# Joint Summer Research Conferences in the Mathematical Sciences

**University of Colorado**
**Boulder, Colorado**
**June 13–July 1, 1999**

The 1999 Joint Summer Research Conferences will be held at the University of Colorado, Boulder, Colorado, from June 13–July 1, 1999. The topics and organizers for the seven conferences were selected by a committee representing the AMS, the Institute of Mathematical Sciences (IMS), and the Society for Industrial and Applied Mathematics (SIAM), whose members at the time were Alejandro Adem, David Brydges, Percy Deift, James W. Demmel, Dipak Dey, Tom Diciccio, Steven Hurder, Alan F. Karr, Barbara Keyfitz, W. Brent Lindquist, Andre Manitius, and Bart Ng.

It is anticipated that the conferences will be partially funded by a grant from the National Science Foundation and perhaps others. Special encouragement is extended to junior scientists to apply. A special pool of funds expected from grant agencies has been earmarked for this group. Other participants who wish to apply for support funds should so indicate; however, available funds are limited, and individuals who can obtain support from other sources are encouraged to do so.

All persons who are interested in participating in one of the conferences (women and minorities are especially encouraged) should request an invitation by sending the following information to: Summer Research Conferences Coordinator, American Mathematical Society, P.O. Box 6887, Providence, RI 02940, or by e-mail to `wsd@ams.org` **no later than March 3, 1999**.

Please type or print the following:

1. Title and dates of conference.
2. Full name.
3. Mailing address.
4. Phone numbers (including area code) for office, home, and fax.
5. E-mail address.
6. Your anticipated arrival/departure dates.
7. Scientific background relevant to the Institute topics; please indicate if you are a student or if you received your Ph.D. on or after 7/1/93.
8. The amount of financial assistance requested (or indicate if no support is required).

All requests will be forwarded to the appropriate organizing committee for consideration. In late April all applicants will receive formal invitations (including specific offers of support if applicable), a brochure of conference information, program information known to date, along with information on travel and dormitories and other local housing. All participants will be required to pay a nominal conference fee.

Questions concerning the scientific program should be addressed to the organizers. Questions of a nonscientific nature should be directed to the Summer Research Conferences coordinator at the address provided above. Please watch `http://www.ams.org/meetings/` for future developments about these conferences.

**Lectures begin on Sunday morning and run through Thursday. Check-in for housing begins on Saturday. No lectures are held on Saturday.**

## *From Manifolds to Singular Varieties*

**Sunday, June 13–Thursday, June 17, 1999**

Sylvain E. Cappell, Courant Institute
Ronnie Lee, Yale University
Wolfgang Lück, Westfälische Wilhelms-Universität Münster

Recently, researchers in topology, geometry and global analysis have been encountering some related issues in attempts to extend classical methods and results from manifolds to more general settings of singular varieties. These are needed for applications because many of the natural spaces that are the focus of current investigations are usually singular. Examples include: representation spaces, such as those of fundamental groups of Riemann surfaces arising in the study of low dimensional manifolds; moduli space constructions in algebraic geometry; the singular spaces which arise in trying to study and classify general finite or compact group actions on manifolds; and spaces produced in a variety of contexts by natural compactification procedures.

The object of this conference will be to describe some recent advances in this general area and to discuss and compare questions, methods, and applications from a variety of perspectives. Among other subjects, the conference will include talks on the following topics:

1. *Topological invariants and classifications of singular varieties.* A toplogical motivation for studying singular varieties is the study of group actions, because their orbit spaces are stratified spaces. A goal is to make some powerful new classification methods more accessible and applicable by considering spaces arising from natural contexts. A natural question, which can be approached from

several viewpoints, is: what can be said about topological classification of algebraic varieties?

Important recent developments in the theory of singular varieties are related to the study of their characteristic classes. There are, in fact, several closely related theories of characteristic classes developed by a number of workers. Among questions to be addressed are: What are the relations between different theories of characteristic classes and what do they reveal about geometric and analytic structures of the varieties? When can such classes, which for singular varieties generally take values in homology, be lifted back at least partially towards cohomology or to other theories; and what additional structures are necessary for such refinements?

Intersection homology theory has been a powerful tool for the investigation of intersection theories and numbers in singular varieties. But its functoriality, analytical interpretation, e.g., its relation to L2 cohomolgy, as well as other issues are still not fully understood. Moreover, it doesn't cover all the now needed settings, e.g., in symplectic geometry. This meeting will be a forum for such new issues in intersection theory.

2. *3-manifold invariants and moduli spaces.* Some subtle invariants of 3-manifolds are related to representation spaces. But extensions of Casson's SU(2) ideas to more general Lie groups encounter difficulties due to the more singular nature of the representation varieties and require investigations of Lagrangian subvarieties in singular symplectic varieties. These invariants shoud be compared with combinatorial invariants, e.g., those related to Vassiliev's perspective on knot theory and to “finite type invariants” of 3-manifolds.

Representation varieties have been investigated by algebraic geometers as moduli spaces of holomorphic G-bundles over a Riemann surface. Related moduli objects (e.g., of Higgs bundles, of the moduli spaces of stable k-pairs, etc.) arose through interactions with physics. Such moduli spaces exhibit similar symplectic and Kahler structures as well as gauge theory interpretations. It will be desirable to compare different treatments of singularities.

3. *$L^2$-Betti numbers and $L^2$-torsions.* $L^2$-invariants such as $L^2$-Betti numbers, Novikov-Shubin invariants, $L^2$-torsions can be defined analytically in terms of the heat kernel of the universal covering as well as topologically. This gives fruitful links between analysis and topology with applications in differential geometry, topology, group theory and algebraic $K$-theory.

Connections to the first topic come from the relation of intersection homology and $L^2$-cohomology. The Cheeger-Goresky-MacPherson Conjecture and the Zucker Conjecture link the $L^2$-cohomology of the regular part with the intersection homology of an algebraic variety. For applications in group theory and algebraic $K$-theory it was necessary to define $L^2$-Betti numbers for “very singular” spaces. This suggests extending results from actions of finite groups to (proper) actions of discrete groups.

$L^2$-Betti numbers, Novikov-Shubin invariants and $L^2$-torsion have been studied for 3-manifolds and are linked to other invariants, e.g., volume of hyperbolic manifolds and Gromov's simplicial volume. Open conjectures include the Atiyah conjecture, the Singer Conjecture and the zero-in-the-spectrum conjecture which are related to algebraic $K$-theory, global analysis, and topological rigidity conjectures.

## *Computability Theory and Applications*

### Sunday, June 13–Thursday, June 17, 1999

Peter Cholak, University of Notre Dame
Steffen Lempp, University of Wisconsin (co-chair)
Manuel Lerman, University of Connecticut (co-chair)
Richard Shore, Cornell University (co-chair)

Computability theory (or recursion theory) is an area of mathematical logic dealing with the theoretical bounds on and structure of computability and with the interplay between computability and definability in mathematical languages and structures. The field started in the 1930s with ground-breaking work of Gödel and Turing and has developed into a rich theory with applications and connections to areas ranging from computer science to descriptive set theory as well as more traditional branches of mathematics, including algebra, analysis, and combinatorics. The meeting will focus on classical computability theory, an area in which many recent advances have been made, and those applications which currently seem most directly connected to and most likely to benefit from these advances. In particular, applications in algebra, model theory, and proof theory will be highlighted. Lectures will stress open problems, their relationship to some of the recent advances, and further obstacles which need to be overcome to solve the problems. Problems, primarily from the following areas, will be discussed.

1. *Classical computability theory.* There have been a number of major advances in the understanding of substructures of the Turing degrees in the past few years, including a phenomenal number of solutions to diverse problems that had been open for decades and had always been considered very hard. In addition, substantial progress has been made towards the solution of other problems. Results have been obtained about automorphisms of these structures, characterizing definable sets and relations, and decidability and undecidability of fragments of elementary theories of the structures. These results will be discussed with an eye towards the limitations of the methods and the obstacles which need to be overcome in order to solve other problems of a similar nature.

2. *Computable mathematics.* The area of applied computability theory on which we propose to concentrate is computable mathematics. Generally speaking, one wishes to investigate the effective content of mathematical constructions and theorems, that is, to determine which procedures or relations are computable and the relative complexity of those that are not. The problems which we will address deal with determining properties of computable structures which can be decided effectively from their presentations and, if not, on the possible limits on their complexity.

Reverse mathematics is a proof-theoretic and foundational investigation into the axiom systems needed to prove standard theorems of classical mathematics, but many of its arguments and results can also be viewed as belonging to computable mathematics. There is an almost perfect translation between the proof-theoretic systems used and the levels of complexity in computability. Each approach contributes its own techniques, which often produce results with overlapping but supplementary content. An important foundational issue is the existence of classical theorems not equivalent to any of the standard systems. It seems likely that further computability theory analyses using more delicate techniques can shed light on this area.

## *Homotopy Methods in Algebraic Topology*

### Sunday, June 20–Thursday, June 24, 1999

Robert Bruner, Wayne State University (co-chair)
Anthony Elmendorf, Purdue University, Calumet
John Greenlees, Sheffield University (England)
Nicholas J. Kuhn, University of Virginia (co-chair)
James McClure, Purdue University, West Lafayette

Algebraic topology has continually developed sophisticated new homological and homotopical methods, which have then been exported to algebraic settings such as representation theory, group theory, ring theory, and algebraic geometry. Topology currently seems to be going through a period in which much of the most striking work involves such interfacing with algebra. The primary purpose of the conference will be to present a broad range of current work in this direction, with talks in each of five general areas.

**Localization Methods and Group Cohomology**

There has been a renaissance of interest in the axiomatics of triangulated categories and their localizations. Results familiar in algebraic topology such as Brown representability and Bousfield localization have been refined and extended and then fruitfully transported into new algebraic settings such as algebraic geometry and group cohomology. Corresponding computational results include the recent computation of the cohomology of the Steenrod algebra up to $F$-isomorphism and new work on the cohomology of various arithmetic groups.

**Homology Operations, Combinatorics, and Ring Theory**

An ongoing theme in algebraic topology has been the development of the algebraic machinery necessary to efficiently encode information about various sorts of homology operations. Recently this machinery has been used in a number of distinctly purely algebraic settings. Examples include the use of Steenrod algebra technology to prove the Stong-Landweber Conjecture about the depth of rings of invariants, the Manchester school's work relating algebras of operations arising in topology to fundamental combinatorial structures, and new studies on deformations of Hopf algebras arising in topology.

**New Approaches to Homotopy Theory**

A closed model category is a category with structure allowing one to do homotopy theory satisfying expected properties. Voevodsky, Morel, and others have led major developments in the construction of such structures in algebro-geometric settings. One expects that this ongoing work will feed back into classic topology in much the way that the development of étale homotopy did two decades before.

Related to this is recent work on the foundations of stable homotopy. Jeff Smith and his collaborators have developed the theory of symmetric spectra, and the Chicago school, led by J. Peter May, has used modern operadic methods to develop the theory of $S$-modules. Both of these underlie the stable category, and both are influencing, and are influenced by, nearby areas of mathematics.

Goodwillie's theory of polynomial resolutions of homotopy functors, originally developed to answer questions in algebraic K-theory, is now being employed in classical homotopy with ever more success, including applications to $v_n$-homotopy and Hopf invariants and to general homological algebra.

**Cobordism and Homotopy Theory**

By connecting the geometry of manifolds, homotopy theory, and the study of formal groups, cobordism theory plays a pivotal and beautiful role in topology. The MIT school has been using algebro-geometric methods to explain and generalize new invariants of manifolds (e.g., Witten's elliptic genus) while simultaneously illuminating algebraic results in the theory of modular forms. The demands of this work also provided significant motivation for the new results on the foundations of the stable category described above. There are ongoing fundamental questions about good geometric models for cobordism theories, such as elliptic cohomology, which have height greater than one. There has been slow but steady progress towards answering these, involving work in disparate areas: equivariant formal group laws, the effect of Tate cohomology on periodic theories, and connections with differential geometry.

### Historical Talks

There will be a few historical talks by mathematicians with broad interests who have been major contributors to algebraic topology during the last two decades.

**Preliminary List of Speakers**

Jeanne Duflot, Colorado State University; William Dwyer, University of Notre Dame; Michael Hopkins, MIT; Igor Kriz, University of Michigan, Ann Arbor; Ib Madsen, Aarhus University (Denmark); Randy McCarthy, University of Illinois, Urbana; James McClure, Purdue University, West Lafayette; Fabien Morel, École Polytechniques (France); John Palmieri, University of Notre Dame; Nigel Ray, University of Manchester (England); Jeremy Rickard, University of Bristol (England); Hal Sadofsky, University of Oregon; Stephan Stolz, University of Notre Dame; and Saïd Zarati, University of Tunis (Tunisia).

## *Wave Phenomena in Complex Media*

### Sunday, June 20–Thursday, June 24, 1999

Michael Aizenman, Princeton University
Alexander Figotin, University of North Carolina, Charlotte
Svetlana Jitomirskaya, University of California, Irvine
Abel Klein, University of California, Irvine (chair)
Stephanos Venakides, Duke University

The conference will bring together researchers with interests and experience in classical and quantum mechanical waves and in related aspects of complex media and make contact with recent developments in the theory of random matrices.

The topics discussed will include:

- Localization of classical and quantum mechanical waves in disordered systems
- Extended states in the presence of disorder
- Wave localization in nonlinear media
- Wave phenomena in composite media
- Localization and gap statistics
- Insights from random matrices

Wave phenomena in complex media is a subject of great interest. Periodic, perturbed periodic, or random media can be used to filter or amplify waves in a prescribed range of frequencies, to discriminate waves propagating in chosen directions, and more. Phenomena as the existence of spectral gaps for periodic composite materials or Anderson localization for disordered materials are expected to have important new applications, especially in the case of classical waves, which have not been studied as intensively in these types of medium. The utilization of these properties in composite dielectric materials such as photonic crystals can lead to new optical devices: optical transistors, high-efficiency lasers, laser diodes, mirrors, antennas, switches, memories, and more. The quantitative mathematical theory of photonic band structures and disordered dielectrics ought to be advanced in order to fully utilize the potential suggested by the rather qualitative arguments developed up to now. The mathematical theory will play an important role in the existing effort to tailor the optical properties of the materials to our technological needs.

One focus of the conference will be classical waves in complex media. Classical waves can exhibit phenomena normally associated with quantum mechanical electron waves. The quantum mechanical wave nature of electrons has been studied based on an analogy with the scattering and interference of classical waves. But only recently has the analogy been reversed and such phenomena as the localization of classical waves started to be investigated. There is now intensive research on this subject, driven in part by the interest in optical materials that would lead to "lightronics" (optical transistors, etc.), a development with tremendous technological applications. But while electronic bound states, the simplest example of a localized electron wave, are ubiquitous in nature, the analogous phenomena for light are not commonly observed, even if theoretically possible. Mathematics plays an important role in the design of appropriate materials exhibiting localization of light and other classical waves.

Another focus of the conference will be Schrödinger operators in complex media. Localization of Schrödinger operators in disordered media has been an area of intensive mathematical research. Recently, progress was made in applying the mathematical ideas developed in that context to classical waves. Maxwell's and acoustic equations can be rewritten as first-order conservative systems, resembling Schrödinger's equation. Spectral theory becomes relevant, and the methods developed for Schrödinger operators can be transported to the study of Maxwell and acoustic operators. These methods are also relevant to elastic waves. But the analogy is not complete, and there are important technical differences. In particular, the analogy is with localization of Schrödinger operators in spectral gaps, not at the bottom of the spectrum. This analogy will be one of the main themes of the conference.

In addition to localization, the phenomenon of conduction through extended states continues to present a major mathematical challenge. An interesting possibility is that relevant insight can be obtained by analyzing the related issues in the context of random matrices. Different methods are available in that field; however, it seems possible that both areas could be enriched through cross-comparisons.

The preliminary list of speakers includes Michael Aizenman, Princeton University; Carlo Beenakker, Leiden University; Percy Deift, Courant Institute; Alexander Figotin, University of North Carolina, Charlotte; Rainer Hempel, Technische Universität Braunschweig; Peter Hislop, University of Kentucky;, Svetlana Jitomirskaya, University of California, Irvine; Yulia Karpeshina, University of Alabama, Birmingham; Abel Klein, University of California, Irvine; Werner Kohler, Virginia Polytechnic Institute; Peter Kuchment, Wichita State University; Ken McLaughlin, University of Arizona; Graeme Milton, University of Utah; George Papanicolaou, Stanford University; Leonid Pastur, University of Paris VII; Israel Sigal, University of Toronto; Alexander Soshnikov, CALTECH; Stephanos Venakides, Duke University; Eugene Wayne, Boston University; and Michael Weinstein, University of Michigan.

## *Groupoids in Physics, Analysis and Geometry*

### Sunday June 20–Thursday, June 24, 1999

Jerome Kaminker, Indiana University-Purdue University at Indianapolis (co-chair)
Arlan B. Ramsay, University of Colorado (chair)
Jean Renault, Université d'Orleans (co-chair)
Alan D. Weinstein, University of California, Berkeley (co-chair)

Groupoids have recently been used in essential ways in several areas, providing a unifying theme for seemingly diverse topics. It is the goal of this Joint Summer Research Conference to bring together a broad group of researchers to discuss the ways in which the use of groupoids in each of their areas leads to interesting results. The title tells the focus areas.

The uses of groupoids in physics come from two main sources. The first is Alain Connes' theory of noncommutative geometry, in which groupoids are a main source of examples of noncommutative spaces. This theory is being studied very actively by physicists, and by mathematicians. Bellisard's work studying the quantum Hall effect via noncommutative geometry has led to the study of connections between solid state physics and noncommutative geometry models associated with tilings.

The second major source of the use of groupoids in physics is the general theory of quantization in mathematical physics. A theory of quantization has been introduced by V. Maslov and A. Karasev, and a version due to Alan Weinstein has been actively developed by him and his collaborators. One step in this program is to associate a symplectic groupoid to a given Poisson manifold.

Differentiable groupoids and their associated Lie algebroids have proved to be a valuable ingredient in the work of Richard Melrose and Victor Nistor on partial differential equations on manifolds with corners. Further, the approach to quantization based on deformations of symplectic manifolds, introduced by Fedosov and developed by Ryszard Nest and Boris Tzygan, makes strong use of Lie algebroids.

An early use of groupoids was in the approach to group representations due to George Mackey. This provided one link to ergodic theory and von Neumann algebras. A different viewpoint appears in the fundamental paper of Alain Connes on noncommutative integration, which influences much of the work on groupoids in analysis.

Another connection between groupoids and von Neumann algebras appears in recent work by Masamichi Takesaki and his collaborators. Groupoids have played a major role in $C^*$-algebras since the thesis of Jean Renault. An important current direction is the connection between dynamics and $C^*$-algebras as seen in the work of Ian Putnam and Jean Renault and their collaborators.

Finally, the work of Jean-Luc Brylinski and his collaborators using groupoids to understand Deligne cohomology from a geometric point of view has substantial connections and roots in problems in mathematical physics.

## *Differential Geometric Methods in the Control of Partial Differential Equations*

**Sunday, June 27–Thursday, July 1, 1999**

Robert D. Gulliver University of Minnesota, Minneapolis (co-chair)
Walter Littman, University of Minnesota, Minneapolis (co-chair)
Roberto Triggiani, University of Virginia (co-chair)

The proposed conference seeks to explore the infusion of differential geometric methods into the analysis of control theory problems for partial differential equations (P.D.E.s). Very recent research supports the expectation that Bochner techniques in differential geometry, when brought to bear on the classes of P.D.E.s modelling and control problems discussed below, will yield significant mathematical advances. These include:

(a) Intrinsic, coordinate-free models of (nonlinear) shells equations, more suitable for mathematical investigation than present, exceedingly complicated, coordinate-based models, mostly derived in the mechanical literature.

(b) A priori direct (trace regularity) and reverse (continuous observability) inequalities for mixed problems for second order hyperbolic P.D.E.s, Maxwell equations, plate-like equations, Schrodinger P.D.E.s (Petrowski-type) etc., defined on a multidimensional Euclidean domain, with emphasis on the variable coefficient case. In the case of dissipative systems, reverse inequalities, which are generally more challenging to achieve, yield energy decay (stabilization) results.

(c) Establishment of direct and reverse a priori inequalities for highly coupled systems of P.D.E.s arising in modern technological applications, such as: shell models and thermoelastic models defined on 2-dimensional surface-like domains; structurally acoustic models defined on acoustic 3-dimensional chambers with curved walls, possibly subject to thermoelastic effects; etc.

These three groups of results are of fundamental importance, because they constitute necessary prerequisites for well-posedness and solvability of control and stabilization problems for the P.D.E.s systems described above. The class of problems on shells listed in (a) is entirely open; and so are, as a consequence, many of those listed in (c), which depend on the solution of shell problems in (a). As to the problems listed in (b), while a wealth of results has already been obtained, however, they refer so far either to the constant coefficient case or, in the available cases of variable coefficients, the conditions are not readily verifiable and the proofs are highly technical. Very recent research indicates that, in the general case of (space) variable coefficients, differential (Riemann) geometric methods have the potential to enhance and simplify the presently available theory, as well as to extend it by overcoming remaining difficulties. The time is ripe and propitious, therefore, to further explore in a systematic way new advances along this line of research. Thus, the aim is to organize an exploratory, focused, research conference, which involves control theory and P.D.E. experts as well as differential geometers interested in P.D.E.s.

As to (a), the role of Riemann geometry is expected to be paramount in capturing geometric features of general shells, both static and dynamic; to express, in intrinsic form, the correct boundary conditions; and to establish the required estimates.

As to (b), very recent research has indicated that Riemann geometric methods can profitably be used to complement and extend known analysis-based methods of proving the a priori reverse inequalities in the general case of variable coefficients. Riemann geometric methods appear to bring a few advantages: (i) they essentially reduce the analysis to the constant coefficient principal part case, where strategies are well understood; (ii) they ultimately provide easier-to-verify conditions, with a distinct geometric flavor involving notions such as convexity in the Riemann metric and gaussian curvature; (iii) they require only a finite, natural degree of smoothness, rather than high smoothness as in pseudo-differential analysis.

As to (c), the overall system may consist either of two P.D.E.s of the same type (hyperbolic/hyperbolic coupling), or else of different type (hyperbolic/parabolic coupling), possibly defined on different contiguous domains, and with strong, possibly boundary, coupling. For example the elastic wall of an acoustic chamber may be subject to high internal damping, whereby the original plate equation becomes parabolic-like. This is a vastly open research topic for basic P.D.E.s theory in general, and for control and optimization theory in particular. Because of their original description on curved domains (manifolds), these problems appear particularly well suited for differential geometric methods to supplement analytic approaches, at the level of both modeling and analysis, including notions such as operators on manifolds, forms, gaussian curvature of the domain, etc. Here the difficulties are compounded over those described in point a) above for a single shell, since the shell may be just one component of a composite, highly coupled system.

The proposed exploratory conference will show once more that mathematical research knows no boundaries between specific disciplines—analysis versus differential geometry; and that potentially productive interactions may take place between P.D.E. control theory and differential geometry. These will be well served by expanding the traditionally analysis-based P.D.E.s approaches into fields such as Riemannian (and, in the time variable case, Lorentian) geometry.

Of course, the introduction and use of differential geometric methods in more general P.D.E.s theory has long been established. However, the use and role of differential geometric methods toward the solution of any of the modeling, control, and optimization problems mentioned in points a), b), c) above is largely unexplored. It opens up a highly promising area of research.

By contrast, the introduction of differential geometric methods in the study of control problems (such as exact controllability, feedback stabilization, optimization, filtering, etc.) for dynamical systems modeled by ordinary differential equations (O.D.E.s) dates as far back as the early 1970s.

In keeping with the stated character and goals, the proposed conference is intended to be highly focused and exploratory. The conference will feature high caliber speakers from both fields, geometry and P.D.E.s, and seeks likewise to attract a mixed audience of geometers and P.D.E. control theorists. A particular effort will be made to include a representative group of young mathematicians from both fields. The conference's distinctive theme will be "control of P.D.E.s opened to geometry, and geometry infused into P.D.E.s control".

## *Structured Matrices in Operator Theory, Numerical Analysis, Control, Signal and Image Processing*

**Sunday, June 27–Thursday, July 1, 1999**

Richard Brualdi, University of Wisconsin, Madison
Gene Golub, Stanford University
Franklin Luk, Rensellaer Polytechnical Institute
Vadim Olshevsky, Georgia State University (chair)

### Introduction

Many important problems in pure and applied mathematics and engineering can be reduced to linear algebra problems. Unfortunately, practical circumstances impose limitations on the use of available standard linear algebra methods. For example, in many applications the size of the associated matrices is *prohibitively large*, so the available standard methods often require an extremely large amount of arithmetic operations.

This is one reason why one seeks in various applications to identify special/characteristic structures that may be assumed in order to *speed-up computations*. Such additional assumptions are often provided by particular physical properties leading to various structured matrices, such as Toeplitz, Hankel, Vandermonde, Cauchy, Pick matrices, Bezoutians, and others. The *structure* of these dense matrices is understood in the sense that their $n^2$ entries are defined by a smaller number $O(n)$ of parameters. So exploiting such structures allows one to obtain nice solutions for many applied problems as well as to design efficient *fast algorithms* to compute these solutions.

Structured matrices are encountered in a surprising variety of areas and algorithms, including Pade approximations; continuous fractions; classical algorithms of Euclid, Schur, Nevanlinna, Lanzcos, Levinson; and their generalizations and applications.

**Two Examples**

1. **Operator theory.** In the classical Nevanlinna-Pick interpolation problem one seeks a rational interpolant whose norm is bounded by unity in the right half-plane. For this problem the well-known Pick solvability condition (1916) and the Nevanlinna algorithm (1919) both involve a certain structured matrix called the *Pick matrix.*
2. **Electrical engineering.** In the now classical N. Wiener monograph *Extrapolation, Interpolation and Smoothing of Stationary Time Series* a linear prediction problem was reduced to recursive, solving the so-called Yule-Walker equations whose coefficient matrix has the *Toeplitz structure.*

### Further Progress

These problems were among those seeds that grew into deep studies of structured matrices in linear algebra, operator theory, numerical analysis, theoretical computer science, and electrical engineering.

**Interpolation**
There is a vast operator theory literature on far-reaching generalizations of *passive interpolation* of the Nevanlinna-Pick type; we mention only that deep results were obtained in the frameworks of several "languages", including the band extension method, the Buerling-Lax-theorem approach, the state-space approach, and lifting-of-commutants method.

**Electrical Engineering**
In the framework of system and circuit theories, interpolants arise as transfer functions, so *passivity* is naturally imposed by the conservation of energy. Thus, it is not surprising that fruitful connections to many applied areas were discovered. Many applications such as model reduction, sensitivity minimization, and robust stabilization have been addressed in this way.

**Matrix Analysis**
It turns out that many nice results and especially many important *fast algorithms* that were initially obtained for specific patterns of structure can be naturally carried over to the more general important classes of matrices having what is now called *displacement structure*.

**Numerical Analysis**
In floating point arithmetic, where the roundoff errors are present, the crucial factor that makes an algorithm practical is its *numerical accuracy*. Unfortunately, many fast algorithms suffer from often catastrophic propogation of roundoff errors, so one can say that they are often efficient ways to compute "garbage solutions". Moreover, these two targets have even been incorrectly regarded as being unattainable simultaneously, thus leading to the folk conjecture "one has to sacrifice accuracy for speed".

It is remarkable that the results of recent years reveal that the above two targets not only do not conflict with each other but in fact do just the opposite: proper and careful use of structure allows one to design more accurate fast algorithms that can be even better than the standard numerically stable algorithms.

## Conference Scope and Topics

Though special sessions and minisymposia on structured matrices are usually included in the programs of the ILAS, SIAM, SPIE, and MTNS conferences, their narrow frameworks usually allow us to focus on one specific application only. The purpose of this conference is to foster integration between different areas and to bring together leading researchers working on all aspects of structured matrices.

There will be several invited tutorial lectures. Contributed talks will focus on recent advances in the following areas: fast algorithms for structured matrices, displacement structure, abstract interpolation, computer arithmetic, numerical accuracy, applications of structured matrices in system theory, circuits, signal processing, adaptive filtering, control, image processing, and preconditioning.

## Preliminary List of Invited Speakers

Dario Bini, University of Pisa; Patrick Dewilde, Delft University; Israel Gohber, Tel Aviv University; Georg Heinig, Kuwait University; Rien Kaashoek, Vrije University, Amsterdam; Tom Kailath, Stanford University; Franklin Luk, Rensselaer Polytechnical Institute; Vadim Olshevsky, Georgia State University; Haesun Park, University of Minnesota; Bob Plemmons, Wake Forest University; Philip Regalia, Institut National des Telecommunications; Lothar Reichel, Kent State University; and Leiba Rodman, College of William and Mary.

For further information, call for papers, application deadline, and updates see the conference page `http://www.cs.gsu.edu/~matvro/JSRC99.html`.

# 1999 Summer Research Institute

## *Smooth Ergodic Theory and Applications*

**University of Washington**
**Seattle, Washington**
**July 26–August 13, 1999**

The forty-fifth Summer Research Institute sponsored by the American Mathematical Society will be held at the University of Washington, Seattle, Washington. The topic was selected by the Committee on Summer Institutes and Special Symposia, whose members at the time included Michael D. Fried (chair), Robert Osserman, Jeffrey B. Rauch, Leon Takhtajan, and Ruth J. Williams.

## Organizing Committee

Anatole Katok, Pennsylvania State University (co-chair)
Rafael De La Llave, University of Texas (co-chair)
Yakov Pesin, Pennsylvania State University (co-chair)
Howard Weiss, Pennsylvania State University (co-chair)

Smooth ergodic theory deals with the study of invariant measures under differentiable mappings or flows. The relevance of invariant measures is that they describe the frequencies of visits for an orbit and hence they give a probabilistic description of the motion of a deterministic system. The fact that the system is differentiable allows one to use techniques from analysis and geometry. Much of the particular fascination of the field stems from the interaction between measure theory and geometry and the possibility of drawing geometric conclusions from measure theoretic facts and vice versa.

The study of transformations and their long-term behavior is ubiquitous in mathematics and the sciences. They arise not only in applications to the real world—the name "ergodic" was introduced by Boltzmann, who intended to use his "Ergodic Hypothesis" as a justification of thermodynamics—but also to diverse mathematical disciplines, including number theory, Lie groups, algorithms, Riemannian geometry, etc. Hence smooth ergodic theory is the meeting ground of many different ideas in pure and applied mathematics.

The core of the theory includes the study of stochastic properties of the invariant measures of various kinds of systems with hyperbolic behavior (i.e., exponential growth of instabilities). The principal role of smooth ergodic theory is twofold:

1. It provides a paradigm for the rigorous study of complicated or *chaotic* behavior in deterministic systems. Smooth ergodic theory is an essential tool in the study of specific classes of dynamical systems, such as some low-dimensional systems with strange attractors, Hamiltonian systems, geodesic flows, and actions of higher-rank Abelian and semisimple Lie groups by diffeomorphisms.

2. It serves as the basis for applications both inside and outside the theory of dynamical systems. There are many striking applications that use this machinery to prove deep theorems in Riemannian geometry (solution of Klingenberg conjecture on the existence of infinitely many closed geodesics on every convex surface, classification of manifolds of nonpositive curvature), number theory (solution of Oppenheim conjecture on the values of quadratic forms at primitive integral points), Lie groups (rigidity of smooth actions of many large groups, homogeneity of closures and equidistribution of individual orbits of one-parameter unipotent subgroups), statistical physics (substantial progress on the Boltzman hypothesis on the ergodicity of the hard ball gas), and partial differential equations (ergodic properties of coupled map lattices, dimension estimates of the maximal attractor in certain partial differential equations, including the Navier-Stokes equation).

Because smooth ergodic theory overlaps many areas of mathematics and its arguments often cross category lines, it is difficult for a student, or even an established mathematician, to acquire a working knowledge of smooth ergodic theory and to learn how to use its tools. Given the very rapid development of smooth ergodic theory in recent years, it has been difficult, even for specialists in the field, to keep up with the many significant advances in the field.

The five main purposes of our proposed summer institute are: (i) to train young researchers (especially students and postdocs) interested in learning smooth ergodic theory, (ii) to teach mathematicians working in other fields the core machinery of smooth ergodic theory to use in their applications, (iii) to keep specialists in smooth ergodic theory knowledgeable of the current state of the subject and some of its new applications, (iv) to discuss major open problems and to help chart a course of research in the area for the early twenty-first century, and (v) to serve as an effective meeting ground for mathematicians at all stages in their careers, including experts and beginning graduate students.

Our proposed institute will focus on three broad areas of smooth ergodic theory: structural theory (both conservative and dissipative), dimension theory, and applications.

There will be three types of talks catering to the different possible audiences: (i) in-depth minicourses (taught by leading experts in the respective subjects) on both core material, recent exciting developments, open problems, and applications; (ii) survey lectures on the current state of the subject; and (iii) research talks on topics of current interest. Minicourses will usually be about a week long. Preliminary plans for the program are to have two or three minicourse lectures in the morning and two or three survey and research talks in the afternoon.

We plan to run minicourses in the following subjects (instructors' names in parentheses):

1. Ergodic Theory of Nonuniformly Hyperbolic Systems (Katok, Pesin).

2. Decay of Correlations and Zeta Functions (Baladi, Dolgopyat, Pollicott).

3. Ergodic and Geometric Properties of Partially Hyperbolic Systems (Shub, Wilkinson).

4. Geometrical and Statistical Properties of Chaotic Systems (Chernov, Young).

5. KAM Theory and Applications (Eliasson, De La Llave).

6. Applications of Ergodic Theory to Geometry of Manifolds of Nonpositive Curvature (Brin, Knieper, Ballmann).

7. Dimension Theory and Dynamics (Schmelling, Weiss).

8. Applications of Ergodic Theory to Number Theory (Eskin, Kleinbock).

Other minicourses may include Lyapunov Exponents and Their Estimation and Henon Attractors and Related Topics; others are still being developed.

Among the confirmed survey speakers are Ledrappier, Parry, Xia, and Yorke. Other confirmed participants include Afraimovish, Burns, Eberlein, Fathi, Feres, Flaminio, Fornaess, Forni, Foulon, Gerber, Hammenstadt, Hasselblatt, Hunt, Jakobson, Kifer, Levi, Liverani, Przytcki, Rugh, Rychlik, Schmelling, Schmidt, Smillie, Spatzier, Swiatek, Szasz, Viana, and Young. There are still pending invitations.

Proceedings of the Institute will be published in the AMS series *Proceedings of Symposia in Pure Mathematics*.

It is anticipated that the Institute will be partially funded by a grant from the National Science Foundation and perhaps others. The organizers hope to be able to provide some support for subsistence for most of the participants. Special encouragement is extended to junior scientists to apply. A special pool of funds expected from grant agencies has been earmarked for this group. Other participants who wish to apply for support funds should so indicate; however, available funds are limited, and individuals who can obtain support from other sources are encouraged to do so.

All persons who are interested in participating in the Institute should request an invitation. Applicants should send the following information to: Summer Research Institute Coordinator, American Mathematical Society, P.O. Box 6887, Providence, RI 02940, or by e-mail to pop@ams.org **no later than March 3, 1999**.

Please type or print the following:

1. Full name.

2. Mailing address.

3. Phone numbers (including area code) for office, home, and fax.

4. E-mail address.
5. Your anticipated arrival/departure dates.
6. Scientific background relevant to the Institute topics; please indicate if you are a student or if you received your Ph.D. on or after 7/1/93.
7. The amount of financial assistance requested (or indicate if no support is required).

All requests will be forwarded to the organizing committee for consideration. In late April all applicants will receive formal invitations (including specific offers of support if applicable), a brochure of conference information, program information known to date, along with information on travel and dormitories and other local housing. All participants will be required to pay a nominal conference fee.

Questions concerning the scientific program should be addressed to hnwl@glue.umd.edu. Questions of a non-scientific nature should be directed to the Summer Institute coordinator at the address provided above.