

# INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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## IMA NEWSLETTER # 254, REVISED

September 1-30, 1997

1997-98 Program

### EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

See the Winter, Summer and Fall 1997 IMA Update for a full description of the 1997-98 program on Emerging Applications of Dynamical Systems.

<b>News and Notes</b>
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#### New IMA Director Chosen

The Board of Governors of the IMA has chosen Prof. Willard Miller to succeed Avner Friedman as Director of the IMA, beginning September 1, 1997. The appointment is for a five-year term. Willard Miller has had a long association with the IMA. He was the head of the School of Mathematics at Minnesota in 1979 when the proposal for the IMA was originally submitted to the National Science Foundation, and he played a major role in bringing the IMA to Minnesota. He became Associate Director of the IMA in 1987 and served in that position for seven years, before becoming Associate Dean for Finance and Planning of the Institute of Technology at Minnesota.

Professor Miller is a mathematical physicist. His research involves the use of symmetry methods, in particular Lie groups and Lie algebras, in the analysis of the structure of physical theories. He has written extensively on topics in special function theory, separation of variables, and quantum algebras.

With his proven dedication to progress in the mathematical sciences and his outstanding administrative record, the Board of Governors and the current Directors are confident that Willard Miller will lead the IMA to success into the next century.

#### Friedman Awarded SIAM Distinguished Service Prize

Avner Friedman, the IMA Director since 1987, was awarded the Prize for Distinguished Service to the Profession July 15, 1997 at the SIAM Annual Meeting in Palo Alto. The prize was "for his service to applied mathematics with remarkable distinction and dedication. As Director of

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PARTICIPATING INSTITUTIONS: Centre National de la Recherche Scientifique, Consiglio Nazionale delle Ricerche, Georgia Institute of Technology, Indiana University, Iowa State University, Kent State University, Michigan State University, Northern Illinois University, Ohio State University, Pennsylvania State University, Purdue University, Seoul National University (RIM - GARC), Texas A&M University, University of Chicago, University of Cincinnati, University of Houston, University of Illinois (Urbana), University of Iowa, University of Kentucky, University of Manitoba, University of Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Southern California, University of Wisconsin, Wayne State University.

PARTICIPATING CORPORATIONS: Bellcore, Eastman Kodak, EPRI, Ford, Fujitsu, General Motors, Honeywell, IBM, Lockheed Martin, Motorola, Siemens, 3M.

the Institute for Mathematics and its Applications at the University of Minnesota, he enhanced the outreach and visibility of applied mathematics through tireless efforts to nurture strong connections with industry. As SIAM President and Chair of the Board of Mathematical Sciences of the National Research Council, he has initiated numerous activities to strengthen the role of mathematics in the American scientific enterprise.”

This is the third time SIAM has awarded this prize; the previous recipients were Gene Golub and Ed Bloch.

**IMA Tutorial:**

**Numerical Methods for Bifurcation Problems**

September 5–9, 1997

Speakers: John Guckenheimer, Mark Reichelt, Bernold Fiedler,  
Werner Rheinboldt, Linda Petzold, Wolf-Juergen Beyn, Herb Keller,  
Eusebius Doedel, Eugene Allgower

**IMA Workshop:**

**Numerical Methods for Bifurcation Problems**

September 15–19, 1997

Organizers: Eusebius Doedel (chair), Bernold Fiedler (F. U. Berlin),  
Yannis Kevrekidis (Princeton), Wolf-Juergen Beyn (Bielefeld), Jens  
Lorenz (New Mexico)

**IMA Workshop:**

**Large-Scale Dynamical Systems**

September 29–October 3, 1997

Organizers: Laurette Tuckermann (Orsay)(chair), Edriss Titi (Irvine),  
H. B. Keller (Caltech), Don Aronson (Minnesota)

The schedule for this workshop will appear in IMA Newsletter 255.

# EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

September 1, 1997–June 30, 1998

## Dynamical Systems Organizing Committee:

John Guckenheimer (Chair)	Mathematics Department	Cornell University
Eusebius Doedel	Department of Computer Science	Concordia University
Martin Golubitsky	Department of Mathematics	University of Houston
Yannis Kevrekidis	Chemical Engineering Department	Princeton University
Rafael de la Llave	Department of Mathematics	University of Texas, Austin
John Rinzel	Center for Neuroscience	New York University

Dynamical systems theory describes general patterns found in the solutions of systems of nonlinear differential equations. The theory focuses upon those equations representing the change of processes in time. Geometric and analytic study of simple examples has led to tremendous insight into universal aspects of nonlinear dynamics. Experimental studies in diverse areas ranging from fluid flows to chemical reactions to laser dynamics to cardiac rhythms to neural output have confirmed the ubiquity of these dynamical patterns. Harnessing theoretical advances in the mathematics for the solution of larger, more complex practical problems requires further effort in understanding algorithmic and computational issues related to dynamical systems, extensions of the theory to important classes of systems that arise in applications, and attention to the modeling of complex systems that are accessible to only limited measurements of their components.

Work at applying the methods developed by dynamical systems theory to “real world” problems has been a thoroughly interdisciplinary effort. For over fifteen years, there has been a lively dialogue between mathematicians, scientists and engineers concerning the observation and interpretation of dynamical patterns in laboratory and natural systems. To some extent, missing from this discussion has been a set of quantitative models that accurately represent the behavior of the observed systems. The patterns identified by the theory are qualitative, and frequently the theory has been used to classify patterns rather than to build models that can be used for purposes of design or prediction. Computational capabilities have been a limiting factor in constructing such models since they seldom lend themselves to solution solely with analytic methods.

This program offers a set of activities that address the issue of applying dynamical systems methods to a wider circle of problems. There are three components to our approach: a focus on the algorithms that underlie the computation of system behavior, a focus on particular application areas that appear timely for rapid scientific advances through the use of dynamical systems methods, and emphasis upon areas in which existing mathematical theory provides an inadequate substrate for work with applications. The application areas we have selected involve physiological and chemical processes.

The year has been divided into three segments, with a total of seven workshops and a further week-long program of concentrated activity on a smaller scale than the workshops. We intend to work with the Geometry Center on sponsorship of the activities that fall into areas of mutual interest. The workshops are designed with a focal point that is complementary to those of other meetings that have been held in recent years. In each case, we endeavor to bring together groups whom we feel have overlapping interests but tend to move in disjoint scientific circles. Also, we will work to put traditional researchers in dynamical systems in contact with these new areas of activity.

The program will be divided into three parts:

Fall Quarter (Sept. 1 – Dec. 30, 1997): Numerical Analysis of Dynamical Systems

Winter Quarter (Jan. 2 – March 31, 1998): Dynamics in Physiology and Chemistry

Spring Quarter (April 1 – June 30, 1998): Symmetry and Pattern Formation

## Airfare Discounts for IMA Visitors

The IMA has negotiated special airfare discounts with Northwest Airlines. These discounts are available by calling the Travel Company at (800) 328-9131 and identifying yourself as an IMA visitor.

## Improved IMA Home Page

The IMA has substantially improved its home page on the World-Wide Web, accessible through netscape or other web-reading applications at

<http://www.ima.umn.edu>.

The page is continually under construction. We invite comments or suggestions, which may be addressed to

[webmaster@ima.umn.edu](mailto:webmaster@ima.umn.edu).

In particular, we appreciate any information about World-Wide Web links appropriate to current and upcoming IMA programs.

### Schedule for September 1–30, 1997

#### Monday, September 1

Labor Day, a University of Minnesota holiday. IMA offices will be closed.

#### Tuesday, September 2

#### Wednesday, September 3

#### Thursday, September 4

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IMA Tutorial:

### Numerical Methods for Bifurcation Problems

September 5–9, 1997

Speakers: John Guckenheimer, Mark Reichelt, Bernd Fiedler, Werner Rheinboldt, Linda Petzold, Wolf-Juergen Beyn, Herb Keller, Eusebius Doedel, Eugene Allgower

#### Friday, September 5

Talks today are in Conference Hall EE/CS 3-180

8:15 am	<b>Registration and Coffee</b>	Reception Room EE/CS 3-176
8:45 am	<b>Welcome and Orientation</b>	W. Miller, R. Gulliver, J. Guckenheimer
9:00 am	<b>John Guckenheimer</b> Cornell University	Introduction to Bifurcation Theory
10:30 am	<b>Coffee Break</b>	Reception Room EE/CS 3-176

11:00 am	<b>Mark Reichelt</b> The MathWorks, Inc.	Numerical Integration Methods in Matlab
2:00 pm	<b>Bernold Fiedler</b> Free University of Berlin	Introduction to Global Bifurcations
4:00 pm	<b>IMA Tea (and more!)</b>	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

### Saturday, September 6

#### Talks today are in Seminar Room Vincent Hall 570

8:30 am	<b>Coffee</b>	IMA Lounge, Vincent Hall 502
9:00 am	<b>Werner Rheinboldt</b> University of Pittsburgh	Algorithms for implicitly defined manifolds with applications to bifurcations and differential-algebraic systems
10:30 am	<b>Coffee Break</b>	IMA Lounge, Vincent Hall 502
11:00 am	<b>Linda Petzold</b> Univ. of California, Santa Barbara	Differential-Algebraic Equations and Stiff Systems of ODE's

### Monday, September 8

#### Talks today are in Seminar Room Vincent Hall 570

8:30 am	<b>Coffee</b>	IMA Lounge, Vincent Hall 502
9:00 am	<b>Wolf-Jürgen Beyn</b> University of Bielefeld	Numerical analysis of computing bifurcations
10:30 am	<b>Coffee Break</b>	IMA Lounge, Vincent Hall 502
11:00 am	<b>Herbert B. Keller</b> Calif. Inst. of Technology	Numerical methods for solving boundary-value problems
2:00 pm	<b>Eusebius Doedel</b> Concordia University	AUTO – Global algorithms for computing periodic orbits and their bifurcations

### Tuesday, September 9

#### Talks today are in Seminar Room Vincent Hall 570

8:30 am	<b>Coffee</b>	IMA Lounge, Vincent Hall 502
9:00 am	<b>Eugene L. Allgower</b> Colorado State University	Multidimensional continuation

10:30 am	<b>Coffee Break</b>	IMA Lounge, Vincent Hall 502
11:00 am	<b>Panel discussion</b>	Open problems
2:00 pm	<b>Laboratory session</b>	Programs and packages

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**Wednesday, September 10**

9:00 am	<b>Orientation Meeting</b> Room Vincent Hall 570	Long-term IMA visitors and Postdocs
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Long-term IMA visitors and postdocs are invited to attend this meeting to meet members of the IMA Staff and to learn about how to get things done at the IMA. Topics will include IMA policies, payroll, support services, seminars, publications, computer systems, and social events.

**Thursday, September 11**

9:30 am	<b>Informal Discussion:</b> (led by Bernold Fiedler)	Continuous spectra in travelling waves, <i>etc.</i>
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Bjoern Sandstede will speak on “What did Henry do?” The discussion session meets in room Vincent Hall 570.

IMA Special Lecture in Vincent Hall 570:

11:15 am	<b>Angel Jorba</b> University of Barcelona	Computation of normal forms and invariant manifolds in Hamiltonian mechanics. A numerical approach
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*Abstract:* We discuss the numerical computation of normal forms, central manifolds and first integrals in Hamiltonian mechanics. These are typical computations used to study some aspects of the dynamics. The approach presented here is based on manipulating the formal series with numerical coefficients.

The resulting methods allow a global description of a large fraction of the orbits of the system and can be used to predict and analyze the existence (or lack thereof) of certain types of behaviour, their bifurcations and how they fit together. We will also discuss questions of efficiency and applications to some concrete problems of Celestial Mechanics.

Math Department Numerical Analysis Seminar in Vincent Hall 570:

2:00 pm	<b>Pierre Gremaud</b> North Carolina State University	Computation of nonclassical solutions to Hamilton-Jacobi equations
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**Friday, September 12**

**SEMINAR ON INDUSTRIAL PROBLEMS**

11:15 am	<b>Eli Chiprout</b> IBM Austin Research Lab	Model Reduction for Large Circuit Simulation
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*Abstract:* Model reduction techniques have become necessary for circuit models used in high-speed computer and VLSI design. A history of these methods as applied in this field is covered including Elmore’s delay,

asymptotic waveform evaluation, complex frequency hopping, Pade via Lanczos, Arnoldi and rational Krylov methods. The different methods have wide application and have different strengths and drawbacks which will be outlined. Application problems range from linear power, clock, interconnect and noise analysis to nonlinear circuit simulation where model compactness is critical. Multipoint or rational methods become important in the the application of package analysis and board level interconnects. Statistical process variation requires quick model reduction for repeated analysis of many statistical samples. Recently some advances in the area of application to transmission lines, which are typical distributed systems that result from Maxwell equations. The extension of rational Krylov subspaces to these distributed systems is still an open problem at this time.

The seminar meets in the IMA Seminar Room, Vincent Hall 570

**IMA Workshop:**  
**Numerical Methods for Bifurcation Problems**  
 September 15–19, 1997  
 Organizers: Eusebius Doedel (chair), Bernold Fiedler (F. U. Berlin), Yannis Kevrekidis (Princeton), Wolf-Juergen Beyn (Bielefeld), Jens Lorenz (New Mexico)

While computational techniques for low-codimension local bifurcations in few-degree-of-freedom systems are in advanced state of development, much work remains to be done on the numerical treatment of higher-codimension singularities. More importantly, there is a pressing need for the development of numerical methods for computing global objects in phase space, their interactions and bifurcations.

In this workshop we will bring together mathematicians, numerical analysts and computer scientists working on these problems, and study a selected set of important applications. Particular topics we will consider include the numerical computation of invariant manifolds (including invariant tori, homoclinic and heteroclinic manifolds as well as inertial manifolds), the detection of their bifurcations and their visualization.

The Geometry Center will be involved in this workshop.

**Monday, September 15**

**Talks today are in Lecture Hall EE/CS 3-180**

8:30 am	<b>Registration and Coffee</b>	Reception Room EE/CS 3-176
9:15 am	<b>Welcome and Orientation</b>	W. Miller, R. Gulliver, E. Doedel
9:30 am	<b>Bjoern Sandstede</b> Ohio State University	Numerical computation of pulses and their dynamics

*Abstract:* Localized travelling-wave solutions of partial differential equations on the real line correspond to homoclinic orbits of an associated ordinary differential equation. Here, we will focus on the numerical computation of homoclinic orbits and the accurate detection of their bifurcation points. Super-convergence results for the wave speed are presented. Finally, we will study the interaction of pulse packets. These are solutions of the PDE to an initial value which is given by concatenated, widely separated copies of a primary travelling wave. The fate of such solutions under truncation of the real line to a finite interval is investigated.

10:30 am	<b>Coffee Break</b>	Reception Room EE/CS 3-176
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11:00 am      **Andrey Shilnikov**      Qualitatively numerical analysis of some concrete  
 Inst. Appl. Math., Nizhny Novgorod      models with non-trivial dynamics

*Abstract:* The talk includes fragmentarily some aspects of the analysis of a few Lorenz-like systems (3D symmetrical and asymmetrical classical models, 14D model, Shimizu-Marioka system), in particular, details of detection of the region of existence of the Lorenz attractor in the parameter space. The idea begins mainly with selection of codimension-two homoclinic bifurcations.

A recent result on a “blue-sky catastrophe” bifurcation of codimension one for periodic orbits and its connection with dynamics in biophysical models are also discussed.

2:00 pm      **Dimitri Turaev**      Branching homoclinic orbits in Hamiltonian systems  
 Weizmann Institute

*Abstract:* Codimension-one bifurcations of homoclinic orbits in Hamiltonian systems are considered. Two mechanisms of creation of infinite series of homoclinic loops are discussed: the appearance of a saddle periodic orbit near a homoclinic loop (in the same level of the first integral) and the appearance of an orbit which is homoclinic to a homoclinic loop.

**Short Talks: times are approximate**

3:00 pm      **Mercè Ollé**      Numerical Exploration of Bifurcation Phenomena As-  
 Univ. Politècnica de Catalunya      sociated to Complex Instability

*Abstract:* The Hopf-like bifurcation associated to the transition from stability to complex instability of a family of periodic orbits in a Hamiltonian system with three (or more) degrees of freedom is investigated. Numerical techniques to compute the bifurcating objects -periodic orbits, or, more generally,  $2D$  isolated invariant tori- are presented. The evolution and the bifurcation of the  $2D$  tori are described. As a model problem, we consider two  $4D$  symplectic mappings, and, as an application, we give some results for a galactic potential.

3:20 pm      **Timothy J. Burns**      On the Bifurcation from Continuous to Segmented  
 NIST      Chip Formation in Metal Cutting

*Abstract:* We have developed a new model for chip formation in orthogonal machining, which includes a mechanism for thermomechanical feedback. This leads to an interpretation of metal cutting as a process which is similar in many ways to an open chemical reactor. As the cutting speed is increased, there is a bifurcation from steady-state to oscillatory behavior in the stress and temperature fields in the workpiece material at the tooltip, which explains the observed change from continuous to segmented chip formation. (Joint work with Matt Davies and Chris Evans.)

3:40 pm      **Gerald Moore**      Different Algorithms for Connecting Orbits  
 Imperial College, London

4:00 pm      **IMA Tea (and more!)**      Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

**Tuesday, September 16**

**Talks today are in Lecture Hall EE/CS 3-180**

9:15 am      **Coffee**      Reception Room EE/CS 3-176

9:30 am      **Hinke Osinga**      Globalizing two-dimensional unstable manifolds  
 University of Minnesota

*Abstract:* It is well known how to globalize one-dimensional unstable manifolds for planar vector fields and maps. We consider the case of a two-dimensional manifold in a three-dimensional space. The presented algorithm is designed for the computation of the two-dimensional unstable manifold of a normally hyperbolic invariant circle of saddle-type of a three-dimensional map. We briefly discuss how to compute this invariant circle and how to obtain the starting data for the globalization.

The algorithm computes growing pieces of the unstable manifold by using a method that does not depend on the dynamics on the manifold. Also, the algorithm is such that it guarantees the quality of the mesh on this manifold. The same algorithm can be used for the globalization of a two-dimensional unstable manifold of a hyperbolic fixed point. Furthermore, we discuss how to use a similar technique for vector fields.

This is joint work with Bernd Krauskopf.

10:30 am	<b>Coffee Break</b>	Reception Room EE/CS 3-176
11:00 am	<b>Konstantin Mischaikov</b> Georgia Institute of Technology	Computer-Assisted Exploration and Proof in Dynamics
2:00 pm	<b>Michael Dellnitz</b> University of Bayreuth	The Approximation of Complicated Dynamical Behavior

*Abstract:* Multilevel subdivision techniques are presented for the efficient numerical approximation of complicated dynamical behavior. Concretely we develop adaptive methods which allow to extract statistical information on the underlying dynamical system. This is done by an approximation of natural invariant measures as well as (almost) cyclic dynamical components. We discuss issues concerning the implementation (e.g. parallelization strategies) and indicate potential applications of these methods (e.g. to the computation of Lyapunov exponents). The results are illustrated by several numerical examples.

3:00 pm	<b>Coffee</b>	Reception Room EE/CS 3-176
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### Short Talks: times are approximate

3:30 pm	<b>Greg Watson</b> Georgia Institute of Technology	Efficient Computation of the Conley Index
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*Abstract:* The Conley index is well-suited to numerical analysis of dynamical systems since it is robust under perturbations. The best algorithm is fifth-order in the size of the problem. I will describe an algorithm for which subquadratic run times have been observed. (Joint work with K. Mischaikov and W. Kalies.)

3:45 pm	<b>Volker Reichelt</b> RWTH Aachen	Numerical Computation of Invariant Tori in Dynamical Systems
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*Abstract:* We present several versions of an algorithm to compute invariant tori. They are based on the graph transform which is discretized in different ways to meet goals like speed and robustness. Finally we take a closer look at some examples.

4:00 pm	<b>Karin Gaterman</b> Konrad-Zuse-Zentrum Berlin	Orbit Space Reduction
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*Abstract:* In equivariant dynamical systems theory there is one approach known as orbit space reduction. This method rules out the group action. Fundamental invariants are coordinates for this orbit space and a new system of differential equations is defined. Special choice of coordinates simplify the structure of the orbit space as well as the differential equations. This will be illustrated by an example.

4:15 pm	<b>Arnd Scheel</b> Freie Universität Berlin	Exponential Dichotomies in Elliptic Equations
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*Abstract:* We present a dynamical-systems approach to study elliptic PDE's in infinite cylinders, using exponential dichotomies. Applications to continuation, bifurcations and numerical studies of wave solutions for reaction-diffusion equations are given.

4:30 pm            **Gian Mario Maggio**            Nonlinear Dynamics of the Colpitts Operator  
Fed. Inst. of Technology, Lausanne

*Abstract:* Sinusoidal oscillators lie at the heart of modern electronic devices and communication systems. The design techniques for oscillators of this kind are based primarily upon linear analysis. In many cases these are unsatisfactory, forcing the designer to perform extensive simulations. We apply nonlinear analysis techniques to the Colpitts oscillator with a view of developing rigorous design rules. The system exhibit a stable limit cycle originating from a Hopf bifurcation. From a design point of view is important to locate the first period-doubling bifurcation and to develop techniques for predicting it. A more extensive bifurcation analysis of the system is required, with particular reference to homoclinic bifurcations, for characterizing its chaotic dynamics. (Joint work with Michael P. Kennedy)

4:45 pm            **Ale Jan Homburg**            Homoclinic Doubling Cascades  
Freie Universität Berlin

*Abstract:* Cascades of period-doubling bifurcations have attracted much interest of researchers of dynamical systems in the past two decades as it is one of the routes to onset of chaos. In this paper we consider routes to onset of chaos involving homoclinic-doubling bifurcations. We show the existence of cascades of homoclinic-doubling bifurcations, persistently in two parameter families of vector fields on  $\mathbb{R}^3$ . The cascades are found in an unfolding of a codimension-three homoclinic bifurcation; an orbit-flip at resonant eigenvalues. We develop a continuation theory for homoclinic orbits in order to follow homoclinic orbits through infinitely many homoclinic-doubling bifurcations.

### Wednesday, September 17

#### Talks today are in Lecture Hall EE/CS 3-180

9:15 am            **Coffee**            Reception Room EE/CS 3-176

9:30 am            **Vemuri Balakotaiah**            Numerical Bifurcation Techniques for Chemical Re-  
University of Houston            actor Problems

*Abstract:* Mathematical models of chemical reactors are known to exhibit very complex bifurcation behavior due to the strong coupling between the transport processes and chemical kinetics, and the exponential dependence of the reaction rates on temperature. This talk will focus on the numerical computation of singularities and bifurcation diagrams of chemical reactor models with emphasis on the following aspects: (i) detection and computation of singularities on the boundaries of the parameter space; (ii) discretization of the governing PDEs without destroying the underlying spatial symmetries or creating spurious solutions; and (iii) computation and continuation of high-codimension singular points of discretized models of very high dimension ( $N > 10,000$ ).

10:30 am            **Coffee Break**            Reception Room EE/CS 3-176

11:00 am            **Yannis Kevrekidis**            A computer-assisted study of reaction-diffusion pat-  
Princeton University            terns in microcomposite media

*Abstract:* We study computational aspects of modeling reaction-diffusion patterns on microdesigned and microcomposite catalysts in one and two spatial dimensions. Special emphasis is placed on the numerical bifurcations of pulse-type solutions (possibly involving the continuous spectrum of the pulses) as well as the computation of modulated travelling waves for the full PDEs. We also discuss the transition to “effective behavior” of composite catalysts with fine-grained component geometry. The computations are presented along with comparable experimental results from our collaboration with the Fritz-Haber-Institut in Berlin.

2:00 pm	<b>Ray Adomaitis</b> University of Maryland	Numerical Continuation of Bifurcations and Global Dynamic Behavior Transitions for a Noninvertible System
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*Abstract:* We will discuss numerical techniques for discretizing invariant circles and numerical continuation of bifurcations and phase-space features that determine transitions in the complexity of basins of attraction for a noninvertible, discrete-time system.

3:00 pm	<b>Coffee</b>	Reception Room EE/CS 3-176
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3:30 pm	<b>Alastair Spence</b> University of Bath	Numerical methods for detecting Hopf points and computing periodic orbits in large systems
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*Abstract:* This talk is about the efficient detection of Hopf bifurcation points and computation of periodic orbits in large-scale dynamical systems that might arise after spatial discretization of PDEs. Several different approaches are discussed: 1) methods based on locating high-order singularities (“organising centres”), 2) methods based on the direct calculation of dangerous eigenvalues, 3) methods based on counting ideas from complex analysis, and 4) Reduced basis methods.

Examples will be given from a variety of physical problems, including large systems arising from mixed finite-element discretizations of the Navier-Stokes equations.

### Graphics Demos at the Geometry Center

5:00 pm	<b>Bernd Krauskopf/Hinke Osinga</b> F. U. Amsterdam/Geom. Center	Growing 1D unstable manifolds of maps
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5:20 pm	<b>Mark Johnson</b> Princeton/IMA	The latest on SCIGMA
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5:40–6:10	<b>John Guckenheimer/Won Gyu Choe</b> Cornell University	Solving BVP’s with automatic differentiation & the latest on DsTool
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### Thursday, September 18

#### Talks today are in Lecture Hall EE/CS 3-180

9:15 am	<b>Coffee</b>	Reception Room EE/CS 3-176
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9:30 am	<b>Patrick Miller</b> Brown University	Using Invariant Manifolds to Characterize Transport in Numerically-Generated Velocity Fields
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*Abstract:* Geometric methods from dynamical systems are used to characterize Lagrangian transport in numerically-generated, time-dependent, two-dimensional velocity fields. In many geophysical models the velocity field is given only as a numerical solution to an appropriate governing system of partial differential equations. This talk presents current progress in developing numerical techniques for characterizing chaotic-like transport in such numerical vector fields, where the vector field has aperiodic time-dependence and is known only on a finite time interval. Invariant manifolds are constructed numerically to create a template for describing the exchange of fluid between different flow regimes. Results are presented from simulations modeling geophysical flows.

10:30 am	<b>Coffee Break</b>	Reception Room EE/CS 3-176
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11:00 am      **Jens Lorenz**      Self-Organized Criticality: A Sandpile Model  
 University of New Mexico

*Abstract:* The paradigm of self-organized criticality was introduced about a decade ago by Bak, Tang, and Wiesenfeld. Good arguments can be given that the concept applies to a wide variety of systems far from equilibrium. Mathematical models, so-called sandpiles, can be viewed as discrete-time dynamical systems whose evolution contains simple random and simple deterministic elements. In principle, Markov matrices can be used to describe the statistical features of the evolution, but a complete analysis is out of reach. In the talk, I present results of direct numerical simulation, some limited analysis based on Markov matrices, and non-rigorous arguments of non-equilibrium statistical mechanics.

2:00 pm      **Luca Dieci**      On Smooth Decomposition of Matrices  
 Georgia Tech

*Abstract:* We consider smooth orthogonal decomposition of matrices depending on a real parameter. Among others, we discuss QR, Schur, and singular value decompositions, and their block analogues. Sufficient conditions for existence of such decompositions are given, and differential equations for the factors are derived. Also generic smoothness of these factors is discussed.

This is joint work with Timo Eirola.

3:00 pm      **Coffee**      Reception Room EE/CS 3-176

3:30 pm      **Yuri A. Kuznetsov**      Normal form computations in CONTENT  
 CWI/RIACA, Amsterdam

*Abstract:* CONTENT is an interactive environment for detection, analysis, and continuation of various bifurcations of ODEs, iterated maps, and other dynamical systems. An important part of the analysis of local bifurcations is the computation of their normal forms at the critical parameter values. This means restricting the system to the corresponding center manifold and then normalizing the system on the center manifold by appropriate changes of variables, parameters, and time.

The algorithms used in CONTENT to compute numerically the coefficients of the normal forms for • fold, • Hopf, • cusp, and • Bogdanov-Takens bifurcations of ODEs, as well as for • fold, • flip, and • Neimark-Sacker bifurcations of iterated maps, will be presented in detail. An important feature of these algorithms is that no preliminary transformation of the linear part to the Jordan normal form is applied.

### Graphics Demos at the Geometry Center

5:00 pm      **Bruce Peckham**      To Be Continued : Automatic computation of an  
 University of Minnesota-Duluth      Arnold tongue for a periodically forced oscillator  
 (without computing saddle-nodes)

5:20 pm      **Yuri Kuznetsov/Bart Sijnave**      CONTENT : A Continuation Environment  
 CWI Amsterdam/Univ. of Gent

6:00 pm      **Workshop Dinner**      Regents' Room, second floor  
 Radisson Hotel

Reception at 6:00 in the foyer outside the Regents' Room, dinner at 6:45 in the Regents' Room.

**Friday, September 19**

**Talks today are in Lecture Hall EE/CS 3-180**

9:15 am      **Coffee**      Reception Room EE/CS 3-176

9:30 am	<b>Mark Levi</b> Rensselaer Polytechnic Institute	Curvature effects in the averaging of high-frequency vibrations
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*Abstract:* We will show that some well known but counterintuitive phenomena arising due to high frequency vibration in dynamical systems have a very simple geometrical explanation. We will describe how the curvature and some non-holonomic mechanics play the role in systems such as (1) an inverted pendulum stabilized by the vibration of its hinge; (2) the Paul trap, used to suspend charged particles; (3) a forced sine-Gordon equation exhibiting so-called  $\pi$ -kinks; (4) a composition of symplectic matrices; and others. Bifurcational, numerical and topological questions (some still without answers) arising in this study will be mentioned as well.

10:30 am	<b>Coffee Break</b>	Reception Room EE/CS 3-176
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11:00 am	<b>Don Aronson</b> University of Minnesota	Dynamics of Josephson Junctions Coupled through a Shared LRC-Load
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*Abstract:* We consider a system of  $N$  identical current-biased Josephson point junctions coupled via a shared LCR-load. The mathematical model involves a system of  $N$  “pendulum-type” equations with a load-induced forcing term together with a second-order load equation which is forced by the mean velocity of the pendula. In addition to the three load parameters, the system involves two additional parameters describing the intrinsic capacity of the junctions and the common bias current. The system is equivariant with respect to permutations and is consequently amenable to a considerable amount of analysis. Numerical studies for specific loads have shown that the system has extremely complicated dynamics. We will describe some of these observations, and show how continuation studies using AUTO together with geometrical and classical analysis have led to a nearly complete picture of the dynamics in certain cases. Much work remains to be done and there are many open problems. One of the main open problems involves the singular limit in which the individual junction capacities tend to zero.

2:45 pm	<b>Welcome &amp; Introduction</b> D. Aronson, R. McGehee, R. Moeckel	Midwest Dynamical Systems Conference
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**The following talk is joint with the Midwest Dynamical Systems Conference**

3:00 pm	<b>James A. Yorke</b> University of Maryland	Discontinuous Bifurcations for Dissipative Maps in the Plane
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*Abstract:* As a parameter is varied the invariant sets of a process can change discontinuously. One kind is a saddle node bifurcation. The other kinds are included in the term “Omega Explosions”. In joint work with Kathleen Alligood and others, we claim the list of possible “Omega Explosions” is quite small. Computer videos will illustrate our techniques.

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4:00-4:20	<b>James A. Yorke</b> University of Maryland	Software Demonstration
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4:30-5:20	<b>Samuel Kaplan</b> Bowdoin College	A Model of the Collinear Three-Body Problem
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7:30-9:30	<b>Reception</b> The Geometry Center	The Geometry Center is located at 400 Lind Hall
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**Saturday, September 20**

**Midwest Dynamical Systems Conference. Talks today are in Lecture Hall EE/CS 3-180**

9:00-9:50	<b>Robert Ghrist</b> University of Texas, Austin	Contact topology and hydrodynamics
10:00-10:50	<b>Hector Lomeli</b> University of Colorado, Boulder	Quadratic Volume-Preserving Maps
10:50-11:30	<b>Coffee Break</b>	Reception Room EE/CS 3-176
11:30-12:20	<b>Amadeu Delshams</b> Universitat Politecnica de Catalunya	Singular separatrix splitting and Melnikov method for standard-like maps
2:30-3:20	<b>Youngna Choi</b> Northwestern University	One Dimensional Lorenz-like Attractors
3:20-4:00	<b>Coffee Break</b>	Reception Room EE/CS 3-176
4:00-4:50	<b>Arek Goetz</b> Boston University	Dynamics of Piecewise Isometries
6:30 pm	<b>Conference Dinner</b> Jewel of India	RSVP by September 15; \$15 per meal to be paid on September 19

**Sunday, September 21**

**Midwest Dynamical Systems Conference. Talks today are in Lecture Hall EE/CS 3-180**

9:00-9:50	<b>James Murdock</b> Iowa State University	Asymptotic unfoldings for dynamical systems near a rest point
10:00-10:50	<b>Andre de Carvalho</b> University of California at Berkeley	The dynamics of surface diffeomorphisms and the Pruning Front Conjecture
11:00-11:50	<b>Martin Golubitsky</b> University of Houston	Patterns by Hopf Bifurcation from Rotating Waves

Further information about the Midwest Dynamical Systems Conference is available at  
<http://www.geom.umn.edu/events/workshops/future.html>.

**Monday, September 22**

IMA Seminar and Informal Discussion in Vincent Hall 570:

11:00 am	<b>Bodo Werner</b> Universität Hamburg	Numerical Analysis of Invariant Curves and Circle Maps
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**Tuesday, September 23**

11:00 am      **Introducing: the IMA Postdocs!**      Each of the 13 postdocs will speak for five minutes.  
Vincent Hall 570      IMA visitors and Math Department members are  
urged to attend.

**IMA Postdoc Seminar:**

2:30 pm      **Mark Friedman**      ConCont: a collection of subroutines for computing  
Univ. of Alabama in Huntsville      connecting orbits

*Abstract:* We discuss: Algorithm for locating and continuation of connecting orbits [Doedel, Friedman, Kunin '97], including Algorithm for continuation of invariant subspaces [Friedman '97]. As an example we consider a continuation of the heteroclinic loop bifurcation [Deng, Friedman '97].

Organizer: Kurt Lust

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

**Wednesday, September 24**

9:30 am      **Informal Discussion:**      Continuous spectra in travelling waves, *etc.*  
(led by Bernold Fiedler)

Peter Rejto will speak on "Compactness estimates." The discussion session meets in room Vincent Hall 570.

**IMA Industrial Postdocs Seminar**

The seminar will meet from 1:00 – 4:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Kodak, Siemens, 3M and Lockheed Martin) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Fadil Santosa, Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform one of the organizers.

The seminar meets in Vincent Hall 570

**Thursday, September 25**

**Math Department Seminar on Dynamics and Mechanics**

10:10 am      **Edriss S. Titi**      Rigorous Estimates on Small Scales in Turbulent  
Univ. of California at Irvine      Flows

*Abstract:* In this talk we will present the concepts of determining modes, nodes, volume elements and determining finite elements for the Navier-Stokes equations, and other dissipative systems, and we will relate these concepts to the Takens Embedding Theorem. Conceptually, the number of these determining modes, nodes and elements is comparable to the number of degrees of freedom in turbulent flows, in the case of the Navier-Stokes equations. We will derive rigorous estimates on the number of these degrees of freedom in terms of the physical quantities, such as the Reynolds number and the rate of dissipation of energy. We will compare these rigorous estimates with those provided by the conventional theory of turbulence using heuristic physical arguments. We will also present rigorous estimates on the dimension of the global attractor for the three-dimensional Navier-Stokes Equations in terms of the above-mentioned physical quantities.

## IMA Special Lecture

2:30 pm      **Helen Lopes**  
Indiana University

On existence of weak solutions of the incompressible  
2D Euler equations and elliptic regularity

*Abstract:* In this talk I will discuss recent results on existence of weak solutions of the 2D incompressible Euler equations with very irregular initial vorticity. I will emphasize the role of elliptic regularity in deriving a priori estimates. My goal is to explain certain recurring difficulties in applying elliptic regularity theory to these problems and how they can be addressed.

Friday, September 26

## SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am      **Nick Tuffaro**  
Hewlett-Packard

Symbolic dynamics in mathematics, physics, and engineering

*Abstract:* Applications of symbolic dynamics from mathematics, physics, and engineering are discussed. Results from braid theory allow one to generalize ideas about unimodal interval maps to two-dimensional “single-fold” maps. These results from topological dynamics are then used to help unravel the dynamical motions of experiments with a mechanical string. Finally, a more empirical approach to the symbolic analysis of time series is used to resolve a long standing problem of cycle-variability in internal combustion engines. In each of these examples a symbolic analysis is utilized to help identify nonlinear models and parameters.

The seminar meets in the IMA Seminar Room, Vincent Hall 570

### IMA Workshop on “Large-Scale Dynamical Systems” September 29–October 3, 1997

This workshop schedule will appear in IMA Newsletter 255.

Monday, September 29

### IMA Workshop on “Large-Scale Dynamical Systems”

Tuesday, September 30

### IMA Workshop on “Large-Scale Dynamical Systems”

<b>CURRENT IMA PARTICIPANTS</b>
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#### POSTDOCTORAL MEMBERS FOR 1997–98 PROGRAM YEAR

NAME	PREVIOUS INSTITUTION
JIANG, MIAOHUA	Georgia Inst. of Technology
JOHNSON, MARK	Princeton University
MANTEL, ROLF-MARTIN	University of Warwick
LUST, KURT	Kath. University Leuven
OLIVA, RICARDO	Cornell University
ROGERS, KATHLEEN	University of Maryland
SHARDLOW, TONY	Stanford University
WATANABE, SHINYA	Neils Bohr Inst., Copenhagen
WECKESSER, WARREN	Rensselaer Polytechnic Inst.

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1997-98

NAME	PREVIOUS INSTITUTION	INDUSTRIAL AFFILIATION
LOPEZ, GILBERTO	Northwestern University	Eastman Kodak
OSIPCHUK, MARINA V.	University of California	Honeywell

VISITORS IN RESIDENCE (as of 8/19)

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ADOMAITIS, RAY	University of Maryland	SEP 14 - 19
ALLGOWER, EUGENE L.	Colorado State University	SEP 7 - 8
ARONSON, DON	University of Minnesota	SEP 1 - AUG 31
BALAKOTAIAH, VEMURI	University of Houston	SEP 14 - 19
BARKLEY, DWIGHT	University of Warwick	AUG 15 - JUN 30
BATES, PETER W.	Brigham Young University	SEP 28 - OCT 31
BERGEON, ALAIN	Université Paul Sabatier	SEP 28 - OCT 3
BEYN, WOLF-JUERGEN	University of Bielefeld	SEP 4 - OCT 4
BOEHMER, KLAUS	University of Marburg	SEP 24 - OCT 5
BROER, HENK W.	Groningen University	SEP 14 - 19
BRUIN, HENK	Royal Institute of Technology	SEP 14 - 19
BURNS, TIM	NIST	SEP 14 - 19
CARVER, SEAN G.	Cornell University	AUG 25 - JUL 30
COUGHLIN, KATIE	Université de Montréal	SEP 28 - OCT 3
CURRY, JAMES H.	University of Colorado	SEP 1 - 30
DE LA LLAVE, RAFAEL	University of Texas	SEP 1 - DEC 30
DELLNITZ, MICHAEL	Universität Bayreuth	SEP 3 - 20
DELSHAMS, AMADEU	Univ. Politècnica de Catalunya	AUG 15 - DEC 15
DIECI, LUCA	Georgia Institute of Technology	SEP 14 - 20
DIONNE, BENOIT	University of Ottawa	SEP 1 - OCT 31
DOEDEL, EUSEBIUS	Concordia University	SEP 3 - DEC 15
DOYLE, JOHN	Caltech	SEP 2 - 10
EDOH, KOSSI DELALI	Elizabeth City State University	SEP 14 - 19
FIEDLER, BERNOLD	Free University of Berlin	AUG 27 - DEC 21
FOIAS, CIPRIAN	Indiana University	JAN 1 - JUN 30
FRENCH, DONALD	University of Cincinnati	SEP 1 - AUG 31
FRIEDMAN, MARK	Univ. of Alabama in Huntsville	SEP 14 - OCT 4
GATERMAN, KARIN	Konrad-Zuse-Zentrum Berlin	SEP 14 - 19
GICQUEL, NATALIE	Princeton University	SEP 14 - 19
GOLUBITSKY, MARTIN	University of Houston	SEP 14 - 19, SEP 28 - OCT 3
GOMES, GABRIELA	University of Warwick	SEP 1 - JUL 31
GOVAERTS, WILLY J. F.	University of Ghent	SEP 7 - OCT 4
GUCKENHEIMER, JOHN	Cornell University	SEP 1 - JUN 30
HENDERSON, RONALD	California Inst. of Technology	SEP 28 - OCT 3
HENRY, DANIEL	École Centrale de Lyon	SEP 4 - NOV 21
HOLMES, PHILLIP J.	Princeton University	SEP 14 - OCT 15
HOMBURG, ALEJAN	Freie Universität Berlin	SEP 14 - 19
HU, BEI	University of Notre Dame	SEP 1 - MAY 31
JANOVSKY, VLADIMIR	Charles University of Prague	SEP 14 - 19
JOLLY, MIKE	Indiana University	JUL 14 - JUN 30
JORBA, ANGEL	Universitat de Barcelona	SEP 6 - 20
KELLER, HERBERT B.	California Inst. of Technology	SEP 1 - DEC 30
KETEMA, YOHANNES	University of Minnesota	SEP 15 - NOV 21
KEVREKIDIS, YANNIS	Princeton University	SEP 14 - 19, 28 - OCT 3
KING, GREGORY P.	University of Warwick	SEP 3 - JUL 31
KOSTELICH, ERIC J.	Arizona State University	SEP 14 - 19
KRAUSKOPF, BERND	Free University Amsterdam	SEP 2 - DEC 7

KRUPA, MACIEJ	Technical Institute Vienna	SEP 29 - NOV 21
KUKAVICA, IGOR	University of Chicago	SEP 28 - OCT 3
KUZNETSOV, YURI	CWI	SEP 13 - 20
LANGFORD, WILLIAM	University of Guelph	SEP 28 - OCT 3
LEVERMORE, DAVID	University of Arizona	SEP 28 - OCT 3
LEVI, MARK	Rensselaer Polytechnic Institute	SEP 14 - 23
LITTMAN, WALTER	University of Minnesota	SEP 1 - AUG 31
LIU, LIPING	University of Alberta	SEP 4 - 19
LORENZ, JENS	University of New Mexico	SEP 13 - 20
MADDOCKS, JOHN H	University of Maryland	SEP 28 - OCT 3
MAGGIO, GIAN MARIO	Fed. Inst. of Technology, Lausanne	SEP 4 - 9
MARCUS, PHILIP	Univ. of California at Berkeley	SEP 28 - OCT 3
MCGEHEE, RICHARD P.	University of Minnesota	SEP 14 - 19
MEI, ZHEN	Philipps-University of Marburg	SEP 14 - OCT 4
MILIK, ALEXANDRA	Technische Universität Wien	SEP 1 - JUN 30
MILLER, PATRICK	Brown University	SEP 14 - 19
MISCHAIKOV, KONSTANTIN	Georgia Institute of Technology	SEP 14 - 19
MOECKEL, RICK	University of Minnesota	SEP 1 - AUG 31
MOORE, GERALD	Imperial College	SEP 14 - 21
NI, WEI-MING	University of Minnesota	SEP 1 - AUG 31
NIE, QING	Ohio State University	SEP 1 - 30
OLLE, MERCÈ	E.T.S.E.I.B. Barcelona	SEP 13 - 20
OSINGA, HINKE	University of Minnesota	SEP 1 - AUG 31
PAL, MIHAELA MICHELLE	University of Texas at Austin	SEP 3 - 9
PECKHAM, BRUCE B.	University of Minnesota-Duluth	SEP 14 - 19
PERRY, PETER	University of Kentucky	SEP 27 - OCT 3
PESIN, YAKOV B.	Penn State University	SEP 28 - OCT 3
PETZOLD, LINDA R.	Univ. of California-Santa Barbara	SEP 4 - 9
POSBERGH, THOMAS. A.	University of Minnesota	SEP 1 - JUN 15
REICHEL, MARK	The MathWorks, Inc	SEP 4 - 6
REICHEL, VOLKER	RWTH Aachen	SEP 14 - 19
RHEINBOLDT, WERNER C.	University of Pittsburgh	SEP 4 - 7
RILEY, DOUGLAS	University of Kentucky	SEP 27 - OCT 3
RODRIGUEZ, ANTONIO	DBCC	SEP 14 - 19
ROOSE, DIRK	Katholieke University Leuven	SEP 27 - OCT 3
RUSSELL, ROBERT D.	Simon Fraser University	SEP 14 - 19
SAAD, YOUSEF	University of Minnesota	SEP 28 - OCT 3
SALDANHA, KENNETH	University of Chicago	SEP 28 - OCT 3
SANDSTED, BJORN	Ohio State University	SEP 1 - DEC 20
SATTINGER, DAVID	University of Minnesota	SEP 1 - AUG 31
SCHECTER, STEPHEN	North Carolina State Univ.	SEP 7 - 19
SHEEL, ARND	Freie Universität Berlin	SEP 7 - OCT 6
SELL, GEORGE R.	University of Minnesota	SEP 1 - AUG 31
SEYDEL, RUDIGER	Universität Ulm	SEP 27 - OCT 4
SHEN, JIE	Penn State	SEP 3 - 9
SHILNIKOV, ANDREY	Inst. Appl. Math. & Cybernetics	SEP 14 - 19
SIJNAVE, BART	University of Gent	SEP 7 - OCT 5
SPENCE, ALASTAIR	University of Bath	SEP 5 - 19, SEP 28 - OCT 5
STEEN, PAUL	Cornell University	SEP 28 - OCT 3
STUART, ANDREW M.	Stanford University	SEP 30 - OCT 3
ŠVERÁK, VLADIMIR	University of Minnesota	SEP 1 - AUG 31
SZMOLYAN, PETER	Technical University	SEP 14 - NOV 30
TITI, EDRISS SALEH	Univ. of California-Irvine	SEP 14 - OCT 5
TUCKERMAN, LAURETTE	LIMSI, Orsay, France	SEP 5 - JUN 30
TURAEV, D. V.	Weizmann Institute of Science	SEP 14 - 19
VANDERBAUWHEDE, ANDRE	University of Gent	SEP 12 - 20

VARGHAESE, ANTHONY  
VITILLARO, ENZO  
WERNER, BODO  
YORKE, JAMES A.  
ZAFARULLAH, IJAZ

University of Oxford  
Università di Perugia  
Universität Hamburg  
University of Maryland  
University of Nottingham

SEP 1 - AUG 31  
JUL 30 - SEP 5  
SEP 12 - 23  
SEP 14 - 19  
SEP 3 - 19