the mathematics curriculum. The application deadline for all positions is February 12, 1999. Review of completed applicant files will begin on February 12 and will continue until all positions are filled. We encourage applications from all ranks for the position in applied mathematics and at the assistant professor level for any additional positions.

Colorado College, a leading national liberal arts college, is dedicated to greater diversity among its faculty and in its curriculum. The College welcomes members of all minority groups and reaffirms its commitment not to discriminate on the basis of race, color, age, religion, sex, national origin, sexual orientation, or disability in its educational programs, activities, and employment practices.

The Department of Mathematics values both excellence in teaching and vigorous mathematical scholarship. Candidates should send a letter of application describing both their commitment to teaching and mathematical interests, a curriculum vitae, and three letters of recommendation (at least one of which should address abilities as a teacher) to Mike Siddoway at the address above. Please indicate whether you will be available to meet with representatives of the College at the joint MAA/AMS meetings in San Antonio in January 1999. Equal Opportunity Employer.

GEORGIA

GEORGIA SOUTHERN UNIVERSITY
Karl Peace Endowed Chair in Mathematics and Computer Science
Department of Mathematics and Computer Science
Statesboro, GA

The Department of Mathematics and Computer Science at Georgia Southern University invites nominations and applications for the Karl Peace Endowed Chair. Starting date of the position is August 1, 1999. Applicants are expected to have a Ph.D. in mathematics, computer science, statistics, or a closely related field, and credentials that merit appointment at the rank of professor with tenure. We are searching for an individual with distinguished academic credentials, the proven ability to conduct and direct high-quality research, and an established record of attracting support for that research. Candidates should have the qualifications to provide academic and scientific leadership to a developing department. The successful candidate will be expected to establish a vigorous research program, to have a commitment to excellence in undergraduate and graduate education, and to lead our efforts to establish a cooperative program with industry. We are particularly interested in an individual whose area of expertise lies in the intersection of mathematics and computer science, but exceptional candidates from all fields of the mathematical sciences will be seriously considered. Among the duties will be program development, fund raising and preparation of proposals, and involvement with the Center of Applied Mathematical Sciences.

The Department of Mathematics and Computer Science, in the Allen E. Paulson College of Science and Technology, offers programs in mathematics at the baccalaureate and master's levels. Our B.S. in computer science is fully accredited by the Computer Science Accreditation Commission. The Department has five state-of-the-art computer laboratories, as well as a networked computer (UNIX, PC or Mac) in the office of each faculty member. The Department has steadily increased its quantity and quality of scholarship during the past decade in applied mathematics, computer science, and statistics. Our Web pages are at http://www.cs.gasou.edu/.

Georgia Southern University, a unit of the University System of Georgia, is the largest and leading center of higher education in the southern half of Georgia and is third in student enrollment among public universities, serving approximately 14,000 students. As a comprehensive, residential university its mission is strongly centered on the education of undergraduate students. The University offers approximately 150 degree programs at the baccalaureate, master's, and doctoral levels through six colleges. Founded in 1906, Georgia Southern became a regional university in 1990. The 634-acre campus is located in Statesboro, a community of approximately 30,000 residents 50 miles northwest of historic Savannah and 200 miles southeast of Atlanta.

A complete application consists of a letter of application addressing the above qualifications, a curriculum vitae, and five letters of reference. Send application materials to Richard Hathaway, Search Chair, Karl Peace Endowed Chair of Mathematics and Computer Science, P.O. Box 8093, Department of Mathematics and Computer Science, Georgia Southern University, Statesboro, GA 30460-8093. Review of the applications will begin on February 15, 1999.

Georgia Southern is an Equal Opportunity/Affirmative Action Institution. Georgia is an Open Records state. Persons who need reasonable accommodations in order to participate in the application process should notify the search chair.

INDIANA

INDIANA UNIVERSITY-PURDUE UNIVERSITY, INDIANAPOLIS
Indianapolis, IN

The Department of Mathematical Sciences has a tenure-track assistant professor position in statistics to begin August 1999. The Department has a growing graduate program in statistics and offers a competitive salary and excellent benefits. A Ph.D. in statistics or in a related area, strong research potential, and a commitment to excellence in teaching are required. A letter of application, résumé, and three letters of recommendation should be sent to Robert Kleyle, Department of Mathematical Sciences, Indiana University-Purdue University, Indianapolis, 402 N. Blackford St., Indianapolis, IN 46202. Review of applications will begin 1/15/99 and will continue until the position is filled. Women and minorities are encouraged to apply. AA/EOE.

PURDUE UNIVERSITY CALUMET
School of Engineering, Mathematics and Sciences

Applications and nominations are invited for the position of dean, School of Engineering, Mathematics and Sciences. Starting date: July 1, 1999. The School consists of departments of: Biological Sciences; Chemistry & Physics; Engineering; and Mathematics, Computer Science & Statistics. PUC is a comprehensive university of 9,400 students. The University is located in Hammond, Indiana, a metropolitan area adjacent to Chicago.

The successful candidate will have the following characteristics: earned doctorate in a discipline with the purview of the School; record of personal academic accomplishments at the university level commensurate with appointment to the faculty at the rank of professor; demonstrated excellence in teaching; proven record of scholarship; prior administrative experience as dean, department head, or equivalent; understanding of the disciplines within the School.

Applications must include: letter of application, including a personal statement of qualifications; curriculum vitae; names, addresses, and telephone numbers of five professional references. Review of applications will begin February 1, 1999, and will continue until position is filled. Send materials to:

Secretary, EMS Dean Selection
Advisory Committee
Academic Affairs
Purdue University Calumet
Hammond, IN 46323

For more information about Purdue University Calumet, visit `http://www.calumet.purdue.edu/`. Purdue University Calumet is an Equal Access/Equal Opportunity University.

IOWA

IOWA STATE UNIVERSITY
Department of Mathematics

The Department seeks applicants, pending funding, for two tenure-track positions to begin in the fall of 1999. The positions are expected to be at the assistant professor level, but exceptional applicants for a higher rank may be considered. An excellent record in research and teaching is required, and experience beyond the Ph.D. is desirable.

One position is targeted at control theory and practice. We are interested in a mathematician who can interact with current faculty in the Department as well as with the numerous faculty in other departments interested in control problems.

The second position is targeted at areas of applied mathematics that are complementary to the existing strengths in the Department. These include partial differential equations, numerical analysis, control theory, computational and mathematical biology, stochastic analysis, and discrete mathematics applied to computer science and other problems.

Applicants must indicate which position(s) they are applying for and submit a vita and a brief statement describing their research accomplishments and plans. They must also arrange for the submission of their graduate transcripts and four letters of recommendation, one of which must address the applicant's teaching ability and experience. All application materials should be sent to: Max Gunzburger, Department of Mathematics, Iowa State University, Ames, IA 50011-2064. Applicants whose completed applications are received by February 15, 1999, are assured of receiving full consideration.

Iowa State University strongly encourages women and members of underrepresented groups to apply.

MASSACHUSETTS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Applied Mathematics

Applications are invited for a limited number of positions in applied mathematics starting fall 1999. Available positions include instructorships, lectureships, assistant professorships, and possibly higher levels. Appointments will be made mainly on the basis of demonstrated research accomplishment and potential. Complete applications must be received by January 8. To apply, please send a vita with a description of your recent research and research plans, and arrange to have three letters of reference sent. Address: Committee on Applied Mathematics, Room 2-345, Department of Mathematics, Massachusetts Institute of Technology, Cambridge, MA 02139-4307. M.I.T. is an Equal Opportunity/Affirmative Action Employer.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Mathematics

The Department of Mathematics may make a few appointments at the lecturer and at the assistant professor or higher levels in pure mathematics for the year 1999–2000. The teaching load will be six hours per week in one semester and three hours per week in the other or other combinations totaling nine hours. Open to mathematicians with doctorates who show definite promise in research. Applications should be completed by January 15. Applicants please arrange to have sent (a) a vita, (b) three letters of reference, (c) a description of your most recent research, and (d) the research that you plan for the next few years to: Pure Mathematics Committee, Massachusetts Institute of Technology, Room 2-263, Cambridge, MA 02139-4307. M.I.T. is an Equal Opportunity/Affirmative Action Employer.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Mathematics
C.L.E. Moore Instructorships in Mathematics

Open to mathematicians with doctorates who show definite promise in research. Teaching loads are six hours per week during one semester and three hours per week during the other. Applications should be completed by January 1. Please arrange to have sent (a) a vita, (b) three letters of reference, (c) a description of the research in your thesis, and (d) the research which you plan for next year to: Pure Mathematics Committee, Massachusetts Institute of Technology, Room 2-263, Cambridge, MA 02139-4307. M.I.T. is an Equal Opportunity/Affirmative Action Employer.

UNIVERSITY OF MASSACHUSETTS, AMHERST
Mathematics & Statistics

The Department of Mathematics & Statistics (`http://www.math.umass.edu/`) invites applications for tenure-track positions at the assistant professor level. In addition, two-year non-tenure-track positions will be available. The search will focus within the following areas: algebraic geometry, applied analysis, geometric analysis, Lie theory, number theory, probability, scientific computation, and statistics. Exceptional promise in research and in teaching (at all levels of the curriculum) is required. Although this search focuses on junior-level appointments, candidates for more senior-level appointments will be considered. Applicants should send a curriculum vitae and at least three letters of recommendation to: Search Committee, Department of Mathematics & Statistics, University of Massachusetts, Amherst, MA 01003-4515. Review of applications will begin immediately. Women and members of minority groups are encouraged to apply. Applications will continue to be accepted until all positions are filled. Please include the AMS Application Cover Sheet. Equal Opportunity/Affirmative Action Employer.

UNIVERSITY OF MASSACHUSETTS, AMHERST
Mathematics & Statistics

The Department of Mathematics & Statistics (http://www.math.umass.edu/) invites applications for tenure-track positions at the assistant professor level. In addition, two-year non-tenure-track positions will be available. Applicants should have a background in theoretical statistics and have an interest in applications, interdisciplinary work, and computation. Exceptional promise in research and in teaching (at all levels of the curriculum) is required. Although this search focuses on junior-level appointments, candidates for more senior-level appointments will be considered. Applicants should send a curriculum vitae and at least three letters of recommendation to: Search Committee, Department of Mathematics & Statistics, University of Massachusetts, Amherst, MA 01003-4515. Review of applications will begin immediately. Women and members of minority groups are encouraged to apply. Applications will continue to be accepted until all positions are filled. Please include the AMS Application Cover Sheet. Equal Opportunity/Affirmative Action Employer.

MICHIGAN

WESTERN MICHIGAN UNIVERSITY
Department of Mathematics and Statistics

Western Michigan University seeks applications for two tenure-track assistant professor positions in algebra to begin in August 1999, pending budgetary approval. A doctorate degree, excellent teaching ability, and a strong commitment to research are required. Preference will be given to applicants with research interests in one of the areas of representation theory of finite groups, group algebras, group rings, or algebraic number theory. Outstanding applicants will be considered at the associate professor level. Salary and fringe benefits are competitive. Western Michigan University, a Carnegie Classification Doctoral I Institution and Equal Opportunity Employer, has an affirmative action program which encourages applications from underrepresented groups.

Send letter of application, vita, statement of research plans, academic transcripts, and three letters of recommendation to:

John W. Petro, Chair
Department of Mathematics
and Statistics
Western Michigan University
Kalamazoo, MI 49008-5152
E-mail: john.petro@wmich.edu
Phone: 616-387-4551
Fax: 616-387-4530

For information about the Department see http://www.wmich.edu/math-stat/. Review of applications will begin December 1, 1998. Applications will be accepted until the positions are filled.

MINNESOTA

UNIVERSITY OF MINNESOTA, DULUTH
Department of Mathematics and Statistics

Tenure-track asst. or assoc. professor in the applied mathematical sciences starting 8/30/99. Preferred expertise in environment-related uses of applied and/or computational mathematics or statistics. Teach two courses per term at graduate and undergraduate level, assist in master's program, direct student research, conduct active research program, perform usual service responsibilities. Ph.D. in mathematics, statistics, or related field required by 8/30/99. Competitive salary. For more information contact: Dr. Bruce Peckham, Search Committee Chair, Dept. of Math. & Stat., University of Minnesota-Duluth, Duluth, MN 55812. Review of completed applications starts 2/1/99 and continues until position filled. Full position description and application procedures at http://www.d.umn.edu/math/ or e-mail: math@d.umn.edu. The University of Minnesota is an Equal Opportunity Educator and Employer.

NEBRASKA

UNIVERSITY OF NEBRASKA, KEARNEY

Tenure-track assistant professor of mathematics, starting August 1999. Earned doctorate in mathematics education required. Applicants must have a strong background in mathematics and excellent oral and written communication skills. Evidence of successful post-secondary-level teaching expected. May teach mathematics at all levels and will fully participate in secondary teacher preparation. Position requires departmental and university service and meaningful research in mathematics education. Preference given to candidates with experience in using technology in teaching and with a K-12 background. Competitive salary and benefits.

Review of applications will start February 1, 1999. Send application letter, curriculum vitae, three letters of reference, and undergraduate and graduate transcripts to Dr. Barton Willis, Mathematics and Statistics Faculty Search, University of Nebraska at Kearney, Kearney, NE 68849; http://www.unk.edu/. AA/EO/ADA.

NEW JERSEY

THE WILLIAM PATERSON UNIVERSITY OF NEW JERSEY

The Department of Mathematics invites applications for two tenure-track positions at the assistant professor level starting September 1, 1999. The requirements are a Ph.D. in mathematics (or, for appointment as instructor, ABD with compelling evidence of expected completion), a commitment to quality teaching, and a well-defined research agenda. The Department is committed to improving retention and recruitment of students via advisement, summer and precollege programs, independent student research, and curriculum development. The Department is also involved in teacher-training programs. Preference will be given to candidates with demonstrated interest in these activities.

For the first position in applied mathematics (Position #MA1), the Department seeks candidates with specialty in an area of applied analysis. For the second position (Position #MS2), preference will be given to candidates with demonstrated interest or experience in teaching statistics and developing statistics curriculum.

Send a letter of interest clearly stating the name and number of the position, current vita, graduate transcript (unofficial), and three letters of reference (at least one letter or other evidence should address the applicant's ability to teach effectively) to Dr. Mahendra Jani, Chairperson, Department of Mathematics, William Paterson University, Wayne, NJ 07470. Review of applications will begin immediately and will continue until the position is filled. WPUNJ is an Equal Opportunity/AA Employer and actively seeks applications from women, minorities, and underrepresented groups.

NEW YORK

DAEMAN COLLEGE
Dept. of Mathematics & Computer Science

Applications invited for tenure-track assistant professor position beginning 8/99. Duties include teaching 12 credit hours/semester, including computer science courses.

Ph.D. in mathematics or statistics, teaching experience, and a strong commitment to quality teaching and research required.

Daemen College is a private coeducational institution offering baccalaureate- and master's-level degree programs. Located on a scenic suburban campus in western New York, Daemen College is a dynamic independent institution with

2,000 students. For additional information see the College's home page at http://www.daemen.edu/.

Review of candidates will begin 2/15/99 and will continue until a qualified candidate is identified. For consideration send a letter of application including statement of teaching and research philosophies, transcripts, and four letters of reference to Daemen College, Personnel Dept., 4380 Main St., Amherst, NY 14226. AA/EOE.

RENSSELAER POLYTECHNIC INSTITUTE
Department of Mathematical Sciences

Applications are invited for a tenure-track assistant professor position in applied mathematics to begin in August 1999. Applicants are expected to have demonstrated outstanding research potential and to have a strong interest and ability in teaching. Of particular interest are candidates with a commitment to interdisciplinary research and who are knowledgeable in scientific computation.

Applicants should submit a letter of application, a curriculum vitae, a description of research interests, and three letters of recommendation to: Search Committee Chair, Department of Mathematical Sciences, Rensselaer Polytechnic Institute, Troy, NY 12180. Evaluation of applications will begin January 15, 1999, and will continue until a candidate is selected.

Rensselaer is an Equal Opportunity/Affirmative Action Employer and strongly encourages applications from women and underrepresented minorities.

NORTH CAROLINA

UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Mathematics

Applications are invited for a tenure-track assistant professor in mathematics beginning in fall 1999. Minimum requirements are (1) a Ph.D. in probability theory, partial differential equations, or numerical analysis; and (2) evidence of potential for excellence in research, teaching, and external funding. The candidate will contribute toward the establishment of a Center for Applied Analysis and Computation. The Department also anticipates 2-3 entry-level visiting positions for 1999-2000 in all areas of mathematics.

Please send a letter of application, vita, a short statement of your specific teaching and research objectives, and at least three letters of recommendation to Professor Zhi Yi Zhang, Department of Mathematics, University of North Carolina at Charlotte, Charlotte, NC 28223. Letters of recommendation should be addressed directly to Professor Zhang. Review of applications will begin December 1, 1998, and will continue until the position is filled. AA/EOE. Women and underrepresented minorities are encouraged to apply.

OKLAHOMA

THE UNIVERSITY OF OKLAHOMA
Department of Mathematics

Applications are invited for one full-time, tenure-track position beginning August 16, 1999. The position is initially budgeted at the assistant professor level, but an appointment at the associate professor level may be possible for an exceptional candidate with qualifications and experience appropriate to that rank. Normal duties consist of teaching two courses per semester, conducting research, and rendering service to the department, university, and profession at a level appropriate to the faculty member's experience. The position requires an earned doctorate and research interests that are compatible with those of the existing faculty; preference will be given to applicants with potential or demonstrated excellence in research and prior successful undergraduate teaching experience. Salary and benefits are competitive. For full consideration applicants should send a completed AMS Cover Sheet, curriculum vitae, a description of current and planned research, and three letters of recommendation (at least one of which must address the applicant's teaching experience and proficiency) to:

Search Committee
Department of Mathematics
University of Oklahoma
601 Elm, Phsc 423
Norman, OK 73019
Tel: 405-325-6711
Fax: 405-325-7484
E-mail: search@math.ou.edu

Screening of applications will begin on December 15, 1998, and will continue until the position is filled.

The University of Oklahoma is an Equal Opportunity/Affirmative Action Employer. Women and minorities are encouraged to apply. OU has a policy of being responsive to the needs of dual-career couples.

OREGON

PORTLAND STATE UNIVERSITY
Department of Mathematical Sciences
Assistant Professor Positions

Applications are invited for one or more assistant professor positions in analysis, applied mathematics/numerical methods, and/or statistics beginning September 16, 1999. Applicants are expected to have completed a doctoral degree in a mathematical science and show evidence of outstanding research potential and a strong commitment to excellence in teaching. Preference will be given to applicants with a commitment to interdisciplinary research and to developing collaborations with industry. Further program information is available on our home page (http://www.mth.pdx.edu/). Qualified applicants are invited to submit an application including (1) the AMS Cover Sheet for Academic Employment, (2) a curriculum vitae, and (3) three letters of recommendation. Send materials to

Search Committee
Department of Mathematical Sciences
Portland State University
P. O. Box 751
Portland, OR 97207-0751
E-mail: msearch@mth.pdx.edu

All materials should be received by March 1, 1999. Portland State University is an Affirmative Action/Equal Opportunity Institution. Applications from women and minorities are especially welcome.

PENNSYLVANIA

WEST CHESTER UNIVERSITY

The Department of Mathematics invites applications for a tenure-track assistant professor position in statistics beginning August 1999. Responsibilities include teaching twelve hours per semester assigned from among undergraduate and graduate courses in statistics and mathematics. Candidates must possess a Ph.D. in mathematics with at least a master's degree in statistics or possess a Ph.D. in statistics. Preference will be given to candidates holding a Ph.D. in statistics as well as to those with applied statistical experience. A strong potential for excellence in teaching and a proven record of excellence in scholarship are required.

To apply, submit a curriculum vitae, a brief statement of teaching philosophy, a brief research prospectus, graduate degree transcripts, and three letters of recommendation. Submission of evidence of teaching effectiveness is encouraged. Review of applications will begin immediately and will continue until the position is filled. Finalists must successfully complete an interview and demonstration of teaching effectiveness. Applicants should submit all materials to Dr. Richard Branton, Chair, Search Committee, Department of Mathematics, West Chester University, West Chester, PA 19383. No applications by fax or e-mail.

West Chester University is an Affirmative Action/Equal Opportunity Employer. Women and minorities are encouraged to apply.

TENNESSEE

UNIVERSITY OF TENNESSEE AT KNOXVILLE

The mathematics department at the University of Tennessee at Knoxville seeks to fill a postdoctoral position in some part of algebra. The position is guaranteed for two years and may be extended for a third year if performance is satisfactory. Continuation at the University of Tennessee beyond the third year is not possible. The teaching load for this position will be three semester-long courses during each academic year.

Candidates should provide evidence of their ability to teach in English and should have had their Ph.D. for no more than two years by September 1999.

Candidates should submit a curriculum vitae, a description of their research accomplishments and plans, and a statement about teaching. These documents as well as three letters of recommendation should be submitted to Professor John B. Conway, Dept. of Mathematics, University of Tennessee, Knoxville, TN 37996-1300. Use of the recent AMS application form is encouraged.

UTK is an EEO/AA/Title IX/Section 504/ADA Employer.

SWITZERLAND

THE SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH (ETHZ)

The Swiss Federal Institute of Technology Zurich (ETHZ) invites applications for an assistant professor of mathematics.

Duties of this position include, in addition to research, an active participation in the teaching of courses for students of mathematics, natural sciences, and engineering.

Candidates should have a doctorate or equivalent and have demonstrated the ability to carry out independent research. Willingness to teach at all university levels and to collaborate with colleagues is expected.

This assistant professorship has been established to promote the careers of younger scientists. Initial appointment is for three years, with the possibility of renewal for an additional three years.

Applications with curriculum vitae and a list of publications should be submitted to the president of ETH Zurich, Prof. Dr. O. Kübler, ETH Zentrum, CH-8092 Zurich, no later than March 31, 1999. The ETHZ specifically encourages female candidates to apply with a view toward increasing the proportion of female professors.

SERVICES AVAILABLE

DocuTEXing

DocuTEXing is a high-quality TEX typesetting facility for mathematical journals and monographs. Our services also include HTML coding, reference validation, and illustrations. We can see an electronic journal through from start to finish. For more information, samples, and references, please e-mail main-office@DocuTeXing.com or visit http://www.DocuTeXing.com/.

PUBLICATIONS WANTED

MATHEMATICS BOOKS PURCHASED

Pure & appl. adv. & research level, any age, usable cond. Reprints OK. One box to whole libraries sought. Contact: Collier Brown or Kirsten Berg @ **Powell's Technical Bks.**, Portland, OR. Call 800-225-6911, fax 503-228-0505, or e-mail: kirsten@technical.powells.com.

AMERICAN MATHEMATICAL SOCIETY

Application for Membership 1999

(January–December)

Date .... 19 ....

Please read the "Membership Categories" section of this form to determine the membership category for which you are eligible. Then fill out this application and return it as soon as possible.

....
Family Name ***First*** ***Middle***

Place of Birth ....
City ***State*** ***Country***

Date of Birth ....
Day ***Month*** ***Year***

If formerly a member of AMS, please indicate dates ....

Check here if you are now a member of either MAA ☐ or SIAM ☐

Degrees, with institutions and dates ....

....

....

Present position ....

Firm or institution ....

....
City ***State*** ***Zip/Country***

Primary Fields of Interest (choose five from the list at right)

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Secondary Fields of Interest (choose from the list at right)

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Address for all mail

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Telephone number(s) ....

Electronic address ....

....
Signature

Prepayment Methods and Mailing Addresses

All prices quoted in U.S. dollars.
Payment by check must be drawn on U.S. bank if paid in U.S. dollars.

Send checks, money orders, UNESCO coupons to American Mathematical Society, P.O. Box 5904, Boston, MA 02206-5904

To use credit cards, fill in information requested and mail to American Mathematical Society, P.O. Box 6248, Providence, RI 02940-6248 or call (401) 455-4000 or 1-800-321-4AMS.

For Foreign Bank Transfers: American Mathematical Society, State Street Bank and Trust Company, 225 Franklin St., ABA #011000028, Account #0128-262-3, Boston, MA 02110.

American Express ☐ *Discover* ☐ *VISA* ☐ *MasterCard* ☐

....
Account number ***Expiration date***

M9NO

Fields of Interest

If you wish to be on the mailing lists to receive information about publications in fields of mathematics in which you have an interest, please consult the list of major headings below. These categories will be added to your computer record so that you will be informed of new publications or special sales in the fields you have indicated.

EME	Education/Mathematics Education
00	General
01	History and biography
03	Mathematical logic and foundations
04	Set theory
05	Combinatorics
06	Order, lattices, ordered algebraic structures
08	General algebraic systems
11	Number theory
12	Field theory and polynomials
13	Commutative rings and algebras
14	Algebraic geometry
15	Linear and multilinear algebra; matrix theory
16	Associative rings and algebras
17	Nonassociative rings and algebras
18	Category theory, homological algebra
19	*K*-theory
20	Group theory and generalizations
22	Topological groups, Lie groups
26	Real functions
28	Measure and integration
30	Functions of a complex variable
31	Potential theory
32	Several complex variables and analytic spaces
33	Special functions
34	Ordinary differential equations
35	Partial differential equations
39	Finite differences and functional equations
40	Sequences, series, summability
41	Approximations and expansions
42	Fourier analysis
43	Abstract harmonic analysis
44	Integral transforms, operational calculus
45	Integral equations
46	Functional analysis
47	Operator theory
49	Calculus of variations and optimal control; optimization
51	Geometry
52	Convex and discrete geometry
53	Differential geometry
54	General topology
55	Algebraic topology
57	Manifolds and cell complexes
58	Global analysis, analysis on manifolds
60	Probability theory and stochastic processes
62	Statistics
65	Numerical analysis
68	Computer science
70	Mechanics of particles and systems
73	Mechanics of solids
76	Fluid mechanics
78	Optics, electromagnetic theory
80	Classical thermodynamics, heat transfer
81	Quantum theory
82	Statistical mechanics, structure of matter
83	Relativity and gravitational theory
85	Astronomy and astrophysics
86	Geophysics
90	Economics, operations research, programming, games
92	Biology and other natural sciences, behavioral sciences
93	Systems theory; control
94	Information and communication, circuits

Membership Categories

Please read the following to determine what membership category you are eligible for, and then indicate below the category for which you are applying.

Introductory ordinary member rate *applies to the first five* ***consecutive*** *years of ordinary membership. Eligibility begins with the first year of membership in any category other than student and nominee. Dues are $50.*

For ***ordinary members*** *whose annual professional income is below $55,000, the dues are $99; for those whose annual professional income is $55,000 or more, the dues are $132.*

The ***CMS cooperative rate*** *applies to ordinary members of the AMS who are also members of the Canadian Mathematical Society and reside outside of the U.S. For members whose annual professional income is $55,000 or less, the dues are $84; for those whose annual professional income is above $55,000, the dues are $112.*

For a ***joint family membership,*** *one member pays ordinary dues, based on his or her income; the other pays ordinary dues based on his or her income, less $20. (Only the member paying full dues will receive the* Notices *and the* Bulletin *as a privilege of membership, but both members will be accorded all other privileges of membership.)*

Minimum dues for ***contributing members*** *are $198. The amount paid which exceeds the higher ordinary dues level and is purely voluntary may be treated as a charitable contribution.*

For either ***students*** *or* ***unemployed individuals,*** *dues are $33, and annual verification is required.*

The annual dues for ***reciprocity members*** *who reside outside the U.S. and Canada are $66. To be eligible for this classification, members must belong to one of those foreign societies with which the AMS has established a reciprocity agreement, and annual verification is required. Reciprocity members who reside in the U.S. or Canada must pay ordinary member dues ($99 or $132).*

The annual dues for ***category-S members,*** *those who reside in developing countries, are $16. Members can chose only one privilege journal. Please indicate your choice below.*

Members can purchase a ***multi-year membership*** *by prepaying their current dues rate for either two, three, four or five years. This option is not available to category-S, unemployed, or student members.*

1999 Dues Schedule (January through December)

Introductory ordinary member rate .... ☐ $50

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CMS cooperative rate .... ☐ $84 ☐ $112

Joint family member (full rate) .... ☐ $99 ☐ $132

Joint family member (reduced rate) .... ☐ $79 ☐ $112

Contributing member (minimum $192) .... ☐

Student member (please verify)[1] .... ☐ $33

Unemployed member (please verify)[2] .... ☐ $33

Reciprocity member (please verify)[3] .... ☐ $66 ☐ $99 ☐ $132

Category-S member[4] .... ☐ $16

Multi-year membership .... $ .... for .... years

[1] ***Student Verification*** (sign below)

I am a full-time student at ....

.... *currently working toward a degree.*

[2] ***Unemployed Verification*** (sign below) *I am currently unemployed and actively seeking employment.*

[3] ***Reciprocity Membership Verification*** (sign below) *I am currently a member of the society indicated on the right and am therefore eligible for reciprocity membership.*

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Signature

[4] ☐ *send* **NOTICES** ☐ *send* **BULLETIN**

Reciprocating Societies

- ☐ Allahabad Mathematical Society
- ☐ Australian Mathematical Society
- ☐ Azerbaijan Mathematical Society
- ☐ Balkan Society of Geometers
- ☐ Berliner Mathematische Gessellschaft e.V.
- ☐ Calcutta Mathematical Society
- ☐ Croatian Mathematical Society
- ☐ Cyprus Mathematical Society
- ☐ Dansk Matematisk Forening
- ☐ Deutsche Mathematiker-Vereinigung e.V.
- ☐ Edinburgh Mathematical Society
- ☐ Egyptian Mathematical Society
- ☐ Gesellschaft für Angewandte Mathematik und Mechanik
- ☐ Glasgow Mathematical Association
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- ☐ Indian Mathematical Society
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- ☐ Palestine Society for Mathematical Sciences
- ☐ Polskie Towarzystwo Matematyczne
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- ☐ Real Sociedad Matemática Española
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- ☐ Society of Mathematicians, Physicists, and Astronomers of Slovenia
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Journal mailing lists must be printed four to six weeks before the issue date. Therefore, in order to avoid disruption of service, members are requested to provide the required notice well in advance.

Besides mailing addresses for members, the Society's records contain information about members' positions and their employers (for publication in the Combined Membership List). In addition, the AMS maintains records of members' honors, awards, and information on Society service.

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Meetings & Conferences of the AMS

PROGRAM ALERT: In order that AMS meeting programs include the most timely information for each speaker, abstract deadlines have been moved to dates much closer to the meeting. What this means is that most meeting programs will appear in the *Notices* ***after*** the meeting takes place. However, complete meeting programs will be available on e-MATH about two to three weeks after the abstract deadline. ***Remember***, e-MATH is your most comprehensive source for up-to-date meeting information. See `http://www.ams.org/meetings/`.

Gainesville, Florida

University of Florida

March 12–13, 1999

Meeting #940

Southeastern Section
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: January 1999
Program issue of *Notices*: May 1999
Issue of *Abstracts*: Volume 20, Issue 2

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: January 20, 1999

Urbana, Illinois

University of Illinois, Urbana-Champaign

March 18–21, 1999

Meeting #941

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: January 1999
Program issue of *Notices*: May 1999
Issue of *Abstracts*: Volume 20, Issue 2

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: January 27, 1999

Las Vegas, Nevada

University of Nevada, Las Vegas

April 10–11, 1999

Meeting #942

Western Section
Associate secretary: Bernard Russo
Announcement issue of *Notices*: February 1999
Program issue of *Notices*: June 1999
Issue of *Abstracts*: Volume 20, Issue 3

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: February 17, 1999

Invited Addresses

Igor Frenkel, Yale University, *Representations theory and four dimensional conformal field theory.*

Gregory J. Kuperberg, University of California, Davis, *Title to be announced.*

Lorenzo A. Sadun, University of Texas, Austin, *Title to be announced.*

John Steel, University of California, Berkeley, *Title to be announced.*

Special Sessions

Analysis and Geometry (Code: AMS SS I1), **Peter Li** and **Song-Ying Li**, University of California, Irvine.

Combinatorial Theory (Code: AMS SS G1), **Kequan Ding**, University of Illinois, Urbana, **Peter Shiue**, University of Nevada, Las Vegas, and **Yeong-Nan Yeh**, Academia Sinica.

Control and Dynamics of Partial Differential Equations (Code: AMS SS A1), **Zhonghai Ding**, University of Nevada, Las Vegas.

Diophantine Problems (Code: AMS SS J1), **Arthur Baragar**, University of Nevada, Las Vegas, and **Michael Bennett**, University of Illinois.

Geometric Group Theory (Code: AMS SS H1), **Eric M. Freden**, Southern Utah University, and **Eric Lewis Swenson**, Brigham Young University.

Graph Theory (Code: AMS SS B1), **Hung-Lin Fu**, National Chiao-Tung University, Taiwan, **Chris A. Rodger**, Auburn University, and **Michelle Schultz**, University of Nevada, Las Vegas.

Invariants, Distributions, Differential Operators and Harmonic Analysis (Code: AMS SS K1), **Ronald L. Lipsman**, University of Maryland, College Park.

Nonlinear PDEs—Methods and Applications (Code: AMS SS C1), **David Costa**, University of Nevada, Las Vegas.

Number Theory (Code: AMS SS F1), **Gennady Bachman**, University of Nevada, Las Vegas, **Richard A. Mollin**, University of Calgary, and **Peter J. Shiue**, University of Nevada, Las Vegas.

Numerical Analysis and Computational Mathematics (Code: AMS SS E1), **Jun Zhang**, University of Minnesota and University of Kentucky, and **Jennifer Zhao**, University of Michigan, Dearborn.

Set Theory (Code: AMS SS D1), **Douglas Burke** and **Derrick DuBose**, University of Nevada, Las Vegas.

Symmetries of Knots and Three-Manifolds (Code: AMS SS M1), **Swatee Naik**, University of Nevada, Reno, and **Jozef H. Przytycki**, George Washington University.

Accommodations

Participants should make their own arrangements directly with the hotel of their choice and state that they will be attending the American Mathematical Society meeting. The AMS is not responsible for rate changes or for the quality of the accommodations. Hotels listed provide free airport shuttle service upon request.

Days-Inn Airport, 5125 Swenson, Las Vegas, NV; 800-634-6439; $49.50/single or double. Rate includes tax.

La Quinta, 3970 Paradise Road, Las Vegas, NV; 702-7796-9000; $65.40/single or double. Rate includes tax and continental breakfast.

Quality Inn, 377 E. Flamingo Road, Las Vegas, NV; 702-733-7777; $75.21/single or double.

Food Service

There are a number of restaurants located near Classroom Building Complex-C. A list of restaurants will be available at the registration desk.

Local Information

Please visit the Web site maintained by the Department of Mathematical Sciences at `www.unlv.edu/Colleges/Sciences/Mathematics/` and the University of Nevada Web site, `www.unlv.edu/`.

Other Activities

AMS Book Sale: Examine the newest titles from the AMS! Most books will be available at a special 50% discount offered only at meetings. Complimentary coffee will be served, courtesy of AMS Membership Services.

Parking

Participants should park in the Thomas & Mack parking area and may use any meter, student, or staff area. There is no charge for weekend parking. Due to construction, participants should use the parking lot entrance from Tropicana onto Thomas & Mack Drive, not the Swenson entrance.

Registration and Meeting Information

The registration desk will be located in the 2nd floor lobby of Classroom Building Complex-C (CBC-C) and will be open from 7:30 a.m. to 5:00 p.m. on Saturday and from 8:00 a.m. to noon on Sunday.

Registration fees: (payable on-site only) $30/AMS members; $45/nonmembers; $10/emeritus members, students, or unemployed mathematicians. Fees are payable by cash, check, VISA, MasterCard, Discover, or American Express.

Travel

By air: McCarren International Airport is located approximately 2 miles from the UNLV campus. Several auto rental companies are located at the airport. Taxi, shuttle, and limousine services are readily available at the airport.

Driving: UNLV is located north of the Tropicana Avenue and Maryland Parkway intersection. The airport exits by way of Swenson Avenue to Tropicana Avenue. From Swenson go right on to Tropicana, then left onto Thomas & Mack Drive.

Weather

The April average high temperature is 78°F and low temperature is 50°F. The climate is typically dry, with an average of .17 inches of rainfall in April.

Buffalo, New York

State University of New York at Buffalo

April 24–25, 1999

Meeting #943

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: February 1999
Program issue of *Notices*: June 1999
Issue of *Abstracts*: Volume 20, Issue 3

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: January 6, 1999
For abstracts: March 3, 1999

Invited Addresses

Michèle M. Audin, Université Louis Pasteur, *Integrable systems and spaces of curves.*

Russel Caflisch, University of California, Los Angeles, *Title to be announced.*

Jeffrey H. Smith, Purdue University, *Symmetric spectra.*

Alexander Voronov, MIT, *Operad theory and some applications.*

Gregg J. Zuckerman, Yale University, *Harmonic algebra.*

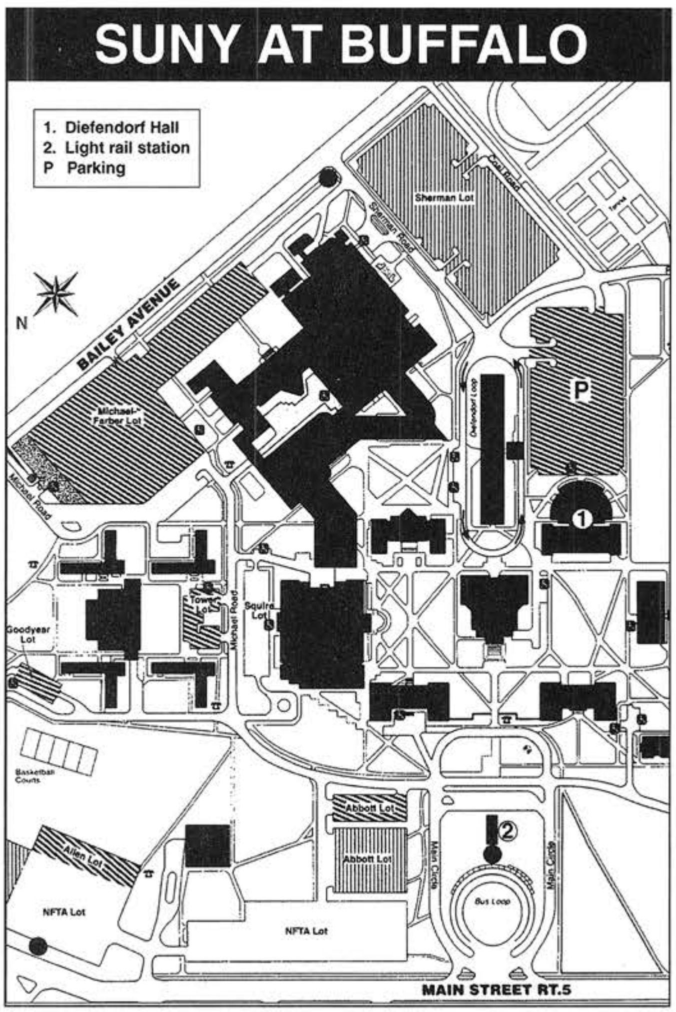
Special Sessions

Combinatorics and Graph Theory (Code: AMS SS C1), **Harris Kwong**, SUNY College at Fredonia.

Complex Geometry (Code: AMS SS G1), **Terrence Napier**, Lehigh University, and **Mohan Ramachandran**, SUNY at Buffalo.

Integrable Systems (Code: AMS SS J1), **Michèle M. Audin**, Université Louis Pasteur and NCRS, and **Lisa Claire Jeffrey**, McGill University.

Knots and 3-Manifolds (Code: AMS SS E1), **Thang T. Q. Le**, SUNY at Buffalo, **William W. Menasco**, SUNY at Buffalo, and **Morwen B. Thistlethwaite**, University of Tennessee.



Mathematical Physics (Code: AMS SS D1), **Jonathan Dimock**, SUNY at Buffalo.

Operads, Algebras, and Their Applications (Code: AMS SS H1), **Alexander A. Voronov**, Massachusetts Institute of Technology.

Representations of Lie Algebras (Code: AMS SS F1), **Duncan J. Melville**, Saint Lawrence University.

Smooth Categories in Geometry and Mechanics (Code: AMS SS A1), **F. William Lawvere**, SUNY at Buffalo.

Thin Films: Solid and Liquid (Code: AMS SS B1), **E. Bruce Pitman**, SUNY at Buffalo, and **Brian Spencer**, SUNY at Buffalo.

Accommodations

Participants should make their own arrangements directly with a hotel of their choice. Special rates have been negotiated at the hotel listed below. Participants should state that they will be attending the American Mathematical Society meeting and cite any special codes shown below. **Reservations should be made as early as possible.** Rate cited does not include tax of 13%.

Hyatt Regency Buffalo, Two Fountain Plaza (in the heart of downtown), 716-856-1234 (fax: 716-852-6157); $69/single or double; restaurant and lounge on premises (within walking distance of many restaurants); access from lobby to light rail line which goes directly to the UB South Campus (approximately $1.25 one way, $2.50 round trip; purchase a ticket from the vending machines prior to boarding the train and keep the ticket with you. There is a substantial penalty for lost tickets. Because of the later Sunday schedule for the light rail line, the University will sponsor a limited shuttle on Sunday morning from this hotel only for those who wish to get to the campus before 9:30 a.m.); free parking. **Deadline for reservations is March 26, 1999.**

Food Service and Local Information

There are a number of restaurants available within walking distance of the meeting location, and other restaurants within walking distance of the various recommended hotels and motels. More detailed information will be available at the registration desk and on the UB Department of Mathematics Web site; see `www.math.buffalo.edu/` and `www.buffalo.edu/`.

Other Activities

AMS Book Sale: Examine the newest titles from the AMS. Most books will be available at a special 50% discount offered only at meetings. Complimentary coffee will be served courtesy of AMS Membership Services.

Parking

Diefendorf Lot on UB's South Campus will be open for parking without charge throughout the weekend. The lot is located adjacent to Diefendorf Hall and is accessed via Sherman Road from Bailey Avenue (Rte. 62). For those wishing to visit the mathematics department during the week, visitor's hang tags are available from the department.

Registration and Meeting Information

N.B. This meeting will be held on the South Campus of the State University of New York at Buffalo.

Registration will take place in Room 114, Diefendorf Hall (Math Department Lounge), from 7:30 a.m. to 4:00 p.m. on Saturday and from 8:00 a.m. to noon on Sunday. All sessions and talks will take place in Diefendorf Hall.

Registration fees (payable on-site only) are $30/AMS or CMS members; $45 nonmembers; $10 emeritus members, students, or unemployed mathematicians. Fees are payable by cash, check, VISA, MasterCard, Discover, or American Express.

Travel

By air: The Greater Buffalo International Airport is the closest airport.

Delta Air Lines has been selected as the official airline for this meeting. The following specially negotiated rates are available exclusively to mathematicians and their families for the period April 21–28, 1999, on Delta Air Lines:

5% discount off published round-trip fares within the continental U.S., Hawaii, Alaska, Canada, Mexico, Bermuda, San Juan, Nassau, and the U.S. Virgin Islands. Some restrictions apply and seats are limited (no discounts apply on Delta Express). By purchasing your ticket 60 days or more prior to departure, you can receive an additional 5% bonus discount.

10% discount on Delta's domestic system for travel based on the published unrestricted round-trip coach (Y06) rates. No advance reservations or ticketing is required; however, by purchasing your ticket 60 days or more prior to departure, you can receive an additional 5% bonus discount (no discounts on Delta Express).

Special guaranteed round-trip Zone Fares to all cities served by Delta and Delta Express in the continental U.S., Hawaii, Alaska, Canada, Mexico, Bermuda, San Juan, Nassau, and the U.S. Virgin Islands for savings on midweek travel. Two-day minimum stay, no Saturday-night stay required, seven days' advanced reservations and ticketed. Fares are fully refundable, less administrative service fee. Zone Fares are not valid for destinations served only by a Delta Connection carrier. For reservations call (or have your travel agent call) Delta Meeting Network Reservations at 1-800-241-6760 weekdays between 7:30 a.m. and 11:00 p.m. (8:30 a.m.–11:00 p.m. on weekends) Eastern Standard Time. Refer to file number 117809A. These discounts are available only through Delta Meeting Network Reservation's toll-free number.

Taxi fare from the airport to South Campus is approximately $15. Ask for the UB South Campus (not UB North Campus or UB Amherst Campus or Buffalo State). The taxi driver should be instructed to take Sherman Road off Bailey Avenue and to stop at the far end of Diefendorf Loop; this takes one directly to Diefendorf Hall.

If driving from the airport, take Rte. 33 West (inbound) to I-90 North, then to I-290 North. Take the Rte. 5 (Main Street) West exit and proceed to Route 62.

Driving directions: The South Campus is located at the corner of state Routes 5 (Main Street) and 62 (Bailey Avenue). From the New York State Thruway (I-90), take Exit 50 to Rte. 5 West. Proceed to Rte. 62.

Weather

By the end of April, average high temperature in Buffalo is 60°F.; average low temperature is 40°F. Buffalo averages about three inches of rain per month in April and May.

Denton, Texas

University of North Texas

May 19–22, 1999

Meeting #944

Fourth International Joint Meeting of the AMS and the Sociedad Matemática Mexicana (SMM).
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: February 1999
Program issue of *Notices*: June/July 1999
Issue of *Abstracts*: Volume 20, Issue 3

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: January 27, 1999
For abstracts: March 24, 1999

Invited Addresses

Raymundo Bautista, UNAM, *Title to be announced.*

William Fulton, University of Michigan, Ann Arbor, *Title to be announced.*

Francisco Gonzalez Acuna, UNAM, *Title to be announced.*

Ronald L. Graham, AT&T Labs, *Title to be announced* (Erdős Memorial Lecture).

Jack K. Hale, Georgia Institute of Technology, *Title to be announced.*

Onesimo Hernandez-Lerma, CINVESTAV del IPN, *Title to be announced.*

Special Sessions

Algebraic Geometry and Commutative Algebra (Code: AMS SS F1), **Javier Elizondo**, UNAM, **Xavier Gomez-Mont**, CIMAT, **Alberto Corso**, Michigan State University, and **David A. Jorgensen**, University of Texas at Austin.

Algebraic Topology (Code: AMS SS Q1), **Frederick R. Cohen** and **Samuel Gitler**, University of Rochester, and **Carlos Prieto**, UNAM.

Combinatorics (Code: AMS SS N1), **Jorge Urrutia**, IMATE-UNAM and University of Ottawa, and **Wlodzimierz Kuperberg**, Auburn University.

Complex Analysis (Code: AMS SS R1), **E. Ramirez de Arellano**, CINVESTAV, and **John E. Fornaess**, University of Michigan, Ann Arbor.

Continuum Theory (Code: AMS SS D1), **Wayne Lewis**, Texas Tech University, and **Sergio Macias** and **Alejandro Illanes**, UNAM.

Differential Equations, Nonlinear Analysis, and Numerical Solutions to PDEs. (Code: AMS SS E1), **John W. Neuberger**, University of North Texas, and **Alfredo C. Nicolas**, UAM.

Functional Analysis and Its Applications (Code: AMS SS C1), **S. Perez-Esteva**, UNAM, and **Josefina Alvarez**, University of New Mexico.

Geometric and Symbolic Dynamical Systems (Code: AMS SS G1), **Luca Q. Zamboni**, University of North Texas, and **Edgardo Ugalde**, University of San Luis Potosi.

Low Dimensional Topology (Code: AMS SS H1), **Mark W. Brittenham**, University of North Texas, **Francisco Gonzalez Acuna**, IM-UNAM, and **Luis Valdez-Sanchez**, University of Texas at El Paso.

Noncommutative Geometry, Quantum Groups, and Applications (Code: AMS SS L1), **Micho Durdevich**, UNAM, and **Hanna Ewa Makaruk** and **Robert M. Owczarek**, Los Alamos National Laboratory.

Nonlinear Models in Biology and Celestial Mechanics (Code: AMS SS M1), **Ernesto Perez-Chavela** and **Jorge X. Velasco-Hernandez**, UAM, **Mary E. Parrott**, University of South Florida, and **Ernesto A. Lacomba**, UAM.

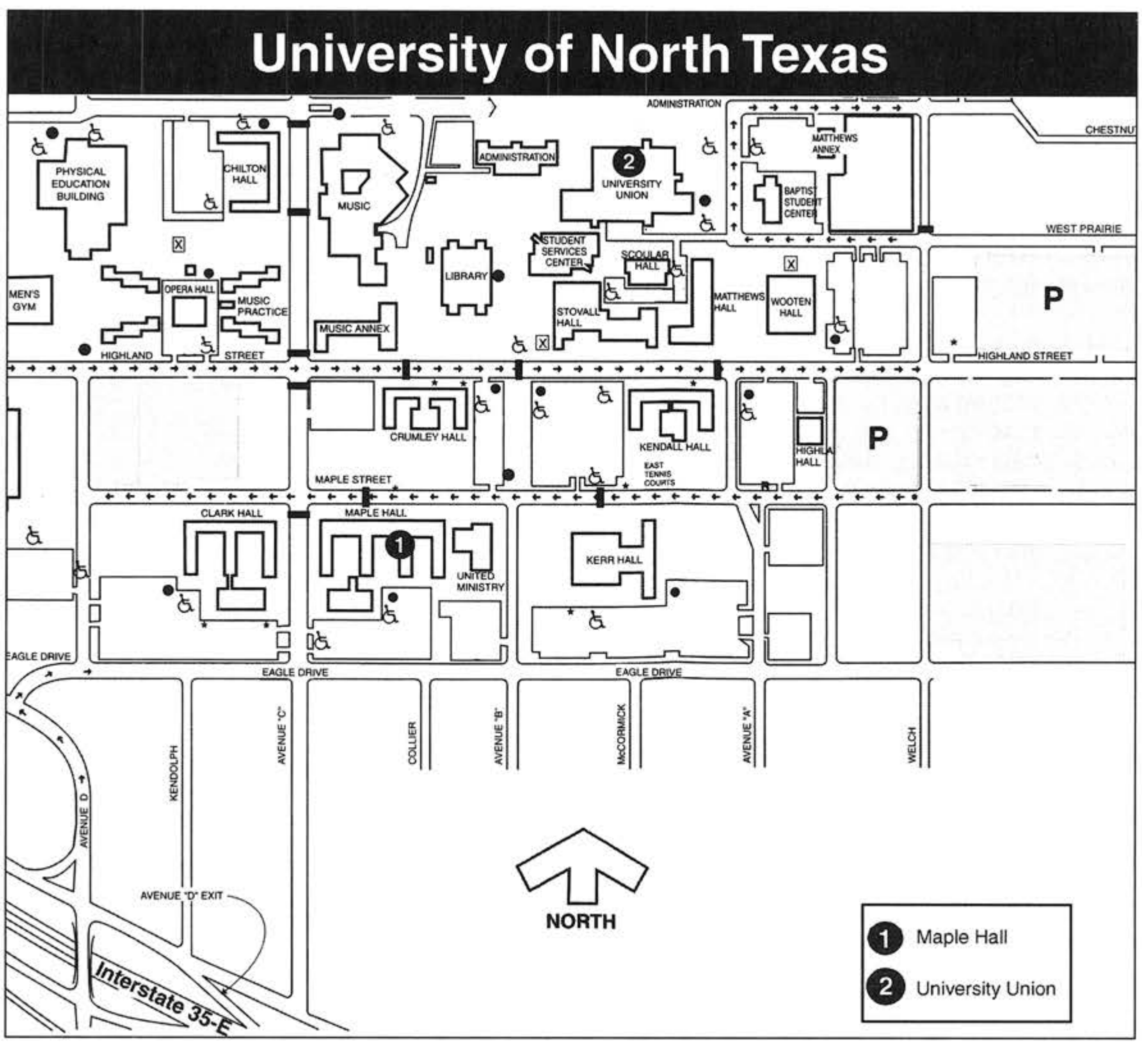
Representation Theory of Algebras (Code: AMS SS A1), **Jose A. de la Pena** and **Christof Geiss**, UNAM, and **Birge Zimmermann**, University of California, Berkeley.

Ring Theory (Code: AMS SS K1), **Carlos Signoret-Poillon**, UNAM-UAM, **Sergio Lopez-Permouth**, Ohio University, and **Ricardo Alfaro**, University of Michigan, Flint.

Smooth Dynamical Systems (Code: AMS SS P1), **David A. Delatte** and **Dan Mauldin**, University of North Texas, **Jose Seade**, UNAM, **Mariusz Urbanski**, University of North Texas, and **Alberto Verjovsky**, UNAM.

Stochastic Processes (Code: AMS SS J1), **Frederi G. Viens**, University of North Texas, **Jorge A. Leon**, CINVESTAV, and **Juan Ruiz de Chavez**, UAM.

Stochastic Systems and Control (Code: AMS SS B1), **Daniel Hernandez-Hernandez** and **Onesimo Hernandez-Lerma**, CINVESTAV, and **Guillermo Ferrayra**, Louisiana State University.



Accommodations

Participants should make their own arrangements directly with a hotel of their choice. Special rates have been negotiated at the hotels listed below. Participants should state that they are with the Joint Meeting of the AMS and SMM and cite any special codes shown below. **Reservations should be made as early as possible**; some properties are small, so the number of rooms may be very limited. Rates cited do not include tax of 13.25%. The AMS is not responsible for rate changes or the quality of the accommodations chosen.

Hotels

Radisson Hotel Denton (headquarters), 2211 I-35 East North, 940-565-8499 (fax: 940-387-4729); $80 single/$85 double. Full-service hotel with restaurant, lounge, exercise room, and pool, adjacent to the university's golf course; about a 10- or 15-minute walk to the meeting. **Deadline for reservations is April 19, 1999.**

Super 8 Motel, 620 I-35E (SW corner of Teasley/I-35E), 940-380-8888; $50/single or $60/double/triple; rates include Super Star breakfast; about a 10-minute drive to campus. **Deadline for reservations is May 5, 1999**; cite group name: AMS-SMM, and group code: AMSS.

Redbud Inn Bed and Breakfast, 815 N. Locust, 1-888-565-6414 (toll free); fax: 817-565-6515; e-mail: redbudbb@gte.net; see www.bbhost.com/redbudbb/; inn with seven rooms, $56–105/single or double, $10 for each additional person; about a 10-minute drive to campus. **Deadline for reservations is April 18, 1999.**

Royal Hotel Suites, 1210 N. I-35E (I-35E at McCormick), 940-383-2007 (same number for fax); $35/single, $44/double/king/single suite, rates include continental breakfast; very few nonsmoking rooms; suites have efficiency kitchens but no supplies; pool; about a 12-minute walk to campus. **Deadline for reservations is April 10, 1999.**

Campus Residence Hall

The University is pleased to offer accommodations in a campus residence hall. Maple Hall has suites of two twin-bedded rooms which share one bath per suite. Linens are provided; participants must make their own beds. There is no maid service or room service; participants should bring all amenities, including soap, clothes hangers, alarm clock, etc. The check-in desk is staffed 24 hours a day. Rates are $12 per person double occupancy and $17 for single occupancy, payable by cash, check, or credit card (VISA, MasterCard, or Discover); pay in full when you check in at Maple Hall. There is no tax on these room rates. There will be no refunds for those who depart earlier than their paid reservation period. Rooms are available for the period May 19 to May 23; contact Diana Forson, Business Services, P.O. Box 311008, UNT, Denton, TX 76203-1008; 940-565-2894; fax: 940-369-7072; e-mail: dvf@hsl.unt.edu. See below for information on residence hall parking permits. **Deadline for reservations is May 1, 1999.**

Food Service and Local Information

One of the dormitory cafeterias will be open for inexpensive meals. Details on this and nearby restaurants will be available at the meeting. Watch the University of North Texas meeting Web site at www.math.unt.edu/conf.htm for up-to-the-minute developments on this and other conference details.

Other Activities

AMS Book Sale: Examine the newest titles from the AMS. Most books will be available at a special 50% discount offered only at meetings.

Complimentary refreshment breaks will be served daily courtesy of the University of North Texas Department of Mathematics. Visit the hospitality center near the AMS book sale for free brochures of area attractions.

Parking

Parking permits cost $1/day and must be purchased at the desk in Maple Hall for participants staying in the residence hall. Other participants should purchase permits (also $1/day) at the meeting registration desk in the Lyceum Lobby on the 4th floor of the University Union. You may park in the garage next to the Union ($1.15/hr.) while you purchase your parking permit; then you must move your car to an appropriate lot. The most convenient to the meeting are three lots about one block south of the parking garage, accessed from West Prairie or Highland Streets.

Registration and Meeting Information

Registration will take place in the Lyceum Lobby in the University Union on Wednesday, 3:00 p.m. to 6:00 p.m.; Thursday and Friday, 8:00 a.m. to 4:00 p.m.; and Saturday, 9:00 a.m. to noon. Sessions will take place in the University Union and another facility to be determined. The registration fee is $50, payable by cash, check, or credit card (VISA, MasterCard, Discover, or American Express). Registration in advance is strongly encouraged! Many of the social events may sell out through advance registration, so register early! The deadline for advance registration is **April 12**. See the paper form at the back of this issue, or see the Web form at www.ams.org/amsmtgs/2053_other.html.

Social Events

N.B. Because of the guarantees that must be given to the suppliers of the following events, tickets are AVAILABLE THROUGH ADVANCE REGISTRATION ONLY! Please register early to be assured of securing a ticket to the events which interest you.

All registered participants are invited to a gala Opening Reception to be held after the Erdős Lecture (7:00 p.m.) on Wednesday, May 19. Hot and cold h'ors d'oevres will be served, and there will be a cash bar.

Arrangements are under-way for a private showing for meeting participants at the Sky Theater planetarium on campus on Thursday evening. This spectacular multimedia display will surround you with the heavens as you've never seen them before! Admission to this stellar event is $2/person.

The best place to experience the legend of the Old West is in Fort Worth! On Friday evening at 5:00 p.m. your motorcoach will depart from campus and travel to the Fort

Worth Stockyards (about 40 minutes away). Here you can walk along covered boardwalks and listen to local balladeers, watch hats and boots being crafted, and browse the shops and galleries. Dinner is on your own: order a Texas-size steak or barbecue at Cattleman's, the White Elephant Saloon, Riskey's, Spaghetti Warehouse, or one of the other fine restaurants in the area (list will be provided). At 8:00 p.m. participants should make their way over to the Cowtown Coliseum for general admission to Friday night's indoor rodeo. At 10:00 p.m. Billy Bob's Texas, the world's largest honky tonk, is waiting for you! Learn the two-step or just listen to live music, play pool, or outfit yourself in western wear at the Dry Goods Store. Buses will return to campus beginning at midnight.

Tickets are $16 and include round-trip transportation, general admission to the Cowtown Coliseum rodeo, and general admission to Billy Bob's Texas.

The meeting will come to an end with the Closing Ceremonies and Banquet on Saturday evening. There will be a cash bar reception at 6:30 p.m., and dinner will be served at 7:00 p.m. Enjoy your colleagues and new friends over a delightful dinner. Music will be provided by the One O'Clock Lab Band. This jazz band is without peer among university jazz bands, having performed at the White House and been nominated for several Grammy awards. Tickets are $20 per person and include two glasses of wine with dinner.

Travel

By air: Delta Air Lines has been selected as the official airline for this meeting. The following specially negotiated rates are available exclusively to mathematicians and their families for the period May 16–25, 1999, on Delta Air Lines:

5% discount off published round-trip fares within the continental U.S., Hawaii, Alaska, Canada, Mexico, Bermuda, San Juan, Nassau, and the U.S. Virgin Islands. Some restrictions apply and seats are limited (no discounts apply on Delta Express). By purchasing your ticket 60 days or more prior to departure, you can receive an additional 5% bonus discount.

10% discount on Delta's domestic system for travel based on the published unrestricted round-trip coach (Y06) rates. No advance reservations or ticketing is required; however, by purchasing your ticket 60 days or more prior to departure, you can receive an additional 5% bonus discount (no discounts on Delta Express).

Special guaranteed round-trip Zone Fares to all cities served by Delta and Delta Express in the continental U.S., Hawaii, Alaska, Canada, Mexico, Bermuda, San Juan, Nassau, and the U.S. Virgin Islands for savings on midweek travel. Two-day minimum stay, no Saturday-night stay required, seven days' advanced reservations and ticketing. Fares are fully refundable, less administrative service fee. Zone Fares are not valid for destinations served only by a Delta Connection carrier. For reservations call (or have your travel agent call) Delta Meeting Network Reservations at 1-800-241-6760 weekdays between 7:30 a.m. and 11:00 p.m. (8:30 a.m.–11:00 p.m. on weekends) Eastern Standard Time. Refer to file number 117809A. These discounts are available only through Delta Meeting Network Reservation's toll-free number.

Participants should fly into the Dallas-Fort Worth International Airport. The University of North Texas in Denton is located 28 miles from the airport via Interstate 35E and Highway 121. Taxi fares are expensive, and shuttle service may not be convenient. Most participants may find it more suitable to rent a car for transportation during their stay. If you choose to rent a car, please make arrangements well in advance; the availability can be very limited. See `www.bnm.com/dal.htm` for deals on rental cars at the Dallas-Fort Worth Airport. For information about the airport itself, see `www.dfwairport.com/`.

Driving directions: From the airport: Take 121 north to I35E; follow I35E north to Denton and exit onto McCormick Street. Turn right onto McCormick, then right onto Eagle. Turn left onto Welch and left again on Prairie. The campus parking garage will be on your right.

Because of construction on the west side of campus scheduled throughout 1999, participants should check the UNT conference Web site for accurate driving directions, and Web sites for other driving directions, closer to the meeting dates.

Weather

Denton weather in mid-May normally provides daily temperatures between 63° and 84°F. Average rainfall is about 4 inches during the month, and participants should be prepared for thunderstorms that clear away the humidity.

Melbourne, Australia

Melbourne, Australia

July 12–16, 1999

Meeting #945

First International Joint Meeting of the American Mathematical Society and the Australian Mathematical Society
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: March 1999
Program issue of *Notices*: Not applicable
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Jennifer Chayes, Microsoft, *Title to be announced.*

Michael Eastwood, University of Adelaide, *Title to be announced.*

Roger Grimshaw, Monash University, *Title to be announced.*

Gerhard Huisken, University of Tuebingen, *Title to be announced.*

Vaughan Jones, University of California, Berkeley, *Title to be announced.*

Hyam Rubinstein, Melbourne University, *Title to be announced.*

Richard M. Schoen, Stanford University, *Title to be announced.*

Neil Trudinger, Australian National University, *Title to be announced.*

Special Sessions

Algebraic Groups and Related Topics, **Eric Friedlander**, Northwestern University, and **Gustav I. Lehrer**, University of Sydney.

Fluid Dynamics, **Susan Friedlander**, Northwestern University, and **Roger H. J. Grimshaw**, Monash University.

Geometric Analysis and Partial Differential Equations, **Benjamin H. Andrews**, Australian National University, **Michael G. Eastwood**, University of Adelaide, **Klaus Ecker**, Monash University, and **Gerhard Huisken**, Princeton University and University of Tuebingen.

Geometric Group Theory, **Swarup Gadde** and **Walter Neumann**, University of Melbourne.

Geometric Themes in Group Theory, **Gustav I. Lehrer**, University of Sydney, **Cheryl E. Praeger**, University of Western Australia, and **Stephen D. Smith**, University of Illinois at Chicago.

Group Actions, **Marston Conder**, **Gaven Martin**, and **Eamonn O'Brien**, University of Auckland.

Low Dimensional Topology, **William H. Jaco**, Oklahoma State University, and **Hyam Rubinstein**, Melbourne University.

Mathematical Physics: Many Body Systems, **Alan L. Carey**, University of Adelaide, **Paul A. Pearce**, University of Melbourne, and **Mary Beth Ruskai**, University of Massachusetts, Lowell.

Mathematics Learning Centers, **Judith Baxter**, University of Illinois, Chicago, **Jackie Nicholas**, University of Sydney, and **Jeanne Wald**, Michigan State University.

Moduli Spaces of Riemann Surfaces, Mapping Class Groups and Invariants of 3-Manifolds, **Ezra Getzler**, Northwestern University, and **Richard Hain**, Duke University.

Nonlinear Dynamics and Optimization, **A. F. Ivanov**, Penn State University and University of Ballarat, **A. Mees**, University of Western Australia, and **A. Rubinov**, University of Ballarat.

Probability Theory and Its Applications, **Timothy Brown**, University of Melbourne, **Phil Pollett**, University of Queensland, and **Ruth J. Williams**, University of California, San Diego.

Recent Trends in Operator Theory and Harmonic Analysis, **Michael T. Lacey**, Georgia Institute of Technology, and **Alan G. R. McIntosh**, Macquarie University.

Salt Lake City, Utah

University of Utah

September 25-26, 1999

Meeting #946

Western Section
Associate secretary: Bernard Russo
Announcement issue of *Notices*: June 1999
Program issue of *Notices*: November 1999
Issue of *Abstracts*: Volume 20, Issue 4

Deadlines

For organizers: January 21, 1999
For consideration of contributed papers in Special Sessions: June 8, 1999
For abstracts: August 3, 1999

Providence, Rhode Island

Providence College

October 2-3, 1999

Meeting #947

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: August 1999
Program issue of *Notices*: November 1999
Issue of *Abstracts*: Volume 20, Issue 4

Deadlines

For organizers: January 6, 1999
For consideration of contributed papers in Special Sessions: June 16, 1999
For abstracts: August 11, 1999

Invited Addresses

Dan M. Barbasch, Cornell University, *Title to be announced.*

Henri Berestycki, Université Paris VI and École Normale Superieure, *Title to be announced.*

David Mumford, Brown University, *Title to be announced.*

Guoliang Yu, University of Colorado, *Title to be announced.*

Special Sessions

Algebraic and Geometric Combinatorics (Code: AMS SS A1), **Vesselin N. Gasharov**, Cornell University, and **Ira M. Gessel**, Brandeis University.

Representation Theory of Reductive Groups (Code: AMS SS B1), **Dan M. Barbasch** and **Birgit Speh**, Cornell University.

Austin, Texas

University of Texas at Austin

October 8-10, 1999

Meeting #948

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: August 1999
Program issue of *Notices*: December 1999
Issue of *Abstracts*: Volume 20, Issue 4

Deadlines

For organizers: January 6, 1999
For consideration of contributed papers in Special Sessions: June 16, 1999
For abstracts: August 11, 1999

Invited Addresses

Mikhail Kapranov, Northwestern University, *Title to be announced.*

John Roe, Oxford and Pennsylvania State University, *Title to be announced.*

Catherine Sulem, University of Toronto, *Title to be announced.*

Tatiana Toro, University of Washington, *Title to be announced.*

Special Sessions

Aperiodic Tiling (Code: AMS SS D1), **Charles Radin** and **Lorenzo Sadun**, University of Texas at Austin.

Banach and Operator Spaces: Isomorphic and Geometric Structure (Code: AMS SS E1), **Edward Odell** and **Haskell P. Rosenthal**, University of Texas at Austin.

DNA Topology (Code: AMS SS J1), **Isabel K. Darcy**, University of Texas at Austin, and **Makkuni Jayaram**, University of Texas at Austin.

Harmonic Analysis and PDEs (Code: AMS SS C1), **William Beckner** and **Luis A. Caffarelli**, University of Texas at Austin, **Toti Daskalopoulos**, University of California, Irvine, and **Tatiana Toro**, University of Washington.

Mathematical and Computational Finance (Code: AMS SS H1), **Stathis Tompaidis**, University of Texas at Austin.

Nonlinear Waves (Code: AMS SS G1), **Catherine Sulem**, University of Toronto.

Recent Developments in Index Theory (Code: AMS SS F1), **Daniel S. Freed**, University of Texas at Austin, and **John Roe**, Pennsylvania State University.

The Development of Topology in the Americas (Code: AMS SS A1), **Cameron Gordon**, University of Texas at Austin, and **Ioan Mackenzie James**, University of Oxford.

Wavelets and Approximation Theory (Code: AMS SS B1), **Don Hong**, Eastern Tennessee State University, and **Michael Prophet**, Murray State University.

Charlotte, North Carolina

University of North Carolina at Charlotte

October 15-17, 1999

Meeting #949

Southeastern Section
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: August 1999
Program issue of *Notices*: December 1999
Issue of *Abstracts*: Volume 20, Issue 4

Deadlines

For organizers: January 20, 1999
For consideration of contributed papers in Special Sessions: June 23, 1999
For abstracts: August 18, 1999

Invited Addresses

Valery Alexeev, University of Georgia, *Title to be announced.*

Béla Bollobás, University of Memphis and Cambridge University, *Title to be announced.*

Konstantin M. Mischaikow, Georgia Institute of Technology, *Title to be announced.*

Yakov Sinai, Princeton University, *Title to be announced.*

Special Sessions

Commutative Algebra (Code: AMS SS B1), **Sarah Glaz**, University of Connecticut, and **Evan G. Houston** and **Thomas G. Lucas**, University of North Carolina at Charlotte.

Knot Theory and Its Applications (Code: AMS SS A1), **Yuanan Diao**, University of North Carolina at Charlotte.

Optimal Control and Computational Optimization (Code: AMS SS D1), **Mohammed A. Kazemi**, University of North Carolina at Charlotte, and **Gamal N. Elnagar**, University of South Carolina, Spartanburg.

Spectral Theory of Differential Operators and Applications (Code: AMS SS C1), **Boris R. Vainberg** and **Stanislav Molchanov**, University of North Carolina at Charlotte.

Stochastic PDEs and Turbulence (Code: AMS SS E1), **Weinan E**, Courant Institute, New York University.

Washington, District of Columbia

Marriott Wardman Park Hotel and Omni Shoreham Hotel

January 19–22, 2000

Note: This is a World Math Year 2000 (WMY2000) event.

Meeting #950

Joint Mathematics Meetings, including the 106th Annual Meeting of the AMS, 83rd Meeting of the Mathematical Association of America (MAA), with minisymposia and other special events contributed by the Society for Industrial and Applied Mathematics (SIAM), and the annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM).
Associate secretary: Robert M. Fossum
Announcement issue of *Notices*: October 1999
Program issue of *Notices*: January 2000
Issue of *Abstracts*: Volume 21, Issue 1

Deadlines

For organizers: April 20, 1999
For consideration of contributed papers in Special Sessions: August 10, 1999
For abstracts: October 5, 1999
For summaries of papers to MAA organizers: To be announced

Lowell, Massachusetts

University of Massachusetts, Lowell

April 1–2, 2000

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: July 1, 1999
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Walter Craig, Brown University, *Title to be announced.*

Erwin Lutwak, Polytechnic University, *Title to be announced.*

Alexander Nabutovsky, Courant Institute of Mathematical Sciences, NYU, *Title to be announced.*

Mary Beth Ruskai, University of Massachusetts, Lowell, *Title to be announced.*

Special Sessions

Invariance in Convex Geometry (Code: AMS SS A1), **Daniel A. Klain**, Georgia Institute of Technology, and **Elisabeth Werner**, Case Western Reserve University.

Notre Dame, Indiana

University of Notre Dame

April 7–9, 2000

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: July 7, 1999
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Lafayette, Louisiana

University of Southwestern Louisiana

April 14–16, 2000

Southeastern Section
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: July 14, 1999
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Odense, Denmark

Odense University

June 12–15, 2000

First AMS-Scandinavian International Mathematics Meeting. Sponsored by the AMS, Dansk Matematisk Forening, Suomen matemaattinen yhdistys, Icelandic Mathematical Society,

Norsk Matematisk Forening, and Svenska matematikersamfundet.
Associate secretary: Robert M. Fossum
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Los Angeles, California

University of California, Los Angeles

August 7–12, 2000

Note: This is a World Math Year 2000 (WMY2000) event.

Associate secretary: Robert M. Fossum
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Toronto, Ontario, Canada

University of Toronto

September 22–24, 2000

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

New York, New York

Columbia University

November 3–5, 2000

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: February 3, 2000
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Paula Cohen, Université des Sciences et Technologies de Lille, France, *Title to be announced.*

New Orleans, Louisiana

New Orleans Marriott and ITT Sheraton New Orleans Hotel

January 10–13, 2001

Joint Mathematics Meetings, including the 107th Annual Meeting of the AMS, 84th Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM).
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 11, 2000
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced
For summaries of papers to MAA organizers: To be announced

Columbia, South Carolina

University of South Carolina

March 16–18, 2001

Southeastern Section
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: To be announced

Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: June 15, 2000
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Lawrence, Kansas

University of Kansas

March 30–31, 2001

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: June 28, 2000
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Hoboken, New Jersey

Stevens Institute of Technology

April 28–29, 2001

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: July 28, 2000
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Williamstown, Massachusetts

Williams College

October 13–14, 2001

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: January 11, 2001
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

San Diego, California

San Diego Convention Center

January 6–9, 2002

Joint Mathematics Meetings, including the 108th Annual Meeting of the AMS and 85th Meeting of the Mathematical Association of America (MAA).
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: To be announced
Program issue of *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 4, 2001
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced
For summaries of papers to MAA organizers: To be announced

SOCIEDAD MATEMATICA MEXICANA

May 19–22, 1999
University of North Texas, Denton, TX

Fourth International Joint Meeting of the AMS and the SMM

Name ______________________________

Mailing Address ______________________________

____

City ____________ State ________ Zip ________ Country ____________

Phone ____________ Fax ____________

Email ______________________________

College/University/Company Name (for name badge) ______________________________

If you want confirmation of this registration by regular mail instead of email, check here: ☐

Registration Fee

	Price	Total
Registration Fee	**$50**	**$**__________

Social Events

Social Events	**Veg**	**# tickets**	**Price per**	**Total**
(05/22/99) Banquet (check box for vegetarian)	☐	______	$20	$__________
(05/21/99) *A Night in Fort Worth* (includes Rodeo)		______	$16	$__________
(05/20/99) Planetarium		______	$ 2	$__________
		Subtotal for Events:		**$**__________
		Grand Total to be paid:		**$**__________

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Providence, RI 02940 For questions, call 401-455-4143 or 1-800-321-4267 x 4143, FAX 401-455-4004

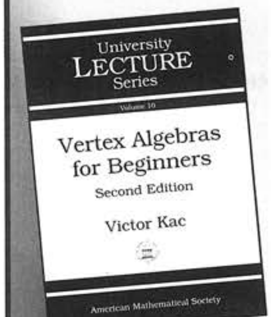
Deadlines

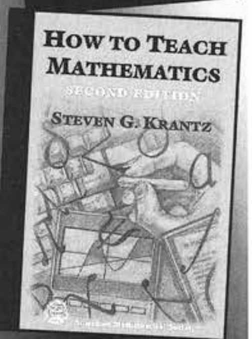
Preregistration	**April 12, 1999**
50% Refund on Social Events	**May 4, 1999**
50% Refund on Preregistration Cancellation	**May 11, 1999***

*no refunds after this date

AMERICAN MATHEMATICAL SOCIETY

Recently Published Titles from the AMS





Back in Print from the AMS

Introduction to Approximation Theory
Second Edition

E. W. Cheney

E. W. Cheney's highly respected and well-known book ... covers an enormous amount of material ... [It] is written with a clarity and precision which those who are familiar with the author's many papers have come to expect ... [T]he notes are invaluable; their effect is to make a small book almost encyclopedic in character ... In the quality of its exposition and the skill and craft manifest in its organization, the book is a classic with few competitors. Anyone involved with computer mathematics will want it nearby.

—Computing Reviews

AMS Chelsea Publishing; 1982; 259 pages; Hardcover; ISBN 0-8218-1374-9; List $29; All AMS members $26; Order code CHEL/317.HRT92

Partial Differential Equations

P. R. Garabedian

This book is primarily a text for a graduate course in partial differential equations, although the later chapters are devoted to special topics not ordinarily covered in books in this field ... [T]he author has made use of an interesting combination of classical and modern analysis in his proofs ... Because of the author's emphasis on constructive methods for solving problems which are of physical interest, his book will likely be as welcome to the engineer and the physicist as to the mathematician ... The author and publisher are to be complimented on the general appearance of the book.

—Mathematical Reviews

This book is a gem. It fills the gap between the standard introductory material on PDEs that an undergraduate is likely to encounter after a good ODE course (separation of variables, the basics of the second-order equations from mathematical physics) and the advanced methods (such as Sobolev spaces and fixed point theorems) that one finds in modern books.

The text contains the standard topics that one expects in an intermediate PDE course: the Dirichlet and Neumann problems, Cauchy's problem, characteristics, the fundamental solution, PDEs in the complex domain, plus a chapter on finite differences, on nonlinear fluid mechanics, and another on integral equations.

AMS Chelsea Publishing; 1964; 672 pages; Hardcover; ISBN 0-8218-1377-3; List $45; All AMS members $41; Order code CHEL/325.HRT92

Classical Galois Theory with Examples

Lisl Gaal

This book is strongly recommended to beginning graduate students who already have some background in abstract algebra. The exposition and proofs are intended to present Galois theory in as simple a manner as possible ... The large number of partially or fully solved examples is its special feature.

—Mathematical Reviews

AMS Chelsea Publishing; 1971; 248 pages; Hardcover; ISBN 0-8218-1375-7; List $29; All AMS members $26; Order code CHEL/268.HRT92

Introduction to Hilbert Space and the Theory of Spectral Multiplicity
Second Edition

Paul R. Halmos

The main purpose of this book is to present the so-called multiplicity theory and the theory of unitary equivalence, for arbitrary spectral measures, in separable or not separable Hilbert space ... The approach to this theory, as presented by the author, has much claim to novelty. By a skillful permutation of the fundamental ideas of Wecken and Nakano and consistently referring to the simple situation in the finite-dimensional case, the author succeeds in presenting the theory in a clear and perspicuous form.

—Mathematical Reviews

AMS Chelsea Publishing; 1957; 114 pages; Hardcover; ISBN 0-8218-1378-1; List $19; All AMS members $17; Order code CHEL/82.HRT92

Recommended Texts

Vertex Algebras for Beginners
Second Edition

Victor Kac, *Massachusetts Institute of Technology, Cambridge*

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The Meetings and Conferences section of the *Notices* gives information on all AMS meetings and conferences approved by press time for this issue. Please refer to the page numbers cited in the table of contents on this page for more detailed information on each event. Invited Speakers and Special Sessions are listed as soon as they are approved by the cognizant program committee; the codes listed are needed for electronic abstract submission. For some meetings the list may be incomplete. **Information in this issue may be dated. Up-to-date meeting and conference information is available on the World Wide Web at www.ams.org/meetings/.**

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1999:

June 13-July 1: Joint Summer Research Conferences in the Mathematical Sciences, Boulder, CO. See pp. 1435-1441 for details.

July 26-August 13: Summer Research Institute on Smooth Ergodic Theory and Applications, Seattle, WA. See pp. 1442-1443 for details.

Cosponsored Conference:

July 18-28, 1999: Foundations of Computational Mathematics (FoCM), University of Oxford, England. See http://www-sccm.stanford.edu/FoCM/ for details.

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