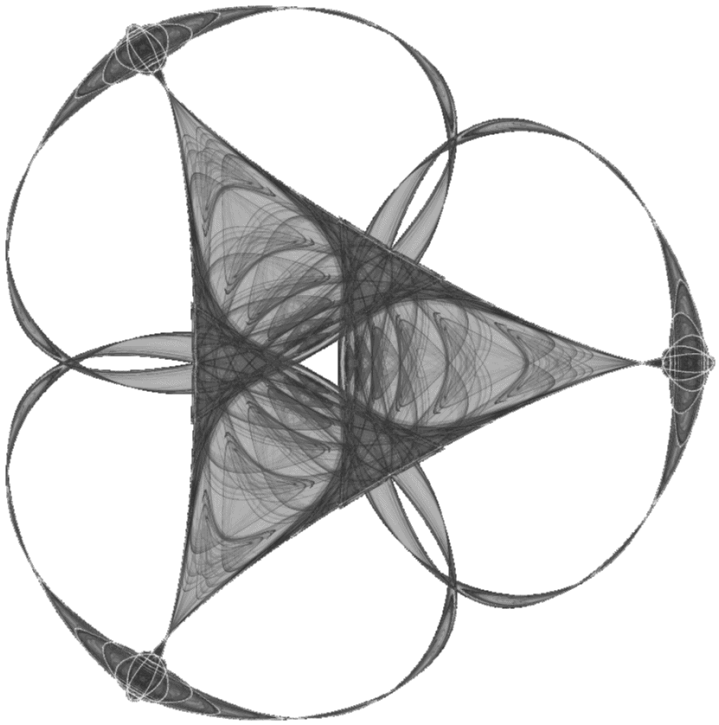
IMA ANNUAL REPORT

FOR THE YEAR

September 1, 1997 – August 31, 1998



INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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I. PREFACE

This annual report contains a summary of the activities in the Institute for Mathematics and its Applications (IMA) during the fifteenth year of operation, September 1, 1997, to August 31, 1998. The program for the academic year was **Emerging Applications of Dynamical Systems.** The coordinators for this program were:

Rafael de la Llave	University of Texas, Austin
Eusebius Doedel	Concordia University
Martin Golubitsky	University of Houston
John Guckenheimer, (Chair)	Cornell University
Yannis Kevrekedis	Princeton University
John Rinzel	National Institutes of Health

The 1998 Summer program was **Coding and Cryptography**. The organizers were

Vera Pless (Chair)	University of Illinois at Chicago
Ian Blake	Hewlett-Packard
Robert Calderbank	AT&T
Andrew Odlyzko	AT&T

We also report on the ongoing Seminar in Industrial Problems and on IMA publications, as well as other activities which took place at the IMA during the year.

Research at the IMA was supported by a major grant from

National Science Foundation, Division of Mathematical Sciences.

Additional support was made available by

Office of Naval Research

The University of Minnesota

as well as the IMA Participating Institutions:

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

The workshop on “Knowledge and Distributed Intelligence (KDI) Opportunities in the Mathematical Sciences” was supported by a special grant from

the National Science Foundation.

The workshops on " Nonlinear Identification and Control" and "Dynamical Systems Techniques in Oceanography: Chaotic Advection in Ocean Mesoscale Structure" were supported by a special grant from

the Office of Naval Research.

Support for the Postdoctorates in Industrial Mathematics program was received from

Honeywell Kodak

General support for industrial programming was received from

AT&T

and from the Participating Corporations for 1996–97:

Bellcore	Lucent Technologies
Eastman Kodak	Honeywell
EPRI	IBM
Ford	Lockheed Martin
Fujitsu	Motorola
General Motors	Siemens
3M	

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Persons wishing further information are invited to write to the IMA, or to consult the web page http://www.ima.umn.edu.

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II. THE CONCEPT OF THE IMA

1. The Mission.

The Institute for Mathematics and its Applications is a unique institute which addresses a national need that is not met by any other programs. The IMA is attempting to revive and strengthen the historical ties between mathematics and the other sciences (including the engineering disciplines). Thus it has taken on a three-fold task:

(A) To foster linkage between mathematics and the other sciences (and industry) by:

- identifying problems and areas of mathematical research of concern to other sciences,
- encouraging the development and study of new areas of mathematics needed for progress in other sciences, and
- stimulating collaboration between mathematicians and other scientists.

(B) To encourage the participation of mathematicians in areas of application by:

- providing an atmosphere conducive to the solution of major problems in various areas of mathematics,
- presenting important scientific and technological problems which provide real challenges to top level mathematicians, and
- demonstrating that first-rate mathematics can make a real impact in the sciences.

(C) To broaden the education of mathematicians by:

- introducing graduate students and instructors to the art of mathematical modeling through relevant examples,
- developing a curriculum in industrial mathematics, and
- broadening the horizon of graduate students from Participating Institutions who wish to pursue research in selected areas.

A mathematical research institute dedicated to this mission is particularly important at a time of heightened awareness of the importance of mathematical ideas to the sciences. Many mathematicians are seeking genuine problems to which such ideas can be applied. This redirection of emphasis comes at a time when many of the other sciences are encountering an ever-increasing demand for precise formulations of their problems. This is a time of unusual opportunity for the mathematical sciences. The need for mathematics can be found in many places. If the mathematical sciences are to take advantage of this opportunity for additional support by society as a whole, a major effort to improve communications between mathematicians and other scientists is essential.

2. The Mechanism.

The IMA addresses the realization of its mission by enabling both mathematicians and other scientists to share a stimulating research environment. The mechanisms used are flexible, appropriate to the chosen topic, and responsive to the needs of the participants.

Five types of programming have been developed: the **yearly programs**, the **summer program**, the seminar on **industrial problems**, the **industrial postdoc** program, and **educational** programs.

(A) The Academic Year Program

The yearly programs are carefully chosen to provide a meeting ground for mathematicians with engineers and other scientists from academia, industry, and government laboratories. The year's topic may be an area of application which requires a number of different mathematical fields (see for example the 1995–96 program on Mathematical Methods in Materials Science at

`http://www.ima.umn.edu/past_programs/msp/`),

or it may be a broad area of mathematics which is known to have applications in a number of scientific disciplines (for example, the 1997–98 program on Dynamical Systems at

`http://www.ima.umn.edu/dynsys/`).

Although the actual selection of topics is the responsibility of the Board of Governors, suggestions for topics and for persons to coordinate them are solicited from throughout the mathematical community. Suggestions are forwarded to the IMA's Scientific Advisory Board which evaluates ideas and advises the Director on the process of assembling organizers and developing formal proposals for presentation to the Board of Governors. The IMA is advised by an Industrial Advisory Panel, the department heads of Participating Institutions, and through informal contacts. There is no permanent faculty beyond the Director and Associate Director. This allows for maximum flexibility in the direction of resources and the choice of topics.

The form of coordination for each of the yearly programs has been evolving during the twelve years of IMA activity. During the first two years (starting in 1982) there were single coordinators in charge of the various programs or program segments. The third year had two co-coordinators together with two more members of an organizing committee. More recent programs have been developed by organizing committees of four to nine senior mathematicians.

A typical yearly program is designed around a cadre of senior scientists who have agreed to be in residence for longer periods, usually from three to ten months. These visitors provide continuity for the program and scientific guidance for the postdocs.

Each of these programs is divided into periods of concentration, and mathematicians, scientists and engineers with expertise in these areas are invited to stay at the IMA for periods of time varying between one week and an entire year. ¿From ten to fifteen workshops and tutorials, which are periods of activity of higher intensity lasting one or two weeks, are included as a part of the academic-year program. For the full list, see `http://www.ima.umn.edu/past.html`.

(B) The Summer Program

In order to be of service to a wider audience, the IMA (beginning in 1987) expanded its offerings and introduced a separate summer program. The basic objective here is to interest a broad set of mathematicians in research on challenging problems in a specific area of application (Robotics in 1987, Signal Processing in 1988, Robustness, Diagnostics, Computing and Graphics in Statistics 1989, Radar and Sonar 1990, Time Series 1990, Semiconductors 1991, Environmental Studies 1992, Adaptive Numerical Methods 1993, Molecular Biology 1994, Large-Scale Optimization 1995, Emerging Applications of Number Theory 1996, Application and Theory of Random sets 1996, Statistics in Health Sciences, 1997 and Coding and Cryptography 1998.) Topics are solicited and approved by the Board of Governors, just as for the academic-year programs. The IMA selects an Organizing Committee consisting of experts in the area of application who are familiar with mathematicians and who can plan a constructive and fruitful one- or two-month program. The summer program is much more than an ordinary conference in an area of application of mathematics. The primary objective is to broaden the base of mathematical scientists and of scientists working in the applied area. A secondary objective is to provide an atmosphere for intense interaction between experts in several aspects of the applied area. The training and guidance which these programs offer to the mathematical audience will, we believe, provide mathematical scientists with sufficient exposure to the fascinating problems of the applied areas to induce them to work in the areas. Such an influx of new blood can be expected to greatly accelerate progress in these important fields and, in turn, to assist in the development of technology.

(C) The Seminar on Industrial Problems

One of the major purposes of the IMA is to facilitate interaction between mathematicians and industrial and government laboratory scientists. An important component is to bring problems from industry and government laboratories to the attention of mathematicians and to encourage them to work on such problems. In order to achieve this goal the IMA developed a new program beginning fall 1987: A weekly Seminar on Industrial Problems. Industrial Scientists present one-hour talks, followed by informal discussion. During each year there are a number of visitors invited to spend time at the IMA for the purpose of studying such problems. In addition to faculty and IMA visitors, the Seminar includes a number of Ph.D. students as well as some undergraduate students. Serious mathematical problems of real significance in Industry are presented, and some faculty and students work to solve these problems. Follow-up contact between speakers and those who become interested in their problems is fostered. The IMA Seminar has been conceived as a model for interaction between industrial and academic scientists which can be replicated at other academic institutions.

Avner Friedman, the most recent past Director, has written ten books with the title, "Mathematics in Industrial Problems," detailing the problems presented during the first ten years of the Seminar and progress made by the participants toward their solution. All ten books have been published by Springer-Verlag as volumes in the series, *IMA Volumes in Mathematics and its Applications.* The first book was published as Vol. #17 (1988); Part 2 is Vol. # 24 (1989); Part 3 is Vol. # 31 (1990); Part 4 is Vol. # 38 (1991); Part 5 is Vol. # 49 (1992); Part 6 is Vol. # 57 (1993), Part 7 is Vol. # 67 (1994), Part 8 is Vol. # 83 (1995), Part 9 is Vol. #88 (1997), and Part 10 is Vol. 100.

As of this year, Industrial Problems talks are summarized shortly after they are presented on the world-wide web. See `http://www.ima.umn.edu/industrial/`.

(D) The Postdoctorates in Industrial Mathematics Program.

As an outgrowth of the Industrial Problems Seminar, the IMA has developed a program of Postdoctorates in Industrial Mathematics. Financial support comes 50% from an industrial corporation and 50% from the National Science Foundation. The program began September 1990 and has had twenty postdoctorates. These positions are designed to prepare mathematicians for research careers involving industrial interaction. Familiarity with partial differential equations and/or numerical analysis is desired, but no knowledge in engineering is required. Postdoctorates spend 50% effort working with a team of scientists from a sponsoring industry and 50% effort in their own research. The IMA provides scientific support for these postdocs, within the framework of a research seminar. See
`http://www.ima.umn.edu/people/all-ind-postdocs.html` for the complete list.

(E) Educational Programs

The IMA is running several educational programs at various levels:

(1) Mathematical modeling workshops.

In the Summer of 1992 the IMA introduced a four-week program in Mathematical Modeling for graduate students. Thirty students were chosen from a pool of about sixty applicants, worldwide; twenty-seven of the students chosen were from the United States. Each week three problems were presented by three instructors; the students broke up into three teams, and each worked for the entire week on one of the problems. Each team presented an oral report, followed by a written report; the totality of the written reports was published as an IMA Technical Report. The program was supported by a grant from the Sloan Foundation.

In the Summer of 1994, a similar program was held for instructors of undergraduates, both from four-year colleges and from universities. The program lasted three weeks, divided into two ten-day periods. At the beginning of each period four problems were presented by four tutors. The thirty participants were subsequently divided into four teams. Each team worked on one of the problems for ten days, and produced oral and written reports, at a level accessible to undergraduate students. The totality of the written reports was published as an IMA Technical Report, and was distributed around the country. The program was supported by the NSF Division of Undergraduate Science, Engineering and Mathematics Education.

A program in Mathematical Modeling for both graduate students and instructors of undergraduates was held in July 1998. The format was similar to the 1994 and 1996 programs. More details are given later in this Annual Report. The IMA intends to continue this program and further expand it to include high-school teachers. For information about the 1998 Modeling program, see `http://www.ima.umn.edu/modeling/`.

(2) A course in Industrial Mathematics.

Based on material developed in the IMA Seminar on Industrial Problems, a course was developed by Avner Friedman and Walter Littman. It is called, "Industrial Mathematics for Undergraduates." The course is based on case studies, and built in such a way that the student is not only exposed to real-life problems, but also gradually develops skills in differential equations and numerical methods. The development of the course was supported by two divisions of the National Science Foundation: the Division of Mathematical Sciences and the Division of Undergraduate Education. Two workshops have been held (in the Springs of 1993 and 1994) to brief instructors from other colleges and universities who are interested in teaching this course. The lecture notes have been published by SIAM in July 1994. There are currently about six institutions where the course is being taught. At the University of Minnesota, ten students enrolled in the course the first year, and the number has increased to 23 in the fourth year. See `http://www.ima.umn.edu/industrial/textbook.html`.

(3) Summer Schools for PI Graduate Students.

The IMA holds each year a Summer school for graduate students from its 29 Participating Institutions. The program lasts four weeks, and is based on four minicourses focused on one broad theme (*e.g.*, Probability, Partial Differential Equations, Differential Geometry, or Harmonic Analysis.) The program takes place on one of the Participating Institution campuses. It offers students a wide exposure to areas of research in their general field of interest, contact with students from many other schools, and team work experience in the afternoons. Approximately 40 to 45 students have been participating in this program each year. See `http://www.ima.umn.edu/PI/summergrad.html`.

(F) Software Benchmarking

It was suggested by the IMA Industrial Advisory Committee that the multiplicity of available software packages for scientific problems is difficult for industrial research groups to sort out. In particular, materials supplied by the developers typically do not delineate the type of problem for which the software is useful. Beginning with the April 21–25, 1997 **PDE Software** conference, the IMA has compared available software on scientifically challenging problems. This can be expected to save time and effort for scientists at universities and government labs as well as in industrial research groups.

See http://www.ima.umn.edu/resources/archives.html.

3. Regular Postdoctoral Members.

The postdoctoral members are a key component of the IMA programs. Postdoc positions are intended as research training and broadening appointments. We hope and expect that the postdocs will interact well with each other and with the senior visitors. In addition to offering a scientific challenge to the senior visitors and providing continuity, they bring flexibility and enthusiasm to the program. The postdocs are selected by means of an open competition. Promising and, if possible, proven research workers, who are open to new problems and who can be expected to have new ideas, are aggressively sought.

The active participation of the postdoctoral members is vital to the mission of the IMA. Their interests are regularly taken into account in the planning of workshops, lectures, and seminars and in the selection of short term visitors for the IMA programs. Various mechanisms are used to encourage the senior visitors to go out of their way to interact with the postdocs. Informal bag lunches, a postdoc seminar, a daily coffee hour, and Institute teas have all proved to be helpful. The IMA directors and coordinators strive to walk the fine line between over-direction and under-direction of research. It is hoped that the postdocs will use their IMA experience to grow to be among the future leaders in the mathematical-scientific community. For the complete list of the 165 Regular Postdoctoral Members, including current affiliations, see http://www.ima.umn.edu/people/all-reg-postdocs.html.

III. BOARD OF GOVERNORS

A twelve-member Board of Governors has been charged with giving overall scientific guidance to the IMA. Major policy decisions, including the appointment of the directors and the choice of topics of study and coordinators for each program, are made by the Board.

The membership of the Board during 1997–1998 and the periods of appointment are:

NAME	INSTITUTION	PERIOD OF TENURE
Lynne Billard	University of Georgia	Jan. 1, 1998–Dec. 31, 2000
Jennifer Chayes	Microsoft	Jan. 1, 1998–Dec. 31, 2000
James Keener	University of Utah	Jan. 1, 1998–Dec. 31, 2000
Paul Rabinowitz	University of Wisconsin	Jan. 1, 1998–Dec. 31, 2000
Robert Calderbank	AT&T Labs	Jan. 1, 1997–Dec. 31, 1999
Rosemary Chang	SGI, Incorporated	Jan. 1, 1997–Dec. 31, 1999
John Polking	Rice University	Jan. 1, 1997–Dec. 31, 1999
Ridgway Scott	University of Houston	Jan. 1, 1997–Dec. 31, 1999
David H. Bailey	NASA Ames Research Center	Jan. 1, 1996–Dec. 31, 1998
William Pulleyblank	IBM Thomas J. Watson Research Center	Jan. 1, 1996–Dec. 31, 1998
Al Taylor	University of Michigan	Jan. 1, 1996-Dec. 31, 1998
James Turner	Arizona State University	Jan. 1, 1996–Dec. 31, 1998
Mary Ellen Bock	Purdue University	Jan. 1, 1995-Dec. 31, 1997
David Levermore	University of Arizona	Jan. 1, 1995–Dec. 31, 1997
James McKenna	Bellcore	Jan. 1, 1995–Dec. 31, 1997
Alan Perelson	Los Alamos National Laboratory	Jan. 1, 1995–Dec. 31, 1997

FOR FUTURE REFERENCE ONLY:

1999–2001:

Douglas Arnold	Pennsylvania State University
Richard Karp	University of Washington
Thomas Magnanti	Massachusetts Institute of Technology
and **Juan Meza**	Sandia National Laboratory

IV. RESEARCH ACCOMPLISHMENTS IN MATHEMATICS FOR 1997-98: EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

1. ANNUAL PROGRAM ORGANIZERS

Martin Golubitsky of the University of Houston, Department of Mathematics is one of the organizers for the 1997-98 program year on "Emerging Applications of Dynamical Systems." He also co-organized the IMA workshop on "Pattern Formation in Continuous and Coupled Systems." He writes:

Pattern formation has been studied intensively for most of this century by both experimentalists and theoreticians, and there have been many workshops and conferences devoted to the subject. In the IMA workshop on Pattern Formation in Continuous and Coupled Systems held May 11-15, 1998 we attempted to focus on new directions in the patterns literature. In particular, we stressed systems and phenomena that generate new types of pattern (those that appear in discrete coupled systems, those that appear in systems with global coupling, and those that appear in combustion experiments) and on well-known patterns where there has been significant recent development (for example, spiral waves and superlattice patterns).

The participants at this meeting included, in more or less equal parts, experimentalists and theoreticians. One goal was to continue communication between these groups, and we were pleased by the result. Another goal was to familiarize a larger audience with some of the newer directions in the field, and again the result was very satisfying.

With these goals in mind, we decided to produce a nonstandard workshop proceedings. We did not want to publish a collection of research articles, which could have appeared elsewhere as refereed journal articles, nor did we want to publish a list of abstracts. Instead, we attempted to collect a series of mini-review articles of at most 15 to 20 pages (with extensive bibliographies) that would discuss why certain topics are interesting and merit additional research. The response has been quite heartening and we hope that readers will find these reviews a useful entry into the literature.

Joint work with Dan Luss, University of Houston (Chemical Engineering) and Steven H. Strogatz, Cornell University (Theoretical and Applied Mechanics).

John Guckenheimer from Cornell University, Department of Mathematics was the chair of the organizing committee for the 1997-98 year on "Emerging Applications of Dynamical Systems." His report follows:

I served as chair of the organizing committee for the program "Emerging Applications of Dynamical Systems" during the 1997-98 academic year. Thus, spending the year visiting the IMA was a unique opportunity for me. I think that I also played an important role in providing mentorship for the postdoctoral fellows in the program. During the course of the year, I engaged in technical discussions about problems of common interest with about half of these fellows, will mentor Kurt Lust at Cornell during 1998-99 and am continuing a collaboration with Kathleen Rogers and Warren Weckesser. The remainder of this report will discuss the research I accomplished and make suggestions for IMA reflecting my role as chair of the organizing committee.

Research

The main topic for my research during this past year has been the formulation and implementation of algorithms for computing periodic orbits of dynamical systems. Periodic orbits, together with their stable and unstable manifolds are fundamental objects in the phase space of a dynamical system. Stable periodic orbits are frequently observed as the limiting behavior of trajectories computed by numerical integration. For some purposes there are more effective ways of computing these orbits. Unstable periodic orbits that cannot be readily observed as the limits of numerical trajectories are also important in applications. I have been investigating algorithms that perform direct calculation of periodic orbits. Such algorithms are constructed in the framework of boundary value problems for ordinary differential equations. The primary innovation in our work has been to use a technique known as automatic or computational differentiation to achieve very high order accuracy in the methods. The results are impressive. The new methods achieve higher accuracy with coarser meshes. They are flexible in their use and straightforward as implementations of the mathematical problems they solve. This work is complementary to the work of Kurt Lust, and we have begun discussions about how to extend our methods to work with large systems.

There are two collaborative projects that I began during the IMA year. The first is a study of models of two coupled Josephson junctions, or equivalently two pendula coupled with a torsional spring. This two degree of freedom conservative

mechanical system has very complex and interesting dynamics. Don Aronson, Sebius Doedel, Bjorn Sandstede and myself have undertaken extensive numerical investigations of this system. We have developed a good understanding of some aspects of how the phase space of the system is organized. We are working on a paper that will describe our conclusions.

Kathleen Rogers, Warren Weckesser and I have been studying a different four dimensional vector field that represents two coupled oscillators. The system we are studying is a representation of two neurons coupled through reciprocal inhibition. Each of the oscillators is a relaxation oscillator with two time scales. Trajectories within the system evolve on the slower time scale, with brief periods of rapid transitions that occur on the faster time scale. As the model parameters of the system are varied, the patterns of transitions undergo bifurcation. Such phenomena have been studied as singular perturbation problems, but bifurcation theory for multiple time scale systems is not yet a highly developed subject. Thus, our numerical investigations are revealing new behavior that is interesting both for mathematical theory and for its biological interpretations.

Organization:

The program was implemented almost exactly as outlined in the original plans. I think that the set of activities was coherent and provided an excellent mix of interdisciplinary applications with emphasis upon the development of mathematical theory and algorithms. There are only a few comments that I offer for future improvements in the IMA programs.

The postdoctoral fellows were the focus of most of the IMA program. The selection committee placed an emphasis upon selecting new recipients of the PhD. In some cases, the participants did not complete their theses and other degree requirements until well into the year. This was a distraction from their ability to plunge into new projects. It is difficult to predict how long students will take to complete their degree requirements, but I recommend that additional attention be given to how IMA can best deal with this issue. There were six senior visitors at IMA for the entire academic year. This provided mentorship whose quality would have been difficult to achieve otherwise. Increased responsibility from the Minnesota faculty in the programs would be helpful, especially with the implementation of two year postdoctoral appointments.

Director's Comment: Starting in fall 1998, a two year postdoctoral appointment has become the standard. All postdocs are assigned faculty mentors. The first year of the postdoc experience involves participation in the IMA theme program. In the second year (when the IMA theme program may be inappropriate for the second year postdocs) there is a special seminar for these second year postdocs (and possibly some small special workshops) with faculty involvement to continue the mentoring experience. Also there will be a special teaching development program for some of the postdocs. This will include participation in the University of Minnesota Bush Foundation teaching development project that involves one-on-one mentoring of junior faculty by master teachers. For other postdocs who are interested, there will be opportunities for industrial interaction as well as teaching mentoring.

There were ten workshops that were included in our original plan for the year. Despite the long delay between original conception and the final workshops, the programs were lively and stimulating. Additional events were added to the program at a later date and contributed further to making the year's activities. For each workshop, we set a goal of bringing together groups of researchers who have not interacted strongly in the past. We achieved this goal in almost all cases, in some cases superbly. The final workshop on animal locomotion was noteworthy in having participants from four communities (dynamical systems, robotics, biomechanics and electrophysiology) engaged in intense discussions seeking to build a common understanding of legged locomotion and swimming. The workshops and tutorials that preceded some of the workshops were a focal point for the entire year. Despite IMA guidelines to limit the number of lectures at workshops, the programs inevitably grew to the point that were was limited time for informal discussions among the workshop participants and no time for anything else. Thus, the atmosphere of the IMA fluctuated from week to week. During some periods, especially at the beginning and end of the academic year, it was hardly possible to both attend IMA events and focus upon individual research. Overall, I think that the amount of time spent in workshops was good. I do not think it should be increased.

The IMA support staff was very helpful. Nonetheless, there were some glitches in the communication between the staff and workshop organizers. These improved during the year, but I recommend that there be clear policies of what reports will be provided to the workshop organizers about responses to invitations. I recommend that a database accessible to organizers of IMA participants be established to facilitate decisions about meeting programs after initial invitations are sent. While the organizing committee was given guidelines for how many invitations should be issued to different categories of visitors, it was not given information about budgets or expected numbers of acceptances. This made it harder to respond to inquiries from potential participants and difficult to know when the committee should consider recommending additional

invitations. I like the fact that the committees were not given fixed budgets, but more information about finances would helped the planning process.

Director's comment: Lists of confirmed workshop participants are now on the web, publicly available, and are updated regularly.

I think that the IMA could improve the interaction of its programs with the University of Minnesota, especially outside the mathematics department. Several of the workshops would have benefited from having a local member of their organizing committees with responsibility for encouraging participation of other members of the university community with the IMA. Conversely, little effort was made by the IMA to advertise University of Minnesota activities outside the mathematics department to its members. In particular, the winter biological sciences segment of the year could have been enriched substantially by greater involvement with other parts of the University.

Director's comment: In fact the IMA made considerable efforts to involve the biological community at the University, including personal phonecalls, regular mailings of the Newsletter to the appropriate biological science departments and a large email list aimed at faculty in these departments, with details of forthcoming workshops. Despite this, there was little success in promoting interaction with the biological and medical community at the University during 1997-98, a continuation of a long-standing problem in connecting the science and engineering disciplines with the biological community. However, during the 1998-99 year on Mathematicas and Biology, striking advances were made. More than 50 reseachers in medicine and biology at the University took part in the 1998-99 program. An ongoing Mathematics-Physiology Seminar was established, with speakers half from math and engineering departments and half from physiology and medicine. The seminar is now being upgraded to the McKnight Seminar in Mathematical Bioscience, hosted by the IMA, co-sponsored by the departments of Neuroscience, Chemical Engineering, Mathematics, and the Biological Process Technology Institute, and funded by the McKnight fund of the Graduate School. Hans Othmer, a distinguished mathematician specializing in Developmental Biology, has just joined the School of Mathematics and the Digital Technology Center. He will play an important role in helping the IMA nurture math-biology links. Additional joint math-biology positions, programs and much more interdiscipinary research effort are clearly in the offing.

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2. WORKSHOP ORGANIZERS

Eusebius Doedel of the California Institute of Technology is one of the organizers of the September 15 - 19, 1997 workshop on "Numerical Methods for Bifurcation Problems." The proceedings for this workshop is combined with that of a related workshop "Large-Scale Dynamical Systems, September 29 - October 3, 1997" and will appear in the IMA Volumes in Mathematics and its Applications as Volume 119: Numerical Methods for Bifurcation Problems and Large-Scale Dynamical Systems. Eusebius Doedel along with Laurette Tuckerman are the editors. The following preface is written for the combined proceedings:

The papers in this volume are based on lectures given at the first two workshops held as part of the 1997–1998 IMA Academic Year on Emerging Applications of Dynamical Systems. This IMA Year was organized by John Guckenheimer (chair), Eusebius Doedel, Martin Golubitsky, Yannis Kevrekidis, Rafael de La Llave, and John Rinzel. The scientific program had a strong computational component, as especially reflected in the first two workshops, which were entirely devoted to computational issues.

Workshop 1, "Numerical Methods for Bifurcation Problems," was held in the week of September 15–19, 1997. The organizing committee of this workshop consisted of Eusebius Doedel (chair), Wolf-Juergen Beyn, Bernold Fiedler, Yannis Kevrekidis, and Jens Lorenz. The workshop concentrated on complex computational issues in dynamical systems. 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. This workshop brought together mathematicians, numerical analysts, and computer scientists working on these problems. Particular topics included the detection of bifurcations and the development of

associated numerical and visualization software. Also considered were important theoretical issues, such as smooth factorization of matrices, self–organized criticality, and singular heteroclinic cycles. The numerical computation of manifolds, such as invariant tori and resonance surfaces were also studied.

Workshop 2, "Large Scale Dynamical Systems," was held during the week of September 29–October 3, 1997. It was organized by Laurette Tuckerman (chair), Edriss Titi, Herbert Keller, and Don Aronson. The numerical study of low-dimensional dynamics in large scale sets of ODEs and discretizations of PDEs necessitates the development of special purpose algorithms for simulations, stability and bifurcation analysis. This workshop addressed the development and application of special iterative methods for large scale systems. It also considered global model reduction schemes for PDEs. A related goal is to encourage the interpretation of large-scale physical problems as dynamical systems which, although high-dimensional, undergo low-codimension bifurcations. Applications of special interest include selected problems arising in fluid flows, and pattern formation in reaction-diffusion systems.

We would like to thank the IMA and the program coordinators for holding this workshop. We thank outgoing and incoming directors Avner Friedman and Willard Miller, and especially Robert Gulliver for coordinating the workshops, and the IMA staff for providing logistic support. We also thank Patricia V. Brick for her important contribution to this volume as editorial and production coordinator at the IMA.

Rafael de la Llave of the Department of Mathematics, University of Texas-Austin is the main organizer of the workshop on "Dynamics of Algorithms" held on November 17–21, 1997. The proceedings for this workshop appears in the IMA Volumes in Mathematics and its Applications as Volume 118. Linda R. Petzold of the Department of Mechanical and Environmental Engineering, University of California-Santa Barbara and Jens Lorenz of the Department Mathematics and Statistics, University of New Mexico serve as co-editors Below is the preface for the book:

Algorithms and dynamics reinforce each other since iterative algorithms can be considered as a dynamical system: a set of numbers produces another set of numbers according to a set of rules and this gets repeated. Issues such as convergence, domains of stability etc. can be approached with the methods of dynamics.

On the other hand, the study of dynamics can profit from the availability of good algorithms to compute dynamical objects.

Fundamental concepts such as entropy in dynamical systems and computational complexity seem remarkably related.

This interaction has been apparent in the study of algorithms for numerical integration of ordinary differential equations and differential algebraic equations from the beginning (Newton already worried how to compute numerical solutions of ODE's) and in other areas such as linear algebra, but it is spreading to more areas now, and deeper tools from one field are being brought to bear on the problems of the other.

This collection of papers represents the talks given by the participants in a workshop on "Dynamics of Algorithms" held at the IMA in November 1997. We hope that it can give a feel for the excitement generated during the workshop and that it can help to further the interest in this important and growing area full of fruitful challenges.

Laurette Tuckerman came with her husband, Dwight Barkley for the entire program year. She is one of the organizers of the IMA Workshop on Large-Scale Dynamical Systems held on September 29 - October 3, 1997. Her report follows:

I. Open shear-driven flows

A. Perturbed plane Couette flow

I collaborated with Dwight Barkley (year-long IMA visitor for 1997-8) on simulations of perturbed plane Couette flow. Plane Couette flow, the flow between two parallel plates translating in opposite directions, has long been known to be linearly stable at all Reynolds numbers, but to undergo a sudden transition to three-dimensional (3D) turbulence in the laboratory and in numerical simulations. In a search for intermediate states which might explain the transition mechanism, the experimental group of Bottin et al. inserted a thin wire into the flow, and observed 3D steady states. Barkley and I were able to numerically simulate these states and to determine that they arose from a subcritical pitchfork bifurcation. We have since been investigating the dependence of the scenario on wire radius, as well as the transition from these steady states to time-dependence and turbulence.

B. Symmetries in cylindrical wake flow

Dwight Barkley (year-long visitor) and Ron Henderson (participant in IMA workshop on Large-Scale Dynamical Systems in September-October 1997) numerically calculated the 3D instabilities of the periodic 2D flow in the wake of a cylinder. Two instabilities were found, called mode A and mode B, with quite different wavelengths and symmetry properties. Experimental evidence suggests that these two modes may interact, with resulting complex dynamics. Guided by Martin Golubitsky (IMA visitor in May 1998, co-organizer of workshop on Symmetry and of the year on Emerging Applications of Dynamical Systems), I began to undertake an analysis of the interaction of these two modes in terms of bifurcation theory in the presence of symmetry. This required mastering the concepts of invariant and equivariant normal forms, isotropy lattices and isotypic decompositions. Of great help in doing so was an informal study group organized by Warren Weckesser (IMA postdoc, 1997-8) in the Spring of 1998 on this very subject. Because the 2D cylindrical wake flow is periodic, the 3D stability analysis carried out by Barkley and Henderson is a Floquet analysis, and the symmetries are spatio-temporal, rather than purely spatial. In fact, one of the main focuses of the IMA workshop on Symmetry in May 1998 became the framework for analyzing spatio-temporal symmetry very recently developed by participants and speakers Peter Ashwin, Jeroen Lamb, Ian Melbourne, and Alistair Rucklidge.

II. Closed convective flows

A. Numerical work

I continued work on convection in various configurations. With Patrick Le Qur and Shihe Xin, I completed an article on convection driven by equal and opposite horizontal thermal and concentration gradients. This turned out to involve a subcritical circle pitchfork followed by a supercritical drift pitchfork in the case of a vertically periodic cavity and a transcritical bifurcation in a square cavity. With Daniel Henry (IMA visitor during September-October 1997) and Alain Bergeon (participant in IMA workshop on Large-Scale Dynamical Systems), I completed a survey article on surface-tension-driven (Marangoni) convection due to combined thermal and concentration gradients. Henry, Bergeon, and I also continued work on Marangoni convection in three-dimensional rectangular containers, and we discussed the interpretation of this work in the context of symmetries of rectangles and squares with Edgar Knobloch (IMA visitor during May 1998) and Gabriela Gomes (year-long IMA visitor during 1997-8).

B. Analytic work

Convection driven by competing thermal and concentration gradients was extensively studied in the 1980's as a physically realizable prototype of a codimension-two point, at which a curve of Hopf bifurcations was annihilated by joining a curve of steady bifurcations, accompanied by the existence of heteroclinic infinite-period cycles. These curves describe the critical Rayleigh number (temperature difference) for convection as a function of separation parameter (ratio of solutal to thermal effects).

I discovered that these bifurcation curves, i.e. the linear stability diagram, could all be derived from the following property: The eigenvalues of a 2 2 matrix whose entries depend linearly on a control parameter undergo either avoided crossing or complex coalescence, depending on the sign of the coupling (product of the off-diagonal terms) near the point at which the diagonal terms intersect. My interpretation would organize binary convection around the case of zero separation parameter, at which the coupling vanishes and the eigenvalues simply cross transversely.

More surprising was the realization that the nonlinear properties could also be explained in this way. The structure of the equations turns out to be such that the system of coupled nonlinear equations describing the steady states reduce to a 2 2 eigenvalue problem with the square of the convection amplitude as eigenvalue. The structure of the matrix is almost identical to that governing the linear stability; only the interpretation changes. For instance, complex coalescence for the nonlinear problem must be interpreted as a saddle-node bifurcation (disappearance of a pair of solutions) instead of as the onset of oscillatory behavior. In developing this framework, I benefitted greatly from conversations with John Guckenheimer (program organizer and year-long visitor), Edgar Knobloch (visitor, May 1998), and Fritz Busse and Hermann Riecke (speakers at the May 1988 workshop on Symmetries).

Publications

Written and submitted while at IMA:

D. Barkley and L.S. Tuckerman, *Stability analysis of perturbed plane Couette flow*, submitted to Phys. Fluids.

D. Barkley and L.S. Tuckerman, *Linear and nonlinear stability analysis of perturbed plane Couette flow*, in Proceedings of the Seventh European Turbulence Conference, ed. by U. Frisch (Kluwer Academic Publishers, Dordrecht, 1998).

L.S. Tuckerman and D. Barkley, *Bifurcation analysis for time-steppers*, in Numerical Methods for Bifurcation Problems and Large-Scale Dynamical Systems ed. by E. Doedel, B. Fiedler, Y. Kevrekides, W.-J. Beyn, J. Lorenz, L.S. Tuckerman, E. Titi, H.B. Keller, and D. Aronson (Springer, New York, to appear).

Revised while at IMA

S. Xin, P. Le Qur, and L.S. Tuckerman, *Bifurcation analysis of double-diffusive convection with opposing horizontal thermal and solutal gradients* Phys. Fluids. 10, 850-858 (1998).

A. Bergeon, D. Henry, H. BenHadid, and L.S. Tuckerman, *Marangoni convection in binary mixtures with Soret effect*, J. Fluid Mech., in press.

Researched at IMA, now being written

L.S. Tuckerman, D. Henry, and A. Bergeon, *Binary fluid convection as a 2 by 2 matrix problem*, to be submitted to Physica D.

A. Bergeon, D. Henry, H. BenHadid, and L.S. Tuckerman, *Three-dimensional Marangoni instability pattern selection*, to be submitted to J. Fluid Mech.

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3. VISITORS/SPEAKERS

Dwight Barkley of University of Warwick, Mathematics Institute was one of the long-term visitors. He submits the following report:

My work at the IMA falls into two broad classes which I shall describe separately.

I. Waves in excitable media.

I completed a new fast computer program for simulating and visualizing in real time waves in three-dimensional excitable media. Two examples of such media are the Belousov-Zhabotinsky chemical reaction and cardiac tissue. It has been known for some time that weak parametric forcing provides a simple method for control of spiral waves in two-dimensional excitable media. Essentially nothing was known, however, about the effect of parametric forcing in three-dimensional excitable media where solutions are much richer. Dr. Rolf Mantel (IMA postdoc) and I investigated in the effect of weak parametric forcing of two of the most fundamental structures in three dimensions: the so-called axisymmetric scroll ring and the twisted scroll ring. We determined to high accuracy the spatio-temporal dynamics of both structures with and without forcing. Most significantly we were able to understand the dynamics through normal form equations based on non-compact symmetry groups. This understanding benefited tremendously from the conversations with several visitors to the IMA (B. Sandstede, I. Melbourne, B. Fiedler, and C. Wulff). The work has been submitted for publication [1].

II. Instabilities and dynamics of fluid flows.

Collaborations took place with both long and short term IMA visitors on several problems in fluid dynamics. L. Tuckerman and I performed extensive numerical linear and nonlinear stability computations of a classical shear flow, so-called plane Couette flow, perturbed with small ribbon in the center of the flow. We were able to confirm that experimentally observed streamwise vortices in this fluid flow resulted from a subcritical symmetry breaking bifurcation of the basic laminar flow [2]. We found transition to temporally complex states, signifying the onset of a weak form of turbulence. We are currently pursuing this line of research to understand the scenario through which the flow becomes turbulent as the size of geometric perturbation in decreased to zero.

I collaborated with L. Tuckerman in her work on developing a suite of large-scale bifurcation methods based in time-stepping algorithms [3].

IMA visitors M.G.M. Gomes, R. Henderson, and I studied three-dimensional transition in the separated flow generated by a sudden expansion in an otherwise parallel flow channel. This geometry is known as a backward-facing step. We found

that the first instability encountered as the Reynolds number is increased leads directly to a three-dimensional state, and that surprisingly the flow remains linearly stable to two-dimensional disturbances for very large Reynolds number [4].

I developed a heuristic description of nonlinear three-dimensional flow patterns in the wake of flow past a circular cylinder [5]. A collaboration was begun with IMA visitors L. Tuckerman and M. Golubitsky in which we plan to extend this work with a combination of symmetric bifurcation theory for bifurcations from periodic orbits and large-scale computer simulations of the governing fluid equations. Based on the initial work done while at the IMA we have successfully obtained a grant of over 1600 hours of supercomputer time at IDRIS (France) for performing the necessary computations. We expect that a number of other fluid flows might also be examined in this way in future years.

References:

1. R.M. Mantel and D. Barkley, "Parametric forcing of scroll-wave patterns in three-dimensional excitable media," Physica D (submitted).
2. D. Barkley and L.S. Tuckerman, "Stability analysis of perturbed plane Couette flow," Phys. Fluids (submitted). IMA preprint 1545.
3. L.S. Tuckerman and D. Barkley, "Bifurcation analysis for Timesteppers," IMA preprint 1564.
4. D. Barkley, M.G.M. Gomes, and R.D. Henderson, "Three-dimensional instability in flow over a backward-facing step" in preparation for J. Fluid Mech.
5. D. Barkley, "Nonlinear stability theory for three-dimensional wake transition," in proceedings of the ASME International Fluids Engineering Division Summer Meeting, Washington, D.C. June 1998.

Fernanda Botelho from the University of Memphis, Department of Mathematics was in the IMA from January 10 - May 31, 1998. She expresses the following:

"I want to thank you for this opportunity. My stay has been most challenging intellectually while profiting from a great work environment. I feel, I return to the University of Memphis in a new and better professional mode, thanks to this productive sabbatical leave at your Institute. Finally, let me add a word about your staff. I was always very impressed by the efficient way all my logistics issues were dealt with, this ranging from housing information to TEXand computer questions as well as local entertainment. Everyone was very helpful. Definitively, IMA is one of the best places I have ever been."

Gene Cao of Michigan Technological University, Department of Mathematical Sciences attended the workshop: Algorithmic Methods for Semi Conductor Circuitry, November 24-25, 1997 and the special Workshop: Knowledge and Distributed Intelligence (KDI) Opportunities in the Mathematical Sciences, March 7, 1998. He has the following impression:

It is certainly a successful workshop, especially in bringing researchers from industry/EE Depts to interact with each other. They seem so happy with the workshop that they will organize another one next year even without IMA's involvement/support. It would be even better for them as well as for mathematicians, however, that more attention is paid to get mathematicians involved.

It was a big commitment for me to attend this workshop (under the $1500/year travel budget. Industrial participants may not have such constraint for math faculty, according to a Bell Labs member). I have to confess that I was a little bit disappointed since it seem too similar to an engineering workshop.

Benoit Dionne, University of Ottawa, Department of Mathematics and Statistics was one of the long term participants. The following summarizes his research activities during his visit at from September 1 to October 31, 1997:

During my visit at the IMA, I worked on a project with Martin Krupa (Technical University of Vienna) who was also visiting the IMA in the Fall 1997. We started on this project shortly before arriving at the IMA. The project is still not complete but we hope to complete it soon.

In this project, we study period doubling in arrays of identically coupled identical cells. Each cell is a system of coupled Josephson junctions. The typical symmetry group of the system of differential equations governing the array of cells is the wreath product of a subgroup of permutations on the cells (global symmetry) and the permutations on the Josephson

junctions in each cells (each cell has the same internal symmetry). The Equivariant Branching Lemma for period doubling of mappings is used to determine the existence and symmetry of each branches of solutions emanating at a period doubling bifurcation point. The Equivariant Branching Lemma for period doubling of mappings is applied to the Poincare map associated to a periodic solution that has the full symmetry.

I also had the opportunity during my visit at the IMA to meet Sebius Doedel (Concordia University). A possible collaboration may come out of our discussions. The project that I have in mind will be to add to auto (a software developed by Sebius Doedel to follow branches of solutions of differential equations) the functionality to do branching at period doubling bifurcation points in systems with symmetries. I should be on leave next Fall and I hope to visit Sebius Doedel at that time.

Bernold Fiedler of Free University of Berlin, Instiute of Mathematics was a long term visitor. He comments on some research activities he undertook during his fall 1997 stay at the IMA:

Sandstede and Scheel have proved a result concerning Hopf bifurcation from constant speed travelling waves to travelling waves with oscillating wave speeds. Their result is the first to account for Hopf bifurcation from the continuous spectrum.

In the seminar "Josephson Junctions," organized by Aronson and Doedel, significant progress was made concerning topologically nontrivial heteroclinic orbits.

D. Lewis and B. Fiedler discussed the behavior of discretization schemes near relative equilibria to compact and noncompact group actions. It turns out that certain discretization schemes are particularly well adapted to the computation of secondary symmetry breaking bifurcations from relative equilibria.

The geometry of intersections of vortex filaments of three-dimensional, time-dependent scroll wave patterns in excitable media was investigated, both analytically and numerically, by the IMA PostDoc R. Mantel and B. Fiedler. Paper & video are in preparation.

During a visit of B. Fiedler to participating institution UW, Madison, progress was made with S. Angenent concerning stationary versus heteroclinic blow-up of maximal compact invariant sets in scalar reaction diffusion equations.

With J. Alexander at participating institution UMD, College Park, B. Fiedler has clarified the two simplest possibilities of transversely nondegenerate Hopf-type bifurcation from a degenerate line of equilibria. Such situations arise in certain graphs of linearly coupled oscillators. R. Pego has pointed out a relation to (spurious) binary oscillations in certain discretization schemes for systems of conservation laws in one space dimensions. Particularly helpful were additional discussions concerning coordinate blow-up and slow-fast singular perturbation decompositions with C.K.R.T. Jones.

With I. Melbourne at participating institution U of Houston, Texas, B. Fiedler discussed new possibilities for an emerging normal form theory of vector fields near relative equilibria to noncompact group actions. An application is bifurcation from twisted scroll waves to genuinely three-dimensional, non-planar waves travelling with oscillating wave speeds along a periodically wobbling axis. The associated circular vortex filament, linked to the axis of propagation, will undergo periodic shape changes which preserve linking. With careful experiments just emerging, these mathematical predictions are ahead of observations, in this case.

Bernold Fiedler also took part in an informal seminar as he describes below.

"Continuous Spectra"

Continuous Spectra arise naturally in linear partial differential equations on unbounded domains. Traditional areas include hyperbolic wave equations, Schroedinger operators, scattering theory, etc.

More recently, a variety of nonlinear wave phenomena and patterns have been investigated, both analytically and numerically, in the context of semilinear reaction diffusion equations. From an applied point of view, patterns in the Belousov-Zhabotinsky reaction are a primary source of inspiration: travelling waves, target patterns, spiral waves, meandering spirals have been observed. Other applications with similar phenomeno- logy include convection patterns in fluids and CO-oxidation on platinum monocrystals.

The seminar started with a thorough review of functional analysis results on (various types of) continuous spectra and their per- turbation properties. Results on travelling waves and their continuous spectra were reviewed next. Progress was made in the understanding of spectra both in the infinitely extended discrete case and the continuous limit. Behavior under truncation was also discussed.

A new result by Bjoern Sandstede and Arnd Scheel was presented, which addresses Hopf bifurcation from a pulse type

travelling waves due to the continuous spectrum crossing the imaginary axis.

Finally, the issue of spectral intervals appearing in the bifurcation of higher-dimensional tori was reviewed by George Sell.

I would like to thank all participants for their active interest and for the pleasant and inspiring atmosphere of this not-so-planned seminar in a wonderful working environment.

Wulfram Gerstner of Swiss Federal Institute of Technology Lausanne, Centre for Neuro-mimetic Systems was a participant in the workshop: Computational Neuroscience held on January 14-23, 1998. He writes:

This is a short note just to say how much I liked my stay at the IMA during the workshop on computational neuroscience in January. I thought it was a great workshop which took place in an environment which was just perfect for such an event. Thanks to all of you who put in so much effort to make things run smoothly.

M. Gabriela M. Gomes of Universidade do Porto was a long-term participant. Following is a direct quotation from her.

"I am looking forward to my next visit to the IMA in May. Let me add that 1997/98 at the IMA was a very good year for me, and I would like to thank the IMA again for having invited me."

Below is her report on research related to visit to the IMA in 1997/98:

Project 1 : Three-dimensional instability in flow over a backward-facing step (with Dwight Barkley and Ronald Henderson) We performed a three-dimensional computational stability analysis of flow over a backward facing step. The analysis shows that, as the Reynolds number is increased, the first absolute linear instability of the steady two-dimensional flow is a steady three-dimensional bifurcation. Stability spectra were obtained for representative Reynolds numbers. (This project was partially carried out while Dwight Barkley and myself were visiting the IMA in 1997/98. The use of the IMA computer facilities was crucial in obtaining the final stability results and flow visualizations.)

Project 2 : Spatial hidden symmetries in pattern formation (with Isabel Labouriau and Eliana Pinho) IMA Preprint Series 1582, August 1998 Partial differential equations that are invariant under Euclidean transformations are traditionally used as models in pattern formation. These models are often posed on finite domains (in particular, multidimensional rectangles). Defining the correct boundary conditions is often a very subtle problem. On the other hand, there is pressure to choose boundary conditions which are attractive to mathematical treatment. Geometrical shapes and mathematically friendly boundary conditions usually imply spatial symmetry. The presence of symmetry effects that are "hidden" in the boundary conditions was noticed and carefully investigated by several researchers during the past 15-20 years. Here we review developments in this subject and introduce a unifying formalism to uncover spatial *hidden symmetries* (hidden translations and hidden rotations) in multidimensional rectangular domains with Neumann boundary conditions. (This review was written during my visit to the IMA in 1997/98.)

Project 3 : Black-eye pattern: a representation of three dimensional symmetries in thin domains The first experimental evidence for Turing patterns was observed in the CIMA reaction by De Kepper and colleagues. Ouyang and Swinney performed further experiments in a "thin" layer of gel. Patterns observed at onset were basically two-dimensional. However, beyond onset a structure that does not typically occur in two-dimensional domains was observed - the black-eye pattern. In this letter we use the full three-dimensionality of the patterned layer to find a setting where black-eye patterns naturally occur. We propose that black-eye patterns have the symmetry of a body centered cubic lattice. (This research was initiated during my visit to the IMA in 1997/98. Discussions with other visitors, including workshop participants, were very helpful. My recent visit to the IMA in September 1998 was also of relevance to this project.)

Project 4 : Symmetry and symmetry-breaking approches to strain formation in pathogen populations The antigenic diversity exhibited by many pathogens motivated the construction of mathematical models describing the interaction of a large number of strains. Depending on the particular pathogens, two strains can either act by inhibition (cross-immunity) or by enhancement. The nonlinear differential equations modeling such systems can achieve a high level of complexity which hides the underlying features of the system. By introducing a set of plausible symmetry assumptions, we provide the systems with a structure that powerful group theoretical tools can handle. These approaches provide a static view of pathogen evolution. From an evolutionary perpective, a natural set of speculative questions which will be addressed is: What is the mechanism responsible for strain formation? How different do the pathogens have to be in order to be classified into different strains? Are new strains created indefinitely? What happens to the

old ones? Is there a limit to the number of different strains that can co-circulate? We will try to answer some of these questions by modeling the mechanism of strain formation as a symmetry-breaking bifurcation. Contact with field work will be maintained through this work. (This project was identified during my visit to the IMA in 1997/98, and will be carried out in the University of Warwick. I will visit the IMA again in May 1999 to attend tutorials and workshops in epidemiology.)

Daniel Henry of Ecole Centrale de Lyon participated in the IMA Tutorial on Numerical Methods for Bifurcation Problem. He shares the following:

- Introduced by Laurette Tuckerman to Gabriela Gomes, we had the project (Alain Bergeon and myself) to collaborate with her on the problem of hidden symmetries. We had done some computations in a 3D Marangoni-Benard situation and it seemed interesting to do some extra computations with different boundary conditions and with a certain size of box, in order to analyse the structure of the solutions. But in fact my stay in Minneapolis was too short to begin practically on the subject, and since my return I was too busy with administrative and educational tasks.
- Before coming to Minneapolis, I got the acceptations from European scientific associations to organize a workshop on "Continuation Methods in Fluid Mechanics." One of the co-organizers was Laurette Tuckerman. During my stay in Minneapolis, we had the opportunity to meet H. Keller and E. Doedel, and so we decided to invite them to our workshop as invited speakers. This workshop will take place in France in Aussois (the Alps) in September 1998.

Mike Jolly from Indiana University, Department of Mathematics was a one year visitor. Below is his report:

1. Accurate Computation of Inertial Manifolds (with R. Rosa and R. Temam)

We have implemented an algorithm developed by Rosa [6] to compute inertial manifolds to arbitrary accuracy. This approach differs from that of most approximate inertial manifolds in that convergence can be achieved with the dimension held fixed. The algorithm was tested on an ODE for which we know an exact inertial manifold. This example serves to demonstrate how to choose certain algorithm parameters to optimize the convergence. We also applied the algorithm to the Kuramoto-Sivashinsky equation, and carried out an analysis of the effect of truncating the higher modes for PDE cases such as this. Finally the algorithm was adapted to compute inertial manifolds with delay and its efficiency compared to a shooting method. A paper on this work is nearly complete. We plan to submit this an IMA preprint, as well as for publication.

2. Accurate Computation of Center Manifolds (with R. Rosa)

We have adapted the algorithm described above to compute center manifolds. We have validated the code on some simple ODEs, and plan to illustrate how it can be advantageous over the traditional method of local approximation by Taylor expansion by considering some cases where the manifold is not smooth. We will restrict the scope of a paper on this work to the ODE case, in order to reach a wide audience.

3. Computation of Solutions to an Elliptic Boundary Value Problem on an Infinite Cylinder. (with R. Rosa and E. Titi)

We are applying the algorithm described above, but now in a PDE context. Kirchgassner [4] showed that for this problem there exists a two-dimensional center manifold. Some analysis is required to ensure that all conditions are met for convergence. This is a computationally intensive application. A code has been developed, and some preliminary analysis carried out. We will compare to work by Fuming Ma [5], which used a different method to compute the manifold for this particular problem.

4. Evaluation of Dimension Estimates for Inertial Manifolds of the Kuramoto-Sivashinsky Equation

Up to now estimates for this dimension have typically been of the form dim cLb, where c is a universal constant and L is the length of the domain. Over the last decade there has been a dramatic reduction of the exponent b, yet c remains an elusive quantity, the end result of a series of transformations of other universal constants after considerable analysis. The purpose of this work is to determine (and to some extent reduce) such universal constants and thereby arrive at a means to calculate the dimension of an inertial manifold. This was done by reworking the analysis of Collet et al. [1] to determine the radius if an absorbing ball, and then that of Temam and Wang [7] to determine the dimension of an inertial manifold.

The numbers in the end are quite large, compared to what we speculate from computational evidence. We then calculated how the dimension would vary if the estimate for the absorbing ball could be reduced, to see what it might take to make the rigorous dimension close to what we conjecture. A paper on this work is nearly ready to turn in as an IMA preprint, and submit for publication.

5. Computing Invariant Manifolds by Evolution (with J. Lowengrub)

A convenient method for the computation of global (un)stable manifolds for ODEs is to evolve the boundary of a local (un)stable manifold. This approach allows for the capture of global manifolds which fold over in a complicated fashion. The basic difficulty in computing in this way manifolds of dimension two and higher is that different growth rates will cause trajectories representing the manifold to ultimately be concentrated in the fastest direction. Guckenheimer and Worfolk [3] get around this by eliminating the flow in the direction tangent to the curve one is evolving. The effect is to generate geodesic curves on the manifold, and in many cases this will result in a good representation of the manifold. Yet there are certain situations where such geodesic curves would miss large portions of the manifold. We have developed a method which replaces the tangential flow with one that preserves equal arclength representation of the curve of evolution. This is tantamount to evolving a PDE, which seems to pose some interesting computational challenges of its own. The computations for this project are nearly complete, and we will soon begin to write up the results.

6. Estimate of an Effective Viscosity Generated by Iterated Approximate Inertial Manifolds (with C. Foias and Oscar Manley)

Approximate inertial manifolds allow for the approximation of an evolutionary equation such as the Navier-Stokes equation (NSE) to an equation governing the evolution of only the low modes. In an earlier work, Foias, Manley and Temam [2] showed that that a certain approximate inertial form (AIF) can be put into the same form as the original NSE, with nonlinearity enjoying the same orthogonality condition to ensure dissipativity. In doing so the viscosity is modified, and becomes dependent on the velocity. The process however can be repeated on the AIF, an indefinite number of times, resulting in final AIF which has the same nonlinearity as the first AIF, but now an infinite number of terms in the "effective" viscosity. We have since obtained a bound for the effective viscosity in most of phase space and interpret a flow across any regions where the effective viscosity is infinite as being a purely linear flow with infinite speed. We have also explored a similar iterated procedure using a better AIF at each stage. Finally we have derived a new recurrent estimate for the high modes of the exact solution of the NSE. The last two results were obtained while the three investigators were together at the IMA in April, 1998. We will put all the work together for an IMA preprint and eventual submission for publication.

7. Visualizing Global Bifurcations of the Kuramoto-Sivashinsky Equation (with M. Johnson and I. Kevrekidis)

We have used the visualization of two-dimensional stable and unstable manifolds to understand a connection between two seemingly unrelated global bifurcations. They involve two heteroclinic connections, one of Silnikov type, the other triggered by the collision of two manifolds. One amusing aspect of this work is that the images are strikingly similar to those of a famous archeological find of a Viking ship (The Oseberg), so much so in fact that we are using nautical terminology for many complicated dynamical objects to make the presentation simpler. A paper on this is nearly ready to submit as an IMA preprint, as well as for publication.

8. Using Inertial Manifolds in the Computation of Lyapunov Exponents (with Erik Van Vleck)

We have outlined a plan to compute Lyapunov exponents using inertial manifolds. We expect that the extra work in computing the flow on the manifold will be more than offset by the reduction in the size of the associated linear system which must be evolved to compute the exponent. The conception of project came as a result of our interaction at the IMA.

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Juergen Moser of Fachinformationszentrum Karlsruhe, Production Division was a guest of the School of Mathematics and had an office in the IMA. He reports:

During my visit , April 1-30,1998 at the University of Minnesota I had scientific contact with various members at the Department of Mathematics, the IMA as well as the Geometry Center. I gave:

1) a Colloquium lecture “Dynamical systems and the viscosity solutions of the Hamilton-Jacobi equation” and

2) a seminar talk “A Lagrangian proof of the invariant curve theorem for twist mappings” (R. Moeckel can provide you with the details).

A manuscript (jointly written with H. Jauslin and H.O. Kreiss) conerning the first lecture was distributed at the time, and a preliminary preprint (jointly with M.Levi) also was left at the IMA. Both topics led to interesting discussions with visitors as well as with permanent members. The first topic was motivated by the goal for constructive methods for finding invariant tori for Hamiltonian systems, methods which can be numerically implemented. This leads to nonlinear partial differential equations, which are modified to parabolic differential equations by adding an artificial viscosity term. We considered, in particular, the model case of the Burgers equation with an added periodic forcing term and asked for periodic solutions. They can be obtained as asymptotic limit, as the time goes to infinity, from the any solution of the initial value problem.

One question is to find quantiative information about the rate of this asymptotic approach, a problem about which H. Weinberger and I had fruitful discussions. We could establish that this rate is exponential in time, but it remains to study the dependence of the exponent in terms of the viscosity coefficient. This leads to a Harnack inequality for a linear parabolic differential equation, where one needs quantitative information about the relevant constant. Numerical experiments indicate a linear dependence. About nonlinear parabolic differential equations I learned interesting ideas, especially about the analyicity of the solutions from (my roommate) Titi, connected with the methods developed by Foias. Also with D. Sattinger I had a valuable exchange about the solutions of the Korteweg-de Vries equation, especially those solutions whose initial values are given by elliptic or hyperelliptic functions, and his numerical experiments. These discussions did not lead to final results, and I was the one who profitted from them.

R. Moeckel explained his interesting work on the n-body problem, trying to find connecting orbits between unstable configurations. With a number of younger mathematicians I discussed the new proof of the twist theorem, presented at my seminar lectures. At the Geometry Center R. McGehee and Eduardo Tabacman were very helpful in providing computer graphics relevant for dynamical systems. I plan to use these in my plenary lecture at the International congress ICM 98 in Berlin.

It goes withought saying that I had many mathematical discussions with other other guests, students and faculty members, such Guckenheimer. Foias, A. Friedman, Aronson, Serrin. The visit was indeed fruitful for me, and hopefully also for the institute.

Yakov Pesin of Penn State University, Department of Mathematics was a visitor from September 27 - October 2. He shares the following:

During my visit I worked with M. Jiang (a postdoc of the Institute) and we completed the paper: “Equilibrium measures for coupled map lattices: existence, uniqueness, and finite-dimensional approximations.”

The paper is accepted for publication in Comm. of Math. Phys. and acknowledgement to the IMA is gladly expressed.

Let me use this oportunity and thank you again for the warm hospitality that I received at the Institute.

Fernando Reitich of the University of Minnesota, School of Mathematics reports the following:

Our IMA-related research activities over the past academic year were mainly focused on initiating a research program in Mathematical Biology, in preparation for the upcoming year at IMA. Due in part to our experience in the mathematics of materials (which, incidentally, was greatly enhanced by our participation in the highly successful 1995-96 IMA program on materials science) we were naturally led to the investigation of a class of free boundary models of biological processes. More precisely, we undertook a study of some simplified models that have been proposed to understand the basic mechanisms and the possible control of tumor growth. Our initial contribution [Friedman and Reitich, 1998b] consisted of a detailed analysis of radially symmetric models applicable, for instance, to the so-called "multi-cellular spheroids." Our results include the nonlinear asymptotic stability of steady states within the class of radial solutions. Stability results are of crucial importance, as they can be directly correlated to a tumor's ability for local invasion of surrounding tissue and subsequent metastasis. A true understanding of stability diagrams, however, demands a thorough description of possible equilibrium configurations. This, in turn, motivated our most recent work [Friedman and Reitich, 1998a] where we established, to our knowledge for the first time, the existence of non-radial steady states. Our current efforts are devoted to the analysis of the stability properties of these newly found equilibria, which will have obvious implications in our concurrent search, jointly with J. Lowengrub, of effective algorithms for the numerical simulation of the growth process.

Regarding the educational activities at IMA we organized, together with F. Santosa, a workshop for graduate students on Mathematical Modeling in Industry which was held from July 22 to July 31, 1998. The workshop, the fourth one convened at IMA, brought together 34 mathematics students from graduate programs across the country for an intensive 10-day modeling experience associated with industrial problems. The students were divided into six teams, each working under the guidance of an experienced industrial researcher who was asked to pose a real-world problem that their companies need to resolve. As we expected (and, in reality, as we desired) the problems that were proposed to the students were not the neat, well-defined academic exercises found in classrooms, but rather they consisted of stimulating open-ended industrial pursuits. In most cases, the problems required new insight for their formulation and solution. The students spent ten days working on the problems and were asked to present their results orally on the last day of the workshop. In addition, the teams prepared written reports which we have collected in [Reitich and Santosa, 1998].

Finally, we have also kept heavily involved in technology transfer activities at IMA. Indeed, over the last few months we have initiated collaborative projects with researchers at the Honeywell Technology Center, Honeywell Inc. (Minneapolis, MN), and at the MR Head Design division, Seagate Recording Heads (Minneapolis, MN). The Honeywell project relates to signal-launching onto multi-mode optical waveguides. The objective is to design an effective numerical tool for the prediction of modal energy distribution upon the guide's illumination. In addition to the difficulties posed by the possible existence of a large number of guided modes, the problem can be compounded by manufacturing imperfections that result in perturbed material or geometrical parameters. We expect that our recent AFOSR supported work on analytic continuation methods for problems of wave propagation will have a bearing on the treatment of this latter problem. On the other hand, our experience in materials science (and, particularly, in magnetic composites [Reitich and Simon, 1997]), should prove valuable in our joint venture with Seagate. The goal there is to design models and numerical algorithms that will aid in the design of the read and write heads within their hard disk drives. The main mathematical issues to be resolved relate to nonlinear macro- and micromagnetics models and calculations.

Relevant Publications

[Friedman and Reitich, 1998a] A. Friedman and F. Reitich, *On the existence of spatially patterned dormant malignancies in a model for the growth of non-necrotic vascular tumors*, submitted.

[Friedman and Reitich, 1998b] A. Friedman and F. Reitich, *Analysis of a mathematical model for the growth of tumors*, J. Math. Biol., to appear.

[Friedman and Reitich, 1998c] A. Friedman and F. Reitich, *Asymptotic behavior of solutions of coagulation-fragmentation models*, Indiana Univ. Math. J., to appear.

[Reitich and Santosa, 1998], F. Reitich and F. Santosa, *Mathematical modeling in industry: IMA summer program for graduate students*, July 22-31, 1998, IMA Preprint #1589, October 1998.

[Reitich and Simon, 1997], F. Reitich and T. Simon, *Modeling and computation of the overall magnetic properties of magnetorheological fluids* , Proc. of the 36th IEEE Conference on Decision and Control (1997).

Frances K. Skinner of the Playfair Neuroscience Unit The Toronto Hospital, Western Division provides the following impression after his visit:

I would like to express my sincere thanks for the invitation to attend the & Computational Neuroscience workshop (Jan 14-23) in IMA's annual program on "Emerging Applications of Dynamical Systems." Thank you for the support and arrangements done on my behalf.

I came home mentally exhausted, but exhilarated at having learnt so much in a short space of time. It was certainly a pleasure to have had this opportunity to learn and interact in this exciting field. I sincerely hope that such a workshop can be repeated sometime in the future.

J. Leo van Hemmen of Physik Department, TU-Muenchen expresses the following:

I would like to express my sincere gratitude to the IMA for such a wonderful meeting on Computational Neuroscience. It is also a great pleasure to me to mention the expert help of the IMA staff. The meeting was important, and timely, in that people could meet and discuss in such a stimulating atmosphere. The more so since the mathematics of neuronal information processing and its modeling, exciting - and florishing - as they may be, are still in their infancy. In short, the meeting was extremely fruitful and stimulating to me - in fact, to nearly all the participants.

Thanks to all of you!

Steven H. Strogatz of Cornell University, Theoretical and Applied Mechanics was a participant in the IMA Workshop on "Computational Neuroscience" held on January 14-23, 1998. He was also in residence for spring quarter 1998, Symmetry and Bifurcation. Below is his report:

I enjoyed the hospitality of the IMA for three months, from April 1, 1998 to June 30, 1998, as part of the year-long program in Emerging Applications of Dynamical Systems. This was an incredible three months for me – I had no idea the IMA was so wonderful. I am now one of its biggest cheerleaders. The administration of the IMA is smooth and seamless, making the lives of the mathematicians as pleasant as possible. And the mathematical program was superb, both in terms of subjects and the caliber of visitors in attendance.

First, let me summarize the collegial aspects that were such an important part of my time at the IMA. Almost every day I had stimulating discussions over lunch or dinner with the postdocs (Warren Weckesser, Kathleen Rogers, Shinya Watanabe, et al.) and some of the other long-term visitors (Dwight Barkley, Laurette Tuckerman, John Guckenheimer, and David Chillingworth were the most frequent companions.) Even breakfast was a special occasion. Several IMA visitors stayed at The Wales House, and we got to know each other in that delightful setting. In particular, for the first month of my stay, I had the pleasure of eating breakfast every day with Jurgen Moser, one of the greatest mathematicians of this century. I'll also have fond memories of breakfast conversations with Bill Langford, Edgar Knobloch, Ian Melbourne, Claudia Wulff, and many others too numerous to list.

When I wasn't eating, I worked on the following mathematical projects:

Laser dynamics:

My time at the IMA allowed me to work intensively (via e-mail) with my graduate student Stephen Yeung, enabling us to complete a paper about the nonlinear dynamics of a laser [1]. Some geometric aspects of that problem had puzzled us, but with the help of IMA postdoc Mark Johnson and his visualization software, we finally began to understand the intricate three-dimensional phase portrait underlying the laser system. IMA postdoc Ricardo Oliva was also a helpful partner in this project. I also benefited from conversations with Rachel Kuske, a professor in the industrial part of Minnesota's math department, and an expert on laser dynamics. Finally, the IMA provided great hospitality to my visitors Raj Roy, Henry Abarbanel, and their students and postdocs – we are all part of an NSF sponsored collaboration on synchronization and communication in nonlinear optical systems, and we held one of our quarterly meetings during a weekend at the IMA.

Time delay in coupled oscillators:

A second paper with Stephen Yeung [2] deals with the effects of time -delayed coupling on the collective behavior of the Kuramoto model, a classic model in nonlinear dynamics. We finished this paper while I was at the IMA, and we also got some ideas for a new direction on the problem, thanks to a penetrating remark made by Kurt Wiesenfeld, a visitor to the IMA during the Pattern Formation workshop. Kurt suggested his idea during a brainstorming session – just the sort of informal discussion that happens all the time at the IMA, and that is so important to mathematical progress.

Small-world networks:

In early June, much of my time was spent dealing with the media excitement about my Nature paper with Duncan Watts

on small-world networks [3]. In a span of just a few days, we were interviewed by several major newspapers, magazines, and radio shows. Articles about our work appeared in the The New York Times, Washington Post, UPI, Reuters, Business Week, Science News, and New Scientist, and are scheduled to appear in Physics Today (September issue), Discover Magazine (December) and Popular Science. We've also been interviewed on TV by CBS News and the BBC, and on radio by National Public Radio (Morning Edition), Voice of America, German Nationwide Radio, and the BBC. (A list of web links to some of these articles appears at the end of this report.) The IMA graciously took messages as needed, and allowed me to make international phone calls to these reporters.

Reviews:

Toward the end of my stay, I wrote a News and Views article for Nature magazine [4] and a book review for Computers in Physics [5].

Workshops and seminars:

I also suggested and participated in an informal seminar on bifurcations with symmetry, led by Warren Weckesser. This seminar helped several of us beginners come up to speed with the symmetry aspects of the Pattern Formation workshop. Other workshops in which I participated were Pattern Formation (co-organizer), Animal Locomotion (participant), Dynamical Systems Methods in Oceanography (participant), and Control theory (participant).

References:

[1] M. K. Stephen Yeung and Steven H. Strogatz, "Nonlinear dynamics of a solid-state laser with injection," Physical Review E (in press, October 1998).

[2] M. K. Stephen Yeung and Steven H. Strogatz, "Time delay in the Kuramoto model of coupled oscillators," submitted to Physical Review Letters, July 1998.

[3] D. J. Watts and S. H. Strogatz, "Collective dynamics of 'small-world' networks," Nature 393, pp.440-442 (1998).

[4] Steven H. Strogatz, "Nonlinear dynamics: Death by delay," Nature 394, pp. 316-317 (1998) (invited News and Views article).

[5] Steven H. Strogatz, Book Review of "The Genesis of Simulation in Dynamics," Computers in Physics (in press).

Giovanni Zanzotto of CNR-Universita di Padova, Dipartimento di Metodi e Modelli Matematici submits the following report:

I have participated to the IMA program on 'Symmetry breaking and pattern formation.' Mostly, during my visit I have studied, with Prof. L. Truskinovsky (Aero Dept., U of MN), the energy landscape of a class of crystalline materials whose solid phases have progressively reduced symmetries and a corresponding sequence of spontaneous symmetry breakdowns. While the project did not originate at the IMA, I developed it a great deal during my 1998 visit; also, during that time I did benefit from some interaction with such renown experts in this field as M. Golubitsky and I. Stewart, who had organized the IMA program.

In detail, my research with Prof. Truskinovsky focused on the description of the temperature-dependent strain energy function for a crystal exhibiting tetragonal-orthorhombic-monoclinic ('t-o-m') martensitic transformations. A very well-known material undergoing these phase transitions is for instance zirconia (ZrO2), which is the main toughening agent in transformation-toughened ceramics. In the applications (for instance in turbine blades) the 'active' zirconia inclusions in an inert ceramic matrix are used to control and enhance the otherwise low ductility of the ceramic composites.

Our main point of interest was the description of an elastic crystal exhibiting a t-o-m triple point in its pressure-temperature phase diagram. As is well known, the variety of available microstructures increases with the number of coexisting phases, so one expects that in the vicinity of a triple point the number of (meta)stable microstructures will also be the highest a desired effect for improving the performance of active materials. On this topic we are finishing a paper titled 'Elastic crystals with a triple point', which later this Fall will be submitted to the Journal of the Mechanics and Physics of Solids (the IMA will be acknowledged in the paper).

In this paper we identified the order parameters and derived an appropriate 'minimal' Landau-type energy for the t-o-m crystals, as the lowest-order polynomial in the strain variables exhibiting the complete sets of minimizers with the desired symmetries. This allowed us to study various features of the triple point and of the nearby region in the phase diagram, where three distinct sets of energy wells with different symmetries (parent phase and product-phase variants) coexist. Our

energy function is suggested in part by the analysis of a simple discrete mechanical system with four particles connected by six Lennard-Jones springs, which shows instabilities and bifurcations analogous to those characteristic of the t-o-m crystals.

To our knowledge, ours is the first analysis of a triple point from the perspective of nonlinear elasticity theory, which presents the energy function exhibiting the complete set of the relevant (local and absolute) minimizers. What we learn from the analysis of the t-o-m crystals is rather general, and can be largely transferred to other elastic crystals with nonvariant points in their phase diagram. Furthermore, our method for writing the constitutive function suggests a general procedure for constructing energy functions also for any other type of martensitic symmetry-breaking transformations involving solid phases with a progressive reduction of symmetry.

There are several mid- and long-term goals that we plan to pursue in the (near) future, because the results obtained so far clarify the status of the triple and other nonvariant points in the phase diagrams of crystalline materials, and pose several questions which we are currently investigating. One question can be phrased as follows: How many (meta)stable phases can be observed for a material in the pressure-temperature region near a triple point? We have reasons to think that it is possible to have more than three phases coexisting in the vicinity of a triple point so that the number of coexisting phases is larger than what is predicted by the celebrated Gibbs phase rule.

Since we take metastable states into account (relative energy minimizers), this observation is actually not in contradiction with Gibbs' results, but rather represents a nontrivial extension that may lead to a better understanding of a variety of processes that take place in the vicinity of the triple or other nonvariant points (this is a significant issue, for instance, in the geological and mineralogical applications).

A natural extension of this line of research is the modeling of materials with more than three phases (numerous materials are known to exhibit several stable phases with distinct symmetries). We have written a prototypical energy function exhibiting up to six types of relative minimizers with distinct symmetries (cubic, tetragonal, rhombohedral, orthorhombic, monoclinic, and triclinic) and we plan to investigate this energy function, studying in particular the pressure-temperature ranges in which there is coexistence of many (meta)stable phases. We plan to compare the prediction of our model with existing experiment.

This research emphasizes the importance of studying specific regions in the phase diagrams characterized by a particular abundance of coexisting energy minimizers (relative or absolute). This is of interest also to materials science because in these regions an 'active' material may exhibit a dramatically increased ability to form equilibrium microstructures in response to the imposed loads, displacements, magnetic fields, etc., and hence display an improved macroscopic behavior.

One of our future goals is obtaining criteria for the design of the new active materials whose phase diagrams exhibit triple points in desirable positions, for instance at pressures and temperatures closer to room conditions than those at which nonvariant points are usually found. One main question regards the methods in which a triple point can be 'moved around' in the phase diagram. Two main ways can be envisaged to do so: (a) by selecting specific compositions for suitable alloys, and (b) by placing transforming inclusions into elastic matrices which may stabilize otherwise unstable phases, or by creating thin films where the stabilizing surface effects are essential.

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4. POSTDOCS

Miaohua Jiang currently affiliated with Wake Forest University, Department of Mathematics and Computer Science has served as an IMA postdoc during the 1997-98 year on "Emerging Applications of Dynamical Systems." He reports:

My year at the Institute for Mathematics and its Applications participating the program Emerging Applications of Dynamical Systems has been an exciting and productive one. I enjoyed the well-organized workshops including those special ones: seminars presented by people from industry; workshop on NSF new programs; and the summer programs. Besides the educational benefit of the program – that will be seen in the years to come, the program provided me an opportunity to work closely with many program participants to complete several of my research projects and also initiated many new directions in my research in applications of dynamical systems. The following is a list of work I have done during the program year.

- 1. Met with Pesin during September workshops on dynamics of large systems. Finalized our joint work on the

existence, uniqueness, and finite dimensional approximation for SRB-measures of hyperbolic lattice systems. The article was accepted by Comm. Math. Phy. and is published in 1998.

- 2. Completed my article on the Entropy Formula for SRB-measures which extends the results of the joint work with Pesin. The article was accepted for publication by the Journal of Statistical Physics and will be published in 1999.
- 3. With the help of the computing facility and personnel at IMA, I finished research on the dynamics of spatial averages of quadratic maps with Monte Carlo methods. The results was submitted to Physics D and the paper is currently under revision.
- 4. Under the direction of John Guckenheimer, I studied the dynamics and bifurcations of a three dimensional system modeling thermo instability. I showed that contrary to common believes, the system does not possess homoclinic orbits. The technical report was issued as a preprint of IMA.
- 5. Initiated a joint work with Rafael de la Llave on the smooth dependence of SRB-measures on the hyperbolic lattice systems (A paper was finished in April 1999 and submitted to Comm. Math. Phy.. It was also issued as a preprint of IMA.)

References

1 M. Jiang and Y. B. Pesin 1998 Equilibrium Measures for Coupled Map Lattices: Existence, Uniqueness, and Finite-Dimensional Approximation Commun. Math. Phys. 193, 675-711 (also IMA Preprint series 1525)

2 M. Jiang 1999 The entropy formula for SRB-measures of lattice dynamical systems, to appear, J. Stat. Phys.

3 M. Jiang, Quasi-Monte Carlo studies of spatial averages of quadratic maps, 1998 1-7 + 16 Illust., IMA Preprint series 1584, submitted.

4 M.Jiang, Dynamics and bifurcations of a 3D system modeling thermal instability, 1998 1-13 + 6 Illust., IMA Preprint series 1583, submitted.

5 M. Jiang and R. de la LLave, Smooth Dependence of Thermodynamic Limits of SRB-measures, 1-34, 1999, IMA Preprint series 1615, submitted.

Mark E. Johnson, who received his PhD from Princeton University's Program in Applied and Computational Mathematics, can now be found in the webspace as a Technical Yahoo at Yahoo!, Inc. His statement follows:

During my one-year position as a postdoc at the IMA's year on Emerging Application of Dynamical Systems, I had the privilege to interact with an excellent cross-section of the dynamical systems community in an environment ideal for such purpose.

Some of the highlights of my year at the IMA are as follows:

1. During one of the initial workshop's Software Demonstration sessions, I performed a real-time demonstration of SCIGMA, a software application which was developed in collaboration with Michael S. Jolly (one of the program's year-long visitors) and Yannis G. Kevrekidis (one of the program's organizers and my PhD advisor). SCIGMA is a interactive graphics tool developed for Silicon Graphics workstations. By computing and visualizing collections of invariant objects with SCIGMA in the phase space of a dynamical system, one can make powerful observations about the geometry of complex objects within this space.

The software demonstration was used to illustrate to the audience some of the powers of such a tool. This demonstration also led to the organization of an exciting evening session, held at the Geometry Center, involving the comparison of several similar algorithms and applications developed by program participants Michael Dellnitz, Hinke Osinga & Bernd Krauskopf, John Guckenheimer, and Eusebius Doedel. In addition to these people, there were several other visitors in attendance (Bernold Fiedler, Jim Yorke, and Marty Golubitsky to name a few).

Such an interaction would normally be considered rare, but in the IMA's environment, is considered typical.

2. Ongoing research with Mike Jolly continued during our overlapping time at the IMA. We continued work, also in collaboration with Yannis Kevrekidis, on using the SCIGMA software application to uncover interesting global bifurcation phenomena found to occur in a three-dimensional approximate inertial form for the one-dimensional periodic Kuramoto-Sivashinky equation. These observations were made by computing and observing the interaction of collections

of two-dimensional stable and unstable invariant manifolds of steady states and limit cycles. The observed phenomena has been described in a recently submitted paper called "The Oseberg transition: visualization of global bifurcations for the Kuramoto-Sivashinsky equation." When this work was still in progress, I delivered a Postdoc Seminar in April, 1998, called "Interacting two-dimensional manifolds and global bifurcations for the Kuramoto-Sivashinsky Equation."

3. The long-time dynamics of the Kuramoto-Sivashinsky equation has been studied extensively under the assumption that the equation model phenomena on a homogenous medium. A question that was studied with Edriss Titi, several times a visitor to the IMA during the year, and Yannis Kevrekidis, was how spatial perturbations might affect the long-time dynamics (such as the existence and radius of its absorbing ball, dimension of the attractor, etc.) of this model equation. The results of our efforts appear as a chapter in my thesis.

In addition to these interactions, I enjoyed numerous interactions with George Sell, Steve Strogatz, Herb Keller, Ciprian Foias, Dwight Barkley, and, of course, the other postdocs and visitors throughout the year. None of this would have been possible without the organization and hospitality of the IMA's staff.

Kurt Lust of United Technologies Research Center is one of the IMA Postdoctoral Members in Industrial Mathematics. He makes the following report:

From September 1997 till June 30, I was a postdoctoral member for the 1997-98 year on Emerging Applications of Dynamical Systems. In July, I became a postdoctoral member in industrial mathematics, working with the Dynamic Modeling and Analysis group at the United Technologies Research Center in East Hartford, Connecticut. Research at the IMA My dissertation research concentrated on numerical methods for bifurcation analysis, in particular for large- scale problems with low-dimensional dynamics. Initially, I continued work in this direction. During my Ph.D. research, I developed methods based on single- and multiple shooting for bifurcation analysis of large-scale problems. I made some improvements to my single shooting based code, and development of the multiple shooting based code continued. I also developed a method to compute the Floquet multipliers in multiple shooting and some collocation codes with very high accuracy. This method is based on a matrix decomposition (the periodic Schur decomposition) developed at the IMA during the year on Applied Linear Algebra (1991-1992) by G. Golub, P. Van Dooren and A. Bojanczyk. During my stay at the IMA, I made some refinements to my implementation. I also set up a test case together with E. Doedel, using matrices generated by AUTO97. The results were very good. J. Guckenheimer and S. Watanabe have also used the code in some of their experiments with a novel method for computing periodic solutions developed by J. Guckenheimer.

I prepared an article on the convergence behavior of my single shooting based methods that will appear in the proceedings of the workshop on Large Scale Dynamical Systems, held at the IMA in September 1997.

Another paper, which I started writing at the K.U.Leuven, was revised and sent back to the IMA Journal on Numerical Analysis. Some time was also spent in investigating future development, e.g., extension towards collocation, both for partial differential equations and delay differential equations, and implementation on parallel computers.

At the end of February, I had a job interview at the United Technologies Research Center. This company is very interested in using dynamical systems techniques to enhance the performance of their products. Though the result of the job interview was positive, I decided that I really wanted to spend a year at Cornell University with J. Guckenheimer. A project was set up together with United Technologies, which lead to the change to industrial postdoc status during July and August. During my stay at United Technologies, I spent most of my time working on an alternative technique for bifurcation analysis of large-scale problems. Instead of doing a bifurcation analysis of the large-scale problem, a low-dimensional model with similar behavior is constructed and analyzed. The goal was to build a model for the large coherent structures observed in fluid flow in a diffuser for varying angles of the diffuser and at a fairly high Reynolds number. The model must be able to capture behavior at varying angles since one goal was to study bifurcations as the angle of the diffuser varies. The approach chosen was to gather data from simulations using a CFD code, analyze the data using the proper orthogonal decomposition technique, and then build a model by projecting on the POD modes. Because of the complex structure of the equations (our large-scale model was the Navier-Stokes equations for a compressible fluid) and the varying spatial domain, we have chosen not to do a Galerkin projection of the system of equations. This would not lead to a cheap in our case, and is very hard to do. Instead, we did a projection of the system of ordinary differential equations defined by the CFD code. This procedure is implemented as a layer around the existing CFD code and grid generation code. This method is not cheap either, but is much easier to program and easier to extend to other equations. The model was implemented as a Matlab MEX routine written in Fortran 77 (the language of the CFD code we used). Some first results with the model were obtained by the end of August. Simultaneously, other researchers at UTRC, together with Y. Keverekidis, P. Holmes and a Ph.D. student at Princeton, are investigating other types of modeling such as black-box modeling using artificial neural networks and a traditional Galerkin projection of the Navier-Stokes equations for incompressible flow. During my stay at UTRC,

I've also optimized their CFD code for their workstations and made various improvements to enhance the robustness of the code. We have also discussed the use of tools for bifurcation analysis of large-scale problems for their problems.

It was very interesting to learn how research is done in an industrial environment. A good understanding of how companies work is essential in setting up successful collaborations with industry. I am convinced that the experiences which I gained during the summer will be very useful in my later career, whether in academics or in an industrial or government research lab, and I feel that more researchers in academics should spend some time in such an environment. Other aspects I joined all the workshops held at the IMA during the period September to June and went to most of the talks in those workshops. From the core program workshops, the fall workshops were most interesting for me though I also learned many interesting ideas from the spring workshops. In the winter workshops, I learned about an other application area I was not familiar with before my stay at the IMA. I also very much enjoyed the workshop on "Algorithmic Methods for Semiconductor Circuitry" held in the fall and the workshop on Dynamical Systems in Oceanography that was added to the program in the spring. The workshop on Algorithmic Methods for Semiconductor Circuitry was a clear proof of the lack of communication between different research areas: in several talks, primitive numerical methods were presented that have been known for a long time in other areas and have reached a high level of sophistication. This clearly demonstrates the importance of bringing together people working in various, strongly or only vaguely related, areas. A successful example of such a workshop is the workshop on Animal Locomotion and Robotics, held at the IMA in June.

I also had many interesting conversations with visitors at the IMA. I had several discussions with H. Keller during the fall. The algorithms which I developed are based on his work with various graduate students, and it was interesting to learn about new developments at Caltech. I also had interesting discussions with some of the other visitors during the fall, including W.-J. Beyn, W. Govaerts, M. Friedman and L. Tuckerman. I had several discussions with Y. Kevrekidis during his visits at the IMA and have tried to set up some collaboration. Due to lack of time, much of that work is done by a Ph.D. student in Leuven. Y. Kevrekidis is also cooperating in the project on low-dimensional modeling using PODs. I hope I can collaborate more intensely with him at Cornell University. I also got in contact with D. Barkley of the University of Warwick in the U.K., and it is very likely that I will move to Warwick after my stay at Cornell University if I decide to stay in academics. Conclusion The environment of the IMA had a very broadening effect on my research. I've laid several contacts that will hopefully last long and determine my further career. The collaboration with United Technologies was also very successful and will be continued during my stay at Cornell. Together with United Technologies, I will continue to work on the modeling of the diffuser and start a new project on modeling of combustion instabilities, which is a new area for me. Combustion is an area of quickly growing importance and a good choice to further broaden my research. My skills on analysis of dynamical systems will be very useful in both projects. I am convinced that the year at the IMA helped me a lot in getting ready for a tenure track position or a senior research position in a research laboratory. It will definitely have a large effect on my further career in research.

Rolf-Martin Mantel was one of the 1997-98 regular postdocs. He writes:

I spent a productive year at the IMA in the programme on Applications of Dynamical Systems. I actively participated in most workshops, especially by giving a computer demonstration on spiral waves at the Workshop on Computational Neuroscience. I also participated in the post-doc seminars, where I presented my PhD research, and in informal seminars on continuous spectra in fall and on bifurcations with symmetry in spring.

I prepared one paper of my PhD thesis for publication as an IMA preprint. It was co-written with Dwight Barkley of the University of Warwick, who was also a year-long visitor at the IMA. Its title is "Parametric forcing of scroll-wave patterns in three-dimensional excitable media."

During my year here, I entered a close collaboration with Bernold Fiedler, who was a visitor in fall and did several subsequent short visits. As a result, we have a multimedia paper in preparation with the working title "Crossover Collisions of Scroll Wave Filaments."

In this paper, we take Dwight Barkley's computer simulation "EZSCROLL" that simulates scroll waves in three space dimensions and adapt it with a new filament detection algorithm that also detects collision of filaments. We show various examples of scroll wave collisions, and we prove analytically that there is only one generic way scroll waves can collide. My contribution to the paper was concentrated on the numerical side. I pursued some research on the meander to hypermeander bifurcations of spiral waves in two dimensions. I was able to detect the onset of several meander frequencies but did not find any unbounded motion at high spatial resolutions. I learned that calculating the locus of the bifurcations leading to the added meander frequencies is a very challenging numerical problem.

The neuroscience workshop encouraged me to look for "lurching" spirals in two space dimensions. I found out that adapting PDE software from diffusion coupling to synnaptic coupling is a major task that challenges several of the core

assumptions of the "EZSPIRAL" software.

Out of the contacts with visitors I made, I was offered a job by Klaus Boehmer, and I aim to do future collaboration with Michael Dellnitz. I was also glad to meet several people working in topics closely related to mine, especially Claudia Wulff and Bernd Sandstede.

Marina Osipchuk of Honeywell Technology Center (HTC) is one of the 1997-98 Industrial Postdoctoral Members. She reports:

As a participant of the Industrial Program affiliated with the Honeywell Technology Center (HTC) I enjoyed the combination of the industry-related research and collaboration with the IMA participants for the program year. In the course of the project at the HTC we developed a low-cost accurate contact establishment and attitude determination strategy for a constellation of low Earth orbit satellites. While working on my industrial project I benefited from discussions with the organizers of the program: Profs. Fadil Santosa, Blaise Morton, Avner Friedman, Walter Littman, Rachel Kuske as well as the other industrial postdocs: Gilberto Lopez and Shari Moscow.

Participation in the annual program on "Emerging Applications of Dynamical Systems" expanded my knowledge in latest theoretical issues in dynamical systems. The scope of application areas presented at the workshops fascinated me. I enjoyed the opportunity to work closely with the participants of the workshops (Edriss Titi, Yannis Kevrekidis, Stas Shvartsman) on control of reaction-diffusion systems.

I also participated in an informal seminar on bifurcations with symmetry organized by Warren Weckesser. The seminar study served as a great introduction for the forthcoming workshop on Pattern Formation. In addition I participated in a weekly postdoc seminar and gave an overview talk on control of nonlinear systems as an introduction to the workshop on Nonlinear Identification and Control.

In addition, I revised a paper on the research that I started at the University of California, Irvine. The paper "Geometry and Inverse Optimality in Global Attitude Stabilization" was published in Journal of Guidance, Control and Dynamics.

Research

Attitude determination in satellite constellation

The "fiber-like" quality along with globally provided, space-based communication are the distinctive features of the broadband low-Earth orbit (LEO) satellite system Teledesic. The high speed, high quality of data transmission is achieved via intersatellite communication (each satellite has laser links to eight adjacent satellites). To handle the system networking the satellites have to be positioned and oriented much more precisely than satellites that communicate only with the ground. In addition, to facilitate satellite crosslinks the satellites will have on-board computers, thus increasing the cost of the system and power consumption in the orbit. Our goal was to develop navigation concepts that employ the existing communication system and thus eliminate the additional cost of conventional sensors.

The developed attitude determination strategy employs maximum probability search to establish contacts between non-oriented satellites in the groups and updates the estimate of the satellite attitude. Once the satellites are linked within the group the accuracy in attitude determination is limited only by hardware resolution. Efficiency in contact establishment is guaranteed while using the suggested nonlinear programming search. Finally, the described attitude determination method exploits existing communication hardware thus eliminating additional cost for conventional sensors.

Nonlinear control of dissipative evolutionary equations

The dynamics of the evolutionary equation is governed by a PDE with infinite-dimensional state of the corresponding control problem. On the other hand, the implementation issues such as discrete location of actuators, limited memory capacity and finite precision of computers call for a finite-dimensional control.

A nonlinear model reduction method of the discretized PDE was employed to approximate the long-term behavior of the PDE dynamics by a dynamical system of finite, small dimension. Closing the obtained system with a linear controller effectively stabilizes the PDE truncation locally; this does not, however, exploit the fully nonlinear reduced model. On the other hand, nonlinear, feedback linearizing control results in large control spillover to the residual modes. We design an inverse optimal control law for the reduced system. The stability and robustness of the full closed-loop system with respect to fast unmodeled dynamics was analyzed using singular perturbation and bifurcation techniques. Simulation results demonstrate the performance advantages of the inverse optimal control law over the linear quadratic regulator in stabilizing models derived from our illustrative example.

Kathleen A. Rogers of the University of Maryland has completed her 1st year as an IMA Postdoc. She writes:

Workshops and Seminars

As a Postdoctoral Member of the IMA during the theme year Emerging Applications of Dynamical Systems, my main responsibilities included attending workshops, seminars and tutorials. This provided a unique opportunity for me to gain a broad perspective of the latest theoretical and numerical issues in dynamical systems as well as to become acquainted with some new application areas. After completing my thesis last year, I felt that I was lacking a more global view of current research in applied mathematics, and dynamical systems in particular. I took this opportunity to expand my knowledge in several areas of dynamical systems such as geometric singular perturbation theory, continuous spectrum of operators, bifurcation in the presence of symmetry, and pattern formation in reaction-diffusion systems, just to name a few. I was also intrigued by the variety of application areas that were presented throughout the year. Workshops which focused on neurobiology, cardiac rhythms, and calcium dynamics provided an in depth look at applications in which mathematics is just starting to make an impact. During the course of the year, I also enjoyed hearing about the other applications of various techniques and methods in dynamical systems. For instance, one invited speaker focused on the role differential-algebraic equations play in modeling chemical reactions and another focused on using reaction-diffusion equations to model the life cycle of mold spores.

In addition to the scheduled workshops and seminars, I participated in two informal weekly seminars. In the fall, Bernold Feidler organized the 'working' seminar on continuous spectra. The seminar began with understanding the definitions of the various kinds of spectra that operators can have and continued onto discussions about algorithms for numerically calculating continuous spectra. During the spring quarter, Warren Weckesser organized a 'working' seminar on bifurcations in the presence of symmetry. This seminar consisted of reading some elementary papers on bifurcations in the presence of symmetry in order to become familiar with the vocabulary. There were also presentations of 'work in progress' on which we tried to offer suggestions.

Talks

In addition to participating in the workshops and seminars associated with dynamical systems, postdoctoral members are expected to organize, attend and speak at the weekly 'Postdoc Seminar'. I volunteered to organize the postdoc seminar for the winter session, in which the workshops focused on biological application areas. Since these were new areas for most of the postdoctoral members, I tried to incorporate an introduction to the areas as part of the regular postdoc seminars. As with all the postdocs, I gave a talk in the postdoc seminar. I was also invited to speak at the Applied Math Seminar at the University of Arizona.

Research

My research accomplishments for this year encompassed three separate projects. The first project involved writing papers on my dissertation research, stability of twisted elastic rods as a model for supercoiling in DNA minicircles. The second project was an industrial problem presented to the IMA by General Motors involving welding and clamping of beams. The third project investigated a system of four ordinary differential equations that serve as an idealized model of two reciprocally inhibitory neurons.

DNA: A twisted elastic rod is widely accepted to be a qualitative model of supercoiled DNA. Mathematically, a twisted elastic rod is represented by an isoperimetrically constrained calculus of variations problem. That is, the equilibria of the rod exactly correspond to critical points of a certain functional subject to integral constraints. Similarly, critical points which correspond to constrained minima are said to be stable equilibria. My thesis comprises a series of practical tests which determine which critical points correspond to constrained minima, or equivalently, which equilibria are stable. My research goals in this particular area were to complete papers that were based on my thesis research. During this year, one of the papers

R.S. Manning, K.A. Rogers, & J.H. Maddocks, *Isoperimetric Conjugate Points with Application to the Stability of DNA Minicircles* was accepted and will appear in the Proceedings of the Royal Society of London: Mathematical, Physical and Engineering Sciences. Additionally, a paper with Leon Greenberg and John Maddocks was written and submitted:

L. Greenberg, J.H. Maddocks, & K.A. Rogers, *The Bordered Operator and the Index of a Constrained Critical Point*.

During a trip to EPFL in Lausanne Switzerland to visit my advisor, the results for the final paper from my dissertation were strengthened and generalized to include stability exchange results at non-simple folds as well as simple folds. These generalizations required a significant rewrite of the paper

K.A. Rogers & J.H. Maddocks, *Distinguished Bifurcation Diagrams for Isoperimetric Calculus of Variations Problems and the Stability of a Twisted Elastic Loop*.

This last paper is still in preparation, but should be submitted shortly.

Welding and Clamping of Beams: Experiments on shells have demonstrated that the sequence in which two shells are clamped and welded affects the final shape of the shells. Such a situation arises in assembling automobiles. In that setting, the consequences of different final shapes can be costly if, for instance, the final shape of the two shells (or automobile parts) causes the larger structure not to meet required specifications. In order to understand why this sequence dependence arises Dr. Danny Baker and Dr. Samuel Marin of General Motors Research and Development Center, Fadil Santosa, Associate Director for Industrial Programs at the IMA, and I proposed models of clamping and welding of beams which demonstrate this sequence dependence.

Consider the variational formulation of beams with small initial curvature derived by Washizu (Variational Methods in Elasticity and Plasticity,Pergamon Press, 1982) in which the initial shape of each beam will be denoted by $f_1(s)$ and $f_2(s)$, the perturbation from the initial shape in the horizontal direction will be denoted by $u_i(s)$ and the perturbation from the initial shape in the vertical direction will be denoted by $w_i(s)$. The coordinates of the beams after displacement will be given by $x_i = s + u_i(s)$ and $y_i = f_{ii}(s)$.

The first model which we considered allowed only vertical displacement of the beam ($u_i(s) \equiv 0$, $w_i(s) \neq 0$), which implies that the clamping mechanism does not allow 'slipping' of the beam as the clamp is closed. Effectively the clamping mechanism takes a prespecified point on each beam, s_1 and s_2, and forces it to a prespecified location y_0 with a prespecified slope y_0'. The clamping problem is modeled by two fourth-order ordinary differential equations subject to left end boundary conditions, continuity conditions at s_i, and the clamping conditions. This model problem has an analytic solution.

Unlike the clamping procedure, the welding procedure does not specify the position y_0 or the orientation y_0' of the beam. The welding conditions specify that the vertical position and tangent of both beams are the same and also that the axial force and bending moment balance at the welding point. This welding procedure is also modeled by two fourth-order ordinary differential equations subject to left end boundary conditions, continuity conditions and the welding conditions. This model also admits an analytic solution.

If one continues to follow the solution to these models of clamping and welding through the application of two clamps and two welds, then one will find no sequence dependence arises in this model. We then conjectured that the sequence dependence arises as a result of horizontal displacement in the clamping procedure. This means that as the clamp closes each beam is allowed to slide without friction. To test this theory, we proposed a model which allows both horizontal and vertical displacements ($u_i(s) \neq 0$, $w_i(s) \neq 0$), where the clamps and welds are modeled in a manner similar to the model described above, except of course, it takes into account the horizontal displacements.

The system of ordinary differential equations including the welding and clamping constraints that accounts for horizontal displacement is significantly more complicated than the simpler model and do not admit an analytic solution. In order to see the sequence dependence in the model, each step must be solved numerically. A multiple shooting algorithm programmed in Matlab is able to compute the solution for one clamp and the solution for one weld. Unfortunately, the problems with one weld and one clamp and two clamps involve two fourth-order equations which are coupled nonlinearly through clamping conditions, welding conditions and continuity conditions. This problem cannot be solved by the current shooting algorithm and is a focus of ongoing research.

Reciprocal Inhibitory Neurons: Many of the behaviors observed in the solutions of the Hodgkin and Huxley equations can also be seen in simpler, yet still biologically reasonable, models. In particular, simple models of the action potential of neurons connected by reciprocally inhibited synapses have been studied to further understand such biological phenomena as heartbeat, swimming, and feeding. Two identical oscillatory neurons connected by reciprocally inhibitory synapses will oscillate exactly out of phase of each other, that is, while one neuron is active the other is quiescent. John Guckenheimer, Warren Weckesser and I studied an idealized model of a pair of reciprocally inhibited neurons in the gastric mill circuit of a lobster. Our goal is to understand solutions of a set of four differential equations which model two asymmetric oscillators in terms of geometric singular perturbation theory, an effective tool for understanding equations with multiple time scales. Essentially, singular perturbation theory pieces together solutions from the fast system and solutions from the slow system to get a solution of the singularly perturbed system. Behavior of a singularly perturbed system consists of motion on the slow manifold (the set of equilibria of the fast system) and fast jumps between different parts of the slow manifold. These fast transitions occur at folds in the slow manifold. A periodic solution to the system of equations which describes a pair of identical reciprocally inhibitory neurons can be described in terms of singular perturbation theory as consisting of two fast transitions. These fast transitions correspond to one neuron jumping from an active to a quiescent state and the other jumping from a quiescent state to an active state.

As we investigated the solution space of the asymmetric problem, we found many solutions that were qualitatively similar to the solutions of the symmetric system. We also found other very different types of behavior. For instance, in a small

parameter range, there exists (at least) two stable periodic orbits of the full system. Both of these periodic solutions correspond to more complicated behavior than the typical reciprocally inhibitory behavior described above. Instead of the orbit consisting of two fast transitions, the periodic orbits consist of nine and eleven fast transitions, respectively, and the behavior of the two neurons can no longer be classified simply as active or quiescent. The possible implications of the existence of two stable periodic solutions as well as the structure of these solutions are a source of continued research.

In addition to bistability in the system, we also found canard solutions, that is, solutions in which part of the orbit occurs on an unstable portion of the slow manifold. We identified two different types of canard solutions. One type of canard solution consists of a fast transition to an unstable part of the slow manifold. In the other type of canard solution, the orbit continues past a fold in the slow manifold onto the unstable part of the manifold. For a small parameter range, the family of canard solutions is stable. Continuation of the two stable periodic solutions reveals that the canard solutions persist for a much larger parameter regime but are unstable.

Tony Shardlow of OCIAM, Mathematical Institute describes his activities and achievements during his stay at the IMA as a postdoctoral member of the Emerging Applications of Dynamical Systems year.

Long time approximation of Markov Chains: This project looks at a class of Markov processes arising from stochastic differential equations and asks to what extent numerical approximations of these processes can reproduce their long time behaviours. To gain results in this direction, the processes are assumed to be geometrically ergodic, which may be verified in a variety of circumstances and is much easier to establish than similar notions (hyperbolic attractors, for example) in deterministic systems. The paper Shardlow and Stuart (An abstract perturbation theory for Markov chains, IMA report no. 1563) describes how long time averages of the approximation converge to the true ergodic average of the underlying process. The approximations must converge to the underlying process, but it is only necessary to do so in the sense of distributions on a time interval bounded away from the origin. This opens the door for example to weak approximations of PDEs, where error estimates for numerical methods are generally singular at time $t = 0$.

Motivated by this paper, I developed the results necessary to apply the above theory to stochastic PDEs. Two results are needed: (i) finite time convergence for the numerical method, which I have worked out for finite difference approximations in (Shardlow, *Numerical methods for stochastic PDEs*, submitted Num. Func. Anal. and Opt.) and (ii) geometric ergodicity, which is discussed in (Shardlow, *Geometric Ergodicity for Stochastic PDEs*, to appear Stoch. Anal. App). Further motivated by the above work, I have started looking into ways of proving geometric ergodicity when the stochastic term is degenerate. One class of such problems (hypoelliptic systems) came up in the IMA workshop on control theory and this may be a direction for further research.

Stochastic PDEs for phase transitions: This project concerns stochastic PDEs arising in the modelling of certain growth processes and are familiar as the Cahn–Hilliard and Allan–Cahn equations with an additional randomly fluctuating driving term. I spent a considerable amount of time reading background on these equations, leading to a proposal to the EPSRC in December for a postdoctoral position at the University of Oxford. There are a number of interesting directions for this work, related to extending the extensive work on the Cahn–Hilliard equation to include the stochastic terms. I'm particularly interested in developing numerical methods and possibly the use of approximating particle systems. This proposal was successful and I start studying these questions in the Oxford Centre for Industrial and Applied Mathematics (OCIAM) in October.

Whilst I've been at the IMA, my research in this area has been focused on the 1d Allan–Cahn equation forced by additive space–time white noise and the development of an SDE to account for the motion of the fronts. Previous work on the deterministic Allan–Cahn equation has been successful in describing the motion of the fronts by an ODE in the relative positions of the fronts; it is an interesting idea to explore this idea in the presence of noise. This work involved formal asymptotics together with thorough numerical experiments, and is currently being written up (Shardlow, *Perturbations of the Allan–Cahn equation*).

Other During my stay at the IMA, I have benefited from attending a large number of seminars in the Dynamical Systems year over a terrific range of mathematics. Stanford (my previous institution) is not a centre for dynamical systems and it has been a breath a fresh air to attend seminars with a different focus. I presented several talks during the year including the IMA postdoc seminar twice (Dec 97, Linear Multistep Methods and Inertial Manifolds; Mar 97, Long time approximation of SDEs) and the applied math seminar at Wisconsin (Feb 97, Long time approximation of stochastic PDEs).

Shinya Watanabe currently affiliated with Ibaraki University, Department of Mathematical Sciences, has served as an IMA postdoc during the 1997-98 year on "Emerging Applications of Dynamical Systems." He reports:

I participated in the IMA year as a postdoctoral fellow from September, 1997, until June, 1998. This followed my doctoral program until 1995 and my first postdoctoral appointment elsewhere during 1995-97. Since I came to the IMA with some research experience that had been focused and rather narrow, my main aim during the IMA year was to broaden my interest and knowledge in the large field of dynamical systems and to come to know active researchers in various branches in the field. With the amazing number of high-quality visitors, seminars, and workshops, the IMA program became an exciting and fruitful year that would benefit me in my future research.

During the year I attended many talks and was exposed to many areas that were new to me, from mathematical biology, locomotion and robotics, to oceanography. There were excellent tutorials before workshops by such experts as Jim Keener, Chris Jones, Marty Golubitsky, Joel Keizer, Nancy Kopell, David Terman, and others. Sometimes postdocs themselves asked long-term visitors, such as John Guckenheimer and David Chillingworth, to help us in extra study sessions. These orientations starting from an elementary level were indispensable for me as pointers when I tried to follow discussions during workshops. My knowledge on mathematical biology, for instance, had been minimal, but, after enduring the winter quarter that was sometimes overwhelming, I gained reasonable understanding of the current state of modelling efforts of neural and cardiac systems. It was also good to learn what kind of gap there was between mathematicians and biologists, and how they were trying to close it. I also learned new techniques in the areas I was more familiar with, such as geometric singular perturbation theory in the multiple-scale workshop. Reduction of large systems into smaller degrees of freedom has been one of the areas of my strong interest, and I came to know different approaches and styles, e.g., inertial manifolds, numerical decompositions, and separation of multiple scales.

The IMA policy limiting the number of seminars made room for interacting with the visitors outside seminar rooms: in offices, hallways, restaurants, cafes, etc. Because guests were so knowledgeable that it was rather difficult for me to have full discussions with them, but I benefitted from conversations with Anatoly Neishtadt, Eusebius Doedel, Kurt Lust, John Guckenheimer, Don Aronson, Jim Swift, Greg King, David Golomb, Richard Haberman, Robert Miura, Steve Strogatz, just to name a few that come to my mind immediately.

Apart from attending the workshops and seminars, I prepared articles on the continuing research projects. In October I finished and submitted a paper with Mauricio Barahona in Stanford which was published in the following spring [1]. Also in October, I received a referee report on a short letter I wrote with my former colleagues and their students in the Niels Bohr Institute. It was edited and resubmitted in November, and appeared also in the following spring [2]. A more detailed manuscript was prepared during my stay in the IMA, and was submitted in the fall of 1998. It appeared shortly later [3]. During the IMA Pattern Formation Workshop in the spring, Herre van der Zant visited the IMA as a speaker. Organizers requested speakers to write a review of the subjects they presented. I joined him in writing a note on dynamics in Josephson junction arrays, which will appear as a contribution to the IMA Proceedings [4].

Since I came to the IMA without a fixed plan after the term, a portion of my time during the winter was spent on searching an academic position. Apart from simply stating that I was offered a satisfying position in the end, I'd like to add an episode during the search process that demonstrated that the IMA was "the place to be" during the year 1997-98. When I went to a university in the U.K. as one of the five finalists to be interviewed (all five in the same day), another candidate was a familiar long-term visitor at the IMA and yet another came for two workshops here. I was quite proud of the fact that one of "us" was offered the job there.

Before concluding the note I would like to thank organizers of the IMA program, the IMA administrative staff, and my fellow postdocs for all the support I received.

References

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[2] C. Ellegaard, A. E. Hansen, A. Haaning, K. Hansen, A. Marcussen, T. Bohr, J. L. Hansen, & S. Watanabe "Creating corners in kitchen sinks" Nature, vol.392 (1998 Apr. 23) 767-768 (Scientific Correspondence).

[3] C. Ellegaard, A. E. Hansen, A. Haaning, K. Hansen, A. Marcussen, T. Bohr, J. L. Hansen, & S. Watanabe "Cover illustration: Polygonal hydraulic jumps" Nonlinearity, vol.12, no.1 (1999 Jan.) 1-7.

[4] H. S. J. van der Zant and S. Watanabe, "Dynamics of kinks and vortices in Josephson-junction arrays" to appear in "Pattern Formation in Continuous and Coupled Systems," IMA Volumes in Mathematics and its Applications, vol.115, (eds. M.Golubitsky, D.Luss, and S.H.Strogatz), 283-302.

Warren Weckesser of Rensselaer Polytechnic Institute is one of the IMA Postdocs. This year was 1st year of a two-year term. His report follows:

The year on Emerging Applications of Dynamical Systems was an exciting one. A large part of my time was spent attending the IMA workshops, and also several informal seminars that ran during the year. I learned a great deal about several areas in dynamical systems, including numerical methods for large scale systems, multiple time scales, bifurcation with symmetry, nonlinear control theory and system identification, and biological applications including calcium dynamics, cardiac dynamics and animal locomotion. The opportunity to meet with leading researchers in these fields was invaluable.

Part of my time was spent preparing and submitting papers based on my Ph.D. thesis. One paper shows that in mechanical systems with rotational symmetry (under a set of conditions that hold generically), the relative equilibria sufficiently close to a stable equilibrium are linearly orbitally stable. I also show in this paper that the first whirling mode to bifurcate is nonlinearly orbitally stable, but the standard variational method for proving nonlinear orbital stability fails in all modes after the first. Another paper applies these ideas to the hanging chain.

Mark Levi visited the IMA in the fall of 1997, and we had several discussions on the kinematics of a constant velocity joint. This led me to begin studying mechanical systems composed of symmetric rigid bodies coupled with constant velocity joints. Unlike a universal joint, a constant velocity joint creates a kinematic constraint that directly couples the angular velocities of the two rigid bodies. I am investigating the bifurcation and stability of whirling configurations of chains of coupled rigid bodies. This work may shed new light on certain gyroscopic phenomena in spinning beams and related mechanical systems. I visited Boston University in the fall, and discussed some of this work with Tasso Kaper, Carson Chow, John Ballieul, and their students.

In the spring, I began collaborating with John Guckenheimer and Kathleen Rogers on an intensive study of the rich dynamical behavior found in a system of two coupled relaxation oscillators. More specifically, we are considering two non-identical Van der Pol-like oscillators. The coupling is based on reciprocal inhibition, as occurs in membrane models of neurons. Our model of two coupled neurons results in a singularly perturbed system of differential equations, with two fast variables and two slow variables. Our observations so far include several families of periodic orbits, a range of parameters for which there are two stable periodic orbits, families of orbits that exhibit a variety of canards, and a possible homoclinic bifurcation from a periodic orbit. One goal of this research is to classify the types of bifurcations that occur in singularly perturbed systems with more than two dimensions. Especially important for this work are the methods of geometric singular perturbation theory. Another important component of the work so far has been the numerical continuation of periodic orbits with the software package AUTO. We benefited from discussions with E. Doedel, the author of AUTO, during his visits to the IMA.

In the spring quarter, I was co-chair of the IMA Postdoc Seminar. I also organized (with some initial inspiration from Steve Strogatz) the "Informal Seminar on Bifurcation with Symmetry," a weekly series of seminars and discussions on bifurcation with symmetry. When a bifurcation problem possesses symmetry, certain degeneracies occur that make standard bifurcation theory inapplicable. However, it is possible to exploit the added structure imposed by the symmetry. There is now an extensive theory and body of literature on this subject. The goal of the informal seminar was to learn about this theory, starting with the most elementary ideas and progressing far enough to be comfortable reading current literature in the field. Here is partial list of fairly regular participants.

Postdocs: Miahua Jiang, Shinya Watanabe, Kathleen Rogers, Rolf Mantel, Tony Shardlow, Ricardo Oliva, Marina Osipchuk, Kurt Lust.

Visitors: David Chillingworth, Laurette Tuckerman, Gabriela Gomes, William Langford, Steve Strogatz, Fernanda Botelho.

I wrote a set of notes based on the these discussions; these notes can be accessed from my web site.

The following lists a few of my other activities during my first year at the IMA.

- I gave a talk in the Math Department's "Dynamics and Mechanics" seminar organized by Rick Moeckel. Title: Stability of the relative equilibria in a class of rotationally symmetric mechanical systems.
- I prepared a report based on the Industrial Seminar presented by Nicholas Tufillaro of Hewlett-Packard on "Symbolic Dynamics in Mathematics, Physics and Engineering." This report is to become part of the IMA web site.
- I attended the conference "Modeling and Analysis in Medicine and Biology" at the University of Michigan in Ann Arbor.
- I refereed papers for *Physica D* and the *American Journal of Physics*.

V. IMA SEMINAR ON INDUSTRIAL PROBLEMS

One of the major purposes of the IMA is to facilitate interaction between mathematicians and industrial and government laboratory scientists. An important component is to bring problems from industry and government labs to the attention of mathematicians and to encourage them to work on such problems.

In order to achieve this goal the IMA developed a program which began in the Fall of 1987: a weekly Seminar on Industrial Problems. In this seminar, researchers from industry present one-hour talks, every non-workshop Friday at 11:15. Typical participation is from 20 to 23 individuals, including IMA visitors, University of Minnesota faculty, graduate students and undergraduate students. The talks are frequently followed by extended informal discussion.

Because the IMA program varies from year to year, we concentrate on two kinds of problems.

The first type is connected with the area of the special year at the IMA. Thus, during the academic year 1987–88 the special topic was Applied Combinatorics, during 1988–89 it was Nonlinear Waves, during 1989–90 it was Dynamical Systems, during 1990–91 it was Phase Transitions and Free Boundaries, during 1991–92 it was Applied Linear Algebra, during 1992–93 it was Control Theory, during 1993–94 it was Emerging Applications of Probability, during 1994–95 Waves and Scattering, during 1995–96 Mathematical Methods in Materials Science and for 1996–97 Mathematics in High-performance Computing.

The second type of problem is related to the areas in which the Director, the Associate Director for Industrial Problems and their colleagues can provide either direct advice or specific referral. The general area of these problems is Mathematical Analysis; more specifically, models involving linear and nonlinear Ordinary or Partial Differential Equations, Fluid Dynamics and Free Boundary Problems, Deterministic and Stochastic Control, etc. During each year there are a number of visitors invited to spend some time at the IMA for the purpose of studying such problems.

We also involve public agencies such as DOD. In particular we believe that it is of mutual benefit to have problems from government labs. In order to identify such problems and speakers, the Director of IMA visits government as well as industrial labs.

In addition to faculty and IMA visitors, the seminar includes a number of Ph.D. students as well as some undergraduate students. We have serious mathematical problems of real significance in Industry presented to us, and some faculty and students subsequently become interested in solving these problems. We create an atmosphere to encourage mathematicians to work on the industrial problems. Follow-up contact between speakers and those who become interested in their problems is fostered.

Writeups of the industrial problems presented during the first ten years (September 1987 – June 1997), including many of the solutions, have appeared as 10 IMA Volumes (Avner Friedman, Mathematics in Industrial Problems, Parts 1–10, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998.) More recently problems have been written up and posted on the IMA web site.

INDUSTRIAL PROBLEMS SEMINAR SPEAKING SCHEDULE FOR 1997–98:

DATE	SPEAKER/COMPANY	TOPIC
September 12	Eli Chiprout IBM Austin Research Lab	Model Reduction for Large Circuit Simulation
September 26	Nick Tufillaro Hewlett-Packard	Symbolic dynamics in mathematics, physics, and engineering
October 3	Gabriel Taubin IBM T. J. Watson Research Center	Geometric Compression based on Topological Surgery
October 17	Cush Hamlen Medtronic	Modeling and Simulation at Medtronic
October 31	Dennis Perchak Kodak	Stokesian Dynamics Simulation of Interacting Solid Particles
November 14	Wim Sweldens Lucent Technologies	Second Generation Wavelets: Theory and Applications
January 9	Martin G. Lüling Schlumberger-Doll Research	Geosteering Horizontal Wells through Electrically Anisotropic Oil Zones using Predictive Log-Modeling Computation
January 30	Dr. Richard Stone Northwest Airlines	Airline Planning Problems
February 20	Philip Fleming Motorola	Diffusion Approximations of Join-the-Least-Loaded Infinite Server Station
March 2	Daniel R. Baker GM Research & Design Center	The Role of Charge Separation in the Response of Electrochemical Systems
March 20	David Ross Kodak	A PDE Model of Fluid Contact Lines
April 17	David Runkle Minneapolis Federal Reserve and Univ. of Minnesota Carlson School of Management	Are Credit-Risk Models Ready for Prime Time?
April 24	Peter A. Blakey Motorola	Links Between The Nonlinear Behavior Of Transistors And The Spectral Characteristics Of Portable Wireless Power Amplifiers
May 1	T. J. Burns NIST	Modeling and Simulation of Some High-Speed Manufacturing Processes

May 22	Todd Salamon Bell Laboratories	Interfacial Flow
May 29	Mrdjan Jankovic Ford Research Laboratories	Robust Nonlinear Controller Design: Application to Diesel Engines

VI. DETAILED DESCRIPTION OF 1997 – 98 PROGRAM

EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

September 1997 – June 1998

1. PROGRAM OUTLINE

The year was divided into three parts described below (corresponding to fall, winter and spring quarters) although there was considerable fluidity between the various parts.

(1) Fall: September 1-December 30, 1997, Numerical Analysis of Dynamical Systems

(2) Winter: January 2 - March 31, 1998, Dynamics in Physiology and Chemistry

(3) Spring: April 1 - June 30, 1998, Symmetry and Pattern Formation

The organizing committee consisted of Rafael de la Llave, (University of Texas, Austin) Eusebius Doedel, (Concordia University) Martin Golubitsky, (University of Houston) John Guckenheimer, (Chair) (Cornell University) Yannis Kevrekedis, (Princeton University) John Rinzel, (National Institutes of Health)

2. LIST OF ACTIVITIES

Fall 1997: Numerical Analysis of Dynamical Systems

- Tutorial: Numerical Methods for Bifurcation Problems, September 5-9, 1997

  Speakers: Eugene Allgower, Colorado State University, Wolf-Jümlrgen Beyn, Universität Bielefeld, Eusebius Doedel, Concordia University, Bernold Fiedler, Free University of Berlin, John Guckenheimer, Cornell University, Herb Keller, California Inst. of Technology, Linda Petzold, Univ. of California-Santa Barbara, Mark Reichelt, The MathWorks, Inc., Werner Rheinboldt, University of Pittsburgh

- Workshop 1: Numerical Methods for Bifurcation Problems, September 15-19, 1997

  Organizers: Wolf-Jümlrgen Beyn, Universität Bielefeld, Eusebius Doedel, Concordia University (Chair), Bernold Fiedler, Free University of Berlin, Yannis Kevrekedis, Princeton University, Jens Lorenz, University of New Mexico

- Workshop 2: Large Scale Dynamical Systems, September 29 - October 3, 1997

  Organizers: Don Aronson, University of Minnesota H. B. Keller, Caltech, Edriss Titi, University of California-Irvine, Laurette Tuckerman, Orsay (Chair)

- Tutorial: Multiple Time-Scale Dynamical Systems, October 23-24, 1997

  Speakers: Christopher Jones, Brown University, Michael Ward, University of British Columbia

- Workshop 3: Multiple Time-Scale Dynamical Systems, October 27-31, 1997

  Organizers: Fred Dumortier, Limburgs Universitair Centrum, Chris Jones, Brown University (Chair), Alexander Khibnik, Cornell University, David Terman, Ohio State, Steve Wiggins, Caltech

- Workshop 4: Dynamics of Algorithms, November 17-21, 1997

  Organizers: Rafael de la Llave, University of Texas (Chair) Jens Lorenz, University of New Mexico Linda Petzold, University of California-Santa Barbara

- Special Workshop: Algorithmic Methods for Semiconductor Circuitry, November 24-25, 1997

  Organizer: Jacob White, MIT

Winter 1998: Dynamics in Physiology and Chemistry

- Workshop 5: Computational Neuroscience, January 14-23, 1998

  Organizers: Larry Abbott, Braneis University, Bard Ermentrout, University of Pittsburgh, Nancy Kopell, Boston University John Rinzel, (Chair) NIH

- Tutorial: Calcium Dynamics in Cells, February 5-6, 1998

  Speakers: Joel Keizer, UC Davis, Robert Miura, NIH, Artie Sherman, NIH

- Workshop 6: Calcium Dynamics in Cells, February 9-13, 1998

  Organizers: A. Goldbeter, Univ. Libre de Bruxelles, Joel Keizer, (Chair) University of California Davis, John Rinzel, NIH

- Special Workshop: Knowledge and Distributed Intelligence (KDI)–Opportunities in the Mathematical Sciences, March 7, 1998

- Workshop 7: Cardiac Dynamics, March 9-14, 1998

  Organizers: Jim Collins, (Chair), James Keener, University of Utah, Charles Peskin, New York University - Courant Institute, Rai Winslow, Johns Hopkins University

Spring 1998: Symmetry and Pattern Formation

- Workshop 8 : Nonlinear Identification and Control , April 27- May 1, 1998

  Organizers: Yannis Kevrekedis, (Chair) Princeton University, P. S. Krishnapasad, University of Maryland, Erik Ydstie, Carnegie Mellon University

- Workshop 9 :Pure, Applied and Industrial Mathematics: Strength through Connections, May 1-3, 1998

  Co-sponsored by the University of Minnesota School of Mathematics

- Workshop 10 : Dynamical Systems in Oceanography: Chaotic Advection in Ocean Mesoscale Structures, May 7-9, 1998

  Organizer: Chris Jones, Brown University

- Workshop 11 : Pattern Formation in Continuous and Coupled Systems, May 11-15, 1998

  Organizers: Martin Golubitsky, (Chair) University of Houston, Dan Luss, University of Houston, Steve Strogatz, Cornell University

- Workshop 12 : Animal Locomotion and Robotics, June 1-5, 1998

  Organizers: James Collins, (Chair) Boston University Martin Golubitsky, University of Houston, Daniel Koditschek, University of Michigan

- Workshop 13 : Continuum Mechanics and Non-linear Partial Differential Equations, June 8-12, 1998

  Organizers: Richard James, University of Minnesota, Stefan Mueller, Max Planck Institute for Mathematics in the Sciences, Vladimir Sverák, University of Minnesota

3. POSTDOCTORAL MEMBERS

POSTDOCTORAL MEMBERSHIPS FOR 1997–98

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

4. LONG–TERM PARTICIPANTS (four weeks or longer)

ARMBRUSTER, DIETER	Arizona State Univ. (Mathematics)	APR 26 – MAY 15
ARONSON, DON	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
BARKLEY, DWIGHT	Univ. of Warwick (Mathematics)	AUG 15 – JUN 30
BATES, PETER W.	Brigham Young Univ. (Mathematics)	SEP 28 – OCT 31
BEYN, WOLF-JUERGEN	Univ. of Bielefeld (Fakultat fur Mathematik)	SEP 4 – OCT 4
BOTELHO, FERNANDA	Univ. of Memphis (Mathematical Sciences)	JAN 10 – MAY 31
CARVER, SEAN G.	Cornell Univ. (Center Applied Math)	AUG 25 – DEC 1
CHILLINGWORTH, DAVID	Univ. of Southampton (Mathematics)	MAR 30 – JUN 5
CHOSSAT, PASCAL	Univ. of California (Mathematics)	MAY 11 – 16
CROOK, SHARON	Montana State Univ. (Center Computational Biology)	JAN 4 – 31
DE LA LLAVE, RAFAEL	Univ. of Texas (Mathematics)	SEP 1 – DEC 30
DELLNITZ, MICHAEL	Univ. Bayreuth (Mathematisches)	SEP 3 – 20
DELSHAMS, AMADEU	Univ. Politecnica de Catalunya (Matematica Aplicada I)	AUG 15 – DEC 20
DIONNE, BENOIT	Univ. of Ottawa (Math and Statistics)	SEP 1 – OCT 31
DOEDEL, EUSEBIUS	Concordia Univ. (Computer Science)	SEP 3 – DEC 15
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	SEP 3 – DEC 21
FIELD, MICHAEL J	Univ. of Houston (Mathematics)	MAY 1 – 15
FOIAS, CIPRIAN	Rawles Hall (Indiana University)	MAR 29 – MAY 2
FONTELOS, MARCO ANTONIO	Univ. Complutense de Madrid (Aplicada)	JAN 11 – DEC 31
FRENCH, DONALD	Univ. of Cincinnati (Mathematical Sciences)	SEP 1 – AUG 31
GOLOMB, DAVID	Ben-Gurion Univ. of the Negev (Physiology)	JAN 12 – 27
GOLUBITSKY, MARTIN	(University Houston)	MAY 3 – JUN 5
GOMES, GABRIELA	Univ. do Porto (CentroMatematica Aplicada)	SEP 1 – JUL 31
GOVAERTS, WILLY J.F.	Univ. of Ghent (Applied Mathematics)	SEP 7 – OCT 4
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HANSEL, DAVID	Ecole Polytechnique (Centre Physique Theorique)	JAN 12 – 30

HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
HU, BEI	Univ. of Notre Dame (Mathematics)	SEP 1 – MAY 31
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
JORBA, ANGEL	Univ. de Barcelona	SEP 6 – 20
KELLER, HERBERT B.	California Institute of Technology	SEP 1 – NOV 30
KETEMA, YOHANNES	Univ. of Minnesota (AEM)	SEP 15 – NOV 21
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KNOBLOCH, EDGAR	Univ. of California Berkeley (Physics)	MAY 7 – JUN 5
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	SEP 2 – DEC 7
KRISCHER, KATHARINA	Fritz-Haber Institut (Max-Planck-Gesellschaft)	MAY 9 – 16
KRUPA, MARTIN (MACIEJ)	Technical Institute Vienna (Inst Applied Mathematics)	SEP 28 – NOV 21
LAMB, JEROEN	Univ. of Warwick (Mathematics)	MAY 10 – JUN 10
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LEBLANC, VICTOR	Univ. of Ottawa (Mathematics and Statistics)	MAY 4 – JUN 12
LEONARD, NAOMI	Princeton Univ. (Mechanical and Aerospace Engineering)	JUN 2 – 5
LITTMAN, WALTER	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
MATO, GERMAN	Centro Atomico Bariloche	JAN 5 – 28
MELBOURNE, IAN	Univ. of Houston (Mathematics)	MAY 10 – JUN 6
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MOECKEL, RICK	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
MOSER, JRGEN	ETH-Zentrum (Forschunginstitut fur Mathematik)	APR 1 – 30
NEISHTADT, ANATOLY	Space Research , Moscow	OCT 2 – NOV 1
NI, WEI-MING	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
NIE, QING	Univ. of Chicago (Mathematics)	SEP 1 – 30
OSINGA, HINKE	University of Minnesota	SEP 1 – AUG 31
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
ROSENAU, PHILIP	Tel Aviv Univ. (Applied Math)	FEB 24 – 28
RUCKLIDGE, ALASTAIR	Univ. of Cambridge (Applied Maths)	MAY 8 – 15
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	SEP 13 – DEC 20
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	MAY 9 – 12
SATTINGER, DAVID	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
SCHEEL, ARND	Freie Univ. Berlin (fuer Mathematik I)	SEP 7 – OCT 6
SELL, GEORGE R.	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
SHEINTUCH, MOSHE	Technion (Chemical Engineering)	MAY 10 – 15
SIJNAVE, BART	Univ. of Gent (Applied Mathematics & CS)	SEP 7 – OCT 4
SILBER, MARY	Northwestern Univ. (Eng Sci & Appl Math)	MAY 11 – 19
SPENCE, ALASTAIR	Univ. of Bath (School of Mathematical Sciences)	SEP 5 – 19
STEWART, IAN	Univ. of Warwick (Mathematics)	APR 19 – JUN 6
STROGATZ, STEVEN H.	Cornell Univ. (Theoretical and Applied Mechanics)	APR 1 – JUN 30
SVERAK, VLADIMIR	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
SZMOLYAN, PETER	Technische Univ. Wien (Angewandte Mathematik)	SEP 14 – NOV 30
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30
VAN VLECK, ERIK	Colorado School of Mines (Math and Computer Science)	OCT 18 – NOV 20
VELAZQUEZ, JUAN J. L.	Univ. Complutense de Madrid (Aplicada)	APR 27 – MAY 3
VITILLARO, ENZO	Universita di Perugia	JUL 30 – SEP 5
WULFF, CLAUDIA	Freie Univ. Berlin (für Mathematik I)	MAY 4 – JUN 7
XIE, MIN	Univ. of Utah (Mathematics)	FEB 28 – MAR 30

5. FALL 1997 WORKSHOP AND TUTORIAL PARTICIPANTS Tutorial: Numerical Methods for Bifurcation Problems September 5-9, 1997

AGGELIDIS, COSTAS Univ. of Minnesota (Chemical Engineering) SEP 4 – 9

ALLGOWER, EUGENE L.	Colorado State Univ. (Mathematics)	SEP 7 – 8
BEYN, WOLF-JUERGEN	Univ. of Bielefeld (Fakultat fur Mathematik)	SEP 4 – OCT 4
CARSTEANU, ALIN-ANDREI	Univ. of Minnesota (SAFHL)	SEP 4 – 9
CARVER, SEAN G.	Cornell Univ. (Applied Math)	AUG 25 – DEC 1
DELLNITZ, MICHAEL	Univ. Bayreuth (Mathematisches)	SEP 3 – 20
DELSHAMS, AMADEU	Univ. Politecnica de Catalunya (Matematica Aplicada I)	AUG 15 – DEC 20
DOEDEL, EUSEBIUS	Concordia Univ. (Computer Science)	SEP 3 – DEC 15
DOYLE, JOHN	Caltech	SEP 2 – 10
ERNSTHAUSEN, JOHN	Univ. of Pittsburgh (Mathematics)	SEP 4 – 9
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	SEP 3 – DEC 21
GEORGIOU, TRYPHON	Univ. of Minnesota (Electrical Engineering)	SEP 4 – 5
GOVAERTS, WILLY J.F.	Univ. of Ghent (Applied Mathematics)	SEP 7 – OCT 4
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
JORBA, ANGEL	Univ. de Barcelona	SEP 6 – 20
KELLER, HERBERT B.	California Institute of Technology	SEP 1 – NOV 30
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	SEP 2 – DEC 7
LIU, LIPING	Univ. of Alberta (Mathematical Sciences)	SEP 4 – 19
LUSKIN, MITCH	Univ. of Minnesota (Mathematics)	SEP 4 – 9
MAGGIO, GIAN MARIO	Univ. College Dublin	SEP 4 – 19
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
OSINGA, HINKE	University of Minnesota	SEP 1 – AUG 31
PAL, MIHAELA MICHELLE	Univ. of Texas at Austin	SEP 3 – 9
PETZOLD, LINDA R.	Univ. of California-Santa Barbara	SEP 4 – 9
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
PROMISLOW, KEITH	Simon Fraser Univ. (Math and Statistics)	SEP 3 – 9
REICHELT, MARK	The MathWorks, Inc	SEP 4 – 6
RHEINBOLDT, WERNER C.	Univ. of Pittsburgh (Mathematics)	SEP 4 – 7
SCHECTER, STEPHEN	North Carolina State Univ. (Mathematics)	SEP 7 – 19
SHEN, JIE	Penn State (Mathematics)	SEP 3 – 9
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30
ZAFARULLAH, IJAZ	Univ. of Nottingham (Theoretical Mechanics)	SEP 3 – 19

Workshop: Numerical Methods for Bifurcation Problems September 15-19, 1997

ADOMAITIS, RAY	Univ. of Maryland (Chemical Engineering)	SEP 14 – 19
ARONSON, DON	Univ. of Minnesota (Mathematics)	SEP 15 – 19
BALAKOTAIAH, VEMURI	Univ. of Houston (Chemical Engineering)	SEP 14 – 19
BARKLEY, DWIGHT	Univ. of Warwick (Mathematics)	AUG 15 – JUN 30
BEYN, WOLF-JUERGEN	Univ. of Bielefeld (Fakultat fur Mathematik)	SEP 4 – OCT 4
BROER, HENK W.	Groningen Univ. (Mathematics)	SEP 14 – 19
BRUIN, HENK	Royal Institute of Technology (Mathematisches)	SEP 14 – 19
BURNS, TIM	NIST	SEP 14 – 19
CARSTEANU, ALIN-ANDREI	Univ. of Minnesota (SAFHL)	SEP 4 – 9
CARVER, SEAN G.	Cornell Univ. (Applied Math)	AUG 25 – DEC 1
CHOE, WON-GYU	Cornell University	SEP 14 – 26
CHUN, CHANGBUM	Iowa State Univ. (Math)	SEP 17 – 18
DE LA LLAVE, RAFAEL	Univ. of Texas (Mathematics)	SEP 1 – DEC 30
DELLNITZ, MICHAEL	Univ. Bayreuth (Mathematisches)	SEP 3 – 20
DELSHAMS, AMADEU	Univ. Politecnica de Catalunya (Matematica Aplicada I)	AUG 15 – DEC 20
DIECI, LUCA	Georgia Institute of Technology (School of Mathematics)	SEP 14 – 21
DIONNE, BENOIT	Univ. of Ottawa (Math and Statistics)	SEP 1 – OCT 31

DOEDEL, EUSEBIUS	Concordia Univ. (Computer Science)	SEP 3 – DEC 15
EDOH, KOSSI DELALI	Elizabeth City State Univ. (Mathematics)	SEP 13 – 17
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	SEP 3 – DEC 21
FRIEDMAN, MARK	Univ. of Alabama in Huntsville (Mathematical Sciences)	SEP 14 – OCT 4
GATERMAN, KARIN	Konrad-Zuse-Zentrum Berlin	SEP 13 – 20
GOLUBITSKY, MARTIN	University Houston	SEP 14 – 19
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
GOVAERTS, WILLY J.F.	Univ. of Ghent (Applied Mathematics)	SEP 7 – OCT 4
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
HOMBURG, ALEJAN	Freie Univ. Berlin (fuer Mathematik)	SEP 14 – 19
JANOVSKY, VLADIMIR	Charles Univ. of Prague (Numerical Analysis)	SEP 13 – 19
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
JORBA, ANGEL	Univ. de Barcelona	SEP 6 – 20
KELLER, HERBERT B.	California Institute of Technology	SEP 1 – NOV 30
KETEMA, YOHANNES	Univ. of Minnesota (AEM)	SEP 15 – NOV 21
KEVREKIDIS, YANNIS	Princeton Univ. (Chemical Engineering)	SEP 14 – 19
KHINAST, JOHANNES	Univ. of Houston (Chemical Engineering)	SEP 14 – 19
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	SEP 2 – DEC 7
KRUPA, MARTIN (MACIEJ)	Technical Institute Vienna (Inst Applied Mathematics)	SEP 28 – NOV 21
KUZNETSOV, YURI	CWI (Netherlands)	SEP 13 – 20
LEVI, MARK	Rensselaer Polytechnic Institute (Mathematical Sciences)	SEP 14 – 23
LIU, LIPING	Univ. of Alberta (Mathematical Sciences)	SEP 4 – 19
LORENZ, JENS	Univ. of New Mexico (Mathematics and Statistics)	SEP 13 – 20
MAGGIO, GIAN MARIO	Univ. College Dublin	SEP 4 – 19
MCGEHEE, RICHARD P.	Univ. of Minnesota (School of Mathematics)	SEP 14 – 19
MEI, ZHEN	Philipps-Univ. of Marburg (Math)	SEP 14 – OCT 4
MELOON, BRIAN	Cornell Univ. (Mathematics)	SEP 13 – OCT 4
MEYER, KEN	Univ. of Cincinnatti (Math)	SEP 17 – 21
MIKHAIL, EGOROV	Univ. of Minnesota (AEM)	SEP 14 – 19
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MILLER, PATRICK	Stevens Institute of Technology (Mathematical Sciences)	SEP 14 – 21
MISCHAIKOW, KONSTANTIN	Georgia Institute of Technology (School of Mathematics)	SEP 14 – 21
MOORE, GERALD	Imperial College (Mathematics)	SEP 14 – 21
OLLE, MERCE	E.T.S.E.I.B. Barcelona (Mathematica Aplicada)	SEP 13 – 20
OSINGA, HINKE	University of Minnesota	SEP 1 – AUG 31
PECKHAM, BRUCE B.	University Minnesota-Duluth	SEP 14 – 19
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
REICHELT, VOLKER	RWTH Aachen (Lehrstuhl fuer Numerische Mathematik)	SEP 14 – 21
RUSSELL, ROBERT D.	Simon Fraser Univ. (Mathematics)	SEP 15 – 19
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	SEP 13 – DEC 20
SCHECTER, STEPHEN	North Carolina State Univ. (Mathematics)	SEP 7 – 19
SCHEEL, ARND	Freie Univ. Berlin (fuer Mathematik I)	SEP 7 – OCT 6
SHILNIKOV, ANDREY	Inst. for Appl. Math. & Cybernetics	SEP 14 – 20
SIJNAVE, BART	Univ. of Gent (Applied Mathematics & CS)	SEP 7 – OCT 4
SMILEY, MICHAEL	Iowa State Univ. (Mathematics)	SEP 17 – 18
SPENCE, ALASTAIR	Univ. of Bath (Mathematical Sciences)	SEP 5 – 19
SZMOLYAN, PETER	Technische Univ. Wien (Angewandte Mathematik)	SEP 14 – NOV 30
TITI, EDRISS SALEH	Univ. of California-Irvine (Mathematics)	SEP 14 – OCT 4
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30

TURAEV, D.V.	Weizmann Institute of Science (Math Faculty)	SEP 14 – 19
VANDERBAUWHEDE, ANDRE	Univ. of Gent (Pure Mathematics & Comp)	SEP 12 – 20
WATSON, GREG	Georgia Institute of Technology (Math)	SEP 14 – 21
WERNER, BODO	Univ. Hamburg (fuer Angewandte Mathematik)	SEP 12 – 23
YORKE, JAMES A.	Univ. of Maryland	SEP 15 – 20
ZAFARULLAH, IJAZ	Univ. of Nottingham (Theoretical Mechanics)	SEP 3 – 19
ZHU, DEMING	North Carolina Univ. (Mathematics)	SEP 13 – 20

Workshop: Large Scale Dynamical Systems September 29 - October 3, 1997

BERGEON, ALAIN	Univ. Paul Sabatier (UFR MIG Dpt Mecanique)	SEP 28 – OCT 4
BOEHMER, KLAUS	Univ. of Marburg (Mathematics)	SEP 24 – OCT 5
COUGHLIN, KATIE	Univ. de Montreal	SEP 28 – OCT 3
GOLUBITSKY, MARTIN	University Houston	SEP 28 – OCT 1
GOVAERTS, WILLY J.F.	Univ. of Ghent (Applied Mathematics)	SEP 7 – OCT 4
HENDERSON, RONALD	California Institute of Technology	SEP 27 – OCT 4
HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
KELLER, HERBERT B.	California Institute of Technology	SEP 1 – NOV 30
KETEMA, YOHANNES	Univ. of Minnesota (AEM)	SEP 15 – NOV 21
KEVREKIDIS, YANNIS	Princeton Univ. (Chemical Engineering)	SEP 28 – OCT 3
KUKAVICA, IGOR	Univ. of Chicago (Mathematics)	SEP 28 – OCT 5
LANGFORD, WILLIAM	The Fields Institute	SEP 28 – OCT 3
LEVERMORE, DAVID	Univ. of Arizona (Mathematics)	SEP 30 – OCT 5
LOPES, MILTON	Indiana Univ. (Mathematics)	SEP 24 – OCT 1
LOPEZ, JUAN	Penn State Univ. (Mathematics)	SEP 28 – OCT 3
MARCUS, PHILIP	Univ. of California at Berkeley (Mechanical Engineering)	SEP 29 – OCT 2
MEI, ZHEN	Philipps-Univ. of Marburg (Math)	SEP 14 – OCT 4
MELOON, BRIAN	Cornell Univ. (Mathematics)	SEP 13 – OCT 4
MILEWSKI, PAUL	Univ. of Wisconsin (Math)	SEP 28 – OCT 4
MOLEMAKER, JEROEN	Institute for Marine and Atmospheric Research	SEP 28 – OCT 5
OTHMER, HANS	Univ. of Utah (Mathematics)	OCT 1 – 5
PERRY, PETER	Univ. of Kentucky (Mathematics)	SEP 27 – OCT 3
PROMISLOW, KEITH	Simon Fraser Univ. (Math and Statistics)	SEP 28 – OCT 3
RILEY, DOUGLAS	Univ. of Kentucky (Mathematics)	SEP 27 – OCT 3
ROOSE, DIRK	Katholieke Univ. Leuven (Computer Science)	SEP 27 – OCT 3
SAAD, YOUSEF	Univ. of Minnesota (Computer Science)	SEP 28 – OCT 3
SALDANHA, KENNETH	Univ. of Chicago (Mathematics)	SEP 28 – OCT 4
SCHEEL, ARND	Freie Univ. Berlin (fuer Mathematik I)	SEP 7 – OCT 6
SEYDEL, RUDIGER	Univ. Ulm (Abteilung fur Numerik)	SEP 27 – OCT 4
SHEN, JIE	Penn State (Mathematics)	SEP 27 – OCT 2
SIJNAVE, BART	Univ. of Gent (Applied Mathematics & CS)	SEP 7 – OCT 4
SMILEY, MICHAEL	Iowa State Univ. (Mathematics)	SEP 30 – OCT 1
STEEN, PAUL	Cornell Univ. (Chemical Engineering)	SEP 27 – OCT 2
STUART, ANDREW M.	Stanford Univ.	SEP 30 – OCT 3
TITI, EDRISS SALEH	Univ. of California-Irvine (Mathematics)	SEP 14 – OCT 4
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30

Tutorial: Multiple Time-Scale Dynamical Systems October 23-24, 1997

JONES, CHRIS	Brown Univ. (Applied Mathematics)	OCT 22 – 31

MCCORD, CHRISTOPHER	Univ. of Cincinnati (Mathematics)	OCT 22 – 26
MENON, GOVIND	Brown Univ. (Applied Mathematics)	OCT 22 – 31
PROMISLOW, KEITH	Simon Fraser Univ. (Math and Statistics)	OCT 22 – 30
WECHSELBERGER, MARTIN	Technische Universität Wien)	OCT 23 – NOV 6

Workshop 3: Multiple Time-Scale Dynamical Systems October 27-31, 1997

AI, SHANGBING	Univ. of Pittsburgh (Mathematics)	OCT 22 – 31
BATES, PETER W.	Brigham Young Univ. (Mathematics)	SEP 28 – OCT 31
BELL, DARYL C.	Univ. of Nebraska (Mathematics and Statistic)	OCT 25 – 31
BOSE, AMITABHA	NJIT (Math)	OCT 25 – 31
BRONSKI, JARED	Stanford Univ. (Mathematics)	OCT 26 – 31
BRUNOVSKY, PAVOL	Comenius Univ. (Math)	OCT 26 – NOV 1
CHOE, WON-GYU	Cornell Univ. (Mathematics)	OCT 26 – NOV 3
DAVIS, MICHAEL J.	Argonne National Laboratory (Chemistry)	OCT 26 – 31
DE LA LLAVE, RAFAEL	Univ. of Texas (Mathematics)	SEP 1 – DEC 30
DELSHAMS, AMADEU	Univ. Politecnica de Catalunya (Matematica Aplicada I)	AUG 15 – DEC 20
DIENER, MARC	Univ. de Nice-Sophia-Antipolis (CNRS)	OCT 25 – NOV 1
DIONNE, BENOIT	Univ. of Ottawa (Math and Statistics)	SEP 1 – OCT 31
DOELMAN, ARJEN	Utrecht Univ. (Mathematisch Inst)	OCT 25 – NOV 1
DUMORTIER, FREDDY	Univ. Campus (Limburgs Universitair Centrum)	OCT 26 – 31
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	SEP 3 – DEC 21
FIFE, PAUL	Univ. of Utah (Mathematics)	OCT 27 – NOV 2
GARDNER, ROB	Univ. of Massachusettes (Mathematics)	OCT 27 – NOV 2
GOLDENFELD, NIGEL	Univ. of Illinois- Urbana/Champaig	OCT 26 – 29
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HABERMAN, RICHARD	Southern Methodist Univ. (Mathematics)	OCT 22 – 31
HALLER, GYORGY	Brown Univ. (Applied Mathematics)	OCT 25 – NOV 1
HAYES, MICHAEL	Boston Univ. (Math)	OCT 26 – NOV 1
HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
ILYASHENKO, YULIJ S.	Cornell Univ. (Mathematics)	OCT 26 – 31
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
JONES, CHRIS	Brown Univ. (Applied Mathematics)	OCT 22 – 31
KAPER, TASSO J.	Boston Univ. (Mathematics)	OCT 25 – 31
KETEMA, YOHANNES	Univ. of Minnesota (Aerospace Engineering and)	SEP 15 – NOV 21
KHIBNIK, ALEXANDER I.	United Technologies Research Center	OCT 26 – 31
KOKOTOVIC, PETAR V.	Univ. of California-Santa Barbara (ECE)	OCT 29 – 31
KOVACIC, GREGOR	Rensselaer Polytech Institute (Mathematical Science)	OCT 30 – NOV 1
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	SEP 2 – DEC 7
KRUPA, MARTIN (MACIEJ)	Technical Institute Vienna (Applied Mathematics)	SEP 28 – NOV 21
LEBOVITZ, NORMAN	Univ. of Chicago (Mathematics)	OCT 26 – 31
LIN, XIAO-BIAO	North Carolina State Univ. (Mathematics)	OCT 25 – 31
MCLAUGHLIN, DAVID	NYU-Courant Institute	OCT 25 – 31
MENON, GOVIND	Brown Univ. (Applied Mathematics)	OCT 22 – 31
MISCHAIKOW, KONSTANTIN	Georgia Institute of Technology (Mathematics)	OCT 26 – NOV 2
NEISHTADT, ANATOLY	pace Research , Moscow	OCT 2 – NOV 1
OSINGA, HINKE	University of Minnesota	SEP 1 – AUG 31
PETZOLD, LINDA R.	Univ. of California-Santa Barbara	OCT 24 – NOV 3
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
PROMISLOW, KEITH	Simon Fraser Univ. (Math and Statistics)	OCT 22 – 30

RALFS, ARTHUR C.	Ohio State Univ. (Mathematics)	OCT 26 – NOV 2
REICH, SEBASTIAN	Konrad-Zuse-Zentrum	OCT 26 – 31
ROUSSARIE, ROBERT	Univ. of Bourgogne (Mathematics)	OCT 26 – NOV 2
RUDNEV, MICHAEL	Univ. of Texas-Austin (Math)	OCT 27 – 31
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	SEP 13 – DEC 20
SCHECTER, STEPHEN	North Carolina State Univ. (Mathematics)	OCT 19 – 31
SEARA, TERESA M.	Univ. Politecnica de Catalunya (Aplicada I)	OCT 20 – NOV 1
SU, JIANZHONG	Univ. of Texas at Arlington (Mathematics)	OCT 26 – 31
SZMOLYAN, PETER	Technische Univ. Wien (Angewandte Mathematik)	SEP 14 – NOV 30
TERMAN, DAVID	Ohio State (Mathematics)	OCT 26 – 31
WARD, MICHAEL	Univ. of British Columbia (Mathematics)	OCT 23 – 28
WECHSELBERGER, MARTIN	Technische Universitat Wien	OCT 23 – NOV 6
ZENG, CHONGCHUN	NYU-Courant Institute	OCT 22 – NOV 1
ZIANE, MOHAMMED	Stanford Univ. (Center Turbulence Research)	OCT 26 – 31

Workshop 4: Dynamics of Algorithms November 17-21, 1997

ASCHER, URI M.	Univ. of British Columbia (Computer Science)	NOV 16 – 21
BRADLEY, ELIZABETH	Univ. of Colorado (Computer Science)	NOV 17 – 21
CHIERCHIA, LUIGI	Univ. of Rome 3 (Mathematics)	NOV 16 – 21
CORLISS, GEORGE F.	Marquette Univ. (Math)	NOV 16 – 21
DE LA LLAVE, RAFAEL	Univ. of Texas (Mathematics)	SEP 1 – DEC 30
DELSHAMS, AMADEU	Univ. Politecnica de Catalunya (Matematica Aplicada I)	AUG 15 – DEC 20
DIECI, LUCA	Georgia Institute of Technology (School of Mathematics)	NOV 16 – 21
ESTEP, DONALD J.	Georgia Institute of Technology (School of Mathematics)	NOV 16 – 21
GAVOSTO, ESTELA A.	Univ. of Kansas (Math)	NOV 16 – 21
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HAIRER, ERNST	University Geneva	NOV 16 – 23
HENRY, DANIEL	Ecole Centrale de Lyon	SEP 4 – NOV 1
IWANSKI, JOE	Univ. of Colorado at Boulder (Applied Mathematics)	NOV 16 – 21
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
KEARFOTT, R. BAKER	Univ. of Southwestern Louisiana (Mathematics)	NOV 15 – 21
KETEMA, YOHANNES	Univ. of Minnesota (AEM)	SEP 15 – NOV 21
KOCH, HANS	Univ. of Texas (Mathematics)	NOV 16 – 21
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	SEP 2 – DEC 7
LAMBA, HARBIR	Stanford (Mechanics and Computation)	NOV 16 – 21
LEIMKUHLER, BEN	Univ. of Kansas (Mathematics)	NOV 16 – 21
LEWIS, DEBRA	Univ. of California-Santa Cruz (Mathematics)	NOV 16 – 21
LUBICH, CHRISTIAN	Univ. Tuebingen (Mathematisches)	NOV 16 – 23
LUSKIN, MITCH	Univ. of Minnesota (Mathematics)	SEP 4 – 9
MARZ, ROSWITHA	Humboldt-Univ. of Berlin (Mathematics)	NOV 16 – 23
MASCARI, GIANFRANCO	Univ. of Naples / CNR	NOV 16 – 22
MROZEK, MARIAN	Krakow, Poland (University Krakow)	NOV 16 – 21
NEUBERT, ROLF	Siemens AG	NOV 16 – 25
OLVER, PETER J.	Univ. of Minnesota (Mathematics)	NOV 16 – 21
PETZOLD, LINDA R.	Univ. of California-Santa Barbara	NOV 19 – 21
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
REICH, SEBASTIAN	Konrad-Zuse-Zentrum	NOV 16 – 21
RYCHLIK, MAREK	Univ. of Arizona (Mathematics)	NOV 15 – 21
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	SEP 13 – DEC 20
SAUER, TIMOTHY D.	George Mason Univ. (Mathematical Sciences)	NOV 18 – 23

SCHELTER, WILLIAM	Univ. of Texas (Mathematics)	NOV 16 – 21
SCHMIDT, DIETER	Univ. of Cincinnati (Mathematics)	NOV 17 – 23
SHUB, MICHAEL	IBM (T.J. Watson Res Ctr.)	NOV 18 – 21
STUART, ANDREW M.	Stanford Univ.	NOV 18 – 21
SZMOLYAN, PETER	Technische Univ. Wien (Angewandte Mathematik)	SEP 14 – NOV 30
SZYMCZAK, ANDRZEJ	Georgia Institute of Technology (Math)	NOV 15 – 21
VAN VLECK, ERIK	Colorado School of Mines (Math and Computer Science)	OCT 18 – NOV 20
WARNOCK, ROBERT L.	Stanford Linear Accelerator	NOV 16 – 21
YORKE, JAMES A.	Univ. of Maryland	NOV 17 – 21
YUAN, GUOCHENG	Univ. of Maryland (Mathematics)	NOV 15 – 21

Special Workshop: Algorithmic Methods for Semiconductor Circuitry November 24-25, 1997

CAMPBELL, STEPHEN L.	North Carolina State Univ. (Mathematics)	NOV 23 – 25
CAO, GENE	Michigan Technological Univ. (Mathematical Sciences)	NOV 20 – 30
CHIPROUT, ELI	IBM Austin Research Lab	NOV 23 – 25
ELFADEL, ABE	IBM (T.J. Watson Research Center)	NOV 22 – 25
FELDMANN, PETER	Bell Labs Innovations (Lucent Technology)	NOV 23 – 25
FREUND, ROLAND	Bell Laboratories	NOV 22 – 26
GREEN, MICHAEL	Univ. of California-Irvine (Electrical and Computer Eng.)	NOV 23 – 26
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
GUENTHER, MICHAEL	TH Darmstadt (Fachbereich Mathematik)	NOV 23 – 25
HOLTE, JIM	Univ. of Minnesota	NOV 24 – 25
KAHLERT, MARTIN	Siemens AG	NOV 22 – 26
KELLER, HERBERT B.	California Institute of Technology	SEP 1 – NOV 30
KLAASSEN, BERNHARD	GMD/German Research Centre for Computer	NOV 22 – 26
KUNDERT, KEN	Cadence	NOV 23 – 25
NEUBERT, ROLF	Siemens AG	NOV 16 – 25
NGUYEN, TUYEN	IBM	NOV 23 – 25
PHILLIPS, JOEL	Cadence	NOV 23 – 25
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
ROYCHOWDHURY, JAIJEET	Bell Laboratories (Communications Sciences Research)	NOV 23 – 25
RUEHLI, ALBERT	IBM (Thomas J Watson Research Center)	NOV 23 – 25
SAPATNEKAR, SACHIN	Univ. of Minnesota	NOV 24 – 25
TRAJKOVIC, LJILJANA	Simon Fraser Univ. (School Engineering Science)	NOV 22 – 25
VINNAKOTA, BAPI	Univ. of Minnesota (Electical Engineering)	NOV 24 – 25
WAGNER, ROB	Ansof)	NOV 22 – 25
WHITE, JACOB	MIT (Computer Science and Elect. En)	NOV 23 – 25
WU, TING	Michigan Tech (Math)	NOV 23 – 25

6. WINTER 1998 WORKSHOP AND TUTORIAL PARTICIPANTS

Workshop 5: Computational Neuroscience January 14-23, 1998

ABBOTT, LARRY	Brandeis Univ. (Volen Center)	JAN 13 – 19
BAER, STEVE	Arizona State Univ. (Mathematics)	JAN 19 – 25
BELL, TONY	Interval Research Corporation	JAN 14 – 18
BERTRAM, RICHARD	Penn State-Behrend (Science)	JAN 13 – 23
BLUM, KENNETH I.	M.I.T. (Brain and Cognitive Science)	JAN 13 – 23
BOOTH, VICTORIA	New Jersey Institute of Technology (Mathematics)	JAN 13 – 23
BOWER, JIM	Caltech (Biology)	JAN 16 – 23

BUTERA, ROB	NIH (Mathematical Research Branch)	JAN 17 – 23
CAMPBELL, SUE ANN	Univ. of Waterloo (Applied Mathematics)	JAN 13 – 18
CHAPMAN, BARBARA	Univ. of California, Davis (Ctr Neuroscience)	JAN 13 – 23
CHOW, CARSON	Boston Univ. (Mathematics)	JAN 13 – 23
COWAN, JACK D.	Univ. of Chicago (Math)	JAN 13 – 23
CROOK, SHARON	Montana State Univ. (Center Computational Biology)	JAN 4 – 31
DAN, YANG	Univ. of California (Molecular and Cell Biology)	JAN 13 – 23
DAYAN, PETER	M.I.T. (Brain & Cognitive Science)	JAN 13 – 23
DESTEXHE, ALAIN	Laval Univ. School of Medicine (Physiology)	JAN 17 – 23
EPSTEIN, STEVE	Boston Univ. (Mathematics)	JAN 17 – 23
ERMENTROUT, BARD	Univ. of Pittsburgh (Mathematics)	JAN 17 – 22
FERSTER, DAVID	Northwestern Univ. (Neurobiology/Physiology)	JAN 13 – 23
FREEMAN, RALPH D.	University California-Berkeley	JAN 13 – 17
GERSTNER, WULFRAM	Swiss Federal Institute of Technology	JAN 13 – 23
GOLOMB, DAVID	Ben-Gurion Univ. of the Negev (Physiology)	JAN 12 – 27
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HANSEL, DAVID	Ecole Polytechnique (Centre Physique Theorique)	JAN 12 – 30
HIRSCH, JUDITH	Rockefeller Univ. (Laboratory Neurobiology)	JAN 13 – 17
HOLMES, PHILIP JOHN	Princeton Univ. (Applied and Computational Mathematics)	JAN 13 – 23
IZHIKEVICH, EUGENE M.	Arizona State Univ. (Center System Sci and Eng Research)	JAN 13 – 23
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
JUNG, RANU	Univ. of Kentucky (Center Biomedical Engineering)	JAN 13 – 23
KIEMEL, TIM	Univ. of Maryland (Zoology)	JAN 13 – 23
KIM, SEUNGHWAN	POSTECH (RIM-GARC) (Physics and Math)	JAN 12 – 25
KOPELL, NANCY	Boston Univ. (Mathematics)	JAN 17 – 23
LEWIS, JOHN	Univ. of Ottawa (Cellular and Molecular Medicine)	JAN 13 – 23
LEWIS, TIM	Univ. of Utah (Math)	JAN 14 – 23
LISMAN, JOHN	Brandeis Univ.	JAN 17 – 20
LYTTON, BILL	Univ. of Wisconsin (Neurology)	JAN 15 – 23
MATO, GERMAN	Centro Atomico Bariloche	JAN 5 – 28
MATVEEV, VICTOR	Brandeis Univ. (Center Complex Systems)	JAN 13 – 24
MCLAUGHLIN, DAVID	NYU-CourantInstitute	JAN 13 – 22
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MILLER, KEN	UC San Francisco (Physiology)	JAN 13 – 19
MORELLI, MICHAEL	University Wisconsin-Stout	JAN 20 – 20
NADIM, FARZAN	Brandeis Univ. (Volen Center)	JAN 17 – 23
NICOLELIS, MIGUEL	Duke Univ. Medical Center (Neurobiology)	JAN 13 – 23
NOONBURG, VIRGINIA ANNE	Univ. of Hartford (Mathematics)	JAN 13 – 23
PINTO, DAVID	Boston Univ. (Math)	JAN 14 – 24
PUGH, MARY	Univ. of Pennsylvania (Mathematics)	JAN 15 – 18
RINZEL, JOHN	New York Univ. (Center Neural Science)	JAN 13 – 23
RUBIN, JONATHAN	Ohio State Univ. (Mathematics)	JAN 20 – 23
RUSH, MAUREEN	Cal State Univ. Bakersfield (Mathematics)	JAN 15 – 23
SEN, ASOK	Indiana Univ. Purdue University (Mathematical Sciences)	JAN 13 – 23
SHAPLEY, ROBERT	New York Univ. (Center Neural Science)	JAN 13 – 18
SHELLEY, MICHAEL J.	New York Univ. (Courant Mathematical Scien)	JAN 13 – 23
SHERMAN, ARTHUR	NIH (Mathematical Research Branch, NIDDK)	JAN 17 – 23
SHERMAN, MURRAY	State Univ. of New York (Neurobiology)	JAN 13 – 19
SKAGGS, BILL	Univ. of Pittsburgh (Neuroscience)	JAN 17 – 23
SKINNER, FRANCIS	Toronto Hospital, Western Division (Playfair Neuroscience Unit)	JAN 13 – 23
SMITH, GREGORY	NIH (Mathematical Research Branch, NIDDK)	JAN 13 – 23

SOMERS, DAVID	MIT (Brain & Cog. Sciences)	JAN 13 – 19
SOMPOLINSKY, HAIM	Hebrew Univ. (Racah Physics)	JAN 13 – 23
SWINDALE, NICHOLAS V.	Univ. of British Columbia (Ophthalmology)	JAN 13 – 23
TERMAN, DAVID	Ohio State Univ. (Mathematics)	JAN 12 – 23
THEUNISSEN, FREDERIC	Univ. of California at San Francis	JAN 16 – 21
TRAUB, ROGER	Univ. of Birmingham (Physiology, Neuroscience)	JAN 17 – 22
TROYER, TODD	Univ. of California at San Francis (Physiology)	JAN 13 – 23
TSODYKS, MISHA V.	Weizmann Institute of Science (Neurobiology, Brain Research B)	JAN 14 – 21
TURNER, ROBERT	Univ. of Wisconsin-Madison (Mathematics)	JAN 17 – 20
VAN HEMMEN, J. LEO	TU Muenchen (Physics)	JAN 13 – 23
WANG, DELIANG	Ohio State Univ.	JAN 13 – 23
WANG, XIAO-JING	Brandeis Univ. (Center Complex Systems)	JAN 13 – 23
WEARNE, SUSAN	Univ. of New South Wales (Math)	JAN 13 – 23
WHITE, JOHN A.	Boston Univ. (Biomedical Engineering)	JAN 13 – 23
WILLMS, ALLAN	Univ. of Canterbury (Mathematics and Statistic)	JAN 14 – 23
WILSON, CHARLES	Univ of Tennessee Ctr Health Sciences (Anatomy)	JAN 13 – 23

Tutorial: Calcium Dynamics in Cells February 5-6, 1998

BIEBERICH, ANDREA	(University Notre Dame)	FEB 4 – 6
CHAN, SAMUEL	Univ. of California, Davis (Mathematics)	FEB 2 – 7
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
KAKALIOS, JAMES	Univ. of Minnesota (Physics)	FEB 5 – 6
KEIZER, JOEL	Univ. of California-Davis	FEB 4 – 13
MILLER, CHARLES	Univ. of Notre Dame (Mathematics)	FEB 4 – 13
MIURA, ROBERT	NIH (Mathematics Research Branch)	FEB 4 – 13
MORELLI, MICHAEL	University Wisconsin-Stout	JAN 20 – 20
NI, WEI-MING	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31

Workshop 6: Calcium Dynamics in Cells February 9-13, 1998

ALLBRITTON, NANCY L.	Univ. of California-Irvine (Physiology)	FEB 7 – 13
ARMBRUSTER, DIETER	Arizona State Univ. (Mathematics)	FEB 8 – 13
ATWATER, ILLANI	NIDDK, NIH (LCBB)	FEB 8 – 13
BIEBERICH, ANDREA	University Notre Dame	FEB 4 – 6
BUGRIM, ANDREJ	Univ. of California-Davis (Theoretical Dynamics)	FEB 7 – 13
CARBINATTO, MARIA C.	Univ. de Sao Paulo (ICMSC)	FEB 8 – 13
CHARLES, ANDREW	UCLA (Neurology)	FEB 7 – 13
DAI, LONG	NIH (Mathematical Research Branch)	FEB 8 – 13
DE YOUNG, GARY	Mesa State College of Colorado (Mathematics)	FEB 7 – 13
DUPONT, GENEVIEVE	Univ Libre Bruxelles	FEB 7 – 14
EPSTEIN, IRVING	Brandeis University	FEB 8 – 13
FRIEDMAN, MARK	Univ. of Alabama-Huntsville (Mathematics)	FEB 7 – 13
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
HUNTER, JOHN	Univ. of California-Davis (Mathematics)	FEB 7 – 13
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
KEIZER, JOEL	Univ. of California-Davis	FEB 4 – 13
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KISAALITA, WILLIAM S.	Univ. of Georgia (Biological and Agricultural Engineering)	FEB 7 – 13
LECHLEITER, JAMES D.	Univ. of Virginia (Neuroscience, Markey Center)	FEB 7 – 13
LI, YUE-XIAN	Univ. of California-Davis (Inst Theoretical Dynamics)	FEB 8 – 13

LOEW, LESLIE	Univ. of Conn. Health Center (Physiology)	FEB 8 – 12
MAGNUS, GERHARD		FEB 8 – 15
MEARS, DAVID	NIH (LCBB)	FEB 10 – 14
MILLER, CHARLES	Univ. of Notre Dame (Mathematics)	FEB 4 – 13
MIURA, ROBERT	NIH (Mathematics Research Branch)	FEB 4 – 13
NUCCITELLI, RICHARD	Univ. of California-Davis (Molecular and Cellular Biology)	FEB 8 – 13
OTHMER, HANS	Univ. of Utah (Mathematics)	FEB 9 – 13
PEARSON, JOHN	Los Alamos National Laboratory	FEB 9 – 14
PERNAROWSKI, MARK	Montana State Univ. (Mathematical Science)	FEB 7 – 13
RAO, RAJ R.	Univ. of Georgia (Biological & Agricultural Engineering)	FEB 7 – 13
ROJAS, EDUARDO E.	NIH (LCBB)	FEB 8 – 13
RUSSELL, JAMES T.	NIH	FEB 8 – 13
SANDERSON, MICHAEL J.	Univ. of Massachusetts Medical School (Physiology)	FEB 8 – 13
SHERMAN, ARTHUR	NIDDK, NIH (Mathematical Research Branch)	FEB 4 – 13
SMITH, GREGORY D.	NIDDK, NIH (Mathematical Research Branch)	FEB 8 – 13
SMOLEN, PAUL	Univ. of Texas-Medical School (Neurobiology & Anatomy)	FEB 8 – 13
STOJIKOVIC, STANKO	NICHD, NIH (Endocrine and Reproductive Research)	FEB 8 – 12
TERMAN, DAVID	Ohio State (Mathematics)	FEB 7 – 13
THOMAS, ANDREW P.	New Jersey Medical School of UMDNJ	FEB 7 – 13
ZIMLIKI, CHARLES	NIH (LCBB)	FEB 10 – 14
ZUCKER, ROBERT S.	Univ. of California-Berkeley (Molecular and Cell Biology)	FEB 10 – 12

Special Workshop: Knowledge and Distributed Intelligence (KDI)–Opportunities in the Mathematical Sciences
March 7, 1998

ALI, SYED S.	Univ. of Wisconsin-Milwaukee (Mathematical Sciences)	MAR 6 – 8
AMIN, MASSOUD	Electric Power Research Institute	MAR 5 – 7
ANDERSON, MEREDITH	American Express Financial Advisors	MAR 7 – 7
APTE, CHID	IBM T.J. Watson Research Center (Data Abstraction Research)	MAR 6 – 8
BACH, ERIC	Univ. of Wisconsin	MAR 6 – 7
BAKER, RICHARD	Univ. of Iowa (Mathematics)	MAR 7 – 8
BAXTER, JOHN	Univ. of Minnesota (Mathematics)	MAR 7 – 7
BOLEY, DANIEL	Univ. of Minnesota (Computer Science)	MAR 7 – 7
BOTELHO, FERNANDA	Univ. of Memphis (Mathematical Sciences)	JAN 10 – MAY 31
BUCK, GREGORY	Saint Anselm College (Mathematics)	MAR 7 – 8
CAO, GENE	Michigan Tech (Mathematics)	MAR 13 – 16
CARMEIN, DAVID	Minnesota Virtual Simulations	MAR 7 – 7
CHERKASSKY, VLADIMIR	Univ. of Minnesota (Electrical Engineering)	MAR 7 – 7
COCKBURN, BERNARDO	Univ. of Minnesota (School of Mathematics)	MAR 7 – 7
COOK, DIANNE	Iowa State Univ. (Statistics)	MAR 7 – 7
CROUCH, CAROLYN J.	Univ. of Minnesota, Duluth (Computer Science)	MAR 6 – 8
CROUCH, DONALD B.	Univ. of Minnesota, Duluth (Computer Science)	MAR 6 – 8
CYBENKO, GEORGE	Dartmouth College (Engineering)	MAR 6 – 8
DAVIS, WILLIAM J.	Ohio State University	MAR 7 – 8
DICKERSON, JULIE	Iowa State University	MAR 7 – 7
DUNHAM, DOUGLAS	Univ. of Minnesota - Duluth (Computer Science)	MAR 7 – 7
FLUGRAD, DONALD	Iowa State Univ. (Mechanical Engineering)	MAR 7 – 7
FRENCH, DONALD	Univ. of Cincinnati (Mathematical Sciences)	SEP 1 – AUG 31
FRIEDMAN, AVNER	Univ. of Minnesota (Minnesota Center Industrial Mathema)	SEP 1 – AUG 31
GARRETT, PAUL	Univ. of Minnesota (Mathematics)	MAR 7 – 7
GERSHENFELD, NEIL	MIT Media Lab	MAR 7 – 7
GINI, MARIA	University Minnesota	MAR 7 – 7
GREENE, JOE	Univ. of Illinois-Urbana (ESB)	MAR 6 – 8

GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HAGBERG, ARIC	Los Alamos National Laboratory	MAR 6 – 8
HONAVAR, VASANT	Iowa State Univ. (Computer Science)	MAR 6 – 7
KARNIK, NEERAN	Univ. of Minnesota (Computer Science)	MAR 7 – 7
KARYPIS, GEORGE	Univ. of Minnesota (CS&E)	MAR 7 – 7
KETTENRING, JON	Bell Communications Research	MAR 6 – 8
KLAMECKI, BARNEY	Univ. of Minnesota (Mechanical Engineering)	MAR 7 – 7
KLEINBERG, JON	Cornell Univ. (Computer Science)	MAR 6 – 8
KOH, JEE HEUB	Indiana Univ. (Mathematics)	MAR 6 – 7
KUMAR, VIPIN	Univ. of Minnesota (Computer Science)	MAR 7 – 7
LEE, NAMYONG	Univ. of Minnesta (School of Mathematics)	MAR 7 – 7
LI, PERRY	Univ. of Minnesota (Mechanical Engineering)	MAR 7 – 7
MCCURLEY, KEVIN	IBM Almaden Research Center (IBM Research)	MAR 6 – 7
MCGEHEE, RICHARD	Univ. of Minnesota (Geometry Center)	MAR 7 – 7
MCROY, SUSAN W.	Univ. of Wisconsin-Milwaukee (EECS)	MAR 6 – 8
MITREA, IRINA	Univ. of Minnesota (Math)	MAR 7 – 7
MORTON, BLAISE	Honeywell	MAR 7 – 7
MULIER, FILIP	3M (Engineering Systems and Technology Lab)	MAR 7 – 7
MUNCASTER, ROBERT	Univ. of Illinois at Urbana-Champa (Mathematics)	MAR 6 – 8
NOSTRAND, BARBARA	State College at Oneonta (Mathematical Sciences)	MAR 6 – 9
RALESCU, ANCA	Univ. of Cincinnati (Elec Engineering and Com)	MAR 6 – 8
RALESCU, DAN	Univ. of Cincinnati (Mathematical Sciences)	MAR 6 – 8
RAPHAEL, CHRISTOPHER	Univ. of Massachusetts-Amherst (Math and Statistics)	MAR 6 – 8
REITICH, FERNANDO	Univ. of Minnesota (Mathematics)	MAR 7 – 7
RON, AMOS	Univ. of Wisconsin, Madison (Computer Science)	MAR 6 – 7
RUDNAYA, SVETLANA	Univ. of Minnesota (School of Mathematics)	MAR 7 – 7
SAHINIDIS, NIKOLAOS	Univ. of Illinois-Urbana (Chemical Engineering)	MAR 6 – 8
SEJNOWSKI, TERRY	Salk Institute	MAR 6 – 8
SKEEL, ROBERT D.	Univ. of Illinois (Computer Science)	MAR 6 – 8
SRIVASTAVA, JAIDEEP	Univ. of Minnesota (CSE)	MAR 7 – 7
STEUERWALT, MIKE	NSF	MAR 6 – 8
SULLIVAN, JOHN	Univ. of Illinois (Mathematics)	MAR 6 – 7
TANNENBAUM, ALLEN	Univ. of Minnesota (Electrical and Computer E)	MAR 7 – 7
THALER, AL	NSF	MAR 6 – 8
TIDRIRI, MOULAY	Iowa State Univ. (Mathematics)	MAR 6 – 8
TORRES, RODOLFO	Univ. of Kansas (Mathematics)	MAR 6 – 7
TRIPATHI, ANAND	Unversity of Minnesota (Computer Science)	MAR 7 – 7
WARMUTH, MANFRED	University California at Santa Cruz	MAR 6 – 7
WEICHSEL, PAUL M	Univ. of Illinois at Urbana-Champaigne	MAR 6 – 8
YIN, GEORGE	Wayne State Univ. (Mathematics)	MAR 7 – 7
YUNES, LUIS	Univ. of Minnesota (Math)	MAR 7 – 7
ZHANG, BINGYU	Univ. of Cincinnati (Mathematical Sciences)	MAR 6 – 8

Workshop 7: Cardiac Dynamics March 9-14, 1998

BARKLEY, DWIGHT	Univ. of Warwick (Mathematics)	AUG 15 – JUN 30
BRONSTERING, ROLF	Univ. of Muenster (fuer Numerische Mathematik)	MAR 7 – 15
BUONO, PIETRO-LUCIANO	Univ. of Houston (Mathematics)	MAR 8 – 14
CACCIOLA, GIOVANNA	Eindhoven Univ. of Tech (Mechanical Engineering)	MAR 8 – 14
CHAO, YI-JU	Univ. of Minnesota (Math)	MAR 9 – 14
CHAY, TERESA	Univ. of Pittsburgh (Biological Sciences)	MAR 8 – 15
CHIPOT, MICHEL	Univ. of Zuerich (CNRS) (Andgewandte Mathematik)	MAR 8 – 13
CHRISTINI, DAVID	Cornell Medical Center (Cardiology)	MAR 9 – 15
COLLINS, JIM	Boston Univ. (Biomedical Engineering)	MAR 13 – 14

DIETZ, DONNA	Rensselaer Polytechnic Inst. (Math)	MAR 8 – 14
DINH, THOMAS	Medtronic (Science and Technology)	MAR 12 – 14
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	MAR 10 – APR 6
GARFINKEL, ALAN	UCLA (Cardiology)	MAR 11 – 14
GILLBERG, JEFFREY	Medtronic (Tachyarrhythmia Research)	MAR 9 – 13
GLASS, LEON	McGill Univ. (Physiology)	MAR 11 – 15
GOMES, GABRIELA	Univ. do Porto (CentroMatematica Aplicada)	SEP 1 – JUL 31
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
GUNNEY, BRIAN	Medtronic	MAR 9 – 14
HALL, KEVIN	McGill Univ. (Center Nonlinear Dynamics)	MAR 8 – 14
HAMLEN, CUSHING	Center for Biomaterials Research (Medtronic)	MAR 9 – 14
HAN, KEESOOK	Univ. of Minnesota (Electrical Engineering)	MAR 9 – 14
HOBBIE, RUSSELL	Univ. of Minnesota (Physics)	MAR 9 – 14
HOLTE, JIM	Univ. of Minnesota (Electrical Engineering)	MAR 9 – 14
HONDEGHEM, LUC	Hondeghem Pharmaceuticals, Inc.	MAR 7 – 14
IRVINE, LISA	Johns Hopkins Univ. (Biomedical Engineering)	MAR 12 – 15
ISAACSON, DAVID	Rensselaer Polytechnic Inst. (Math)	MAR 8 – 14
JAFRI, SALEET	Johns Hopkins Univ. School of Medicine	MAR 8 – 14
JENISON, TROY	Medtronic	MAR 13 – 13
JOHNSON, CHRIS	Univ. of Utah (Computer Science)	MAR 8 – 13
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
KAPLAN, DANNY	Macalaster College (Math and Computer Science)	MAR 9 – 14
KARMA, ALAIN	Northeastern Univ. (Physics)	MAR 8 – 15
KEENER, JAMES	Univ. of Utah (Mathematics)	MAR 7 – 14
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
LITTMAN, WALTER	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
MANRODT, CHRIS	Medtronic (Bradycardia Technology)	MAR 9 – 14
MAY, STEVE	Medtronic	MAR 9 – 14
MCCULLOCH, ANDREW	Univ. of California - San Diego (Bioengineering)	MAR 10 – 14
MCQUEEN, DAVID	NYU-Courant Institute	MAR 8 – 15
MEHDI, KHAWAR	Medtronic (Brady Research)	MAR 9 – 13
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MIN, SHIRLEY	Medtronic, In)	MAR 9 – 14
MIURA, ROBERT	NIDDK/NIH	MAR 8 – 14
MORISSETTE, JOSEE	Medtronic	MAR 9 – 14
MORRIS, MILTON	Guidant Corporation	MAR 9 – 14
MUELLER, STEFAN	MPI for Mathematics in the Sciences	JAN 22 – FEB 1
OLSON, WALTER	Medtronic, In)	MAR 9 – 14
PESKIN, CHARLES S.	New York Univ. (Courant)	MAR 8 – 13
PRINTZ, BETH	Columbia College of Physicians and Surg (Pediatric Cardiology)	MAR 9 – 14
RASMUSSON, RANDY	Allegheny Univ. (Cardiovascular and Pulmonary Research I)	MAR 8 – 15
RUDY, YORAM	Case Western Reserve Univ. (Biomedical Engineering)	MAR 10 – 12
SNYDERS, DIRK	Vanderbilt Univ. School of Medicin (Clinical Phyarmacology)	MAR 9 – 14
TABER, LARRY	Washington Univ. (Biomedical Engineering)	MAR 10 – 13
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30
VOTH, ERIC	Endocardial Solutions, Inc	MAR 13 – 13
WARMAN, EDUARDO	Medtronic, Inc. (Research Scientist)	MAR 8 – 15
WEINBERGER, HANS	Univ. of Minnesota (School of Mathematics)	JUN 8 – 12
WINSLOW, RAI	The Johns Hopkins Univ. School of Medicine	MAR 10 – 14
WOODWARD, PAUL	Univ. of Minnesota (Astronomy)	MAR 12 – 14
XIE, MIN	Univ. of Utah (Mathematics)	FEB 28 – MAR 30

YI, CHUNG SEON	Univ. of Utah (Math)	MAR 8 – 15
YU, WEIPING	Medtronic	MAR 9 – 14
ZHAO, YONG	Medtronic	MAR 9 – 14

7. SPRING 1998 WORKSHOP AND TUTORIAL PARTICIPANTS

Workshop 8 : Nonlinear Identification and Control April 27- May 1, 1998

ADOMAITIS, RAY	Univ. of Maryland (Chemical Engineering)	APR 26 – MAY 1
ANDERSH, JONATHAN	3M (Process and Control)	APR 27 – MAY 1
ARIS, RUTHERFORD	Univ. of Minnesota (Chemical Eng)	APR 27 – MAY 1
ARMBRUSTER, DIETER	Arizona State Univ. (Mathematics)	APR 26 – MAY 15
AXELROD, ANTHONY	3M	APR 26 – MAY 1
BAILLIEUL, JOHN	Boston Univ. (Engineering)	APR 26 – MAY 1
BANASZUK, ANDRZEJ	United Technologies Research Center	APR 26 – 29
BLOCH, ANTHONY	Univ. of Michigan (Mathematics)	APR 26 – 30
BOTELHO, FERNANDA	Univ. of Memphis (Mathematical Sciences)	JAN 10 – MAY 31
BROCKETT, ROGER	Harvard University	APR 28 – 28
BURNS, TIM	NIST	APR 27 – MAY 2
CO, TOMAS	Michigan Technological Univ. (Chemical Engineering)	APR 27 – MAY 1
DAOUTIDIS, PRODROMOS	Univ. of Minnesota (Chemical Engineering)	APR 26 – MAY 1
DIPPERY, KYLE	Univ. of Kentucky (Mechanical Engineering)	APR 25 – MAY 1
DOYLE, FRANK	Univ. of Delaware (Chemical Engineering)	APR 27 – 30
EIAN, JOHN	Univ. of Minnesota (Biomedical Engineering)	APR 27 – MAY 1
EMAMI-NAEINI, ABBAS	SC Solutions, Inc.	APR 26 – 28
GEORGIOU, TRYPHON	Univ. of Minnesota (Electrical Engineering)	APR 27 – MAY 1
GOMES, GABRIELA	Univ. do Porto (CentroMatematica Aplicada)	SEP 1 – JUL 31
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
KANELLAKOPOULOS, IOANNIS	UCLA (Electrical Engineering)	APR 26 – MAY 1
KEVREKIDIS, YANNIS	Princeton Univ. (Chemical Engineering)	APR 26 – MAY 1
KHIBNIK, ALEXANDER I.	United Technologies Research Center	APR 28 – MAY 1
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KLIEMANN, WOLFGANG	Iowa State Univ. (Mathematics)	APR 30 – MAY 1
KOKOTOVIC, PETAR V.	Univ. of California-Santa Barbara (ECE)	APR 30 – MAY 1
KRAVARIS, COSTAS	Univ. of Michigan (Chemical Engineering)	APR 27 – 29
KRISHNAPRASAD, P.S.	Univ. of Maryland (Electrical Engineering)	APR 26 – MAY 1
KRSTIC, MIROSLAV	University California at San Diego	APR 26 – 29
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LEE, BRUCE	Univ. of Minnesota (Electrical Engineering)	APR 27 – MAY 1
LI, PERRY	Univ. of Minnesota (Mechanical Engineering)	APR 27 – MAY 1
LUO, J.C.	Univ. of Minnesota (ECE)	APR 27 – MAY 1
MAREELS, IVEN	Univ. of Melbourne (Electrical Engineering)	APR 24 – MAY 3
MAYNE, D. Q.	Imperial College, London	APR 27 – 28
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
ORSI, ROBERT	Univ. of Melbourne	APR 24 – MAY 3
PISMEN, L.M.	Technion- Israel Institute of Technolog	APR 26 – MAY 2
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
RAWLINGS, JAMES B	Univ. of Wisconsin (Chemical Engineering)	APR 27 – 28
ROOSE, DIRK	Katholieke Univ. Leuven (Computer Science)	APR 25 – MAY 1
SAAD, YOUSEF	Univ. of Minnesota (Computer Science)	APR 27 – MAY 1

SAIMEK, SAROJ	Univ. of Minnesota (Mechanical Engineering)	APR 27 – MAY 1
SAMAD, TARIQ	Honeywell	APR 26 – MAY 1
SHVARTSMAN, STANISLAV	(Princeton University)	APR 26 – MAY 1
SONTAG, EDUARDO	Rutgers Univ. (Mathematics)	APR 28 – MAY 3
STACHOWICZ, MARIAN	Univ. of Minnesota-Duluth	APR 27 – MAY 1
STARK, JAROSLAV	UCL (Centre for Nonlinear Dynamics)	APR 26 – MAY 2
TITI, EDRISS SALEH	Univ. of California-Irvine (Mathematics)	APR 19 – MAY 3
YDSTIE, ERIC	Carnegie-Mellon Univ.	APR 26 – MAY 1

Workshop 9: Pure, Applied and Industrial Mathematics: Strength through Connections May 1-3, 1998

ADAMS, DAVID	Univ. of Kentucky (Mathematics)	MAY 1 – 3
ANDERSON, ROGER	3M Center (3M)	MAY 1 – 3
ARONSON, DON	Univ. of Minnesota (Mathematics)	MAY 1 – 3
BEMELMANS, JOSEF	Rheinisch-Westf Tech Hochschule (Inst Math)	APR 29 – MAY 3
BORUCKI, LEN	Motorola Inc.	MAY 2 – 3
BRAUER, BARBARA		MAY 1 – 3
BRAUER, GEORGE	University of Minnesota	MAY 1 – 3
BRUNO, OSCAR	Caltech (Applied Math)	APR 29 – MAY 3
CAFFARELLI, LUIS A.	Univ. of Texas at Austin (Math)	APR 30 – MAY 3
CASTRO, PETER	Eastman Kodak Co. (Computational Science lab)	MAY 1 – 3
CELADA, PIETRO	Univ. Degili Studi Di Trieste	MAY 1 – 3
CHADAM, JOHN	Univ. of Pittsburgh (Math and Stat)	MAY 1 – 5
CHOCK, DAVID	Ford Motor Company (Chemistry)	MAY 2 – 3
CUI, SHANGBIN	Lanzhou Univ. (Mathematics)	MAY 1 – 3
DIBENEDETTO, EMMANUELE	Northwestern Univ. (Mathematics)	APR 30 – MAY 3
EVANS, DEBBIE		MAY 1 – 3
FABES, ESTER		MAY 1 – 3
FLEMING, WENDELL H.	Brown Univ. (Applied Math)	APR 30 – MAY 3
FOLGUERA, ALEJANDRA	Univ. of Illinois	MAY 1 – 3
FONTELOS, MARCO ANTONIO	Univ. Complutense de Madrid (Aplicada)	MAY 1 – 3
FOSDICK, ROGER	Univ. of Minnesota (Aerospace Eng. and Mech.)	MAY 1 – 3
FRENCH, DONALD	Univ. of Cincinnati (Mathematical Sciences)	MAY 1 – 3
FRIEDMAN, ALISSA		MAY 1 – 3
FRIEDMAN, AVNER	Univ. of Minnesota	SEP 1 – AUG 31
FRIEDMAN, ISRAEL		MAY 1 – 3
FRIEDMAN, LYNN		MAY 1 – 3
FRIEDMAN, NAOMI		MAY 1 – 3
FRIEDMAN, TAMARA		MAY 1 – 3
GAMBA, IRENE	University Texas - Austin	MAY 2 – 3
GLIMM, JAMES G.	SUNY at Stony Brook (Applied Math and Statistics)	APR 30 – MAY 3
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
GREGORY, BOB		MAY 1 – 3
GULLIVER, ROBERT	University Minnesota	SEP 1 – AUG 31
HERTZOG, VICTORIA		MAY 1 – 3
HU, XIAOPING	Univ. of Minnesota (Radiology)	MAY 1 – 3
HUANG, CHAOCHENG	Wright State Univ. (Math)	MAY 1 – 3
INDELICATO, ART		MAY 1 – 3
INDELICATO, MARY		MAY 1 – 3
JAIN, NARESH	Univ. of Minnesota (Mathematics)	NOV 9 – 9
JOSEPH, DAN	Univ. of Minnesota (Aerospace Eng & Mech.)	MAY 1 – 3

KAHN, DONALD	University Minnesota	MAY 1 – 3
KAVEH, MOS	Univ. of Minnesota (Electrical Eng.)	MAY 1 – 3
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KRYLOV, NICOLAI	University Minnesota	MAY 1 – 3
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LEVERMORE, DAVID	Univ. of Arizona (Mathematics)	MAY 2 – 3
LI, REN-CANG	Univ. of Kentucky (Mathematics)	MAY 1 – 3
LIN, MRS. NAIGUO	University Minnesota	MAY 1 – 3
LIN, NAIGUO	Univ. of Minnesota (Physics and Astronomy)	MAY 1 – 3
LITTMAN, WALTER	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
LUSKIN, MITCH	Univ. of Minnesota (Mathematics)	MAY 1 – 3
MARKUS, LAWRENCE	University Minnesota	MAY 1 – 3
MCAREE, CEIL		MAY 1 – 3
MCCARTHY, CHARLES	University Minnesota	MAY 1 – 3
MEYERS, NORMAN G.		MAY 1 – 3
MISEMER, DAVID	3M	MAY 1 – 3
MORELLI, MICHAEL	Unviersity of Wisconsin-Stout	MAY 2 – 3
MOSKOW, SHARI	MCIM	MAY 1 – 3
OCKENDON, HILLARY	Univ. of Oxford (OCIAM, Math)	APR 30 – MAY 3
OCKENDON, JOHN	Univ. of Oxford (OCIAM, Math)	APR 30 – MAY 3
OLVER, PETER J.	Univ. of Minnesota (Mathematics)	MAY 1 – 3
PINSKY, MARK	Northwestern Univ. (Math)	MAY 1 – 2
POUR-EL, MARIAN	University Minnesota	MAY 1 – 3
PRIKRY, KAREL	Univ. of Minnesota (Mathematics)	MAY 1 – 3
REITICH, FERNANDO	Univ. of Minnesota (Mathematics)	MAY 1 – 3
RINGHOFER, CHRISTIAN	Arizona State University	MAY 2 – 3
SAFONOV, MIKHAIL	University Minnesota (School of Mathematics)	MAY 1 – 3
SANTOSA, FADIL	Univ. of Minnesota (School of Mathematics)	MAY 1 – 3
SONTAG, EDUARDO	Rutgers Univ. (Mathematics)	APR 28 – MAY 3
SOPER, JULIE		MAY 1 – 3
STEIN, MARVIN		MAY 2 – 2
STOJANOVIC, SRDJAN	Univ. of Cincinnati (Mathematical Sciences)	MAY 2 – 3
TAGUCHI, DEBBIE		MAY 1 – 3
TAGUCHI, KEN		MAY 1 – 3
TANNENBAUM, ALLEN	Univ. of Minnesota (ECE)	MAY 1 – 3
TITI, EDRISS SALEH	Univ. of California-Irvine (Mathematics)	APR 19 – MAY 3
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30
USISKIN, ZALMAN	Univ. of Chicago (Education)	APR 30 – MAY 3
VELAZQUEZ, JUAN J. L.	Univ. Complutense de Madrid (Aplicada)	APR 27 – MAY 3
VOS, REBECCA		MAY 1 – 3
WEINBERGER, HANS	Univ. of Minnesota (School of Mathematics)	MAY 1 – 3
WINOGRAD, SHMUEL	IBM (T. J. Watson Research Center)	APR 30 – MAY 3
XIA, XINYUN	Univ. of Minnesota (Chemical Engineering))	MAY 1 – 3

Workshop 10 : Dynamical Systems in Oceanography: Chaotic Advection in Ocean Mesoscale Structures May 7-9, 1998

BERLOFF, PAVEL	UCLA (Atmostpheric Sciences)	MAY 6 – 10
BOWMAN, KENNETH	Texas A&M Univ. (Meteorology)	MAY 6 – 9
CASTILLO-NEGRETE, DIEGO	UCSD (Scripps Institute)	MAY 6 – 10
COULLIETTE, CHAD	Caltech (Control and Dynamical Systems)	MAY 6 – 10
DIBATTISTA, MARK	NYU-Courant	MAY 6 – 9
GOMES, GABRIELA	Univ. do Porto (CentroMatematica Aplicada)	SEP 1 – JUL 31
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30

HALLER, GYORGY	Brown Univ. (Applied Mathematics)	MAY 6 – 9
HOLM, DARRYL	LANL	MAY 2 – 10
IDE, KAYO	UCLA (Atmospheric Sciences)	MAY 6 – 10
JONES, CHRIS	Brown Univ. (Applied Mathematics)	MAY 6 – 10
JONES, DON	Arizona State Univ. (Math)	MAY 6 – 9
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
MAJDA, ANDREW	NYU-Courant Institute	MAY 6 – 9
MCWILLIAMS, JAMES	UCLA (Atmospheric Sciences)	MAY 6 – 10
MEACHAM, STEVE	Florida State Univ. (Oceanography)	MAY 6 – 10
MEZIC, IGOR	Univ. of California-Santa Barbara (Mechanical Engineering)	MAY 6 – 10
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MILLER, PATRICK	Stevens Institute of Technology (Mathematical Sciences)	MAY 6 – 10
POJE, ANDREW	Brown Univ. (Applied Mathematics)	MAY 6 – 9
PRATT, LARRY	Woods Hole Oceanographic Institute (Physical Oceanography)	MAY 6 – 9
SAMELSON, ROGER	Oregon State Univ.	MAY 6 – 9
WANG, SHOUHONG	Indiana Univ. (Mathematics)	MAY 6 – 9
WANG, XIAOMING	New York Univ. (Courant)	MAY 6 – 9
WIGGINS, STEVE	Caltech	MAY 6 – 9

Workshop 11 : Pattern Formation in Continuous and Coupled Systems May 11-15, 1998

AHLERS, GUENTER	Univ. of California-Santa Barbara (Physics)	MAY 9 – 13
ARIS, RUTHERFORD	Univ. of Minnesota (Chemical Eng)	MAY 15 – 15
ARMBRUSTER, DIETER	Arizona State Univ. (Mathematics)	APR 26 – MAY 15
ASHWIN, PETER	Univ. of Surrey (Maths & Statistics)	MAY 9 – 16
BARKLEY, DWIGHT	Univ. of Warwick (Mathematics)	AUG 15 – JUN 30
BERGER, KURT	Univ. of Wisonsin, Madison (Mathematics)	MAY 10 – 16
BODENSCHATZ, EBERHARD	Cornell Univ. (Physics)	MAY 9 – 14
BRONSKI, JARED	Stanford Univ. (Mathematics)	MAY 7 – 13
BUONO, PIETRO-LUCIANO	Univ. of Houston (Mathematics)	MAY 4 – JUN 7
BUSSE, F.H.	Univ. Bayreuth (Physikalisches)	MAY 10 – 15
CHILLINGWORTH, DAVID	Univ. of Southampton (Mathematics)	MAR 30 – JUN 5
CHOSSAT, PASCAL	Univ. of California (Mathematics)	MAY 11 – 16
COSTA DE ABREU, STELLA MARIA	Univ. of Porto (Applied Mathematics)	APR 26 – MAY 30
CRAWFORD, JOHN DAVID	Univ. of Pittsburgh (Physics)	MAY 9 – 15
CUI, SHANGBIN	Lanzhou Univ. (Mathematics)	MAR 29 – FEB 28
DA SILVA DIAS, ANA PAULA	Univ. of Warwick (Mathematics)	APR 29 – JUN 7
DANGELMAYR, GERHARD	Colorado State Univ. (Mathematics)	MAY 10 – 23
DIONNE, BENOIT	Univ. of Ottawa (Math and Statistics)	MAY 9 – 15
DUAN, JINQIAO	Clemson Univ. (Mathematical Sciences)	MAY 13 – 17
EARL, MATTHEW	Cornell University	MAY 10 – 18
FIELD, MICHAEL J	Univ. of Houston (Mathematics)	MAY 1 – 15
GOLLUB, JERRY	Haverford College (Physics)	MAY 12 – 14
GOLUBITSKY, MARTIN	University Houston	MAY 3 – JUN 5
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
GORMAN, MICHAEL	Univ. of Houston (Physics)	MAY 10 – 15
GRIMM, HANS PETER	Northwestern Univ. (Applied Mathematics)	MAY 10 – 15
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
GUNARATNE, GEMUNU	Univ. of Houston (Physics)	MAY 11 – 15
HAGBERG, ARIC	Los Alamos National Laboratory	MAY 13 – 17
HALLEY, J WOODS	Univ. of Minnestota (Physics and Astronomy)	MAY 14 – 14

HUDSON, JOHN L.	Univ. of Virginia	MAY 9 – 14
IMBIHL, RONALD	Institut für Physikalische Chemie (Universitt Hannover)	MAY 10 – 15
JOLLY, MIKE	Indiana Univ. (Math)	JUL 14 – JUN 30
JUSTH, ERIC W.	Univ. of Maryland, College Park (Electrical Engineering)	MAY 10 – 15
KEVREKIDIS, YANNIS	Princeton Univ. (Chemical Engineering)	MAY 12 – 15
KNOBLOCH, EDGAR	Univ. of California Berkeley (Physics)	MAY 7 – JUN 5
KRAUSKOPF, BERND	Univ. of Bristol (Engineering Mathematics)	MAY 11 – 15
KRISCHER, KATHARINA	Fritz-Haber Institut (Max-Planck-Gesellschaft)	MAY 9 – 16
KRUPA, MARTIN (MACIEJ)	Technical Institute Vienna	MAY 9 – 23
LAMB, JEROEN	Univ. of Warwick (Mathematics)	MAY 10 – JUN 10
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LARI-LAVASSANI, ALI	Univ. of Calgary (Mathematics and Statistic)	MAY 10 – 19
LAUTERBACH, REINER	Institut fr Angewandte Analysis	MAY 9 – 15
LEBLANC, VICTOR	Univ. of Ottawa (Mathematics and Statistics)	MAY 4 – JUN 12
LIM, CHJAN	RPI (Mathematical Sciences)	MAY 10 – 15
LUSS, DAN	Univ. of Houston (Chemical Engineering)	MAY 10 – 15
MALLET-PARET, JOHN	Brown Univ. (Applied Mathematics)	MAY 8 – 15
MATKOWSKY, BERNARD J	Northwestern Univ.	MAY 10 – 13
MELBOURNE, IAN	Univ. of Houston (Mathematics)	MAY 10 – JUN 6
MERON, EHUD	Ben-Gurion Univ. (Physics)	MAY 10 – 17
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
MIROLLO, RENNIE	Boston College (Math)	MAY 9 – 15
MURATOV, CYRILL	NYU-Courant Institute	MAY 11 – 15
NAGATA, WAYNE	Univ. of British Columbia (Math)	MAY 9 – 15
NERURKAR, MAHESH	Rutgers Univ. (Math)	MAY 11 – 15
OSINGA, HINKE	University of Minnesota	SEP 1 – AUG 31
PURWINS, H.G.	Univ. Munster	MAY 9 – 17
RAGHAVACHARI, SRIDHAR	Univ. of Notre Dame (Physics)	MAY 10 – 16
RENARDY, YURIKO	Viriginia Tech (Math)	MAY 10 – 16
RIECKE, HERMANN	Northwestern Univ. (Applied Mathematics)	MAY 10 – 15
ROTERMUND, H.H.	Fritz-Haber-Institut (Abt Physikalische Chemie)	MAY 10 – 17
ROY, RAJARSHI	Georgia Tech (School Physics)	MAY 11 – 17
RUCKLIDGE, ALASTAIR	Univ. of Cambridge	MAY 8 – 15
RUSU, DUMITRU DAN	CMS-Univ. of Guelph (Mathematics and Statistic)	MAY 10 – 16
SANDSTEDE, BJORN	Ohio State Univ. (Mathematics)	MAY 9 – 12
SHEINTUCH, MOSHE	Technion (Chemical Engineering)	MAY 10 – 15
SILBER, MARY	Northwestern Univ. (Eng Sci & Appl Math)	MAY 11 – 19
STEWART, IAN	Univ. of Warwick (Mathematics)	APR 19 – JUN 6
STROGATZ, STEVEN H.	Cornell Univ. (Theoretical and Applied Mechanics)	APR 1 – JUN 30
SWIFT, JIM	Northern Arizona Univ.	MAY 11 – 15
SWINNEY, HARRY L.	Univ. of Texas (Physics)	MAY 9 – 15
TUCKERMAN, LAURETTE	LIMSI Orsay/CNRS	AUG 20 – JUN 30
UMBANHOWAR, PAUL	Univ. of Pennsylvania (Physics & Astronomy)	MAY 10 – 15
VAN DER ZANT, HERRE	T. U. Delft (Applied Physics)	MAY 9 – 14
VAN GILS, STEPHAN	Univ. Twente (Applied Mathematics)	MAY 9 – 16
VANDERBAUWHEDE, A.	Univ. of Gent (Pure Mathematics & Comp)	MAY 9 – 15
WEINBERGER, HANS	Univ. of Minnesota (School of Mathematics)	MAY 15 – 15
WIESENFELD, KURT	Georgia Tech (Physics)	MAY 9 – 15
WITTENBERG, RALF	Princeton University	MAY 10 – 15
WULFF, CLAUDIA	Freie Univ. Berlin	MAY 4 – JUN 7
YEUNG, STEPHEN	Cornell University	MAY 10 – 18

ZIMMERMANN, WILLIAM Univ. of Minnesota (Physics and Astronomy) MAY 14 – 14

Workshop 12 : Animal Locomotion and Robotics June 1-5, 1998

BEER, RANDY	Case Western Univ. (Computer Eng. and Science)	MAY 31 – JUN 5
BERKEMEIER, MATT	Boston Univ. (Aero-Mech Engineering)	MAY 31 – JUN 6
BUEHLER, MARTIN	McGill Univ. (Mechanical Engineering)	MAY 31 – JUN 5
BUONO, PIETRO-LUCIANO	Univ. of Houston (Mathematics)	MAY 4 – JUN 7
BURDICK, JOEL	California Institute of Technology	MAY 30 – JUN 5
CALVITTI, ALAN	Case Western Univ. (Computer Engineering/Science)	JUN 1 – 5
CANAVIER, CARMEN C.	Univ. of New Orleans (Psychology)	MAY 30 – JUN 5
CARVER, SEAN G.	Cornell Univ. (Center Applied Math)	JUN 1 – 5
CASEY, RICHARD	Cornell Univ. (Theoretical and Applied M)	MAY 31 – JUN 7
CHILLINGWORTH, DAVID	Univ. of Southampton (Mathematics)	MAR 30 – JUN 5
COHEN, AVIS H.	Univ. of Maryland (Zoology)	MAY 31 – JUN 5
COLLINS, JIM	Boston Univ. (Biomedical Engineering)	MAY 31 – JUN 5
DA SILVA DIAS, ANA PAULA	Univ. of Warwick (Mathematics)	APR 29 – JUN 7
DELCOMYN, FRED	Univ. of Illinois at Urbana (Entomology)	MAY 31 – JUN 5
DONATH, MAX	Univ. of Minnesota (ITS)	JUN 1 – 5
DREW, TREVOR	Univ. of Montreal (Physiology)	MAY 30 – JUN 5
EGOROV, MIKHAIL	Univ. of Minnesota (AEM)	JUN 1 – 5
EPSTEIN, STEVE	Boston Univ. (Mathematics)	JUN 2 – 5
FARLEY, CLAIRE	Univ. of California at Berkeley (Integrative Biology)	MAY 31 – JUN 5
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	MAY 29 – JUN 14
FLANDERS, MARTHA	Univ. of Minnesota (Physiology)	JUN 1 – 5
FULL, ROBERT J.	Univ. of California, Berkeley (Integrative Biology)	MAY 31 – JUN 4
GOLUBITSKY, MARTIN	University Houston	MAY 3 – JUN 5
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
GRILLNER, STEN	Nobel Institute for Neurophysiology (Karolinska)	MAY 31 – JUN 3
GUCKENHEIMER, JOHN	Cornell Univ. (Mathematics)	SEP 1 – JUN 30
HOLMES, PHILIP JOHN	Princeton Univ.	MAY 31 – JUN 12
HOWELL, GEOFF	Boston Univ. (ECE)	MAY 31 – JUN 7
JINDRICH, DEVIN	Univ. of California, Berkeley (Integrative Biology)	MAY 30 – JUN 6
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KNOBLOCH, EDGAR	Univ. of California Berkeley (Physics)	MAY 7 – JUN 5
KODITSCHEK, DANIEL E.	Univ. of Michigan (EECS)	JUN 1 – 7
KOPELL, NANCY	Boston Univ. (Mathematics)	JUN 2 – 5
KRISHNAPRASAD, P.S.	Univ. of Maryland (Electrical Engineering)	MAY 30 – JUN 5
KUO, ARTHUR D.	Univ. of Michigan (Mech Engr & Applied Mech)	MAY 30 – JUN 5
LAMB, JEROEN	Univ. of Warwick (Mathematics)	MAY 10 – JUN 10
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LEBLANC, VICTOR	Univ. of Ottawa (Mathematics and Statistics)	MAY 4 – JUN 12
LEONARD, NAOMI	Princeton Univ. (Mechanical and Aerospace Eng.)	JUN 2 – 5
LEVI, MARK	Rennsselaer Polytech Institute (Mathematics)	MAY 30 – JUN 5
MAHADEVAN, L.	MIT	JUN 1 – 5
MARSDEN, JERRY	Caltech (Control and Dynamical Systems)	JUN 3 – 11
MELBOURNE, IAN	Univ. of Houston (Mathematics)	MAY 10 – JUN 6
MILIK, ALEXANDRA	Technische Univ. Wien	AUG 22 – JUN 30
OSTROWSKI, JAMES	University Pennsylvania	JUN 3 – 5
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15

ROSE, TODD	Donaldson Co. Inc. (Corporate Technology)	JUN 1 – 5
RUINA, ANDY	Cornell University	MAY 30 – JUN 6
SAIMEK, SAROJ	Univ. of Minnesota (Mechanical Engineering)	JUN 1 – 5
SARANLI, ULUC	Univ. of Michigan (Elect Eng. and Computer)	JUN 1 – 7
SATTINGER, DAVID	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
SCHAAL, STEFAN	Univ. of Southern California (Computer Science)	MAY 31 – JUN 5
SCHOTLAND, JUDY	Boston Univ. (Health Sciences)	MAY 31 – JUN 5
SCHWIND, WILLIAM	Univ. of Michigan (Elec Engineering and Com)	JUN 3 – 7
STEIN, PAUL S.G.	Washington Univ. (Biology)	MAY 31 – JUN 5
STEWART, IAN	Univ. of Warwick (Mathematics)	APR 19 – JUN 6
STROGATZ, STEVEN H.	Cornell Univ. (Theoretical and Applied Mechanics)	APR 1 – JUN 30
WHITALL, JILL	Univ. of Maryland at Baltimore (Physical Therapy)	MAY 30 – JUN 5
WULFF, CLAUDIA	Freie Univ. Berlin	MAY 4 – JUN 7

Workshop 13 : Continuum Mechanics and Non-linear Partial Differential Equations June 8-12, 1998

ANTMAN, STUART	Univ. of Maryland (Mathematics)	JUN 7 – 12
BALL, JOHN	Univ. of Oxford (Mathematics)	JUN 7 – 14
BHATTACHARYA, KAUSHIK	Caltech	JUN 6 – 13
CONSTANTIN, PETER	University Chicago	JUN 7 – 12
CUI, SHANGBIN	Lanzhou Univ. (Mathematics)	MAR 29 – FEB 28
DACOROGNA, BERNARD	EPFL Lausanne (Mathematics)	JUN 6 – 12
DAFERMOS, C.	Brown Univ. (Applied Mathematics)	JUN 6 – 12
E, WEINAN	(Courant)	JUN 7 – 12
ERICKSEN, JERRY		JUN 7 – 12
ESTEBAN, MARIA	Univ. Paris Dauphine	JUN 6 – 13
FIEDLER, BERNOLD	Free Univ. of Berlin (Insitute Mathematics I)	SEP 3 – DEC 21
FONTELOS, MARCO ANTONIO	Univ. Complutense de Madrid (Aplicada)	JAN 11 – DEC 31
FRIESECKE, GERO	University Oxford	JUN 6 – 11
GOMES, GABRIELA	Univ. do Porto (Matematica Aplicada)	SEP 1 – JUL 31
GULLIVER, ROBERT	University Minnesota	SEP 1 – AUG 31
HOLMES, PHILIP JOHN	Princeton Univ.	MAY 31 – JUN 12
JAMES, RICHARD	Univ. of Minnesota (Aerospace Eng and Mech)	JUN 8 – 12
KINDERLEHRER, DAVID	Carnegie Mellon Univ. (Math)	JUN 7 – 12
KING, GREGORY P.	Univ. of Warwick (Fluid Dynamics Research Center)	SEP 3 – JUL 31
KUKAVICA, IGOR	Univ. of Southern California (Mathematics)	JUN 7 – 12
LANGFORD, WILLIAM	The Fields Institute	APR 1 – JUN 14
LEO, PERRY	Univ. of Minnesota (Aerospace Engineering & Mechanics)	JUN 8 – 12
LI, BO	UCLA	JUN 8 – 12
LUSKIN, MITCH	Univ. of Minnesota (Mathematics)	JUN 7 – 12
MARSDEN, JERRY	Caltech (Control and Dynamical Systems)	JUN 3 – 11
MUELLER, STEFAN	MPI for Mathematics in the Sciences	JUN 6 – 14
MURAT, FRANCOIS	Univ. Paris 6 (Laboratorie d'Analyse Numerique)	JUN 7 – 13
NIRENBERG, LOUIS	NYU-Courant Institute	JUN 6 – 12
OTTO, FELIX	UCSB	JUN 7 – 14
OWEN, DAVID	Carnegie Mellon Univ. (Mathematical Sciences)	JUN 6 – 10
PARONI, ROBERTO	Univ. of Kentucky (Mathematics)	JUN 7 – 13
POSBERGH, THOMAS. A.	Univ. of Minnesota	SEP 1 – JUN 15
REITICH, FERNANDO	Univ. of Minnesota (Mathematics)	JUN 8 – 12
SULLIVAN, JOHN	Univ. of Illinois (Mathematics)	JUN 5 – 11
SVERAK, VLADIMIR	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31

TRUSKINOVSKY, LEV	Univ. of Minnesota (AEM)	JUN 8 – 12
WARNER, W.H.	Univ. of Minnesota (AEM)	JUN 8 – 12
WATSON, STEPHEN	Louisana State Univ. (Mathematics)	JUN 6 – 12
WEINBERGER, HANS	Univ. of Minnesota (School of Mathematics)	JUN 8 – 12
WIEGAND, SYLVIA	Univ. of Nebraska (Mathematics and Statistic)	JUN 7 – 11
YANG, DAOQI	Wayne State Univ. (Math)	JUN 7 – 14
YOUNG, L.C.		JUN 7 – 12

8. SUMMER 1998 WORKSHOP AND TUTORIAL PARTICIPANTS

Coding and Cryptography
July 6-18, 1998

Week 1: Codes, Design, and Cryptography July 6-10, 1998

ALLEN, BRIAN	Univ. of Notre Dame (Math)	JUL 5 – 18
ASHIKHMIN, ALEXEI	Los Alamos National Laboratory	JUL 5 – 12
BERNSTEIN, DANIEL	Univ. of Illinois-Chicago (Math, Statistics and Computer)	JUL 5 – 18
BLAKE, IAN	Hewlett Packard	JUL 11 – 18
BLAKLEY, BOB	Texas A & M Univ. (Mathematics)	JUL 5 – 18
BOSTON, NIGEL	Univ. of Illinois at Urbana (Mathematics)	JUL 5 – 10
BULL, EVERETT	Pomona College (Mathematics and Computer)	JUL 5 – 12
CALDERBANK, ROBERT	AT&T Lab)	JUL 4 – 10
CHARPIN, PASCALE	Domaine de Voluceau (INRIA)	JUL 5 – 18
DESMEDT, YVO	Univ. of Wisconsin-Milwaukee	JUL 5 – 18
FIELDS, JOE	Univ. of Illinois-Chicago (Math)	JUL 5 – 18
GABORIT, PHILLIPE	Univ. of Illinois at Chicago (Math)	JUL 5 – 18
GARRETT, PAUL	Univ. of Minnesota (Math)	JUL 6 – 18
GOLDMAN, JAY	Univ. of Minnesota (School of Mathematics)	JUL 6 – 18
GOSSETT, ERIC	Bethel College (Mathematics and CS)	JUL 6 – 18
HALL, JONATHAN	Michigan State Univ. (Mathematics)	JUL 5 – 16
HELLESETH, TOR	Univ. of Bergen (Informatics)	JUL 5 – 18
HOBART, SYLVIA	Univ. of Wyoming (Mathematics)	JUL 4 – 18
HOFFMAN, JOHN	Secure Computing Corporation	JUL 5 – 31
HUFFMAN, W. CARY	Loyola Univ. of Chicago (Math Sci)	JUL 4 – 10
HUH, MISUK	Seoul National Univ. (Mathematics)	JUN 19 – JUL 19
JOHANSSON, THOMAS	Univ. of Lund (Information Technology)	JUL 4 – 11
KABATIANSKI, GRIGORI	Inst. Problems in Information Transfer	JUL 5 – 18
KLOVE, TORLEIV	Univ. of Bergen (Informatics)	JUL 5 – 19
KNILL, EMANUEL	Los Alamos National Laboratory	JUL 5 – 10
LAMKEN, ESTHER ROSE	Caltech (Mathematics)	JUL 5 – 12
LEE, IN-SOK	Seoul National Univ. (Mathematics)	JUL 1 – 31
LEIBAK, ALAR	Tallinn Technical Univ. (Mathematics)	JUL 5 – 18
LEONARD, DOUG	Auburn Univ. (Discrete & Statistical Sc)	JUL 5 – 18
LEVENSHTEIN, VLADIMIR	Keldysh Inst. for Applied Math	JUL 5 – 19
MAGLIVERAS, SPYROS	Univ. of Nebraska (Computer Science & Engine)	JUL 5 – 15
MARTIN, WILLIAM J.	Univ. of Winnipeg (Dep't Mathematics and Statistics)	JUL 3 – 19
MCGUIRE, GARY	Colorado State Univ. (Mathematics)	JUL 5 – 11
MILLER, MARK	Univ. of Colorodo at Denver (Mathematics)	JUL 5 – 10
MORELLI, MICHAEL	Unviersity of Wisconsin-Stout	JUL 8 – 8
MORENO, OSCAR	Univ. of Puerto Rico (Gauss Research Lab)	JUL 6 – 10

PATERA, JIRI	Univ. de Montreal (Centre Recherches Mathematiques)	JUL 5 – 18
PATERSON, KENNETH	Hewlett Packard	JUL 5 – 18
PATINKIN, SETH	Indiana Univ. (Mathematics)	JUL 7 – 31
PHELPS, KEVIN	Auburn Univ.	JUL 5 – 18
PIERCE, STEPHEN	San Diego State Univ. (Mathematical Sciences)	JUL 5 – 9
PLESS, VERA	Univ. of Illinois-Chicago (	JUL 5 – 18
RAHE, MAURICE	Texas A&M Univ. (Mathematics)	JUL 5 – 18
REITER, BOB	National Security Agency (Cryptology)	JUL 8 – 10
SCHULZE-HEWETT, C.	Univ. of Illinois-Chicago (Mathematics)	JUL 5 – 18
SENDRIER, NICOLAS	INRIA-Rocquencourt (Project CODES)	JUL 5 – 18
SIMMONS, GUS	Sandia National Laboratory	JUL 5 – 10
SIMONIS, JURIAAN	Technical Univ. of Delft (Faculty Technical Math and Informati)	JUL 5 – 19
SLOANE, NEIL	A T. & T. Research Labs	JUL 5 – 10
SOLJANIN, EMINA	Bell Labs-Lucent (Mathematics Communication)	JUL 5 – 19
TANNENBAUM, PETER	California State Univ., Fresno (Mathematics)	JUL 5 – 18
TONCHEV, VLADIMIR	Michigan Technological Univ. (Mathematics)	JUL 6 – 15
VAN LINT, JACOBUS	Technical Univ. of Eindhoven (Director Stan Ackermans Inst)	JUL 5 – 10
WILSON, RICHARD	California Institute of Technology (Mathematics)	JUL 5 – 18
XIANG, QING	Univ. of Delaware (Mathematical Sciences)	JUL 5 – 18
ZEMOR, GILLES	ENTS (Network)	JUL 5 – 18

Week 2: Coding, Complexity and Cryptography; Sequences July 13-18, 1998

ALLEN, BRIAN	Univ. of Notre Dame (math)	JUL 5 – 18
BARG, ALEXANDER	Bell Laboratorie)	JUL 12 – 18
BERGMAN, CLIFFORD	Iowa State Univ. (Math)	JUL 12 – 18
BERNSTEIN, DANIEL	Univ. of Illinois-Chicago (Math, Statistics and Computer)	JUL 5 – 18
BLAKE, IAN	Hewlett Packard	JUL 11 – 18
BLAKLEY, BOB	Texas A & M Univ. (Mathematics)	JUL 5 – 18
BREITBACH, MARKUS	Univ. of Tokyo (Industrial Science)	JUL 12 – 18
BULL, EVERETT	Pomona College (Mathematics and Computer)	JUL 5 – 12
CHAN, AGNES	Northeastern Univ. (College Computer Science)	JUL 12 – 18
CHARPIN, PASCALE	Domaine de Voluceau (INRIA)	JUL 5 – 18
DESMEDT, YVO	Univ. of Wisconsin-Milwaukee	JUL 5 – 18
FENG, GUI-LIANG	Univ. of Southwestern Louisiana	JUL 12 – 20
FIELDS, JOE	Univ. of Illinois-Chicago (Math)	JUL 5 – 18
GABORIT, PHILLIPE	Univ. of Illinois at Chicago (Math)	JUL 5 – 18
GAO, LIJUN	Univ. of Minnesota (EE)	JUL 13 – 18
GARRETT, PAUL	Univ. of Minnesota (Math)	JUL 6 – 18
GOLDMAN, JAY	Univ. of Minnesota (School of Mathematics)	JUL 6 – 18
GOSSETT, ERIC	Bethel College (Mathematics and CS)	JUL 6 – 18
HALL, JONATHAN	Michigan State Univ. (Mathematics)	JUL 5 – 16
HELLESETH, TOR	Univ. of Bergen (Informatics)	JUL 5 – 18
HOBART, SYLVIA	Univ. of Wyoming (Mathematics)	JUL 4 – 18
HOFFMAN, JOHN	Secure Computing Corporation	JUL 5 – 31
HUH, MISUK	Seoul National Univ. (Mathematics)	JUN 19 – JUL 19
KABATIANSKI, GRIGORI	Inst. Problems in Information Transfer	JUL 5 – 18
KLAPPER, ANDREW	Univ. of Kentucky (Computer Science)	JUL 12 – 18
KLOVE, TORLEIV	Univ. of Bergen (Informatics)	JUL 5 – 19
KUMAR, VIJAY	Univ. of Southern California (Communication Sciences)	JUL 12 – 18
LAMKEN, ESTHER ROSE	Caltech (Mathematics)	JUL 5 – 12

LEE, IN-SOK	Seoul National Univ. (Mathematics)	JUL 1 – 31
LEIBAK, ALAR	Tallinn Technical Univ. (Mathematics)	JUL 5 – 18
LEONARD, DOUG	Auburn Univ. (Discrete & Statistical Sc)	JUL 5 – 18
LEVENSHTEIN, VLADIMIR	Keldysh Inst. for Applied Math	JUL 5 – 19
MAGLIVERAS, SPYROS	Univ. of Nebraska (Computer Science & Engine)	JUL 5 – 15
MARTIN, WILLIAM J.	Univ. of Winnipeg (Dep't Mathematics and Statistics)	JUL 3 – 19
MCGUIRE, GARY	Colorado State Univ. (Mathematics)	JUL 5 – 11
NIEDERREITER, HARALD	Austrian Academy of Science (Information Processing)	JUL 12 – 19
ODLYZKO, ANDREW	AT.&T. Laboratories	JUL 12 – 16
PATERA, JIRI	Univ. de Montreal (CentreRecherches Mathematiques)	JUL 5 – 18
PATERSON, KENNETH	Stoke Gifford (Hewlett Packard Laboratories)	JUL 5 – 18
PHELPS, KEVIN	Auburn Univ. (Discrete and Statistical)	JUL 5 – 18
PLESS, VERA	Univ. of Illinois-Chicago	JUL 5 – 18
RAHE, MAURICE	Texas A&M Univ. (Mathematics)	JUL 5 – 18
REITER, BOB	National Security Agency (Cryptology)	JUL 8 – 10
SCHMIDT, BERNHARD	Caltech (Math)	JUL 11 – 18
SCHULZE-HEWETT, C.	Univ. of Illinois-Chicago (Mathematics)	JUL 5 – 18
SENDRIER, NICOLAS	INRIA-Rocquencourt (Project CODES)	JUL 5 – 18
SIMONIS, JURIAAN	Technical Univ. of Delft (Faculty Technical Math and Informati)	JUL 5 – 19
SMEETS, BEN	Lund Univ. (Information Theory)	JUL 11 – 19
SOLJANIN, EMINA	Bell Labs-Lucent (Mathematics Communication)	JUL 5 – 19
TANNENBAUM, PETER	California State Univ., Fresno (Mathematics)	JUL 5 – 18
TONCHEV, VLADIMIR	Michigan Technological Univ. (Mathematics)	JUL 6 – 15
XIANG, QING	Univ. of Delaware (Mathematical Sciences)	JUL 5 – 18
ZEMOR, GILLES	ENTS (Network)	JUL 5 – 18

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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anonymous ftp: ftp.ima.umn.edu, www: http://www.ima.umn.edu/

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.

News and Notes

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 the Institute for Mathematics and its Applications at the University of Minnesota, he enhanced the outreach and

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

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`.

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

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

Friday, September 5

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

8:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
8:45 am	**Welcome and Orientation**	W. Miller, R. Gulliver, J. Guckenheimer
9:00 am	**John Guckenheimer** Cornell University	Introduction to Bifurcation Theory
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Mark Reichelt** The MathWorks, Inc.	Numerical Integration Methods in Matlab
2:00 pm	**Bernold Fiedler** Free University of Berlin	Introduction to Global Bifurcations

4:00 pm	**IMA Tea (and more!)**	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	**Coffee**	IMA Lounge, Vincent Hall 502
9:00 am	**Werner Rheinboldt** University of Pittsburgh	Algorithms for implicitly defined manifolds with applications to bifurcations and differential-algebraic systems
10:30 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
11:00 am	**Linda Petzold** 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	**Coffee**	IMA Lounge, Vincent Hall 502
9:00 am	**Wolf-Jürgen Beyn** University of Bielefeld	Numerical analysis of computing bifurcations
10:30 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
11:00 am	**Herbert B. Keller** Calif. Inst. of Technology	Numerical methods for solving boundary-value problems
2:00 pm	**Eusebius Doedel** 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	**Coffee**	IMA Lounge, Vincent Hall 502
9:00 am	**Eugene L. Allgower** Colorado State University	Multidimensional continuation
10:30 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
11:00 am	**Panel discussion**	Open problems
2:00 pm	**Laboratory session**	Programs and packages

Wednesday, September 10

9:00 am	**Orientation Meeting** Room Vincent Hall 570	Long-term IMA visitors and Postdocs

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

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	**Angel Jorba** University of Barcelona	Computation of normal forms and invariant manifolds in Hamiltonian mechanics. A numerical approach

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	**Pierre Gremaud** North Carolina State University	Computation of nonclassical solutions to Hamilton-Jacobi equations

Friday, September 12

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Eli Chiprout** IBM Austin Research Lab	Model Reduction for Large Circuit Simulation

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	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, R. Gulliver, E. Doedel
9:30 am	**Bjoern Sandstede** 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	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Andrey Shilnikov** Inst. Appl. Math., Nizhny Novgorod	Qualitatively numerical analysis of some concrete 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** Weizmann Institute	Branching homoclinic orbits in Hamiltonian systems

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 peiodic 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** Univ. Politècnica de Catalunya	Numerical Exploration of Bifurcation Phenomena Associated 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** NIST	On the Bifurcation from Continuous to Segmented 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** Imperial College, London	Different Algorithms for Connecting Orbits
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** University of Minnesota	Globalizing two-dimensional unstable manifolds

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	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Konstantin Mischaikov** Georgia Institute of Technology	Computer-Assisted Exploration and Proof in Dynamics
2:00 pm	**Michael Dellnitz** 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	**Coffee**	Reception Room EE/CS 3-176

Short Talks: times are approximate

3:30 pm	**Greg Watson** Georgia Institute of Technology	Efficient Computation of the Conley Index

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. Mischaikow and W. Kalies.)

3:45 pm	**Volker Reichelt** RWTH Aachen	Numerical Computation of Invariant Tori in Dynamical Sstems

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	**Karin Gaterman** Konrad-Zuse-Zentrum Berlin	Orbit Space Reduction

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	**Arnd Scheel** Freie Universität Berlin	Exponential Dichotomies in Elliptic Equations

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** Fed. Inst. of Technology, Lausanne	Nonlinear Dynamics of the Colpitts Operator

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** Freie Universität Berlin	Homoclinic Doubling Cascades

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 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** University of Houston	Numerical Bifurcation Techniques for Chemical Reactor 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** Princeton University	A computer-assisted study of reaction-diffusion patterns 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	**Ray Adomaitis** University of Maryland	Numerical Continuation of Bifurcations and Global Dynamic Behavior Transitions for a Noninvertible System

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	**Coffee**	Reception Room EE/CS 3-176
3:30 pm	**Alastair Spence** University of Bath	Numerical methods for detecting Hopf points and computing periodic orbits in large systems

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

Thursday, September 18

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Patrick Miller** Brown University	Using Invariant Manifolds to Characterize Transport in Numerically-Generated Velocity Fields

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

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** Georgia Tech	On Smooth Decomposition of Matrices

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 dicussed.

This is joint work with Timo Eirola.

3:00 pm	**Coffee**	Reception Room EE/CS 3-176
3:30 pm	**Yuri A. Kuznetsov** CWI/RIACA, Amsterdam	Normal form computations in CONTENT

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** University of Minnesota-Duluth	To Be Continued : Automatic computation of an Arnold tongue for a periodically forced oscillator (without computing saddle-nodes)
5:20 pm	**Yuri Kuznetsov/Bart Sijnave** CWI Amsterdam/Univ. of Gent	CONTENT : A Continuation Environment
6:00 pm	**Workshop Dinner** Radisson Hotel	Regents' Room, second floor

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	**Mark Levi** Rensselaer Polytechnic Institute	Curvature effects in the averaging of high-frequency vibrations

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 π–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	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Don Aronson** University of Minnesota	Dynamics of Josephson Junctions Coupled through a Shared LRC-Load

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	**Welcome & Introduction** D. Aronson, R. McGehee, R. Moeckel	Midwest Dynamical Systems Conference

The following talk is joint with the Midwest Dynamical Systems Conference

3:00 pm	**James A. Yorke** University of Maryland	Discontinuous Bifurcations for Dissipative Maps in the Plane

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.

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

Saturday, September 20

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

9:00-9:50	**Robert Ghrist** University of Texas, Austin	Contact topology and hydrodynamics
10:00-10:50	**Hector Lomeli** University of Colorado, Boulder	Quadratic Volume-Preserving Maps
10:50-11:30	**Coffee Break**	Reception Room EE/CS 3-176
11:30-12:20	**Amadeu Delshams** Universitat Politecnica de Catalunya	Singular separatrix splitting and Melnikov method for standard-like maps

2:30-3:20	**Youngna Choi** Northwestern University	One Dimensional Lorenz-like Attractors
3:20-4:00	**Coffee Break**	Reception Room EE/CS 3-176
4:00-4:50	**Arek Goetz** Boston University	Dynamics of Piecewise Isometries
6:30 pm	**Conference Dinner** 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	**James Murdock** Iowa State University	Asymptotic unfoldings for dynamical systems near a rest point
10:00-10:50	**Andre de Carvalho** University of California at Berkeley	The dynamics of surface diffeomorphisms and the Pruning Front Conjecture
11:00-11:50	**Martin Golubitsky** 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	**Bodo Werner** Universität Hamburg	Numerical Analysis of Invariant Curves and Circle Maps

Tuesday, September 23

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

IMA Postdoc Seminar:

2:30 pm	**Mark Friedman** Univ. of Alabama in Huntsville	ConCont: a collection of subroutines for computing 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:** (led by Bernold Fiedler)	Continuous spectra in travelling waves, *etc.*

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** Univ. of California at Irvine	Rigorous Estimates on Small Scales in Turbulent 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 inital 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 Tufillaro** 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"

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IMA NEWSLETTER # 255

October 1–31, 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.

News and Notes

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)

IMA Tutorial:

Multiple-Time-Scale Dynamical Systems

October 23–24, 1997
Speakers: Christopher Jones (Brown), Michael Ward (UBC)

IMA Workshop:

Multiple-Time-Scale Dynamical Systems

October 27–31, 1997
Organizers: Chris Jones (chair), Steve Wiggins (Caltech), Alexander Khibnik (Cornell), Freddy Dumortier (Limburg), David Terman (Ohio State)

New Workshop on "Algorithmic Methods for Semiconductor Circuitry"

The IMA has recently added a workshop to the Fall 1997 schedule, immediately following the November 17–21 workshop on "Dynamics of Algorithms". The new workshop is on a topic which holds strong interest for many industrial scientists, as well as academic researchers: "Algorithmic Methods for Semiconductor Circuitry". The workshop will be held Monday and Tuesday, November 24–25. The organizer is Jacob White of the Department of Computer Science and Electrical Engineering at MIT.

The aim of the workshop is to bring together researchers who work on algorithmic methods together with researchers in semiconductor circuitry, in order to address the difficult computational issues that arise in circuitry. The activities will include informal presentations and discussions.

The topics will include:

- Linear and nonlinear model-order reduction (including eigenvalue-calculation based approach).
- Methods for quasiperiodic analysis (including nonlinear phenomena in oscillating circuits: stability and bifurcation).
- Fast PDE solvers plus MOR
- Partitioning methods covering areas such as waveform relaxation, domain decomposition (parallel circuit simulation) and mixed level simulation.

Researchers are invited from both universities and industry.

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`.

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

Weekly IMA seminar list available by list server

The IMA is happy to offer its e-mail mailing list service. The mailing list "weekly" is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

```
subscribe weekly
```

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

```
subscribe weekly you@e.mail.address
```

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`.

The current weekly schedule is also available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is available by `ftp` or through the world-wide web.

Schedule for October 1–31, 1997

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 numerical study of low-dimensional dynamics in large-scale sets of ODEs and discretizations of PDEs necessitates the development of special-purpose algorithms for simulation, stability and bifurcation analysis. This workshop will address development and application of special iterative methods for large-scale systems that exploit local stability properties of the linearized system. It will also consider global model reduction schemes for PDEs such as approximate inertial manifolds and lattice dynamics. Applications of special interest include selected problems arising in fluid flow and nucleation in alloys.

Monday, September 29

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

8:30 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, R. Gulliver, L. Tuckermann
9:30 am	**Yannis Kevrekidis** Princeton University	Nonlinear Model Reduction for Feedback Control

Abstract: We consider the problem of controlling spatially structured states in reacting systems. The control objectives range from stabilization of linearly unstable solutions to prescribing the dynamics by direct manipulation of coherent structures through feedback.

An important first step in controller synthesis is model reduction of the original reaction-diffusion equations to a (small but accurate) system of ODEs. For this purpose, starting from traditional discretization methods (finite difference, pseudospectral) we proceed to recently introduced POD (Proper Orthogonal Decomposition)-Galerkin and nonlinear Galerkin methods. Linear state-space and modern geometric nonlinear control approaches are then applied to the resulting vector-fields.

POD-Galerkin as well as eigenvector-Galerkin and standard pseudospectral models are further reduced to nonlinear Galerkin models through an Approximate Inertial Manifold methodology; this methodology allows further reduction exploiting the

separation of time scales between "higher" and "lower" modes in the hierarchy. These reduction techniques are compared both in terms of accuracy and computational efficiency in capturing the open- and closed-loop dynamics.

This is joint work with Stanislav Shvartsman and Edriss Titi.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Edriss S. Titi** Univ. of California, Irvine	Postprocessing the Galerkin Method: a Novel Approach to Approximate Inertial Manifolds

Abstract: A postprocess of the standard Galerkin method for the discretization of dissipative equations is presented. The postprocessed Galerkin method uses the same approximate inertial manifold Φ_{app} to approximate the high wave number modes of the solution as in the nonlinear Galerkin method (NLG). However, in this postprocessed Galerkin method the value of Φ_{app} is calculated only once and after the time integration of the standard Galerkin method is completed, contrary to the NLG in which Φ_{app} evolves with time and affects the time evolution of the lower wave number modes. The postprocessed Galerkin method, which is much cheaper to implement computationally than the NLG, is shown to possess the same rate of convergence (accuracy) as the simplest version of the NLG, which is based on either the Foias-Manley-Temam Approximate Inertial Manifold or the Euler-Galerkin Approximate Inertial Manifold of Foias-Sell-Titi. This is proved for some problems in one and two spatial dimensions, including the Navier-Stokes equations. We will also present a computational study to support our analytical results.

2:00 pm	**Mike Jolly** Indiana University	Applications of Rosa's Sequence of Approximate Inertial Manifolds

Abstract: A sequence of approximate inertial manifolds which converges to the exact manifold is implemented in several contexts. We first demonstrate the convergence in a case where the exact manifold is known. We then use the sequence to provide initial conditions for an accurate construction of global (un)stable manifolds. Lastly, we slightly alter the sequence to compute an inertial manifold with delay [Debuscche and Temam] and demonstrate that we can compute a sensitive solution to the Kuramoto-Sivashinsky equation just as accurately in a three-dimensional phase space as we can using a great many modes in a Galerkin approximation. The point in the last application is to not necessarily save in computational effort, but gain in geometric understanding.

3:00–3:20	**Zhen Mei** University of Marburg	An interactive numerical/computer-algebraic bifurcation analysis for reaction-diffusion equations

Abstract: We describe a package being developed at Marburg for analyzing stationary and Hopf bifurcations of a class of reaction-diffusion equations. Krylov subspace iteration with various preconditioning techniques is implemented to treat large linear systems. Numerical Liapunov-Schmidt reduction is used for exploration of bifurcation scenarios.

3:20–3:40	**Klaus Böhmer** University of Marburg	Preconditioning techniques for large systems with applications to bifurcation
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, September 30

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Philip S. Marcus** Univ. of California at Berkeley	Creating Jovian-Like Zonal Flows by Reverse-Energy Cascades

Abstract: Jupiter and Saturn have long-lived east-west (zonal) flows. Little is known about what sets their velocity scales or their length scales (*i.e.,* the number of zones on each planet). Typically, when coherent features spontaneously form

in turbulent flows they span a range of scales. In the rare cases that the features all have the same size, their lengths are usually determined directly by the boundary or forcing length scales: the scale of granulation on the Sun (due to turbulent convection cells) is set by the depth of the convective zone; the diameters of turbulent Taylor vortices in a Couette apparatus are determined by the width of the apparatus; Jupiter's long-lived vortices, such as the Red Spot, are set by the widths of the local zonal flows in which they are situated. By examining a simple forced/dissipated flow we show that the widths of zonal flows on a β–plane are determined by a subtle combination of the forcing and dissipation and not set by boundary conditions or by the length scale of the forcing. We show that under a wide variety of conditions a turbulent flow without east–west winds forms via a reverse energy cascade. Under some circumstances zonal flows all with approximately the same length scale do form. We present a simple theory which determines the parameter values for which they do and which also provides scaling laws for the zones' velocities and widths. Thus we are able to adjust the widths and strengths of the zonal flows by changing the forcing and dissipation rates properly. We discuss the implications for Jupiter, compare the numerical experiments with similar ones carried out previously by others, and show how one could build a laboratory experiment that would form jovian-like winds with two easily adjustable control parameters that determine their widths and strengths.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Katie Coughlin** Université de Montréal	The formation of structures in wall-bounded shear flows

Abstract: In this talk we will discuss the formation and dynamics of vortical structures in wall-bounded, plane parallel shear flows. These structures play an important role in the dynamics of intermittent turbulence in the near-wall region. In spatially periodic domains, this intermittency takes the form of a roughly periodic cycle of onset and collapse of turbulence. We show that the structures play an essential role in provoking the onset of turbulence, and present a theoretical model for their mathematical and physical origin. Experimentally, these flows are spatially as well as temporally intermittent, making it quite difficult to quantitatively define the characteristics of a structure. We discuss several methods of comparison of numerical and experimental data.

2:00 pm	**Paul H. Steen** Cornell University	Influence of constraint on routes to chaotic natural convection in Hele-Shaw slot, loop, and annulus

Abstract: The Lorenz equations are known to be an explicit 'inertial form' for the partial differential equations that govern natural convection in a closed loopof liquid (thermosyphon). What is the fate of the inertial form as the constraint of unidirectional flow imposed by container geometry is relaxed? What happens to the Lorenz-like chaos as secondary parameters are varied? Is there a 'break-up' of the inertial form and, if so, how so?

In this computational study, the loop is embedded in a family of container geometries, including the Hele-Shaw slot and annulus, with consistent thermal boundary conditions. Routes to chaotic convection corresponding to deformations within this family and varying Prandtl number are compared. Along each route, branch-tracing is used whenever possible, complemented by solution of initial-value problems. Galerkin and finite-difference discretizations lead to dynamical systems of order 100 equations, typically. Results extend those of [1,2] and evidence points to the Shilnikov-like breakup described in [3].

1. Yorke, Yorke, and Mallet-Paret, Physica D 24, pp 279-91, 1987.
2. Hu and Steen, Phys. Fluids 8(7), 1929-37, 1996.
3. Lyubimov and Zaks, Physica D 9, pp 52-64, 1983.

3:00–3:20	**Jie Shen** Pennsylvania State University	Numerical Simulation of Incompressible Flows in Cylindrical Geometries Using a Spectral Projection Method
3:20–3:40	**Juan López** Pennsylvania State University	Quasi-periodic Response to Parametric Excitation

Non-workshop event: Special IMA/PDE Seminar in Vincent Hall 570:

3:45 pm	**Milton Lopes** Indiana Univ. & Univ. Campinas, Brasil	Bounds on the dispersion of vorticity in 2D incompressible, inviscid flow

Wednesday, October 1

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**H. B. Keller** Caltech	Bifurcations in Kolmogorov Flows via DAE and RPM

Abstract: Bifurcations in plane Kolmogorov flows were discovered by Meshalkin and Sinai. Subsequent calculations by Platt, Sirovich and Fitzmaurice and by She are concerned with transitions to chaos or turbulence in these flows. Here we show many steady bifurcations and several Hopf bifurcations in the plane case but we also find bifurcations into three dimensional flows. Our numerical techniques are based on a DAE (differential algebraic equations) view of the spatially discretized Navier-Stokes equations. Then we apply RPM (recursive projection methods) to solve for the steady state branches of solutions. We are able to show where the steady flows of Platt et al. lie on various steady bifurcation branches. When we follow the Hopf branches that we have discovered, they may shed some light on the "chaotic" or "turbulent" behavior reported in the previous works.

This is joint work with P. Love.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Dirk Roose** K. U. Leuven, Belgium	Newton-Picard methods for the bifurcation analysis of partial differential equations and delay differential equations

Abstract: We describe efficient methods for the computation and continuation of periodic solutions of parabolic partial differential equations (PDEs) and delay differential equations (DDEs).

A space discretization of a PDE results in a large system of ODEs, which often exhibits only low-dimensional dynamics. Newton-Picard methods exploit this property, by computing periodic solutions using a combination of Newton-based shooting in the low-dimensional subspace where the solution is unstable or weakly stable and a Picard iteration in the orthogonal complement of that subspace. This approach greatly reduce the computational cost, when compared with classical single or multiple shooting. Good estimates for the dominant Floquet multipliers are obtained at no extra cost and can easily be refined.

The Newton-Picard framework can also be used to compute periodic solutions of delay differential equations with several delays. A shooting approach, together with a discretization of the initial function and of the Poincaré operator leads to a large nonlinear system, which can be solved efficiently by a Newton-Picard method, due to the spectral properties of the (discretized) Poincaré operator. Also stability information is available, since (approximations to) the dominant Floquet multipliers are computed.

Newton-Picard methods are especially efficient when they are used in a continuation procedure. The approach can be generalized to construct extended systems for the accurate computation of bifurcation points along branches of periodic solutions (e.g. period-doubling points).

This is joint work with Kurt Lust, Koen Engelborghs and Tatyana Luzyanina.

2:00 pm	**Laurette Tuckermann** LIMSI, Orsay	Bifurcation analysis for time steppers

Abstract: To fully understand the bifurcation-theoretic structure of solutions to a set of nonlinear evolution equations, three types of information are desirable. The first, and most often used in fluid dynamics, is the time evolution of the system from various initial conditions. These constitute the physically realizable phenomena to be explained. The second type of information is the set of steady-state solutions. For equations describing medium and high Reynolds number

hydrodynamic systems, the number of steady states can be vast; however it is useful to obtain as much of the picture as possible, especially concerning unstable steady states. The third type of information is the eigenspectrum of the steady states. Leading eigenvalues are associated with transitions and loss of stability.

These three types of information are usually obtained by separate analyses, involving separate codes and researchers. Here we propose a unified computational approach to the three types of calculation, all based on a single time-dependent code and using the same set of low-level routines. We can readily transfer flow fields between each of the three computational tools: Time-dependent simulations can be used to generate initial states for branch continuation. Unstable steady states, possibly perturbed by the addition of eigenvectors, can serve as initial conditions for time evolution. Suspected bifurcations can be confirmed by linear stability analysis.

A key step is to use iterative Krylov techniques to invert and diagonalize the Jacobian matrix, which is too large to store or to transform directly. At the low and moderate Reynolds numbers for which bifurcation-theoretic analysis is most meaningful, convergence of Krylov techniques is greatly accelerated by preconditioning the Jacobian matrix with the Stokes operator.

3:00 pm	**Yakov Pesin** Penn State university	Chaos in Traveling Waves of Lattice Models of Unbounded Media

Abstract: I illustrate some chaotic phenomena in lattice models of unbounded media which are associated with traveling waves running with large velocities. Although the dynamics on this set is finite dimensional it governs the behavior of "typical" solutions in the infinite-dimensional phase spaces of extended systems with dissipation and high energy pumping (of type of multi-component diffusion equations). I also discuss applications to the theory of dynamical systems and PDE.

Thursday, October 2

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Andrew Stuart** Stanford University	Statistical Properties of Computations for Large Coupled Systems of Oscillators

Abstract: In this talk we introduce a model appropriate for the study of stiffness in certain large, highly oscillatory, systems of ordinary differential equations. The model is motivated by the desire to integrate large systems of interacting particles, such as those that arise in molecular dynamics simulations in materials science and computational chemistry, without using unduly small time-steps but still retaining some form of accuracy.

A protypical model for statistical mechanics is to consider the motion of a single degree of freedom oscillator (the "distinguished particle") coupled by stiff springs to a large number of harmonic oscillators whose natural frequencies span a broad spectrum; the statistical properties of this model are fairly well-understood in the case where randomness is introduced through a measure on the initial data. It is thus a natural test problem within which to study questions concerning the accuracy of numerical simulations of large coupled systems of oscillators. A question of particular importance is to understand whether numerical simulations reproduce the correct statistics for the motion of the distinguished particle when the time-step is large compared to the shortest wavelengths of the coupled harmonic oscillators.

This problem is studied in various distinguished limits described by assumptions made on the natural frequencies of the harmonic oscillators. In particular we study a white noise limit in which the motion of the distinguished particle is governed by the Langevin equation (an Ito stochastic differential equation); this leads naturally to an interesting class of problems concerning approximation theory for ergodic Markov chains. We also study a coloured noise approximation to the white noise limit; this leads to an interesting class of non-Markovian stochastic processes. In both cases computational and analytical results are presented which illustrate some interesting issues concerned with the numerical accuracy of statistical quantities concerned with the distinguished particle.

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

11:00 am	**David Levermore** University of Arizona	The Complex Ginzburg-Landau Equation as a Perturbation of the Nonlinear Schrödinger Equation: A Melnikov Approach

Abstract: The generalized complex Ginzburg-Landau (CGL) equation has a long history in physics as a generic amplitude equation near the onset of instabilities that lead to chaotic dynamics in numerous physical systems. We study it as a damped-driven perturbation of the nonlinear Schrödinger (NLS) equation, which has a Hamiltonian structure. We give conditions that quasi-periodic and homoclinic structures in the NLS phase space must satisfy if they are to persist under the CGL perturbation. We show that for NLS rotating and traveling waves, these conditions genericly determine which of them persist. When the CGL has a global Lyapunov function, a complete bifurcation analysis of persisting solutions can be carried out and their stability analyzed. When the focusing NLS equation is perturbed, we show that none of the NLS orbits homoclinic to rotating waves persist, but rather distinct homoclinic structures are produced by the CGL perturbation.

2:00 pm	**Rüdiger Seydel** Universität Ulm	Two PDE dynamical systems with bifurcations

Abstract: This talk discusses two PDE dynamical systems: a Navier-Stokes problem, and a reaction-diffusion problem.

The first dynamical system is a Marangoni-flow problem. A cylindrical bar of silicon material is subjected to external heat, and is melting. Surface tension induces a flow in the melt. The problem has free surfaces. The outer surface of the cylinder is allowed to oscillate in time. Based on numerical analysis of C. Menke, we show a period-doubling scenario.

The second problem arises in image processing. The aims are twofold: Perturbations in the image must be smoothed out, and edges should be preserved. These aims can be pursued by a modal analysis of a reaction-diffusion problem. It turns out that stabilization of certain modes results in a problem with Turing bifurcation.

6:30 pm	**Workshop Dinner** Jewel of India Restaurant	1427 Washington Ave. S., Minneapolis: a 15-minute walk across the Mississippi.

Friday, October 3

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Hans G. Othmer** University of Utah	Pattern formation in early development of *Dictyostelium discoideum*

Abstract: *Dictyostelium discoideum*, a cellular slime mold, is a widely studied model system from which basic insights into signal transduction, cell movement, chemotaxis and pattern formation have been gained. Shortly after starvation, randomly spaced pacemakers begin to periodically release cAMP which nearby cells detect via surface receptors. These cells amplify the signal by producing more cAMP and relay it by secreting cAMP. Aggregation results from the chemotactic response of dispersed amoeba to the resulting traveling wave of cAMP. In this talk we will describe a model in which the cells are treated as discrete entities that detect and respond to the continuum field of the chemoattractant. The model comprises a mechanism for signal transduction and cAMP production to describe relay, as well as cell movement rules. We will discuss a split-time-step 'particle-in-cell' computational algorithm to solve the reaction-diffusion equations for the chemoattractant, together with the governing equations for the individual cell dynamics.

We show that this model gives insight into the origin of target patterns *vs.* spiral waves and into the mechanism of stream formation. In particular we show that spiral waves can arise spontaneously when the intial cell distribution is random and we give computational evidence that stream formation is the result of a finite-amplitude instability. We also show how aggregation is affected by different movement rules and discuss techniques for incorporating microscopic movement rules into macroscopic continuum descriptions of the aggregation field.

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

11:00 am	**Jeroen Molemaker** University of Utrecht	Path-following techniques for large dynamical systems
2:00 pm	**Yousef Saad** University of Minnesota	Variants of Krylov Projection Methods for Eigenvalue Problems

Abstract: Most of the successful methods for solving large eigenvalue problems consist of combining projection-type techniques with a few other strategies such as deflation and preconditioning. The standard Petrov-Galerkin conditions used to define projection methods give rise to a variety of different methods, some of which have been considered in recent years. These methods involve two subspaces: a subspace K from which the approximate eigenvector is extracted (called the "right" subspace) and a subspace L of the same dimension used to define constraints for computing these eigenvectors (the "left" subspace). One common choice is to take the left and right space to be the same and this leads to a standard orthogonal projection method exemplified by the Lanczos algorithm in the Hermitian case and the Arnoldi algorithm in the non-Hermitian case. A somewhat intriguing variation, derived by comparison with the GMRES algorithm for solving linear systems is to take $L = AK$. An (incorrect) motivation for this approach is that it acts as a projection operator for the inverse of the matrix. We will consider these options and a few others, which involve inverting the operator. We will compare some of these variants both experimentally and theoretically.

Non-workshop event:

IMA SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Gabriel Taubin** IBM T. J. Watson Research Center	Geometric Compression based on Topological Surgery

Abstract: In this talk I will describe a new compressed representation for polyhedral models and associated compression and decompression algorithms.

The Virtual Reality Modeling Language (VRML), is rapidly becoming the standard file format for describing 3D virtual worlds on the Internet. Static and dynamic descriptions of 3D objects along with multimedia hyperlinks to content including text, sounds, movies, and images can be represented as VRML files. VRML browsers, as well as authoring tools for the creation of VRML files, are widely available for several different platforms.

Visually interesting VRML files tend to be large. In this talk I will describe the VRML Compressed Binary Format. The format significantly reduces the file size and, subsequently, the time required to transmit it across the Internet. Compression ratios of up to 50:1 or more are achieved for large models. The VRML Compressed Binary Format combines a binary encoding with geometric compression to create compact, rapidly-parsable VRML files. The format is currently being evaluated by the Compressed Binary Format Working Group of the VRML Consortium for inclusion in the VRML Standard.

The compression scheme represents a polyhedron using two interlocking trees: a spanning tree of vertices and a spanning tree of triangles. The connectivity information represented in other compact schemes, such as triangular strips and generalized triangular meshes, can be directly derived from this representation. The algorithms described in this paper compress connectivity information to an average of roughly two bits per triangle. A variable length, lossy compression technique is used for vertex positions, normals, colors, and texture coordinates.

The seminar meets this week in the Geometry Center, Lind Hall 400

Monday, October 6

Tuesday, October 7

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

The discussion session meets in room Vincent Hall 570.

IMA Postdoc Seminar:

2:30 pm	**Daniel Henry** École Centrale de Lyon	Onset of convection and pattern selection in the Marangoni instability of mixtures

Abstract: The Marangoni instability occurs in fluid systems subjected to surface tension effects. This instability is studied here for binary liquid mixtures submitted to the Soret effect and confined in two- or three-dimensional rectangular cavities. Onset of convection and pattern selection above the thresholds are presented on a large domain of characteristic parameters. Attention is focused on the changes induced by the variation of the concentration effect.

Organizer: Kurt Lust

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

Wednesday, October 8

Math Department/IMA Seminar on Evolutionary Equations
in Vincent Hall 570

2:30 pm	**George R. Sell** University of Minnesota	Introduction to Approximation Dynamics

Abstract: The need to find new theories and new algorithms for the study of the longtime dynamical behavior of very high dimensional systems of differential equations is the basic goal of the relatively new theory of Approximation Dynamics. The basic issue one faces in the theory of Approximation Dynamics is how well one can approximate the longtime dynamics of the solutions of a given differential equation (1) $x' = X(x)$ by those of an approximate equation (2) $y' = X(y) + Y(y)$, where Y is small in a suitable norm. The issues of Approximation Dynamics are fundamental issues one faces when trying to study the longtime dynamics of very high dimensional systems of ordinary differential equations, such as the standard spatial discretizations of partial differential equations. In this introductory lecture we will present an overview of the current theory of Approximation Dynamics.

Thursday, October 9

Seminar on Dynamics and Mechanics in Vincent Hall 570

10:10 am	**Bjoern Sandstede** Ohio State University	Lin's method – a homoclinic Lyapunov-Schmidt reduction

Abstract: The focus of this talk is a detailed review of Lin's method which is a technique for investigating homoclinic bifurcations. Compared with Poincare maps, it is not a geometric approach but similar to Lyapunov-Schmidt reduction. It can be used to investigate bifurcations to N-homoclinic solutions which resemble N copies of a primary homoclinic solutions. In addition, it is related to the PDE stability of pulses. In the talk, the technique is explained in detail and examples are given.

Friday, October 10

Monday, October 13

Short Course on Path Following and Bifurcations in Scientific Computing

11:15 am	**Herbert B. Keller** Caltech	Part I

Abstract: General techniques for following regular paths will be introduced. Several different methods for introducing continuation parameters are shown. Global results and the sign-change lemma are covered. Degree theory and the homotopy invariance of degree follow with applications such as a constructive proof of the Brouwer fixed-point theorem and the computation of periodic orbits.

The short course will meet in Vincent Hall 570

Tuesday, October 14

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

The discussion session meets in room Vincent Hall 570.

IMA Postdoc Seminar:

2:30 pm	**Bernd Krauskopf** Vrije Universiteit Amsterdam	Bifurcations in a Diode Laser with Optical Injection

Abstract: We study a single-mode diode laser subject to optical injection. (Optical injection is a means of stabilizing a laser at a prescribed frequency and is also used for optical amplification.) This system can be described by rate equations, which mathematically define a periodically driven vector field in R^3. Some of the interesting dynamics of this vector field can be studied by a amplitude/phase equation, that is, by a planar vector field. We discuss the bifurcations of this planar vector field and their implications for the behavior of the laser. In particular, we are interested in the dynamics near the onset of so-called relaxation oscillations, when the laser becomes unstable.

Organizer: Kurt Lust

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

Wednesday, October 15

Short Course on Path Following and Bifurcations in Scientific Computing

11:15 am	**Herbert B. Keller** Caltech	Part II

Abstract: The study of steady-state bifurcations and several ways to switch branches at bifurcations are covered. The bordering algorithm and its applications in path following are introduced. Fold following and related matters in higher-codimension bifurcations will be discussed.

The short course will meet in Vincent Hall 570

Math Department/IMA Seminar on Evolutionary Equations
in Vincent Hall 570

2:30 pm	**George R. Sell** University of Minnesota	Robustness of Exponential Dichotomies for Evolutionary Equations

Abstract: The object of this lecture is to outline the proof of a robustness theorem for the existence of exponential dichotomies for ordinary or partial differential equations. The proof is new even in the finite dimensional case. We will give some applications for the study of the longtime dynamics of the Navier-Stokes equations.

Thursday, October 16

Seminar on Dynamics and Mechanics in Vincent Hall 570

10:10 am	**Rafael de la Llave** University of Texas, Austin	Necessary and Sufficient Conditions for Uniform Integrability

Friday, October 17

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Cush Hamlen** Medtronic	Modeling and Simulation at Medtronic

Abstract: Modeling and simulation are playing an increasingly important role in the design, manufacture, and sale of the products manufactured by Medtronic. This is within the context of a highly competitive market where time to produce a product, and the quality of that product, are critical. The devices and products built by Medtronic are based on a wide range of technologies: although sometimes very large problems are solved, the challenge more often is in designing an appropriate model (using existing modeling technologies) that contains appropriate physics, rather than creating new modeling or solution techniques.

In this talk some of the physical systems of interest in products produced by Medtronic are presented. Examples of models of those systems are presented within the context of the driving forces for creating those models: design, manufacture, support for patent applications, and support for marketing.

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

Monday, October 20

Tuesday, October 21

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

The discussion session meets in room Vincent Hall 570.

IMA Postdoc Seminar:

2:30 pm	**Rolf-Martin Mantel** Univ. of Warwick/IMA	Spiral waves in two and three dimensions

In excitable media, spiral-like waves exhibit stable long-term structures. We present a short review of excitable media, spiral waves and Barkley's PDE model that allows extremely fast simulation of spirals.

In two dimensions, spiral waves can be moved by resonant periodic forcing. In three dimensions, spiral-like structures present a wide variety of patterns. We explore several patterns numerically and study whether it is possible to control them in a similar way to two-dimensional spirals. We show that the "twisted scroll ring" can be viewed as a relative equilibrium under the action of the Euclidean group $\mathbb{E}^3$.

Organizer: Kurt Lust

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

Geometry Center / Combinatorics Seminar in room Ford Hall 130:

3:30 pm	**Ilia Itenberg** Universite de Rennes	Combinatorial patchworking of polynomial vector fields

Abstract: We discuss a new combinatorial technique that allows us to construct planar vector fields of any degree d with at least $3d^2/4 + O(d)$ limit cycles, and give a complete classification of collections of nondegenerate singular points of vector fields of any degree in R^2. Joint work with E. Shustin.

4:30 pm	**Informal Discussion** Led by Don Aronson	Models of Josephson Junctions

Meets in Vin H 570

Wednesday, October 22

Math Department/IMA Seminar on Evolutionary Equations
in Vincent Hall 570

2:30 pm	**Peter Szmolyan** Technical University of Vienna	Singular perturbation analysis of self-similar zero-viscosity limits of conservation laws

Abstract: Hyperbolic conservation laws with an artifical viscosity term

$$u_t + f(u)_x = \varepsilon t u_{xx}$$

admit self-similar solutions $u(x,t) = u(x/t)$. Existence of solutions of the corresponding boundary-value problem on the real line and convergence to solutions of the corresponding Riemann problem in the limit $\varepsilon \to 0$ have been investigated by many authors. All results obtained so far rely on *a priori* estimates and compactness arguments, hence uniqueness of limiting solutions is not proved. We present a novel approach to the problem based on the invariant manifold approach of geometric singular perturbation theory. The method is constructive since solutions of the Riemann problem serve as singular solutions in the context of geometric singular perturbation theory. At shocks internal layers occur which have the structure of travelling waves. For solutions of the Riemann problem consisting solely of shock waves separated by constant states our geometric approach leads to a clear, complete picture of the existence, structure, and asymptotic behaviour of self-similar zero-viscosity limits.

IMA Tutorial:

Multiple-Time-Scale Dynamical Systems

October 23–24, 1997
Speakers: Christopher Jones (Brown), Michael Ward (UBC)

Thursday, October 23

Talks today are in the Seminar Room, Vincent Hall 570

8:30 am	**Registration and Coffee**	Vin H 514 & IMA Lounge, Vin H 502
9:20 am	**Welcome and Orientation**	W. Miller, R. Gulliver, C. Jones
9:30 am	**Chris Jones** Brown University	Invariant Manifolds and Singular Perturbations

10:30 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
11:00	**Chris Jones** Brown University	Fenichel Normal Form and Applications
2:00 pm	**Michael Ward** University of British Columbia	Exponential Asymptotics and Boundary Value Problems
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Friday, October 24

8:30 am	**Coffee**	IMA Lounge, Vincent Hall 502
9:30 am	**Michael Ward** University of British Columbia	Metastable Dynamics for Reaction-Diffusion Equations
10:30 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
11:00	**Chris Jones** Brown University	Tracking Invariant Manifolds in Fast/Slow Systems
2:00 pm	**Michael Ward** University of British Columbia	Pulse Dynamics

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IMA Workshop:

Multiple-Time-Scale Dynamical Systems

October 27–31, 1997

Organizers: Chris Jones (chair), Steve Wiggins (Caltech), Alexander Khibnik (Cornell), Freddy Dumortier (Limburg), David Terman (Ohio State)

Many physical problems, particularly in chemical and biological systems, involve processes that occur on widely varying time scales. The resulting model is a system that has a singular perturbation character. Such problems have motivated the development of much mathematical theory, including classical asymptotic theory and a geometric theory based on invariant manifolds. The phenomena that appear in singular-perturbation problems are subtle, often involving expansions in terms of quantities that are exponentially small in terms of a small parameter in the problem. The singular structure of these equations can also pose formidable numerical challenges. The goal of this workshop is to explore the connection between the asymptotic and geometric theories, with a particular emphasis on exponentially small phenomena, and to bring researchers developing these methods together with people working on applications in biology, chemistry and mechanics.

Monday, October 27

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, R. Gulliver, C. Jones
9:30 am	**David McLaughlin** Courant Institute, NYU	Chaotic and Homoclinic Behavior in PDE's

Abstract: Homoclinic behavior in integrable PDE's can be used as a starting point to understand and organize the chaotic behavior which is observed under perturbations. This talk will summarize analytical results on the persistence of homoclinic orbits under damped-driven and hamiltonian perturbations. These analytical results will be correlated with numerical observations, emphasizing new experiments (i) without even symmetry in space, and (ii) for large extended spatial domains. The latter is important for the coexistence of spatial and temporal chaos.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Nigel Goldenfeld** University of Illinois	Renormalization Group Approach to Global Asymptotic Analysis

Abstract: Renormalization and the renormalization group (RG) were originally developed by physicists attempting to understand the divergent terms in perturbation theory and the short distance behaviour of quantum electrodynamics. During the last few years, these methods have been used to study the divergent terms in perturbation theory and the long time behaviour of a variety of partial differential equations. Problems studied include similarity solutions, especially intermediate asymptotics of the second kind (Barenblatt classification), and travelling waves. Most recently, singular perturbation problems have been treated, with particular attention paid to multiple-scale analysis, boundary layers and WKB, and matched asymptotics.

The RG works from the inner expansion alone, and never requires asymptotic matching. The RG method starts from a regular perturbation expansion in the small parameter, and automatically generates an asymptotic sequence without requiring the user to make insightful guesses as to the presence of "unexpected" powers, logarithms, etc. The RG-generated uniform approximation is practically more useful than that generated by matched asymptotics, even when extended to values of the small parameter of order unity. It seems, then, that the RG is widely applicable and can be used mechanically.

All of these results are formal, and require significant mathematical investigation in order to be justified and properly understood.

This is work performed in collaboration with Yoshitsugu Oono, L.-Y. Chen, O. Martin, F. Liu.

2:00 pm	**Amadeu Delshams** Univ. Politècnica de Catalunya	Homoclinic orbits to invariant tori in Hamiltonian systems

Abstract: We consider a perturbation of an integrable Hamiltonian system which possesses invariant tori with coincident whiskers (like some rotators and a pendulum). Our goal is to measure the splitting distance between the perturbed whiskers. Emphasis is put on the detection of their intersections, which give rise to homoclinic orbits to the perturbed tori.

A geometric method is presented which takes into account the Lagrangian properties of the whiskered tori. In this way, the splitting distance is the gradient of an splitting potential. In the regular case (also known as a priori-unstable: the Liapunov exponents of the whiskered tori remain fixed), the splitting potential is well-approximated by a Melnikov potential. This method is designed for the singular case (also known as a priori-stable: the Liapunov exponents of the whiskered tori approach to zero when the perturbation tends to zero), which is currently being researched.

This is a joint work with Pere Gutiérrez.

3:00 pm	**Richard Haberman** Southern Methodist Univ.	Slow passage through a homoclinic orbit with subharmonic resonances

Abstract: The slow passage through a homoclinic orbit is analyzed for a periodically forced and weakly damped oscillator corresponding to a double-well potential. Multiphase averaging fails at an infinite sequence of subharmonic resonance layers which coalesce on the homoclinic orbit. An accurate phase of the strongly nonlinear oscillator after passage through each subharmonic resonance is obtained using a time shift and a constant phase adjustment. Near the unperturbed homo-

clinic orbit, the solution is a large sequence of nearly homoclinic orbits in which one saddle approach is mapped into the next. The method of matched asymptotic expansions is used to relate the solution in subharmonic resonance layers to the solution near the unperturbed homoclinic orbit. In this way, we determine an asymptotically accurate description for the boundaries of the basins of attraction corresponding to capture into each well.

This is joint work with Jerry D. Brothers.

3:30 pm	**Alexandra Milik** Techn. Univ. of Vienna	The Geometry of Mixed-mode Oscillations in a Chemical Oscillator

Abstract: We present a geometric explanation of a basic mechanism generating mixed-mode oscillations in a prototypical simple model of a chemical oscillator. Our approach is based on geometric singular perturbation theory and canard solutions. We explain how the small oscillations are generated near a special point, which is classified as a folded saddle-node for the reduced problem. The canard solution passing through this point separates small oscillations from large relaxation type oscillations. This allows to define a one-dimensional return map in a natural way. This bimodal map is capable of explaining the observed bifurcation sequence convincingly.

This is joint work with Peter Szmolyan.

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

A variety of appetizers and beverages will be served.

Non-workshop event: IMA Industrial Postdocs Seminar

The seminar will meet from 10:00 am – 2:00 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. In particular, participants should indicate choices for the box lunch.

The seminar meets in Vincent Hall 570

Tuesday, October 28

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Konstantin Mischaikow** Georgia Institute of Technology	A topological approach to fast-slow dynamics
9:30 am	**Michael J. Davis** Argonne National Laboratory	Some Multiple-Time-Scale Problems in Chemical Dynamics, Molecular Spectroscopy, & Kinetic Modeling

Abstract: Several problems in the titled areas are discussed in terms of their multiple-time-scale properties. In particular, theories of unimolecular reactions and the description of vibrational spectra and eigenstates are mentioned. The main focus of the talk will be low-dimensional manifolds in problems involving kinetic modeling. The manifolds are generated numerically using two methods. One is the approximate method of Maas and Pope and the other is our modification of Fraser's relaxation algorithm which is able to generate exact low-dimensional manifolds under some conditions. Some simple model problems are discussed as well as applications to gas phase chemical kinetics, vibrational relaxation, and the coarsening of solid surfaces.

This is joint work with Rex T. Skodje.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Linda Petzold** Univ. of California, Santa Barbara	Model Reduction for Nonlinear Dynamical Systems from Chemical Kinetics

Abstract: The kinetics of a detailed chemically reacting system can potentially be very complex. Although the chemist may be interested in only a few species, the reaction model almost always involves a much larger number of species. Some of these species are referred to as radicals. These are highly reactive species (usually of low concentration) which can be important intermediaries in the reaction scheme. A large number of elementary reactions can occur amoung the species; some of these reactions are fast and some are slow. The aim of simplified kinetics modeling is to derive the simplest reaction system which retains the essential features of the full system. In this lecture we describe an optimization-based method for reduction of the number of species and reactions in chemical kinetics models. Numerical results for several reaction mechanisms are given which illustrate the potential of this approach.

2:00 pm	**Michael Ward** University of British Columbia	Dynamic Metastability for Reaction-Diffusion Equations

Abstract: Certain singularly perturbed partial differential equations exhibit a phenomenon known as dynamic metastability, whereby reaction-diffusion patterns evolve asymptotically exponentially slowly in time. For instance, this metastability occurs in the propagation of thin interfaces for phase separation models, including the Cahn-Hilliard equation, which has applications to materials science. It also occurs for the Gierer-Meinhardt reaction-diffusion system that models pattern formation in morphogenesis. The speaker will illustrate metastable behavior for certain classes of partial differential equations of reaction-diffusion type and will show how asymptotic, spectral and numerical analysis can be used to obtain a precise characterization of the slow dynamics. A necessary condition for metastability in these diverse types of reaction-diffusion equations is that the spectrum associated with the linearization of the partial differential equation around a certain robust canonical solution, such as a standing wave, contains exponentially small eigenvalues. As will be shown, this condition is by no means sufficient for the existence of metastable behavior. The talk will be aimed towards a broad audience including those who have interest in partial differential equations, motion by curvature, dynamical systems, and numerical analysis.

3:00 pm	**Xiao-Biao Lin** North Carolina State University	Method of singular characteristics for Hamilton-Jacobi equations that develop shock structures

Abstract: For a quasi-linear hyperbolic system, the method of vanishing viscosity is used to construct solutions with strong discontinuity (shock). The solution consists of two regular regions separated by a free boundary (shock). A system of differential equations that governs the free boundary and its boundary values is derived by Melnikov's method. If the system is a conservation law, the differential equation is the well know Rankine-Hugoniot condition. If the system is non-conservation, the differential equation is in a form of Melnikov type integral that generalizes the Rankin-Hugoniot condition. Solutions in the regular regions are then obtained by the method of characteristics.

3:20 pm	**Mohammed Ziane** Stanford University	A mathematical formulation of the Goldenfeld renormalization group method
3:40 pm	**Jiangzhong Su** Univ. of Texas at Arlington	Delay of bifurcation phenomena and their analysis

Abstract: The phenomena of delay of bifurcation occur in some fast-slow problems (or simply slow passage problems) where a parameter is slowly changing resulting in changes of static stability. The solutions of the equation ($\varepsilon \neq 0$) actually follow the unstable singular solution ($\varepsilon = 0$) until some integral conditions are satisfied. We consider several interesting cases including the FitzHugh-Nagumo Equation, FHN model with periodic forcing and particularly a system with one simple eigenvalue which slowly passes zero.

Wednesday, October 29

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Anatoly Neishtadt** Space Research Institute, Moscow	On stability loss delay for dynamical bifurcations

Abstract: In classical bifurcation theory the behavior of systems, depending on a parameter, is considered for values of the parameter close to some critical, bifurcational value. In the theory of dynamical bifurcations the parameter is changing slowly in time and passes through the value, which would be critical in classical static theory. Some phenomena, arising here, are drastically different from predictions derived by a static approach. At a bifurcational value of the parameter the equilibrium or the limit cycle loses its asymptotic linear stability, but remains nondegenerate. In analytic systems the stability loss is inevitably delayed: the phase points remain near the unstable equilibrium (cycle) for a long time after bifurcation; during this time the parameter changes by a quantity of order 1. Such delay is not in general found in nonanalytic (even infinitely smooth) systems.

The talk is devoted to estimates of delay time. The delay time is controlled by behavior of solutions in the plane of complex time.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Robert A. Gardner** University of Massachusetts	Stability Analysis of Singular Patterns for the 1-D Gray-Scott Model

Abstract: The Gray-Scott equations form a system of two singularly perturbed reaction-diffusion equations which exhibit several interesting and novel spatio-temporal patterns. This talk is concerned with the stability analysis of stationary homoclinic pulse solutions near the singular limit. These solutions are (rigorously) obtained from a matched asymptotic expansion in a previous study by Doelman, Kaper, and Zegeling, in which one component has a singular "spike" which becomes unbounded in the singular limit. In a scaling which resolves the fast dynamics, the spike is approximated by the (unstable) homoclinic solution of the scalar Fisher equation. However, numerical experiments indicate that, contrary to intuition, the singular 1-pulse solutions will sometimes be stable.

The purpose of this lecture is twofold. First, a formal stability analysis is discussed which in which a reduced, scalar nonlocal eigenvalue problem (the NLEP equation) is derived from matched asymptotics which predicts that these waves will indeed be stable in certain ranges of parameters. The formal results are in excellent agrement with the numerical calculations.

The second part of the talk is concerned with a rigorous stability analysis of these solutions based upon the Evans function for the wave and on the stability index. The analysis provides a complete mathematical explanation for the mysterious disappearance of the unstable eigenvalue predicted by the fast reduced equation and it validates the predictions of the formal NLEP equation.

Another aspect of the analysis is the role of the continuous spectrum, which approaches the origin in the singular limit. This is a commonly encountered problem in stability calcuations near a singular limit. A novel method for handling this difficulty is introduced, which involves the analytic continuation of the Evans function and the stability index into the continuous spectrum. This requires that the spectral plane be lifted to a certain Riemann surface, since the Evans function has a branch point near the origin. The branch point plays a crucial role in the calculation of the index and therefore, in obtaining the correct eigenvalue count near the origin of the spectral plane.

This is joint work with Arjen Doelman and Tasso Kaper.

2:00 pm	**David Terman** Ohio State University	Multiple Time Scales in Networks of Neural Oscillators

Abstract: Oscillations arise throughout the central nervous system. The thalamus, for example, is centrally important in the generation of sleep rhythms. It has also been implicated in the generation of Parkinson tremor, epilepsy, and 40 Hz oscillations. These rhythms are often the result of interactions between the intrinsic properties of the individual neurons within the network and the synaptic properties of the coupling between the neurons. Both the intrinsic and synaptic dynamics may involve multiple time-scales; these may have a profound influence on the emergent network behavior. In

this talk, I will review models for some of these rhythms and then discuss recent results concerning the role of fast and slow inhibitory coupling in generating different activity patterns within the networks.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**Tasso Kaper** Boston University	Exchange lemmas: an overview and some new applications

Thursday, October 30

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Chongchun Zeng** Courant Institute, NYU	Invariant Manifolds and Invariant Foliations for Semiflows in Banach Space

Abstract: Invariant manifolds and invariant foliations are important geometric tools in the studies of dynamical systems, which can be used to track asymptotic behaviors. In this work, we extend the results for ODE's and diffeomorphisms to general semiflows and maps in Banach spaces.

9:30 am	**Yulij Ilyashenko** Cornell Univ./Moscow State & Indep. Univs.	Embedding theorems for maps and normal forms for the slow-fast systems

Abstract: Slow-fast systems with periodic orbits as attractors for the corresponding fast systems are called *oscillatory.* The classical theory of the slow-fast systems mostly deals with those having singular points as attractors of the fast systems. We call them *stationary* in order to distinguish from the oscillatory ones.

The theory of the stationary slow-fast systems in well developed. The theory of oscillatory ones is in its very beginning. Yet the second theory may be reduced to the first one through the so-called *embedding theorems.*

The germ of a map at a fixed point is called embeddable if it may be represented as a phase flow transformation of a germ of a vector field, called a generator. Embedding theorems for maps and their families claim that under certain conditions the maps are embeddable; for the maps of smooth families the generator smoothly depends on the parameter. The talk contains new embedding theorems and their applications to the oscillatory slow-fast systems.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**George Haller** Brown University	Homoclinic jumping in evolution equations

Abstract: In many physical systems one can observe fast transitions between resonant states, i.e., states where some of the phase variables become commensurate. Examples include the phenomenon of ultrafast energy transfer in molecular dynamics, and the numerically observed jumping behavior of the perturbed nonlinear Schrödinger equation. In this talk I describe a global perturbation method to construct solutions that connect slow trajectories through fast, intermediate jumps. As applications, I discuss single and coupled NLS equations.

2:00 pm	**Robert Roussarie** University of Bourgogne	Multiple Canard Cycles in Van Der Pol-like Equations

Abstract: A Van der Pol-like equation is a singular differential equation of the type:

$$\dot{x} = y - F(x, b)\,, \qquad \dot{y} = \epsilon\, G(x, a)$$

where ϵ is a small parameter, $F,\ G$ are differentiable functions with parameters $b = (b_1, \cdots, b_k) \in \mathbb{R}^k,\ a \in \mathbb{R}$, such that: $F = \frac{1}{2}x^2 + O(|b|)O(x^3)$ and $G = a - x + O(x^2)$. Depending on F, multiple canard cycles, containing $(0, 0)$ as unique

singular point, can appear along the line $\{y = F(x, b)\}$. Their bifurcations are given by an equation $\{\Delta(y, a, b, \epsilon) = 0\}$ whose derived equation $\{\frac{\partial \Delta}{\partial y} = 0\}$ is equivalent to a differentiable one $\{I(y, b) + O(\epsilon) = 0\}$. The principal part $I(y, b)$ of this last equation is equal to a simple integral in terms of F.

This is joint work with F. Dumortier.

3:00 pm	**Pavol Brunovsky** Cornenius University	C^k inclination theorems for singularly perturbed problems
3:20 pm	**Peter Szmolyan** Technische Universität Wien	Extending Geometric Singular Perturbation Theory to Non-hyperbolic Points
3:40 pm	**Discussion Session**	Panel: Marc Diener, Freddy Dumortier, Paul Fife, Chris Jones, David McLaughlin.
6:00 pm	**Workshop Dinner** Campus Club	Fourth floor of Coffman Union

Reception at 6:00 with wine & cheese, dinner at 6:45.

Friday, October 31

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Petar Kokotovic** Univ. of California, Santa Barbara	Singular Perturbations and Multiple Time Scales in Control System Modeling and Design

Abstract: This presentation will review more than 30 years of successful applications of singular perturbation and multi-time-scale techniques to control theory problems, including optimal control and guidance, as well as reduced-order modeling and robustness to unmodeled dynamics.

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

The following talk is joint with the IMA Seminar on Industrial Problems

11:15 am	**Dennis Perchak** Kodak	Stokesian Dynamics Simulation of Interacting Solid Particles

Abstract: The stability and rheology of solid particle dispersions are important to the manufacture of photographic film and paper. Using the Stokesian Dynamics simulation method developed by Brady *et al.* (Ann. Rev. Fluid Mech., 1988) we report 2D simulations of concentrated, monodisperse, spherical, solid particle dispersions interacting via both simple attractive and repulsive potentials as well as a more complicated DLVO potential. We examine, in particular,the effect of many-particle interactions on the dispersion rheology, stability, and structure, at higher volume fractions.

This is joint work with Richard Klingbiel.

The seminar will meet in Vincent Hall 570.

3:00 pm	**Halloween Party!!** Vincent Hall 502 and 570	Costumes are encouraged—not required. Bring your family for a good time!

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IMA NEWSLETTER # 256

November 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.

News and Notes

IMA Workshop:

Dynamics of Algorithms

November 17–21, 1997
Organizers: Rafael de la Llave (Texas)(chair), Linda Petzold (Santa Barbara), Jens Lorenz (New Mexico)

IMA Workshop:

Algorithmic Methods for Semiconductor Circuitry

November 24–25, 1997
Organizers: Jacob White (MIT)

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.

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

For example, we now have workshop schedules which are linked to speaker abstracts, available toward the end of the month before the workshop. The page is continually under construction. We invite comments or suggestions, which may be addressed to webmaster@ima.umn.edu.
In particular, we appreciate any information about World-Wide Web links appropriate to current and upcoming IMA programs.

Schedule for November 1–30, 1997

Monday, November 3

Tuesday, November 4

AEM Seminar in the Mechanics of Materials:

1:30 pm	**Fernando Reitich** University of Minnesota	Three-phase boundary motions under constant velocities: the vanishing surface tension limit

The seminar will meet in room 227 Akerman Hall

IMA Postdoc Seminar:

2:30 pm	**Tony Shardlow** IMA/Stanford University	Applications of Inertial Manifolds to Linear Multistep Methods

Abstract: I formulate and prove existence and convergence properties of an inertial manifold for a class of linear multistep methods (LMMs) approximating a reaction diffusion equation (subject to a gap condition). Each LMM is shown, moreover, to approximate a one step method on the inertial manifold. This brings the approximation theory of one steps method to bear, and accordingly many results about the continuity of invariant sets of the reaction diffusion equation with respect to approximation by LMMs are easily established.

Organizer: Kurt Lust

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

Wednesday, November 5

Math Department/IMA Seminar on Evolutionary Equations
in Vincent Hall 570

2:30 pm	**David Norman** University of Minnesota	The continuous stirred-tank reactor as the diffusive limit of chemically reacting fluid flows

Abstract: In this talk we consider the relationship between chemically reacting flows and continuous-flow stirred-tank reactors (CSTR). In particular, we show that, in the limit as the diffusivity goes to infinity, the solutions of the reacting flow PDE approach the solutions to the CSTR ODE. We futher show that the global attractors for the reacting flow come arbitrarly close to the CSTR global attractor as the diffusivity goes to infinity.

Thursday, November 6

IMA/Math Department Seminar on Dynamics and Mechanics:

10:10 am **Hinke Osinga** Growing unstable manifolds of planar maps
University of Minnesota

The seminar will meet in room Vincent Hall 570

Friday, November 7

Monday, November 10

Tuesday, November 11

IMA Postdoc Seminar:

2:30 pm **Kurt Lust** Computing Floquet multipliers
IMA/K. U. Leuven

Abstract: In this talk, we will discuss the computation of all or only the dominant Floquet multipliers in single and multiple shooting and Gauss-Legendre collocation codes (e.g. AUTO). We will show how the monodromy matrix can be recovered from the computations and introduce the periodic Schur decomposition (with the corresponding periodic QR algorithm) as a tool to compute the Floquet multipliers in multiple shooting and collocation codes with high accuracy. We will also introduce the orthogonal subspace iteration method to compute the dominant Floquet multipliers.

Organizer: Kurt Lust

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

4:30 pm **Shinya Watanabe** Models of Josephson Junctions
Informal Discussion

This informal discussion is led by Don Aronson and meets in Vin H 570.

Wednesday, November 12

IMA Informal Presentation in Vincent Hall 570:

11:15 am **John Guckenheimer** DSTool + Matlab
Cornell University

Math Department/IMA Seminar on Evolutionary Equations
in Vincent Hall 570

2:30 pm **Bjorn Sandstede** Exponential dichotomies for semilinear elliptic equations
Ohio State University

Abstract: Solitary wave solutions of semilinear elliptic equations in infinite cylinders frequently arise in applications. Interpreting elliptic equations on infinite cylinders as dynamical systems in the unbounded spatial variable has proved very useful when investigating solitary waves. Still, there are major obstacles in obtaining, for instance, bifurcation results similar to those for ODEs. Here, persistence and continuation of exponential dichotomies for linear elliptic equations is proved. With this technique at hands, Lyapunov-Schmidt reduction near solitary waves can be applied.

Thursday, November 13

IMA/Math Department Seminar on Dynamics and Mechanics:

10:10 am **Bernd Krauskopf** Resonant homoclinic flip bifurcations
Free University of Berlin

The seminar will meet in room Vincent Hall 570

Mathematics Department Colloquium in room Vincent Hall 16:

3:30 pm **Herb Keller** Hilbert's Sixteenth Problem: A Numerical Analyst's Approach
California Institute of Technology

Tea will be served at 3:10 pm in room 120 Vincent Hall

Friday, November 14

IMA Seminar on Industrial Problems

11:15 am **Wim Sweldens** Second Generation Wavelets: Theory and Applications
Lucent Technologies

Abstract: In the last decade wavelets have been applied successfully to sound (1D), image (2D), and video (3D) processing. Typical applications include compression, noise reduction, progressive transmission, etc. Each time the data is defined on an Euclidean space and sampled on a regular grid.

Many applications, however, need wavelets defined on general geometries (curves, surfaces, manifolds), wavelets adjusted to irregular sampling, or adaptive wavelet transforms. Therefore we introduce Second Generation Wavelets: wavelets which are not necessarily translates and dilates of one function, but still enjoy all powerful properties such as time-frequency localization, multiresolution, and fast algorithms.

While the Fourier transform has been the principal tool in constructing classical wavelets, e.g. Daubechies, it can no longer be used to build Second Generation Wavelets. We therefore present the lifting scheme, an entirely spatial construction technique.

We give examples how lifting can be used to build wavelets for irregular samples, spherical wavelets, and multiresolution geometry. We also show that all classical wavelets can be obtained through lifting, that lifting speeds up the fast wavelet transform, and that lifting allows for integer-to-integer wavelet transforms which are important in lossy compression.

No preliminary knowledge of wavelets will be assumed.

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

IMA Tutorial on Dynamics of Algorithms

2:30 pm **Rafael de la Llave** Some Constructive Methods in Hamiltonian Mechanics
University of Texas

This one-hour tutorial will be an introduction to theoretical and computational issues related to, for example, periodic and quasi-periodic orbits of Hamiltonian systems. This will serve as preparation for some of the topics which will be treated in next week's workshop on "Dynamics of Algorithms". Certain other topics were adequately covered in the September 4–9 tutorial on "Numerical Methods for Bifurcation Problems".

The tutorial will meet in Vincent Hall 570.

IMA Workshop:

Dynamics of Algorithms

November 17–21, 1997
Organizers: Rafael de la Llave (Texas)(chair), Linda Petzold (Santa Barbara),
Jens Lorenz (New Mexico)

There are deep connections between the theory of algorithms and dynamical systems theory.

On one hand, the transformations of data effected by an algorithm can be considered as a dynamical system and the techniques of dynamical systems can be used to analyze properties such as global convergence, asymptotic rates, *etc.*, and eventually lead to better numerical algorithms.

On the other hand, computations in dynamical systems present special challenges. For example, the objects to be discretized are geometric objects or have a very strong algebraic component. What is known *a priori* of the solutions affects the design of algorithms. Suitably designed algorithms may be used as ingredients in rigorous proofs.

Monday, November 17

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, R. Gulliver, R. de la Llave
9:30 am	**Uri Ascher** University of British Columbia	DAEs that should not be solved

Abstract: The closing decades of the 20th century have seen many scientists recognize that their mathematical models are in fact instances of DAEs, or of ODEs with invariants. Such a recognition has often carried with it the benefit of affording a new, sometimes revealing, computational look at the old problem.

But one must not conclude that reformulating a mathematical model as a DAE is always a good idea. Neither should one automatically assume that a numerical approximation of an ODE with an invariant must respect the invariant first, and only then worry about discretizing the ODE. In this talk we give some examples to the contrary: • enforcing energy conservation in highly oscillatory Hamiltonian systems; • moving meshes for PDEs; and • reproducing an entire homotopy path as a way for reaching its end.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Roswitha März** Humboldt-Universität Berlin	Dynamics of DAE-Algorithms

Abstract: When integrating regular ODEs numerically, one tries carefully to match the dynamics of the numerical algorithm and the true solution behaviour well. Applying analogous numerical methods to DAEs, one expects to reach a similar harmonization. However, surprisingly, now the algorithms may behave very differently.

This talk aims at analysing the reason for that different behaviour. In particular, certain subspaces closely related to the geometry of the DAEs are shown to influence the dynamics of the algorithms significantly. Furthermore, with regard to matching the numerical and true dynamics better, regularization is revisited.

2:00 pm	**Marian Mrozek** University of Krakow	Representable Multivalued Maps as a Topological Bridge between Dynamics and Finite Mathematics

Abstract: Representable multivalued maps may be viewed as a generalization of the concept of interval arithmetic. However, unlike the interval arithmetic, they have fruitful connections via topology with continuous mathematics. The connections combined with the simple but significant idea of inheritance enables one to translate some questions in dynamics to combinatorics, solve them algorithmically and translate the solution back to dynamics. This provides an efficient setting for constructing computer assisted proofs in dynamics.

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

A variety of appetizers and beverages will be served.

Tuesday, November 18

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Benedict Leimkuhler** University of Kansas	Symmetry-Preserving Adaptive Integrators for Coulombic Few-Body Problems

Abstract: Integration of Coulombic N-body problems involving close approaches is a standard problem in astrophysics and is also encountered in certain quasi-classical approaches to atomic problems. Stable integration requires the use of coupled time and coordinate transformations (Kustaanheimo-Stiefel regularization). In this talk, the author will show that the KS framework can be combined with an additional time-transformation and a special integration method to yield a symmetry-preserving integrator. For systems dominated by two-body (as opposed to three-body, or more) close approaches, an argument can be made that preservation of symmetry leads to improved numerical behavior.

Examples such as He^+e^- scattering and perturbed Kepler problems illustrate the dramatic improvements obtainable by the adaptive-reversible schemes.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Debra Lewis** University of California, Santa Cruz	Conserving algorithms on Lie groups

Abstract: Standard algorithms for numerical integration of initial value problems are formulated on vector spaces and make crucial use of that structure; all tangent spaces are identified, allowing averaging of tangent vectors with distinct basepoints, and the update is performed by setting an appropriate difference quotient equal to the resulting average. To extend these algorithms to general manifolds, it is necessary to develop analogs of these operations that are valid and implementable in a nonlinear setting. Lie groups and their tangent or cotangent bundles form a class of manifolds for which particularly natural generalizations of these procedures exist. The group structure can be exploited in the construction of integration schemes generating trajectories lying exactly in the (nonlinear) phase space. The usual weighted averages of vector field evaluations are computed in the Lie algebra or its dual using the natural trivializations of the tangent and cotangent bundles; the resulting update vector is then mapped into the phase space using either the exponential map or an approximate 'algorithmic' exponential map. Thus the computation-intensive steps of the algorithm are carried out on a vector space of the same dimension as the phase space; this is particularly advantageous in implicit schemes, where the residual equation must be solved, typically by an iterative method, at each time step. Various combinations of conservation laws (e.g. conservation of energy, momentum, or the symplectic structure) of the original mechanical system can be incorporated in the associated algorithms. An appropriate choice of trivialization can significantly simplify the implementation of such constraints. Group decompositions can be used to design efficient algorithmic exponentials; these decompositions are often suggested by the symmetries of the relevant mechanical system.

2:00 pm	**Erik Van Vleck** Colorado School of Mines	Applications of Orthogonal Integration Techniques

Abstract: We consider applications in which one needs to compute the (smooth) QR factorization of a fundamental matrix solution Y. Of course, for stability reasons, explicit computation of Y has to be avoided, and one seeks to compute the Q and R factors directly. Applications include approximation of Lyapunov exponents, continuous orthonormalization technique for solving two-point boundary value problems, and eigenvalue calculation (isospectral flow). Both analytical and numerical results are presented.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**Estela Gavosto** University of Kansas	Complex Analysis Techniques for the Hénon Map

Abstract: The complex Hénon map is the complex version of the mapping studied by Hénon,

$$H(x, y) = (1 - ax^2 + by, x).$$

Besides the well–known relevance of this mapping in the real case, fundamental objects in complex analysis arise from the

study of the dynamics of this mapping in $\mathbb{C}^2$. Examples of such objects are Fatou–Bieberbach domains. (These are proper subsets of $\mathbb{C}^2$ biholomorphic to $\mathbb{C}^2$.)

We will describe an analytic method to find the location of homoclinic tangencies and some applications. From the complex analysis perspective, it is important to find such tangencies because close to some of them there are infinitely many Fatou-Bieberbach domains.

4:30 pm	**John Guckenheimer** Cornell University	Computation of periodic orbits using automatic differentiation

Wednesday, November 19

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Andrew Stuart** Stanford University	Convergence Proofs for Numerical Software

Abstract: The study of the running times of algorithms in computer science can be broken down into two broad types: worst-case analyses and average-case analyses. For many problems this distinction is very important as the orders of magnitude (in terms of some measure N of problem size) of the running times may differ significantly in each case, providing useful information about the merits of the algorithm.

A similar situation occurs for certain real number algorithms which are used in commonly available software in numerical analysis although, in the worst case, these algorithms may fail completely. Analysis of real number algorithms from this perspective was initiated by Smale in his pioneering study of Newton's method. Subsequent work in the area of linear algebra was undertaken by Demmel and has been elaborated on by many others. This work on Newton's method and in linear algebra will be reviewed; then recent work by the author and Harbir Lamba concerning similar analysis for commonly used ODE software packages (such as MATLAB) will be described.

A valid criticism of the average-case analyses of theoretical computer science is that they are highly dependent on the measure placed on the space of problems. This viewpoint will be discussed in the context of real number algorithms.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Michael Shub** IBM Watson Research Center	Multihomogeneous and Gauss-Newton Methods

Abstract: We generalize work of Shub and Smale on Newton and Projective Newton Methods to cover multihomogeneous systems and overdetermined systems of analytic maps. Included are the evaluation map of polynomial systems and the generalized eigenvalue problem. By understanding the disc of convergence around the fixed points points we give complexity estimates for continuation algorithms to find the zeros of systems.

This is joint work with J. P. Dedieu.

2:00 pm	**Marek Rychlik** University of Arizona	Complexity and applications of parametric algorithms of computational algebraic geometry

Abstract: The Comprehensive Gröbner Basis algorithm of V. Weispfenning can be applied to compute the maximal dimension of an algebraic variety depending on parameters and a variety of other problems which can be solved in the non-parametric case with the help of Gröbner bases. The algorithm and its experimental implementation in Common Lisp will be described. A variety of examples from several areas of mathematics and science will be presented, including bifurcation theory, mechanics and chemistry. In particular, benchmarks on some scalable dynamical systems will be discussed.

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

3:30 pm	**Ricardo Oliva** IMA/Cornell University	Combinatorics of complex Hénon mappings
3:50 pm	**George Corliss** Marquette University	Interval "all together" method for parameter identification
4:10 pm	**Baker Kearfott** University of Southwestern Louisiana	Automatic verification of dynamical systems properties

Abstract: Properties of dynamical systems are often specified by properties of solutions to nonlinear systems of equations. For example, bifurcation points correspond to parameter values in a parametrized nonlinear system where the number of such solutions changes.

With interval computations, computer arithmetic can be used to rigorously prove that such dynamical systems have certain properties. The following contexts will be highlighted:
• Incorporation of interval arithmetic in path-following algorithms to verify continuation along a single mathematical path.
• Use of interval arithmetic to compute the topological degree of a mapping.
• Use of interval arithmetic to verify a particular value of the topological degree of a mapping.
• Use of interval arithmetic to rigorously find all solutions to a nonlinear system of equations within a particular region of space (finite or infinite-dimensional).
The relative difficulty and practicality of each of these tasks will be discussed.

4:30 pm	**William Schelter** Unversity of Texas	Net Math, a web-based computational tool
4:50 pm	**Marek Rychlik** University of Arizona	Computations with Gröbner bases and applications to dynamical systems

Thursday, November 20

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**James Yorke** University of Maryland	How do we find out what a dynamical system is doing?

Abstract: The Maryland chaos group has developed a number of algorithms aimed at discovering what is happening in a dynamical system of low dimension. In particular I will discuss the BA (Basins and Attractors) routine (developed with Helena Nusse) that aims at finding all the basins and attractors of 2-dimensional maps. It can also find the smallest trapping region that an attractor lies in, with the restriction that the trapping region is a union of grid boxes. Simple reliable algorithms let us find trajectories that lie on the boundary of basins. We call these "basin straddle trajectories". Other routines will discussed with some demonstrations using a PC. Mathematicians have saddled the scientific community with the concept of chaotic or strange attractor. Yet except in very rare cases of hyperbolic attractors, it is impossible to conclude for a specific dynamical system rigorously that such an attractor exists. I will discuss alternatives to this theory.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Tim Sauer** George Mason University	Scaling laws for shadowing time

Abstract: A shadowing trajectory is a true trajectory of a map or differential equation, that closely tracks a computed approximate solution. For systems exhibiting hyperbolic and near-hyperbolic chaos, long shadowing trajectories can be shown to exist, meaning that trajectories constructed in the presence of one-step errors still represent true system behavior.

We will report on recent studies of strongly nonhyperbolic systems, in the case where finite-time Lyapunov exponents fluctuate about zero, for which long shadowing trajectories apparently do not exist. Scaling laws govern the length of shadowing trajectories in terms of one-step error and the statistics of the finite-time Lyapunov exponents.

2:00 pm	**Donald J. Estep** Georgia Inst. of Technology	Preservation under discretization of invariant rectangles for solutions of reaction-diffusion equations

Abstract: The existence of invariant rectangles for solutions of reaction-diffusion equations has powerful consequences for the analysis of these problems. Likewise, the existence of invariant rectangles for numerical solutions has strong consequences on the behavior of the approximation. We explain some of these, especially with respect to estimation of the error, and then describe two ways to perserve invariant rectangles under discretization.

Mathematics Department Colloquium in room Vincent Hall 16:

3:30 pm	**Bernold Fiedler** Freie Universität Berlin	Sturm Attractors

Abstract: The global attractors of parabolic partial differential equations in one space dimension will be described by a combinatorial object: the meandering permutations which arise by the orderings of equilibrium solutions at the boundary.

Thus some discrete, ODE-type information determines the variational PDE dynamics.

The results, based on Sturm-type nodal properties, are joint work with Carlos Rocha.

Tea will be served at 3:10 pm in room 120 Vincent Hall

6:30 pm	**Workshop Dinner** Jewel of India Restaurant	1427 Washington Ave. S., Minneapolis: a 15-minute walk across the Mississippi.

Friday, November 21

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Sebastian Reich** Konrad-Zuse-Zentrum, Berlin	Numerical Integration of Hamiltonian Systems with a Complex Solution Behavior

Abstract: The numerical integration of Hamiltonian systems with different time scales and exponentially diverging trajectories is a challanging task. In particular, standard forward error analysis cannot clarify the question if the obtained numerical results make any sense for long-term simulations. The recent progress in the backward error analysis of symplectic methods for Hamiltonian problems might change this unsatisfying situation. In my talk I will apply backward error analysis, normal form theory, and the concept of shadowing to show that for hyperbolic Hamiltonian systems and systems with adiabatic invariants that are due to separated time scales, the numerical results can be interpreted in a meaningful way.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Ernst Hairer** University of Geneva	Asymptotic expansions versus backward analysis for numerical integrators

Abstract: We consider numerical methods for solving ordinary differential equations. Asymptotic expansions of the global error (Henrici 1962, Gragg 1964, Stetter 1973, ...) on the one hand, and backward error analysis (Feng Kang 1991, Sanz-Serna 1992, Yoshida 1993, ...) on the other hand, both have as objective a better understanding of the global error of integration methods.

On a formal level both approaches yield equivalent representations of the numerical solution, but as soon as rigorous estimates are desired, the results are completely different. The reason is that in the theory of asymptotic expansions the diverging series are truncated in the space of solutions, whereas in the theory of backward error analysis the series are truncated in the space of vector fields. Due to its good approximation properties, backward error analysis gives new insight into numerical methods for a variety of problems: long-time integration of Hamiltonian or reversible differential equations (conservation of energy and of KAM tori), asymptotically stable periodic orbits, Hopf bifurcation, invariant tori of dissipatively perturbed Hamiltonian systems. The theoretical results will be illustrated with several examples.

2:00 pm **Luca Dieci** Integration of Matrix Equations: Orthonormal Integrators
Georgia Institute of Technology

Abstract: Recently, there has been some interest in structure preserving integration methods for solving matrix differential equations. One class of such methods are orthonormal integrators: techniques to solve matrix differential equations whose solution is orthonormal. We discuss analysis and implementation of these techniques. Particular attention is paid to algorithms based on the decomposition of the sought matrix in terms of elementary Householder and Givens transformations.

3:00 pm **Workshop Discussion** Issues for the future

Discussion leaders: Linda Petzold, Andrew Stuart, James Yorke, John Guckenheimer, Rafael de la Llave

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, Schlumberger 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

IMA Workshop:

Algorithmic Methods for Semiconductor Circuitry

November 24–25, 1997
Organizers: Jacob White (MIT)

The aim of the workshop is to bring together researchers who work on algorithmic methods together with researchers in semiconductor circuitry in order to address the difficult computational issues that arise in circuitry. The activities will include informal presentations and discussions.

The topics will include:

- Linear and nonlinear model-order reduction (including eigenvalue-calculation based approach).
- Methods for quasiperiodic analysis (including nonlinear phenomena in oscillating circuits: stability and bifurcation).
- Fast PDE solvers plus MOR

- Partitioning methods covering areas such as waveform relaxation, domain decomposition (parallel circuit simulation) and mixed level simulation.

Researchers are invited from both universities and industry.

Monday, November 24

Talks today are in the Seminar Room, Vincent Hall 570

8:00 am	**Registration and Coffee**	IMA Lounge, Vincent Hall 502
8:30 am	**Welcome and Orientation**	W. Miller, R. Gulliver, J. White

Monday morning topic: Radio–Frequency Circuit Analysis – Part I

8:40 am	**Ken Kundert** Cadence	Open Problems in RF Simulation

Abstract: The increasing demand for low-cost mobile communication systems has greatly expanded the need for simulation algorithms that are both efficient and accurate when applied to RF communication circuits.

RF circuits have several unique characteristics that are barriers to the application of traditional circuit simulation techniques. Over the last decade, researchers have developed many special purpose algorithms that overcome these barriers to provide practical simulation for RF circuits, often by exploiting the very characteristic that represented the barrier to traditional methods.

Despite dramatic progress, the average design cycle of an RFIC is still twice the length of that for other ICs found in a communication system, such as a cellular phone. This represents a significant practical barrier to integration of the RF and baseband sections of a transceiver onto a single chip. Clearly, more progress is necessary.

The principles employed in the development of modern RF simulators are introduced and various techniques currently in use, or expected to be in use in the next few years, are surveyed. Several open problems are identified.

9:00 am	**Peter Feldmann** Bell Labs	Simulation of the periodic and quasi-periodic solutions of nonlinear circuits

Abstract: The talk will focus on algorithms for the computation of the steady-state response of nonlinear circuits excited by periodic and quasi-periodic signals. We first formulate the periodic steady-state problem in time and frequency domains, and describe the method of harmonic-balance, a frequency-domain algorithm. The harmonic-balance algorithm is rendered efficient and practical for large circuits by use of preconditioned, Krylov subspace-based iterative methods for solving the large and dense systems of linear equations which arise. Next, we address the computation of the quasi-periodic steady-state solution of circuits excited by several periodic stimuli of incommensurate frequencies. Here, we discuss a general formulation of the problem, from which we derive the frequency-domain solution method: multitone harmonic balance, and the mixed time-and-frequency domain method: envelope following. Again, these methods rely on the Krylov subspace-based iterative linear solvers.

9:20 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
9:50 am	**Jaijeet Roychowdhury** Bell Labs	A Unifying Formulation for Analysing Multi-Rate Circuits

Abstract: Widely separated time scales arise in many important circuit applications, *e.g.*, switched-capacitor filters, mixers, switching power converters, *etc.* Detailed analysis of such circuits is often difficult or impossible with available methods, especially when strong nonlinearities are present. In this talk, a novel formulation and numerical methods are presented for analyzing nonlinear circuits with widely separated time scales. The key to the new techniques is the use of multivariate functions (functions of several variables) to represent signals with widely separated time scales efficiently. Using multivariate functions leads to a partial differential form for the circuit or system equations, which we call the *Multirate*

Partial Differential Equation or MPDE. Previous methods for quasi-periodic or envelope analysis of multi-rate systems correspond to specific choices for solving the MPDE numerically.

We present new methods for solving the MPDE in the time domain, enabling strong nonlinearities to be handled effectively. Computation and memory are independent of the separation between time scales, leading to considerable savings when the disparity is large. For large circuits, iterative linear techniques are used to circumvent costly matrix factorizations. Representative circuit examples are analyzed with the new methods.

10:10 am	**Jacob White** MIT	Some Numerical Issues in Oscillator Noise Computation

Abstract: The time-averaged spectral density of noise in oscillators can be computed by frequency-domain analysis of the time-varying linear system generated from linearizing about the oscillator's periodic steady state. When computing the component of the noise that is usually referred to as phase noise, there is a numerical difficulty that can be partially resolved by computing certain matrix eigenvectors. In this talk I will describe the difficulty and a resolution that is usually effective.

10:30 am	**Discussion session**	Kundert, Feldmann, Roychowdhury, White *et al.*

Monday afternoon topic: Radio–Frequency Circuit Analysis – Part II

1:40 pm	**Mike Green** Iniv. of California, Irvine	Improved DC and Steady-State Circuit Simulation Using Probability-one Continuation Methods

Abstract: Finding the DC operating points of a nonlinear circuit is one of the most important and difficult tasks in electrical circuit simulation and thus has been an active area of research for many years. In the vast majority of circuit simulations (*e.g.,* SPICE and its variants) the Newton-Raphson algorithm is used. However, this algorithm is not guaranteed to converge. A better approach to finding the solution of a set of nonlinear equations is the use of a continuation method. Recent work in this field by the speaker and others has shown that proper use of a continuation method makes possible global convergence; that is, an operating point is guaranteed to be found.

In this talk the following research will be discussed:

1. Development of an algorithm, based on a novel continuation method, that automatically searches for multiple DC operating points of a circuit without any intervention from the user.

2. Automatic diagnosis and rectification of convergence problems using continuation methods.

3. Generalization of algorithms used for DC operating point analysis to steady–state analysis of autonomous dynamic circuits.

This research has the potential of constructing a globally convergent algorithm that allows the user to avoid the trivial (*i.e.,* DC) state and is capable of searching for multiple modes of oscillation.

2:00 pm	**Ljiljana Trajkovic** Univ. of California, Berkeley	Homotopy Algorithms for Finding DC and Steady State Solutions of Nonlinear Circuits

Abstract: Parameter embedding (also called continuation and homotopy) methods are robust and accurate numerical techniques for solving nonlinear algebraic equations. Past implementation of homotopy algorithms in industrial circuit simulators proved that they were viable options to resolving convergence difficulties when finding circuits' DC operating points. They also show promise in finding steady-state solutions of highly nonlinear transistor circuits.

The main drawback in using homotopy methods is their computational intensity. Therefore, they are most suitable for solving difficult nonlinear problems where initial solutions are hard to estimate or multiple solutions are desired. For circuits that fall in this category, homotopy algorithms offer a very attractive alternative.

We illustrate that successful design of such algorithms and their implementation must exploit fundamental properties of transistor circuits and should rely on thorough understanding of their nonlinear behavior.

2:20 pm	**Coffee Break**	IMA Lounge, Vincent Hall 502

2:50 pm	**Rolf Neubert** Siemens AG	Computation of Periodic Solutions of Electrical Circuits in the Neighborhood of Hopf Bifurcation Points

Abstract: A new method for the computation of periodic solutions of electrical circuits in the neighborhood of Hopf bifurcation points of the underlying dynamical system is proposed. The method is based on an asymptotic energy analysis of the dynamic behavior near the Hopf bifurcation point. The concept of utilizing a corresponding energy function is explained. Finally numerical results using an implementation of the method in the industrial electrical circuit simulator TITAN are given.

3:10 pm	**Roland Freund** AT&T Bell Labs	PVL for Noise Computation and PVLπ
3:30 pm	**Discussion session**	Green, Trajkovic, Neubert, Freund *et al.*
6:30 pm	**Workshop buffet**	Signup is required

Reception at 6:00, Dinner at 6:30 at the Wales House, 1115 – 5th Street S.E.

Tuesday, November 25

Talks today are in the Seminar Room, Vincent Hall 570

8:00	**Coffee**	IMA Lounge, Vincent Hall 502

Tuesday morning topic: Electromagnetic Analysis

9:00 am	**Albert Ruehli** IBM T.J. Watson Research Center	On the Stability of Partial Element Equivalent Circuits for the Electromagnetic Modeling of VLSI Interconnects

Abstract: The Partial Element Equivalent Circuit (PEEC) model technique is an approach for the modeling of tree dimensional geometries. One of the applications is the modeling of VLSI interconnects on chips and packages. For these problems time-domain solutions are of interest. We will give examples of time-domain PEEC models. However, the stability of these models is not guaranteed since so called late-time instabilities may occur. We will give some insight into the problem at hand and we will outline a pseudospectral technique for observing the roots which are responsible for the instabilities.

This is joint work with Jane Cullum.

9:20 am	**Robert Wagner** Ansoft	Efficient Time and Frequency Characterization of Electromagnetic Devices Using Fast-Sweep Methods and Circuit Models

Abstract: An efficient procedure is described for the simultaneous characterization of both the time and frequency domain behavior of electromagnetic devices. Starting with a full-wave electromagnetic analysis based on either the finite element or boundary element method, a reduced order frequency domain model is generated for the electromagnetic system. Two different methods are used to compute the reduced order model: (1) Asymptotic Waveform Evaluation (AWE) or (2) Adaptive Lanczos-Pade Sweep (ALPS). The reduced order electromagnetic model is used to generate a stable equivalent electrical circuit that may be used in a circuit simulator to generate the transient response of the device, either alone or as part of a larger system. Examples will be presented demonstrating the implementation of this procedure in Ansoft's commercial software.

9:40 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
10:10 am	**Joel R. Phillips** Cadence	Combining model-reduction and integral-equation solvers

Abstract: Development of efficient integral-equation based electromagnetic analysis tools has been hampered by the high computational complexity of dense matrix representations and difficulty in obtaining and utilizing the frequency-domain response. In this talk we show that an algorithm based on application of a novel model-order reduction scheme directly to the sparse model generated by a fast integral transform has advantages for frequency- and time-domain simulation.

10:30 am	**Discussion session**	Ruehli, Wagner, Phillips *et al.*

Tuesday afternoon topic: Problems in Digital Circuit Analysis

1:30 pm	**Tuyen V. Nguyen** IBM Austin Research Laboratory	Circuit Analysis Problems in High Frequency Digital Designs

Abstract: In this talk, we will discuss some problems of circuit analysis in the context of high frequency digital designs, especially microprocessor design. In particular, we will discuss the following algorithmic problems: linear model reduction for timing and noise analyis, model reduction for distributed circuits, simulation of nonlinear circuits with regular structures like memory or array circuits, computing bounds on the responses of general linear systems for noise avoidance.

This is joint work with Eli Chiprout and Anirudh Devgan.

1:50 pm	**Martin Kahlert** Siemens AG	A Modified Jakobi-Davidson Algorithm for Parasitic Reduction of Large RC-Interconnect Problems

Abstract: Inclusion of parasitic effects due to interconnects becomes essential when simulating modern high-speed high-density circuits at the chip or board level. Usually, the accurate extraction of interconnects out of the layout yields linear time-invariant subnets consisting of resistors, capacitors, and inductors. Unfortunately, these nets may become so large that their inclusion into standard circuit simulation tasks is inefficient or even prohibitive.

By the determination of a few leading eigenvalues of the matrices describing linear subnets it is possible to reduce the simulation costs. We modified the so called Jakobi Davidson algorithm for generalized eigenproblems in order to achieve a better efficiency for the symmetric positive definite problems arising in this framework. The presentation describes this algorithm together with the reduction ansatz.

2:10 pm	**Coffee Break**	IMA Lounge, Vincent Hall 502
2:40 pm	**Discussion session**	Nguyen, Kahlert, Elfadel (tent.) *et al.*

Wednesday, November 26

Thursday, November 27

Thanksgiving day, a University of Minnesota holiday. IMA offices will be closed.

Friday, November 28

A University of Minnesota holiday. IMA offices will be closed.

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December 1–31, 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.

News and Notes

Four new members elected to IMA Board of Governors

At its recent meeting, the IMA Board of Governors elected four distinguished mathematical scientists as new members, who have agreed to serve on the board for three years beginning January 1, 1998. They are **Lynne Billard** of the University of Georgia, **Jennifer Chayes** of Microsoft, **James Keener** of the University of Utah, and **Paul Rabinowitz** of the University of Wisconsin.

Retiring members are Mary Ellen Bock (Purdue University), David Levermore (University of Arizona), James McKenna (Bellcore) and Alan Perelson (Los Alamos National Laboratory).

Continuing Board members are David H. Bailey (NASA Ames Research Center), Rob Calderbank (AT&T Labs), Rosemary Chang (Silicon Graphics, Incorporated), John Polking (Rice University), William Pulleyblank (chair)(IBM Watson Research Center), Ridgway Scott (University of Houston), Al Taylor (University of Michigan) and James Turner (Arizona State University).

Board of Governors Selects Topic for 2000 – 2001

The Board of Governors approved a proposal to devote the year September 2000 – June 2001 to the topic, **Mathematics in Multi-Media**. The organizing committee is Michael Barnsley (Iterated, Inc.), Rosemary Chang (Silicon Graphics, Inc.), Tony Derose (Pixar, Inc.), Stu Geman (Brown University), Peter Olver (University of Minnesota), Roni Rosenfeld (Carnegie-Mellon University), Larry Schumaker (Vanderbilt University) and Ahmed Tewfik (University of Minnesota).

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

The proposal outlines workshops on Image Processing; Image Analysis; Mathematical Foundations of Speech Processing; Mathematical Foundations of Language Modeling; Compression, Communication and Retrieval; Computer Security, Copyright and Privacy Protection; Geometric Design; and Computer Graphics. All workshops are tentative. A primary goal of these workshops is to educate and interest mathematicians in the mathematical and scientific problems that arise in these dynamic and challenging areas of science and technology.

Weekly IMA seminar list available by list server

The IMA offers an e-mail list service. This service is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`.

The current week's schedule is also available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is available by `ftp` or through the world-wide web.

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`.

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

Schedule for December 1–31, 1997

Monday, December 1

Tuesday, December 2

IMA Postdoc Seminar:

2:30 pm **Shinya Watanabe**, IMA/Neils Bohr Institute — Polygons and jumps in "kitchen sink" flows

Abstract: When a vertical jet comes out of a water nozzle and hits a flat surface, we notice a ring discontinuity (the circular hydraulic jump) at some radius from the jet. By using a more viscous liquid, it was recently found that the familiar jump can change its shape spontaneously to polygons with various numbers of corners, breaking the axial symmetry. I plan to describe the surprising observation, and present an elementary phenomenological model of the beautiful states. A more refined theory requires a good description of the circular basic flow, which itself has been a long outstanding problem due to strong deformation of the free surface. Some progress in this direction is also discussed.

This is research in collaboration with: T.Bohr, V.Putkaradze, J.L.Hansen (theory); C.Ellegaard, A.E.Hansen, A.Haaning, K.Hansen, A.Marcussen (experiment).

Organizer: Kurt Lust

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

Wednesday, December 3

Math Department Seminar in Partial Differential Equations

3:35 pm	**John Heywood** University of British Columbia	A Numerically Based Existence Theorem for the Navier-Stokes Equations

Abstract: We have recently experimented with a new spectral code for the spatially periodic nonstationary Navier-Stokes equations, finding a plethora of apparently steady, periodic and chaotic solutions which seem interesting from the point of view of dynamical systems theory. This has stimulated our interest in the general problem of proving the existence of strict solutions of differential equations corresponding to the computational results of numerical experiments. In this paper we take computational results that seemingly approximate what appears to be an unstable steady solution of the Navier-Stokes equations, and provide a rigorous *a posteriori* analysis, proving that there does indeed exist a corresponding nearby strict solution, and that it is steady. Our method is based on showing that the computed solution satisfies criteria which imply the convergence of a fixed point iteration, in appropriate function spaces for an existence theorem, using the computed solution as the starting value.

The seminar will meet in room Vincent Hall 211.

Thursday, December 4

IMA/Math Department Seminar on Dynamics and Mechanics:

10:10 am	**Warren Weckesser** IMA/Rensselaer Poly. Inst.	Stability of the relative equilibria in a class of rotationally symmetric mechanical systems

The seminar will meet in room Vincent Hall 570

Friday, December 5

Open-ended IMA Informal Discussion (led by Bernold Fiedler):
Continuous spectra in travelling waves, *etc.* Meets in room Murphy Hall 230.

9:30 am	**Björn Sandstede** Ohio State University	Some travelling wave bifurcations from the essential spectrum

Monday, December 8

Tuesday, December 9

Open-ended IMA Informal Discussion (led by Bernold Fiedler):
Continuous spectra in travelling waves, *etc.* Meets in room Vincent Hall 570.

9:30 am	**George Sell** University of Minnesota	On the bifurcation of higher dimensional tori

IMA Postdoc Seminar:

2:30 pm	**Bernold Fiedler** Free University of Berlin	Continuation and homotopy invariants

Organizer: Kurt Lust

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

Wednesday, December 10

3:00 pm **IMA Holiday Party**
IMA Lounge, Vincent Hall 502

We will gather to celebrate the holidays. IMA visitors and staff are invited to bring their families and a few goodies to share!

Thursday, December 11

Friday, December 12

Monday, December 15

Tuesday, December 16

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, Schlumberger 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 will meet this time in Murphy Hall 230.

IMA Postdoc Seminar:

2:30 pm **Miaohua Jiang** SRB-measures for Lattice Dynamical Systems
IMA/Georgia Inst. of Technology

Abstract: The Sinai-Ruelle-Bowen measures are constructed for a class of infinite-dimensional lattice dynamical systems with hyperbolicity. The existence of such measures with strong ergodic properties is considered evidence of spatio-temporal chaos in the dynamical systems.

Organizer: Kurt Lust

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

Wednesday, December 17

Thursday, December 18

Friday, December 19

Monday, December 22

Tuesday, December 23

Wednesday, December 24

A University of Minnesota holiday. IMA offices will be closed.

Thursday, December 25

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

Friday, December 26

A University of Minnesota holiday. IMA offices will be closed.

Monday, December 29

Tuesday, December 30

Wednesday, December 31

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 258

January 1–31, 1998

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.

News and Notes

IMA Workshop:

Computational Neuroscience

January 14–23, 1998
Organizers: John Rinzel (Courant Institute)(chair), Nancy Kopell (Boston), Larry Abbott (Brandeis), Bard Ermentrout (Pittsburgh)

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.

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

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

Schedule for January 1–31, 1998

Thursday, January 1

New Year's Day, a University of Minnesota holiday. IMA offices will be closed.

Friday, January 2

Monday, January 5

Tuesday, January 6

Wednesday, January 7

IMA Postdoc Seminar:

9:30 am	**John Guckenheimer** Cornell University	An Introduction to Neural Models

This informal two-to-three-hour discussion session will meet in room Vincent Hall 570.

Organizer: Kathleen Rogers

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.

Thursday, January 8

Mathematics Department Colloquium in room Vincent Hall 16:

3:30 pm	**John Guckenheimer** Cornell University	The Death of Periodicity: Multiple Time Scale Models of Neurons

Tea will be served at 3:10 pm in room 120 Vincent Hall

Friday, January 9

SEMINAR ON INDUSTRIAL PROBLEMS

10:10 am	**Martin G. Lüling** Schlumberger-Doll Research	Geosteering Horizontal Wells through Electrically Anisotropic Oil Zones using Predictive Log-Modeling Computations

Abstract: Traditionally, oil wells were drilled vertically. Only since the late 1980's, drilling and oil production changed toward directional, frequently horizontal holes. This drilling technology permits profitable exploitation even of thin oil-bearing zones: instead of traversing the layer vertically for a few feet, the borehole trajectory leads along the oil-zone for many hundred feet, even a few miles under favorable conditions. The drill bit is steeerd along the true geologic structure by real-time measurements, made while drilling, of the formation electric resistivity.

The electric-resistivity measurements are used to discriminate resistive oil from more conductive water-bearing zones or shales. For Logging While Drilling, the measurement sonde is integrated into the drill collar close to the bit. The

measurement sonde transmits a 2-MHz radio wave into the rock and measures the phase shift (wave length) and attenuation (skin effect) of the wave. From these two measurements, two resistivities are derived. These resistivity data are transmitted to the surface where they help the driller to control the direction of the borehole trajectory.

The resistivity measurements can be reproduced by log-simulation modeling. The resistivity data from a nearby reference well, usually a vertical well, serve to generate a formation model, namely a layer-cake resistivity profile. Seismic surveys extend the profile from the reference well across the entire reservoir. Into this reservoir model, a directional drilling trajectory is planned. Part of the planning will be a predictive computation of the resistivity measurement along this trajectory through the layer-cake formation. The driller has these modeled data available and compares them to the real-time data acquired while drilling. Several examples from actual field data illustrate the success of the "GeoSteering" procedure.

Many oil zones consist of fine laminates, such as alternating shales and sands which cannot be individually resolved. They induce an effective anisotropy in the electric resistivity with a low resistivity parallel to the laminates and a much higher resistivity perpendicular to the laminates. In vertical wells with horizontally laminated formations, the resistivity measurements only measure the parallel, or "horizontal resistivity". However, in directional wells, the resistivity measurements become sensitive to the perpendicular, or "vertical resistivity". The 2-MHz resistivity measurements can even discriminate the two resistivity components and thus quantify the resistivity-anisotropy tensor. The log-simulation modeling successfully reproduces observed anisotropy effects.

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

Monday, January 12

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 Schlumberger) 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

Tuesday, January 13

IMA Workshop:

Computational Neuroscience

January 14–23, 1998
Organizers: John Rinzel (Courant Institute)(chair), Nancy Kopell (Boston), Larry Abbott (Brandeis), Bard Ermentrout (Pitt)

Of primary interest to neuroscientists are the roles of the highly nonlinear intrinsic properties of individual neurons and coupling properties between cells that determine the dynamical activity of neuronal networks. Unique mathematical features of cell-based neuronal models that underlie complex spatio-temporal patterns are the multiple and vast time scales of ionic currents (from milliseconds to seconds) and the circuit properties which include local as well as long-range coupling,

possibly with random connectivity, and with kinetic aspects (time constants for decay of synaptic variables). This workshop will consist of three intense two to four-day Focus Sessions, each bringing together experimentalists and theoreticians for concentrating on specific active areas of research in computational neuroscience. Overview talks for each Focus Session will provide essential biological and modeling background specific to that Focus Session. These overviews replace the general tutorials that had been included in earlier plans for the workshop's first two days.

Topics will include stereotypical dynamical behavior such as network rhythms seen during sleep and epilepsy, as well as more complex phenomena associated with goal-directed behavior or perception. Models for such higher-level cognitive function may assume that cell-based properties have been averaged into more macroscopic descriptions. Experimental model systems include brain slices of thalamus, hippocampus, and cortex and *in vivo* recordings in sensory and motor areas during visual and movement tasks.

Focus Session #1: Early Vision: receptive fields, feature detecting, feedforward and intracortical tuning mechanisms. (Wednesday, January 14 to Saturday noon, January 17.)

Focus Session #2: Hippocampus and Navigation. (Sunday evening, January 18 and Monday, January 19.)

Focus Session #3: Cortical Dynamics. (Sunday afternoon, January 18; Wednesday, January 21 through Friday noon, January 23.)

Wednesday, January 14

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

8:00 am	**Registration and Coffee**	Reception Room EE/CS 3-176
8:45 am	**Welcome and Orientation**	W. Miller, R. Gulliver, J. Rinzel
9:00 am	**Robert Shapley** Center for Neural Science, NYU	The Neural Basis of Visual Perception
10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**Judith Hirsch** Rockefeller University	Receptive Field Structure at Early Stages of Visual Processing
1:30 pm	**Ralph Freeman** Univ. of California, Berkeley	Receptive field analysis of space and time in the visual cortex

Abstract: Neurophysiological studies will be discussed in which single neurons or neuronal pairs are studied by using microelectrodes in the visual cortex. Stimulation and analysis techniques are used by which it is possible to obtain complete receptive field maps in spatial and temporal dimensions. One of the applications of this procedure is to determine how pairs of neurons, recorded together, compare in terms of a wide range of receptive field properties. Results will be discussed along with theoretical implications.

2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**David Somers** MIT	Choosing the cellular components of large-scale neural circuits: In praise of the integrate-and-fire neuron

Abstract: Construction of large-scale neural circuits involves a trade-off between the complexity of the component neurons and the number of neurons that can be represented and simulated given finite computational resources. When one is primarily investigating network- level effects, it is advantageous to choose a simple representation for single neurons. However, single neurons should not be too simple, as interesting effects may occur in the interplay between cellular and network levels. In my talk, I will discuss how a simple cellular model, the integrate-and-fire neuron, can be modified to capture many important cellular properties, while still maintaining low computational expense.

3:30 pm	**Jack Cowan** University of Chicago	Modelling Large–Scale Cortical Activity

Abstract: It is generally agreed that population coding plays an important role in cortical information processing. It follows that the dynamics of large groups of interacting neurons is worth studying. Here we formulate integro-differential equations to describe such dynamics (the Wilson-Cowan equations) and discuss some of their properties and limitations. In particular we show how various dynamical attractors can arise and how they may underlie spatio-temporal population coding in the cortex.

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

A variety of appetizers and beverages will be served.

Thursday, January 15

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**David Ferster** Northwestern University	Assembly of receptive fields in cat visual cortex

Abstract: The neurons of the mammalian visual cortex perform a remarkable transformation on the visual input they receive from the lateral geniculate nucleus (LGN). The neurons of the LGN have circularly symmetric receptive fields and are unselective for the orientation and direction of motion of visual stimuli. Neurons in the cortex, on the other hand, are exquisitely sensitive to these stimulus properties and will only fire in response to a narrow range of stimuli. A long-standing debate centers on the synaptic circuitry that brings about this dramatic change in the representation of the visual image that takes place at the geniculocortical synapse. Hubel and Wiesel originally proposed in their compellingly simple model that the arrangement of the geniculate input determines orientation selectivity. Yet there are several properties of cortical neurons that Hubel and Weisel's model cannot explain, and that have prompted the development of more complex models that require nonlinear interactions among cortical cells. We have examined the orientation selectivity of the aggregate synaptic input to cortical cells from the LGN by selectively inactivating the cortical circuit, either by cooling or by electrical stimulation of inhibitory circuits. These experiments indicate that the LGN provides a well-tuned excitatory input to cortical simple cells, an input that accounts for approximately 30% of the total synaptic drive. The remainder presumably arises from other cortical neurons and might help to establish the contrast invariance of stimulus selectivity. How this is accomplished remains to be determined.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**Kenneth D. Miller** Univ. of Calif., San Francisco	Contrast-invariant orientation tuning in cat V1: Correlation-Based Feedforward and Intracortical Circuitry

Abstract: The origin of orientation selectivity in visual cortical responses is a central problem for understanding cerebral cortical circuitry. In cats, many experiments suggest that orientation selectivity arises from the arrangement of LGN inputs to layer 4 cortical simple cells. We have shown how such an arrangement of "feedforward" inputs can self-organize through correlation-based mechanisms of synaptic plasticity. However, such a "feedforward" explanation appears insufficient to account for the contrast-invariance of cortical orientation tuning.

We propose a new model consistent with a wide range of experimental data. We demonstrate that the LGN input to cat cortical simple cells has two components: a phase-specific component, which is tuned for orientation; and a phase-nonspecific component, which is untuned. Both components grow with contrast. Contrast-dependent inhibition is required to suppress the untuned input component, and to prevent the broadening of the tuning of spiking responses with increasing contrast. A simple circuit using correlation-based intracortical connectivity (cross-phase inhibition and same-phase excitation, local in orientation), accomplishes this to achieve well-tuned, contrast-invariant orientation tuning. Unlike previous models, this circuit agrees with experimental evidence showing spatial opponency between, and similar orientation tuning of, the excitatory and inhibitory inputs received by a cell. Orientation tuning is primarily input driven, naturally accounting for the observed equality of input tuning and full circuit tuning as well as for the dependence of orientation tuning width on stimulus spatial frequency.

The model predicts that inhibitory neurons in cat layer 4 should respond in a contrast-dependent manner to stimuli of all orientations, although the width of their orientation tuning is similar to that of excitatory neurons. The model demonstrates that fundamental response properties of cortical layer 4 can be explained by circuitry that would be expected to develop under correlation-based rules of synaptic plasticity, and shows how such circuitry allows the cortex to distinguish stimulus intensity from stimulus form.

1:30 pm	**Haim Sompolinsky** Hebrew University	Orientation Tuning in Visual Cortex: From Simple Models to Real Brains
2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**Barbara Chapman** Univ. of Calif., Davis	How the Visual Cortex Got Its Stripes

Abstract: We have studied the development of orientation preference in ferret primary visual cortex at the single cell-level using conventional electrophysiological recording methods, and in activity maps across cortex using chronic optical imaging of intrinsic signals. We are currently testing how altered patterns of activity early in life may affect the emergence of orientation selectivity.

Our results, along with many studies in other laboratories, suggest that the organization of orientation preference may provide a framework which guides the developing organization of other cortical receptive field properties such as ocular dominance. Ongoing experiments designed to test this hypothesis will be discussed.

Friday, January 16

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**S. Murray Sherman** SUNY, Stony Brook	Control of Gating through the LGN

Abstract: The LGN is not a simple, machine-like relay of retinal information to cortex: it instead performs a dynamic, variable relay that presumably reflects the varying behavioral needs of the visual system. Two aspects of this will be reviewed. First is the appreciation that LGN (and other thalamic) relay cells have a variety of voltage-dependent membrane conductances that dramatically alter the way they respond to retinal inputs. Perhaps the most important next to the those underlying the action potential is a voltage-dependent Ca2+ conductance. This can be activated by depolarization (e.g., from a retinal EPSP) only from a hyperpolarized level (e.g., more negative than about -65mV), because the Ca2+ conductance becomes inactive at more depolarized levels. The activation state of this conductance determines whether the relay cell responds in tonic or burst firing mode to its retinal inputs, and which response mode is operating is of critical importance to the nature of information relayed to cortex. Second is the fact that, while the information relayed through LGN to cortex is retinal in origin, retinal synapses represent only about 7of inputs to relay cells. The vast majority of inputs derive from intrinsic local GABAergic cells, from visual cortex, and from the brainstem, and they each contribute about 30of all synapses on relay cells. These nonretinal inputs are modulatory in nature and, among other things, serve to control membrane potential, thereby controlling voltage dependent conductances like the Ca2+ conductance described above. An attempt will be made to bring these observations together in a testable hypothesis that addresses how and under what conditions nonretinal inputs influence the relay through the LGN.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**David W. McLaughlin** Courant Institute, NYU	Modelling the Layered Structure of V1

Abstract: The lecturer will describe our prelimary models of V1. These models emphasize its layered structure, and the effect of its connectivity on temporal dynamics.

This project involves collaborations with Robert Shapley, Michael Shelley, Mary Pugh, and Jim Wiellard.

1:30 pm	**Nicholas Swindale** Univ. British Columbia	Cortical Maps: Gradient Relationships and Learning Rules

Abstract: Mammalian visual cortices contain multiple superimposed maps for different stimulus attributes, such as receptive field position, edge orientation, spatial frequency, direction of motion and eye preference. I will review some of the experimental evidence for the existence of these maps as well as the evidence for gradient relationships and other types of structural link between them. I will compare these data with modelling results obtained using Kohonen's Self-Organising Feature Map algorithm which implements a competitive learning rule. I will discuss the extent to which the maps produced by this model, and a variant of it, are able to reproduce the experimentally observed properties of individual maps, as well as the gradient relationships between different maps.

2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**David Somers** MIT	A local circuit view of integrating long-range cortical inputs
3:30 pm	**Jack Cowan** University of Chicago	A Simple Model for Cortical Orientation Selectivity and its Consequences

Abstract: A simple mathematical model of the orientation tuning of visual cortical neurons is introduced and analysed. It is shown that the basic cortical architecture of recurrent local excitation and lateral inhibition, together with some feedforward inhibition can account quantitatively for such tuning properties, and their modification by inhibitory blocking agents. The model can also account quantitatively for such local effects as cross-orientation suppression. It is also shown that non-local coupling between iso-orientation patches, when added to the model, can satisfactorily reproduce such effects as non-local iso-orientation suppression, and non-local cross-orientation enhancement. These results will be discussed in relation to cortical development and to a number of perceptual phenomena such as the geometric visual patterns seen following the ingesting of hallucinogens, the "pop-out" effect, and both the direct and indirect tilt illusions.

Saturday, January 17

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

9:00 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Yang Dan** Univ. of California, Berkeley	Encoding and Decoding of visual information in the thalamus
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Tony Bell** Interval, Inc.	To be announced

Sunday, January 18

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

1:00 pm	**Coffee**	Reception Room EE/CS 3-176
1:30 pm	**Roger D. Traub** Univ. of Birmingham Medical Sch.	Cellular mechanisms of the 40 Hz cortical oscillation: studies in brain slices and with simulations

Abstract: 40 Hz oscillations can be induced in brain slices by activation of metabotropic glutamate receptors, either on inhibitory neurons, or inhibitory neurons in combination with principal neurons. Oscillations can occur synchronously over distances of several mm, as they do in vivo, despite long expected axon conduction times. Cellular mechanisms include mutual inhibition between interneurons, and the ability of interneuron doublets to signal phase relations between oscillating pyramidal cells (as B. Ermentrout and N Kopell may elaborate further). It has recently been shown in vitro that 40 Hz oscillations induce synaptic plasticity, that in turn alters the properties of the oscillation. Our understanding of these oscillations allows an understanding also of the cellular mechanisms (at least in cortical structures) of 3 types of anesthetic agents: benzodiazepines (e.g. "Valium"), barbiturates, and opiates, all of which either slow the oscillation, abolish it, or prevent it from synchronizing over distance. There may really be a connection between these oscillations and consciousness.

2:30 pm	**Nancy Kopell** Boston University	Synchronization and Modulation in Networks of Neurons

Abstract: This talk is a survery of some mechanisms by which a network of neurons can synchronize, and ways in which the synchronization process can be modulated. The examples are taken from a variety of neural preparations. The talk includes a discussion of the role of in the synchronization process of the wave form of the voltage, the time scales in the synaptic processes, and timing of spikes within a burst. It will serve as an introduction to more detailed talks to be given in the later sessions.

3:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
4:00 pm	**James M. Bower** Calif. Inst. of Technology	Cortical oscillations and the single neuron: Timing is everything

Abstract: Oscillations in the 7-10 Hz and 40 Hz frequencies are characteristic of cerebral cortical circuits. Our laboratory began its study of the origins and possible computational significance of these patterns of activity a number of years ago by constructing biologically realistic network models of cerebellar cortical circuits (Wilson and Bower, 1991; 1992). These models suggested that cerebral cortical circuits naturally oscillate at these frequencies through a mechanism dependent on the interaction of time constants associated with both excitatory and inhibitory synaptic circuits. The dynamical behavior of the models was interpreted to suggest that cortical oscillations were responsible for coordinating the timing of computational cycles within these networks. The models also lead to the prediction that network level oscillations played an important role in coordinating the flow of synaptic information onto the dendrites of cortical pyramidal cells. In this workshop I will present the results of more recent single cell modeling efforts which support this view. I will conclude by presenting a general computational framework for understanding the role of oscillatory behavior in cerebral cortical function.

7:00 pm	**L. F. Abbott** Brandeis University	Navigation Maps Through Population Coding of Location in the Rat Hippocampus

Abstract: Neurons typically encode information collectively in what is known as a population code.

Place cells in the hippocampus of the rat provide a classic example that illustrates the computation implications of population coding. Place cells fire action potentials at a rate that depends on the location of the rat in its environment. Using experimental facts about place cells and the effects of activity on the synapses connecting them, Ken Blum and I modeled how a spatial map of the environment can be created in the rat hippocampus. Sequential place cell firing during exploration modifies synapses between place cells resulting in a shift of the location encoded by their ensemble activity away from the actual location of the animal. These shifts provide a navigational map that can guide locomotion toward a goal. The model demonstrates how behaviorally generated modifications of synaptic strength can be read out to affect subsequent behavior. The shifts in place cell location predicted by the model have recently been observed experimentally.

8:00 pm	**Bill Skaggs** University of Pittsburgh	Theta phase precession of hippocampal place cell activity: data, models, and functional significance

Abstract: O'Keefe and Recce, in 1993, discovered that as a rat moves through the spatial firing field of a hippocampal pyramidal cell, spikes from the cell shift gradually to earlier and earlier phases of the theta cycle. Further research has shown that this "phase precession" reflects a population-wide phenomenon, in which the hippocampus plays in compressed

form brief portions of the trajectory on which the animal is traveling. Several computational models of this effect have been proposed over the past few years: they can be divided roughly into "individual neuron" models, based on mechanisms operating within a single cell, and "network" models, based on interactions between groups of cells. The functional significance of the effect remains speculative. An interesting possibility is that, by compressing the temporal structure of the spike sequence, phase precession increases the influence of temporal structure on the synaptic enhancement produced by long term potentiation in the hippocampus.

Monday, January 19

Martin Luther King Day, a University of Minnesota holiday. IMA offices will be closed, although the workshop will be in session.

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Misha Tsodyks** Weizmann Institute	Network model of theta rhythm and temporal coding in the Hippocampus

Abstract: The firing patterns of pyramidal cells in the CA1 and CA3 regions of the rat hippocampus are related to both the location of the animal in the environment and the theta rhythm, which dominates the hippocampal EEG during exploratory movements. O'Keefe and Recce (1993) have observed that the spatially selective firing of pyramidal cells tends to advance to earlier phases of the theta rhythm as a rat passes through the place field of a cell. The relative timing of a cell's action potential could therefore carry information about the rat's location which would constitute an interesting example of a temporal code. I will present a network model which generates this effect as resulting from the pattern of internal connectivity between pyramidal neurons in the Hippocampus.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**Peter Dayan** MIT	Temporal Difference Models of Navigation

Abstract: We build models of two navigation tasks in the water maze: the standard reference memory task, in which the goal (a hidden platform) is always at a fixed location, and the delayed match to place task, in which the platform is moved on each day. These tasks differ experimentally in the demands they make on hippocampal plasticity.

The models are based on a reinforcement learning method called temporal difference learning, which is a general way of learning near optimal behavior in complicated environments. We show that a place cell representation of position is ideal for learning to solve the reference memory task, and show how to augment it to solve the delayed match to place task.

This is joint work with David Foster and Richard Morris.

2:00 pm	**John Lisman** Brandeis University	Buffers, autoassociators, and heteroassociators

Abstract: Like several other groups, we have proposed that the CA3 region of the hippocampus uses the NMDA channels in recurrent collaterals to store sequences of events (places) and thereby serve as a heteroassociative network. We have specifically argued that the readout of these sequences at a rate of one memory per gamma cycle can account quantitatively for the "phase-advance" of hippocampal place cells. One problem with this proposal is that the phase-advance is also observed in dentate granule cells. We now offer a possible answer to this problem. Theoretical work has suggested that the best method for predicting sequences is to have each step-wise prediction "cleaned up" by an autoassociative network before it serves as a cue in the next step of sequence prediction. We propose that the dentate-hilar region is the autoassociative network that accomplishes this task. Two anatomical findings are relevant. First, it is known that CA3 axons have a branch that turns backward and innervates cells in the dentate/hilar region. Second, although dentate granule cells do not have recurrent axons as required in the simplest autoassociative networks, they do innervate hilar mossy cells. These in turn, make recurrent connections onto granulate cells. This disynaptic circuit could allow the dentate/hilar

region to perform autoassociative function. The interaction of an autoassociative network in the dentate/hilar region and a heteroassociatve CA3 network could produce accurate sequence recall.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**Kenneth Blum** MIT	Knockouts, Networks and Navigation
7:00–9:00	**Poster Session** Hallway of Vincent Hall, 5th Floor	

G. Mato (Centro Atómico Bariloche, Argentina): Self-similarity properties of natural images.
F. Skinner (Toronto Hospital): Bursting: A role for gap-junctional coupling.
B. Lytton (Univ. of Wisconsin): A Dentate Gryras Model.
D. Golumb (Ben-Gurion Univ. of the Negev): Transient synchrony of propagating discharges in neocortex.
E. Izhikevich (Arizona State Univ.): Class 1 Neural Excitability, Weakly Connected Networks, and Mathematical Foundation of Pulse-Coupled Networks.
E. Izhikevich (Arizona State Univ.): Weakly Connected Elliptic Bursters, Strongly Connected Relaxation Oscillators, and Spike/Burst Synchronization.
J. L. Van Hemmen (Techn. Univ. München): Discerning oscillations: Neuronal coincidence detection with periodic spike input.
J. L. Van Hemmen (Techn. Univ. München): Short-term plasticity, coherent oscillations and locking.
R. Butera (NIH): Respiratory Rhythm Generation in the pre-Botinger complex of mammals.
Deliang Wang (Ohio State Univ.): Object selection based on oscillatory correlation.
T. Troyer (U. C. San Francisco): An associational hypothesis for sensorimotor learning of bird song.
J.D. Cowan (Univ. of Chicago): Monte Carlo studies of V1.
J.D. Cowan (Univ. of Chicago): From natural images to V1 structure.

Tuesday, January 20

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

9:00 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Rob Butera** NIH	Respiratory rhythm generation in the pre-Botzinger complex in mammals
10:15 am	**Dave Pinto** University of Pittsburgh	Response tuning in the somato-sensory cortex
11:00 am	**Eugene Izhikevich** Arizona State University	Weakly connected neural neworks: A review

Non-workshop talk on the Mechanics of Materials in 227 Akerman Hall:

1:00 pm	**Giovanni Zanzotto** Universita di Padova	Problems in a Unified Kinematics of Simple and Multilattices
1:30-3:00	**Wave Discussion**	
3:15-5:00	**Synchrony Discussion**	

7:00–9:00 **Poster Session**
Hallway of Vincent Hall, 5th Floor

For presenters and titles, see 7:00 pm Monday, January 19.

Wednesday, January 21

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

8:30 am **Coffee** Reception Room EE/CS 3-176

9:00 am **Arthur Sherman**
NIH
Mechanisms of Synaptic Enhancement and Depression

Abstract: Mechanisms at the terminal level for synaptic enhancement on several time-scales (facilitation, augmentation, post-tetanic potentiation) and depression will be discussed. Issues to be considered will include the roles of residual free Ca2+ and residual Ca2+ bound to "memory proteins", and the roles of domain and macroscopic Ca2+. We will also explore to what extent synaptic depression can be accounted for in terms of vesicle depletion and resupply.

10:00 am **Coffee Break** Reception Room EE/CS 3-176

10:30 am **John Rinzel**
Courant Inst., New York University
Network Dynamics Mediated by Synaptic Depression

Abstract: Many synapses show depression in response to repeated activation. Multiple time scales (100s of msec to many sec) are reported for the depression and its recovery. We will review some models for depression and proposed effects in neuronal interaction dynamics (gain control, phasic responsiveness, direction selectivity, etc). An application to rhythmogenesis will be highlighted.

Spinal cord neuron populations execute synchronized rhythmic activity in isolated embryonic cords and in disinhibited cultures. The multimodal collective oscillations are infrequent episodic bursts of fast cycles (0.5 to 5 Hz). Synaptic coupling is primarily excitatory, and synaptic depression has been implicated as a possible rhythmogenic mechanism. We have developed a two-variable firing rate model in which cells spike tonically when stimulated. Synaptic depression accounts for the fast events - alternately allowing cells to mutually activate each other and then suppressing their interaction. By adding a slow modulatory variable, episodic behavior in the model can occur via several mechanisms.

2:00 pm **Charles Wilson**
Univ. of Tennessee, Memphis
The generation of corticostriatal firing patterns: roles for synaptic and intrinsic mechanisms

Abstract: The neostriatum is a major target of cortical efferent projections, and an important site for convergence of inputs from diverse cortical areas. The pattern of activity in the population of functionally related cortical neurons converging onto individual striatal neurons can be estimated from their membrane potential fluctuations. Likewise, the membrane potential fluctuations of corticostriatal neurons largely reflects the activity of excitatory and inhibitory intracortical circuits Comparison of the membrane potential fluctuations of striatal and cortical projection neurons revealed that these signals were statistically similar. In both cases, excitatory and inhibitory input occurred together in episodes lasting 100 ms or longer. The durations of the episodes and the periods of relative quiet between them were statistically independent, and there were no serial correlations between the durations of successive episodes of synaptic activity. The mean membrane potential during such episodes was subthreshold in both neuron types, with action potentials arising from noisy fluctuations superimposed on the episodes of firing. The episodic pattern of synaptic input led to temporal clustering of firing in both cell types, but firing within the episode was irregular. In both cell types, the maintenance of a subthreshold mean membrane potential during episodes of strong synaptic activation prevented the development of rhythmic firing. Membrane potential was maintained below spike threshold both by synaptic inhibition that is recruited during episodes of excitation, and by voltage dependent potassium channels that are activated by synaptic excitation.

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

3:30 pm	**Xiao-Jing Wang** Brandeis University	Neuronal Mechanisms of Visuospatial Working Memory in Prefrontal Cortex

Abstract: Working memory is a memory function by which humans and animals hold "on-line" and manipulate information for a short time span of a few seconds. In this talk, I shall first review the experimental data about the neuronal correlates of working memory, namely persistent activity and dynamical tuning in the prefrontal cortex (PFC). Then a network model is presented for the PFC neural network behaviors during a visuospatial delayed-response task. It is assumed that the spatial cue stimulus is encoded in working memory storage by a continuum of network activity profiles, which coexist with a spontaneous rest state. Such a bistability can be realized in the model by a neocortical network architecture with recurrent excitation and inhibition. We contrast the bistable PFC-like network to the V1-like network for orientation tuning. Moreover, because of the spatial translational invariance of the network activity profiles, the robustness of memory storage against noise and distractors raises serious problems. Possible cellular/synaptic mechanisms for reliable visuospatial working memory will be discussed.

7:00–9:00	**Poster Session** Hallway of Vincent Hall, 5th Floor	

For presenters and titles, see 7:00 pm Monday, January 19.

Thursday, January 22

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Bard Ermentrout** University of Pittsburgh	Synaptically generated waves

Abstract: The improvements in imaging technology and multi-electrode recordings now make it possible to study spatio-temporal activity in biological neural networks. I will consider a number of different models for such activity with an emphasis on slice preparations. I will show different modes of propagation of activity depending on different mechanisms and how small changes in parameters of the coupling can change the velocity of activity waves by several orders of magnitude. I derive scaling laws for the velocity of waves as a function of the rise time of synaptic potentials. I will also look at some reduced models that arise through averaging methods and how these can be used to understand partially blocked inhibition in slices.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**David Golomb** Ben-Gurion University of the Negev	Synchrony of large sparse neuronal networks

Abstract: We study synchronization in large populations of N identical neurons with random sparse connectivity. Synchrony occurs only when the average number of synapses M a cell receives is larger than a critical value M_c. Below M_c, the system is in an asynchronized state.

In the limit of weak coupling, we use the averaging method to reduce the network model into a model of phases which are coupled via a function Γ of their phase differences. Using mean field theory, we show that the stability of the asynchronized state can be determined exactly in the asymptotic limit $1 \ll M_c \ll N$. In particular we establish that in this limit $M_c/N = O(1/N)$. When the condition $M_c \gg 1$ is not satisfied, our theory is approximate but provides us with an estimate for M_c as a function of the single neuron and synaptic properties.

We apply our analytical theory to study integrate-and-fire neurons with inhibitory coupling. We find that M_c varies non-monotonically with the level of the external input on the neuron, that it is a strongly decreasing function of the the synaptic rise time and of the duration of the refractory period of the neuron. For typical inhibitory synapses and refractory period of 2-5 msec we find that M_c is of the order of 100 synaptic connections per neuron.

Numerical simulations are performed to show that our theory provides very good results also for finite M_c (M_c of the order of ua few tens) and mildly strong coupling. Finally we study numerically the strong coupling regime: in particular our simulations indicate that M_c is an increasing function of the coupling strength.

We conclude by discussing the relevance of our theory to understand the mechanisms of synchrony in neocortex and hippocampus and by proposing experiments to test it.

2:00 pm	**Alain Destexhe** Laval University	How the cortex controls thalamically-generated oscillations

Abstract: Since the forties, it has become clear that the thalamus is essential in the genesis of sleep spindle oscillations in the 10-14 Hz frequency range. In 1962, Andersen and Eccles identified for the first time one essential property of thalamic neurons: the ability to produce a burst of action potentials in response to inhibitory inputs. It was proposed that the interaction between thalamic cells and inhibitory neurons makes an oscillator, a principle still valid today.

With the more recent and more precise data from intracellular recordings *in vivo* and *in vitro*, thalamic oscillations have been thoroughly explored and dissected in detail. The underlying ionic currents and their biophysical properties were characterized, allowing to build computational models of thalamic circuits. The complex interactions that take place in these circuits, implying a variety of ionic currents and synaptic receptors, will be reviewed here.

The focus of the present research is directed to thalamocortical interactions. The questions that will be discussed are:
- Can corticothalamic feedback control thalamic oscillations?
- How is large-scale synchrony generated in the thalamocortical system?
- Can a similar mechanism be applied to explain the genesis of pathological behavior, such as epilepsy ?
- What possible physiological roles can be drawn for these oscillations?

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**David Terman** Ohio State University	The Role of Inhibition in Synchronizing Neural Oscillations: A Geometric Approach

Abstract: A geometric approach for studying the role of inhibitory synaptic coupling in either synchronizing or desynchronizing neural oscillations is presented. This issue has been considered in numerous papers; however, most of these studies have considered very idealized models such as integrate-and-fire model neurons or networks of relaxation oscillators. The geometric analysis allows us to study more realistic models for the underlying neurons and determine how changing biophysical parameters may affect the emergent network behavior. I will demonstrate that fast inhibitory coupling can lead to synchronized rhythms and then apply these techniques to analyze recent models for the spindle sleep rhythm.

6:00 pm	**Workshop Dinner** Campus Club	Fourth floor of Coffman Union

Reception at 6:00 with wine & cheese, dinner at 6:30.

Friday, January 23

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Wulfram Gerstner** Federal Inst. of Techn., Lausanne	Dynamics in homogeneous populations of spiking neurons — stability, locking, and fast transients

Abstract: The population activity in a homogeneous pool of spiking neurons can be described by an integral equation (similar to the original Wilson-Cowan model) which is exact in the limit of $N \to \infty$. Typical dynamical states may be analyzed directly on the level of the integral equation.
(i) fast transients: populations of spiking neurons react instanteneously to step changes in the input (*cf.* Tsodyks and Sejnowski; Van Vreewsijk and Sompolinsky) — which shows that a description of the population activity A with a standard first-order differential equation is not valid (at least not during the initial phase of the transient).
(ii) The 'locking' condition that we have studied earlier, (paper with van Hemmen and Cowan) has a natural generalization in the context of the integral equation.
(iii) Stability of incoherent firing states (splay phase) may be analyzed in the presence of noise as a function of parameters like the transmission delay.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**David Hansel** École Polytechnique	The role of adaptation in shaping spatio-temporal patterns of neural activity of large neural networks
11:30–12:30	**Discussion Session** Leaders to be announced	

Monday, January 26

Tuesday, January 27

IMA Postdoc Seminar:

2:30 pm	**Sharon Crooke** Montana State University	Modeling Cortical Oscillations with Networks of Coupled-Phase Oscillators

Abstract: Oscillations in many regions of the mammalian cerebral cortex have remarkably common temporal characteristics. However, there is much more variability in the spatial domain. For example, some cortical oscillations tend to be synchronous while others produce traveling waves of oscillations or other phase shifts that may be computationally significant. We use coupled cortical oscillators to examine several mechanisms which affect the dynamics of the voltage oscillation of each neuron during repetitive firing where the behavior of the network depends critically on the interaction functions chosen to represent the coupling between oscillators.

Organizer: Kathleen Rogers

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, January 28

Thursday, January 29

Seminar on Dynamics and Mechanics in Vincent Hall 570

11:15 am	**To be announced**	

Friday, January 30

SEMINAR ON INDUSTRIAL PROBLEMS

10:10 am	**Dr. Richard Stone** Northwest Airlines	Airline Planning Problems

Abstract: In many ways a major airline can be viewed as one large planning problem which is usually approached as many interdependent smaller (but still imposing) planning problems. The list of things which need planning seems endless: crews, reservation agents, luggage, flights, through trips, maintenance, gates, inventory, equipment purchases. Each planning problem has its own considerations, its own complexities, its own set of time horizons, its own objectives, but all are interrelated.

In this talk, we will briefly look at a few of these airline planning problems. For each, we will outline the basic problem, considerations, and objectives. In addition, for each planning problem we review, we will discuss how one might quantitatively approach the problem so as to intelligently support the planning process.

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

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IMA NEWSLETTER # 259

February 1–28, 1998

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.

News and Notes

IMA Tutorial:

Calcium Dynamics in Cells

February 5–6, 1998
Speakers: Joel Keizer (Univ. of California, Davis) & Robert Miura (National Institutes of Health)

IMA Workshop:

Calcium Dynamics in Cells

February 9–13, 1998
Organizers: Joel Keizer (Davis)(chair), John Rinzel (Courant Institute), Albert Goldbeter (Brussels)

Lucent Technologies Joins as IMA Participating Corporation

Lucent Technologies has recently joined the IMA as a Participating Corporation. The IMA Participating Corporation program aims at broadening relations between university and industry mathematical scientists and identifying new mathematical research areas of interest to industry.

IMA Reorganization

The IMA Board of Governors has approved reorganization of the senior management of the IMA, initiated by the new IMA Director, **Willard Miller**. **Fadil Santosa** has been appointed to the new position of **Associate Director for Industrial Programs. Robert Gulliver** has announced his resignation as Associate Director, effective this March, and **Frederic Dulles** has been appointed to the new position of **Associate Program Director.** Dr. Dulles will assume part of Dr. Gulliver's responsibilities, the others passing to Dr. Miller. Dr. Santosa's responsibilities will free up time from the Director's position.

New Scientific Program Advisory Committee

This new committee will assist Miller in developing ideas for annual and Summer programs. Members will be **Avner Friedman** (chair) of the University of Minnesota, **Mac Hyman** of Los Alamos National Laboratories, **George Papanicolaou** of Stanford University and **William Pulleyblank** of IBM T. J. Watson Research Center. Friedman was Director of the IMA from 1987–97, and Pulleyblank is currently chair of the IMA Board of Governors.

New Computational Programs and Resources Advisory Committee

Another new committee will advise Miller as to how the computational aspects of current and upcoming IMA programs can be strengthened, and on the establishment and maintenance of appropriate facilities, personnel and software. Members will be **Mitchell Luskin** of the University of Minnesota, **Douglas Arnold** of Penn State University, **George Cybenko** of Dartmouth College, **Leslie Greengard** of the Courant Institute of Mathematical Sciences at NYU, and Jorge Moré of Argonne National Laboratories.

Expanded Programs and Improved IMA Home Page

See the accompanying letter regarding the expanding programs and services of the IMA which motivated Miller to carry out the reorganization outlined above. Many of the new programs are accesible through the IMA home page on the World-Wide Web. For example, recent Industrial Problems talks are summarized and abstracted at

`http://www.ima.umn.edu/industrial/97_98/`.

Formerly, the Industrial Problems talks were first made available to the public many months later in the hard-copy IMA Volumes (volumes # 16, 24, 31, 38, 49, 57, 67, 83 and 88, available through Springer-Verlag.)

The IMA home page is 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`.

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

Schedule for February 1–28, 1998

Monday, February 2

Tuesday, February 3

IMA Postdoc Seminar:

2:30 pm	**Tony Varghese** Oxford University	Calcium Dynamics in Cardiac Purkinje Fibers

Abstract: An introduction and overview of calcium concentration changes in heart cells will be given. Calcium is used as a signal many cells of the body. In quiescent nerve and muscle cells, the resting concentration of calcium is typically 100 nMoles/liter; in cells that are excited, the concentration jumps 10 fold to cause such activity as muscle contraction in heart and skeletal muscle, neurotransmitter release in nerves, release of insulin in the pancreas, etc. This talk will focus on the heart. In addition to a discussion of normal physiological mechanisms, the effect of drug poisoning and the resulting calcium oscillations will be discussed.

Organizer: Kathleen Rogers

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, February 4

IMA Tutorial:

Calcium Dynamics in Cells

February 5–6, 1998

Speakers: Joel Keizer (Univ. of California, Davis) & Robert Miura (National Institutes of Health)

Thursday, February 5

Talks today are in the IMA Seminar Room, Vincent Hall 570

9:30 am	**Registration and Coffee**	IMA Lounge, Vincent Hall 502
10:30 am	**Joel Keizer** UC Davis	Introduction to Calcium Dynamics in Cells

Abstract: This talk will introduce non-experts to some of the dynamical behavior associated with calcium signaling in cells. Mechanisms by which calcium ions serve to transduce one type of cellular signal into another will be discussed along with basic features of calcium transport mechanisms.

2:30 pm	**Artie Sherman** National Institutes of Health	Calcium and Bursting Electrical Activity in Pancreatic Islets

Abstract: An introduction to the roles of ion channels, calcium, and intracellular organelles, such as the endoplasmic reticulum and mitochondria, in generating oscillations in membrane potential and calcium. The pancreatic beta-cell and implications of the above for insulin secretion will be used as the main model system. Mathematical topics will include the use of bifurcation theory to analyze, develop, and evaluate models and emergent behavior of cell populations mediated by electrical coupling through gap junctions.

Friday, February 6

Talks today are in the IMA Seminar Room, Vincent Hall 570

10:00 am	**Coffee Break**	IMA Lounge, Vincent Hall 502
10:30 am	**Joel Keizer** UC Davis	Calcium Sparks and Calcium Waves

Abstract: Using a modular approach, in which kinetic models of various mechanisms of calcium handling in cells are fine-tuned to in vivo and in vitro measurements before combining them into whole-cell models, three distinct modes of transmision of calcium waves in mature and immature frog eggs have been defined. Two modes of transmission are found in immature eggs, where the inositol 1,4,5-trisphosphate receptor (IP3R) controls release of calcium from the endoplasmic reticulum (ER). The first mode corresponds to an excitable physiological state of the cytoplasm and results in solitary waves that can appear as circular or spiral waves in 2 dimensions with the wave speed proportional to the square root of the diffusion constant of calcium. A second mode occurs when the state of the cytoplasm is oscillatory and because of the small size of the buffered diffusion constant for calcium, the wave speed can appear to be weakly dependent on diffusion. In the mature frog egg, where the sperm-induced calcium fertilization wave is a propogating front, the cytoplasm appears to be bistable and in this mode the wave speed is also proportional to the square root of the diffusion constant. Here we investigate a fourth mode of propagation for cardiac myocytes, in which calcium release from the sacroplasmic reticulum (SR) is dominated by clusters of ryanodine receptors spaced at regular intervals. In myocytes a stochastically excitable myoplasm leads to the spontaneous production of calcium "sparks" that under certain conditions can merge into saltatory waves with a speed proportional to the diffusion constant.

3:00 pm	**Robert Miura** National Institutes of Health	Mathematical Analysis of Pancreatic β-Cell Models for Bursting Electrical Activity

Abstract: Bursting electrical activity (BEA) in cells consists of periodic alternating phases of oscillations (active phase) and slow change (silent phase) in the membrane potential. The first generation of models for BEA in pancreatic beta-cells involves third-order systems of ordinary differential equations for the membrane voltage and intracellular calcium concentration. These systems will be analyzed mathematically and numerically to determine the plateau fraction, the ratio of the active phase period to the total period of BEA. The mathematical analysis uses techniques from perturbation theory and dynamical systems theory.

IMA Workshop:

Calcium Dynamics in Cells

February 9–13, 1998

Organizers: Joel Keizer (Davis)(chair), John Rinzel (Courant Institute), Albert Goldbeter (Brussels)

Dynamic changes in cellular free-calcium concentrations are essential for a great variety of cellular processes, including intra- and extra-cellular signalling processes, muscle contraction, and cell motility. Using modern techniques in calcium imaging, experimentalists have recently resolved spatio-temporal patterns (oscillations and various types of nonlinear waves) in both isolated cells and tissue. These dynamical phenomena involve specific molecular mechanisms controlling calcium influx and efflux through the cell's outer membrane (voltage-gated ion channels, calcium exchangers and pumps) as well as calcium release mechanisms from internal compartments (sarcoplasmic or endoplasmic reticulum and mitochondria). A number of complex signalling pathways coupling these mechanisms have been uncovered in the laboratory, and realistic models of these processes are being developed. The workshop will be preceded by a two-day tutorial that provides the necessary biological background for non-experts and an overview of current models. Workshop participants will

include a mix of experimental cell biologists, theorists currently developing mathematical models, and mathematicians from the dynamical systems community. The workshop will explore important current biological questions such as the role of local calcium gradients in cells, how the stochastic properties of individual molecular entities (e.g., ion channels and hormone receptors) lead to organized dynamical behavior, and how calcium signals are transduced into physiological function. The workshop will close with an extended discussion of new mathematical challenges that this area presents in dynamical systems theory.

Any changes made to the workshop schedule below will be updated on the IMA web page at

`http://www.ima.umn.edu/dynsys/winter/dynsys6.html`.

Monday, February 9

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

8:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
8:50 am	**Welcome and Orientation**	W. Miller, R. Gulliver, J. Keizer

Morning session: **Calcium Oscillations: Mechanisms and Functions.** Joel Keizer, chair

9:00 am	**Joel Keizer** Univ. of California, Davis	Overview and Introduction
9:15 am	**Andrew Thomas** Univ. of Medicine & Dentistry New Jersey	Properties and Functions of Calcium Oscillations in the Liver
10:15 am	**Coffee Break**	Reception Room EE/CS 3-176
10:45 am	**Richard Nuccitelli** Univ. of California, Davis	A confocal microscope study of the fertilization-induced calcium wave in the frog egg

Abstract: We have used confocal microscopy to examine the $[Ca^{2+}]_i$ increase in the albino eggs of the frog, *Xenopus laevis*, following fertilization. Eggs were placed in agar wells with their animal poles downward so that fertilization occurred preferentially in the equatorial plane and confocal microscopy was used to provide a two-dimensional optical section through the three-dimensional Ca^{2+} wave. These are the first confocal images of the sperm-induced calcium wave in the frog egg. These data indicate that the wave of increased $[Ca^{2+}]_i$ traverses the entire egg and converges uniformly on the antipode. We show that ratioing two different fluorescent dyes in order to correct for variations in cell thickness is not a reliable technique for this very thick cell due to differential absorption with depth. Indo-1-dextran proves to be a more reliable Ca^{2+} indicator in this respect. Indo-1-dextran measurements indicate that the resting $[Ca^{2+}]_i$ is not uniform throughout the egg but exhibits a 15% higher $[Ca^{2+}]_i$ in the cortex than deep in the cytoplasm. This difference is accentuated during wave propagation and is not dependent on extracellular Ca^{2+}. The average peak $[Ca^{2+}]_i$ in the center of the egg as the wave propagates through it is 0.7 μM, about 60% of the peak cortical $[Ca^{2+}]_i$. The wave velocity through the center of the egg (5.7 μm/s) is slower than that in the cortex (8.9 μm/s) and both velocities vary slightly during transit. The cortical wave speed is particularly high at the beginning (15.7 μm/s) and end (17.2 μ/s) of the wave. Eggs injected with 30-80 μM of 3 kD heparin to compete with Ins(1,4,5)P3 for binding to its receptor exhibited multiple localized spots of elevated $[Ca^{2+}]_i$ and many of these did not initiate a wave. For those that did lead to a wave, it was usually slow moving and exhibited a reduced (60% reduction) amplitude compared to controls.

11:30 am	**Nancy Allbritton** Univ. of California, Irvine	Subcellular Measurement of Inositol 1,4,5-Trisphosphate in *Xenopus* Oocytes

Abstract: The transduction of many hormonal and sensory stimuli is mediated by an increase in the intracellular concentration of inositol 1,4,5-trisphosphate ([IP3]). The interplay of [IP3], the intracellular free Ca^{2+} concentration, and the IP3 receptor/channel is thought to lead to the Ca^{2+} spikes and waves observed in many cell types. Despite the importance

of IP3 in Ca^{2+} signaling, [IP3] in a single cell before, during, and following application of PLC-activating stimuli is not known. No method exists to measure [IP3] in single cells. Most estimates of [IP3] are based on homogenates of large numbers of cells, and represent the average [IP3] of an asynchronous population. This may in part explain the wide range of predicted, physiologic [IP3]. Measuring [IP3] in single cells is fundamental to understanding Ca^{2+} signaling. We combined capillary electrophoresis with a permeabilized IP3-detector cell to develop a method with the sensitivity to measure [IP3] in small regions of a single *Xenopus* oocyte. We will present early results obtained with this new technique.

Afternoon session: **The "Virtual Cell" Project.** Joel Keizer, chair

2:30 pm	**Leslie Loew** Univ. of Connecticut Health Center	The Virtual Cell

Abstract: The Virtual Cell is a fully modular general framework for modeling cell biological processes. An intuitive JAVA interface includes options for database access, geometry definition (including directly from experimental images), specification of compartment topology, species definition and assignment, chemical reaction input, and computational mesh. Deterministic and stochastic physical formulations have been implemented. The algorithms have been rigorously tested against exact solutions including various membrane and boundary conditions.

The Virtual Cell has been used to model calcium waves produced by InsP3-mediated release from endoplasmic reticulum (ER) in differentiated N1E-115 neuroblastoma cells. Experimentally, stimulation with 500 nM bradykinin produces waves that are non-oscillatory and start in the middle of the neurite following a latency of 3 seconds. The $[Ca^{2+}]_{cyt}$ increases to 1μM within 1 second and decays to near baseline levels with a time constant of about 10s. A model was constructed based on the geometry of a cell for which the calcium wave had been experimentally imaged. The distributions of the relevant cellular components (InsP3R, SERCA pumps, bradykinin receptors, and ER) were based on 3D confocal immunofluorescence images. Biochemical and electrophysiological data on the rate of InsP3 production, InsP3R levels, the channel opening characteristics of the InsP3R, calcium flux through the InsP3R channel, binding to fixed and mobile buffers, and the rate of calcium-activated pumping by SERCA were all used to constrain the model. The simulation matched the spatial and temporal characteristics of the experimental calcium wave. It also provided new insights into mechanistic features underlying the wave and predicted the outcome of new experiments.

Math Department Seminar on Math Physics in room Vincent Hall 570

2:30 pm	**Robert Mccann** Brown University	The Geometry of Optimal Transportation
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Math Department Real Analysis Seminar in Vincent Hall 207

4:15 pm	**Radu Balan** Princeton University	Approximations of a Class of Stochastic Processes by Weyl-Heisenberg Pairs

Abstract: In this talk I will present a joint work with I. Daubechies and V. Vaishampayan (ATT) concerning approximations of finite energy nonstationary signals or finite power stationary signals by Weyl-Heisenberg (i.e. windowed-Fourier) sets. I shall analyze the distortion-rate characteristic, the role the redundancy (deficit) plays and a applications to multidescription and watermarking problems.

Tuesday, February 10

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176

Morning session: **Intracellular Calcium Waves.** Richard Nuccitelli, chair

9:00 am	**James Lechleiter** Univ. of Texas Health Sci. Ctr., San Antonio	The impact of Ca^{2+} sequestration and Ca^{2+} buffering on Ca^{2+} wave dynamics

Abstract: Inositol 1,4,5-trisphosphate (IP3)-induced intracellular Ca^{2+} release is an excitable process which mediates the effects of activated hormone and neurotransmitter pathways. Ca^{2+}-induced Ca^{2+} release (CICR) from the IP3-bound IP3 receptor (IP3R) is the fundamental property which generates propagating Ca^{2+} waves when coupled to Ca^{2+} diffusion. These waves annihilate upon collision primarily due to Ca^{2+} inhibition of Ca^{2+} release at high Ca^{2+} concentrations. Since intracellular Ca^{2+} release is clearly controlled by Ca^{2+} feedback mechanisms, by necessity, any cellular process which binds, sequesters, and/or pumps intracellular Ca^{2+} will affect the dynamics of Ca^{2+} signalling. My talk will focus on the molecular control of Ca^{2+} signalling by Ca^{2+} binding proteins (CaBPs), Ca^{2+}-ATPases, and mitochondria in *Xenopus* oocytes.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**James Russell** Nat. Inst. Child Health & Human Devt.	Specialized unitary Ca^{2+} release sites that support long-distance propagation of agonist-evoked calcium waves in glial cells

Abstract: Stimulation by neurotransmitters activates propagating Ca^{2+} waves in cultured astrocytes and oligodendrocytes. Our experiments showed that locally discrete cellular sites with elevated Ca^{2+} release kinetics (increased amplitude and rate of rise of response) which are typically found along processes provide regenerative Ca^{2+} release necessary for propagation. These specialized elementary Ca^{2+} release sites act as wave amplification points. We have characterized the possible involvement of mitochondria and endoplasmic reticulum specializations in achieving such locally elevated Ca^{2+} release kinetics. Cells were loaded with fluo 3 and fluorescence images were analyzed at high resolution (0.8 μm-wide slices along the cell axis, 1 image every 66 ms), followed by immunocytochemistry or direct organellar staining while cells remained on the microscope stage. Using the dyes JC-1 and DiOC6(3), mitochondria were found to be located singly or in convoluted groups along oligodendrocyte processes. Cross-correlation analysis revealed that these mitochondrial groups were closely associated with sites of elevated Ca^{2+} release kinetics. Ca^{2+} uptake into rhod 2-loaded mitochondria occurred during the cytosolic Ca^{2+} wave, and pretreatment with FCCP (1 μM, 2 min) greatly altered response amplitude. In addition, changes in mitochondrial membrane potential were also recorded during the Ca^{2+} wave. Immunocytochemistry revealed that these Ca^{2+} release sites were endowed with higher density of type 2 inositol trisphosphate receptors (InsP3R2), SERCA pumps as shown by staining with fluorescently tagged thapsigargin and bead-like concentration of intraluminal calreticulin. It therefore appears that multiple specializations underlie domains of elevated Ca^{2+} release in oligodendrocyte processes and these include the presence of mitochondria, which may modulate the level of Ca^{2+} near release sites, and by elevated levels of proteins involved in Ca^{2+} signaling such as calreticulin, InsP3R2 Ca^{2+} release channels and SERCA pumps. Two-dimensional images of intracellular Ca^{2+} flux during a propagating wave were developed using a computational method.

11:15 am	**Geneviève Dupont** Université Libre de Bruxelles	Intracellular Ca^{2+} oscillations: modelling their role at fertilization in mammals and the possible mechanisms underlying complex oscillatory behaviour

Abstract: Role of Ca^{2+} oscillations at fertilization in mammals: In all mammalian species, sperm-egg fusion leads to repetitive increases in the level of cytosolic Ca^{2+}. These oscillations play an important role in the relief of the egg from its arrested state. To undestand the mechanism by which egg development could be optimized by an appropriate pattern of Ca^{2+} oscillations, the interactions between the cell cycle and the intracellular Ca^{2+} dynamics have to be investigated. On the basis of the available experimental data, a model involving the well-known activation of calmodulin-dependent kinase II by Ca^{2+} has been developed. To account for experimental observations, it has to be assumed that CaMKII interferes with the cell cycle oscillator at two distinct levels, the 2 pathways being characterized by different kinetics. The model thus accounts for the observed dependence of the time of entry in interphase on the frequency of the Ca^{2+} spikes, as well as for the possible entry in metaphase III, a pathological state of the egg which results from an insufficient activation by Ca^{2+}.

Possible mechanism for bursting-type complex Ca^{2+} oscillations: In most cases, Ca^{2+} oscillations appear as periodic increases of the level of cytosolic Ca^{2+} from the basal level up to a high concentration of the order of 1μM. In response

to specific agonists, some cells as hepatocytes display oscillations of the bursting type, i.e. a large-amplitude Ca^{2+} spike followed by small-amplitude variations around a plateau-level. The possible mechanisms of such complex oscillations have been investigated. Among various possibilities, a model based on the interplay between Ca^{2+}-induced Ca^{2+} release and the Ca^{2+}-activated metabolism of InsP3 by 3-kinase displays interesting properties. In particular, it can explain the experimental observation that Ca^{2+} oscillations are very little affected by the overexpression of InsP3 3-kinase, one of the two enzymes responsible for InsP3 degradation.

AEM Seminar on Mechanics of Materials, 227 Akerman Hall

1:00 pm	**Wendy Crone** University of Minnesota	Experimental Investigation of Slip at a Notch Tip in Ductile Single Crystals

Afternoon session: **Intercellular Calcium Waves.** Andrew Thomas, chair

2:00 pm	**Michael Sanderson** Univ. of Massachusetts Med. Ctr.	Intercellular Ca^{2+} waves: Mechanisms and function
2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15–4:00	**Andrew Charles** UCLA School of Medicine	Spiral Intercellular Calcium Waves in Brain Slices

Abstract: Complex patterns of intercellular calcium signaling occur in hippocampal slice organotypic cultures from neonatal mice. Spontaneous, localized intercellular Ca^{2+} waves involving 5–15 cells propagate concentrically from multiple foci in specific cellular layers of the hippocampus (the stratum oriens and stratum radiatum). In these same regions, extensive intercellular Ca^{2+} waves involving hundreds of cells travel as curvilinear and spiral wavefronts across broad areas of the slice. When two curvilinear wavefronts collide, they annihilate at the point of contact. Intercellular Ca^{2+} waves travel at rates of 5-10 μm/sec, are abolished by thapsigargin, and do not require extracellular Ca^{2+}. Staining for astrocytes and neurons indicate that these intercellular waves occur primarily in astrocytes. The frequency and amplitude of intercellular Ca^{2+} waves increase in response to bath application of N-methyl-D-aspartate, and decrease in response to removal of extracellular Ca^{2+} or application of tetrodotoxin. This novel pattern of intercellular calcium signaling suggests that networks of glial cells in the hippocampus may behave as an excitable medium whose spatial and temporal signaling properties are modulated by neuronal activity.

Wednesday, February 11

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176

Morning session: **Calcium and Membrane Potential.** Illani Atwater, chair

9:00 am	**Eduardo Rojas** NIH	Cell Membrane Voltage-Insensitive Calcium Channels: Properties and Role in Excitable and Non-Excitable Cells
9:45 am	**Stanko Stojilkovic** Endocrinology and Reproduction, NIH	Calcium Mobilization and Entry Channels of Rat Pituitary Cells

Abstract: Cytosolic calcium levels ($[Ca^{2+}]_i$) in pituitary cells are controlled by three families of plasma membrane and endoplasmic reticulum (ER) calcium channels; voltage-, ATP- and InsP3-gated. All anterior pituitary cells generates spontaneous and extracellular Ca^{2+}-dependent $[Ca^{2+}]_i$ transients through L- and T-type voltage-gated Ca^{2+} channels. In

lactotrophs and somatotrophs, but not gonadotrophs, thyrotrophs, and corticotrophs, the spontaneous electrical activity is coupled to hormone secretion. Pituitary cells also express at least two types of P2X purinergic cationic channels. Somatotrophs express wild-type P2X2 channels and several splice variants, whereas gonadotrophs and lactotrophs express a wild-type and spliced forms of P2X5 channels. The native purinergic channels in pituitary cells are heteropolymers of the cloned subunits, activation of which depolarizes the cells. This lead to an increase in the frequency of action potentials, a rise in $[Ca^{2+}]_i$ and an increase in basal hormone secretion. Activation of IP3-gated Ca^{2+} release channels is associated with a non-oscillatory amplitude-modulated $[Ca^{2+}]_i$ responses in lactotrophs and somatotrophs, and oscillatory frequency-modulated $[Ca^{2+}]_i$ responses in gonadotrophs and thyrotrophs. In gonadotrophs, the conductivity of ER calcium channels is also controlled by Ca^{2+}, which exerts both facilitatory and inhibitory actions that lead to periodic Ca^{2+} release from the ER. Such release activates apamin-sensitive and -resistant potassium currents. The former are responsible for cessation of action potential firing, due to transient hyperpolarization, and the latter for gradual depolarization that leads to a bursting pattern of electrical activity. Conversely, Ca^{2+} influx through L-type and P2X channels facilitates Ca^{2+} release from the ER by a direct and instantaneous action on the release mechanism, and magnifies the Ca^{2+} signals due to its gradual effect on the reloading of ER pool. The coordinate actions of these Ca^{2+} channels permit the generation of long-lasting $[Ca^{2+}]_i$ signals in agonist-stimulated cells.

This is joint work with T. Koshimizu, F. Van Goor, and M. Tomic.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Mark Pernarowski** University of Montana	A mathematical caricature of multiple slow calcium processes in a model exhibiting bursting

Abstract: The model of bursting electrical activity in the pancreatic beta cell due to Bertram et al (Biophys J. 1995, Vol. 68) incorporates several channel types including a voltage rectified potassium current, a slowly inactivated transmembrane calcium current and a CRAC current which activates with increased intra-ER calcium stores. Imbedded in this model is a reduced model (which does not include the CRAC current or intra-ER calcium concentration) which has two fast variables and two slow variables.

In the talk preliminary numerical simulations of the reduced model indicate a potential asymptotic construction for the 4-dimensional bursting cycle. The leading silent phase dynamics can be described explicitly if posed as a second order system involing one fast and one slow variable. Fixed points of this system are unstable for parameters in the bursting regime. However, the fixed point of this system can be stablized by changing the value of glucose dependent parameter. Though this implies the existence of a stable equilibrium of the full 4-dimensional system, it does not preclude the possible coexistence of stable equilibria and bursting solutions. Resolution of this issue may come from an examination of the return map describing the bursting cycle.

For a postscript file of the talk, check under "Presentations" at `http://www.math.montana.edu/ pernarow`.

11:45 am	**John Hunter** Univ. of Califonia, Davis	Spatial Patterns in Bursting Systems

Abstract: Spatial pattern formation in bursting systems can be modeled by systems of reaction diffusion equations with weak diffusive coupling. We study a simple two by two model of bursting systems in which stable limit cycle oscillations coexist with a stable steady state. This system combines features of oscillatory media and bistable media with two stable steady states. A natural question for such systems concerns the spatial propagation of "phase boundaries" between oscillatory, bursting states and stable steady states. Numerical computations and supporting analysis show a rather surprising behavior: a spatial wave extinguishes the oscillatory state and replaces it with an unstable steady state. The unstable steady state is connected to the stable steady state by a travelling wave.

Oscillations and Waves

2:00 pm	**Informal Group Discussion** Albert Goldbeter, chair	Discussion Leaders: Genevieve Dupont, FU Brussels; Yue-Xian Li, UBC

Thursday, February 12

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176

Morning session: **Calcium Puffs and Calcium Sparks.** Hans Othmer, chair

9:00 am	**Joel Keizer** Univ. of California, Davis	Elementary events of intracellular calcium liberation

Abstract: This talk is based on work of Ian Parker (Univ. of California, Irvine).

The application of confocal imaging techniques has resolved a hierarchy of subcellular release events that underlie calcium spikes and waves. The best known paradigm for such a hierarchical organization of calcium release events evoked by inositol trisphosphate (IP_3) is illustrated by progressive recruitment of calcium 'blips' and 'puffs' in *Xenopus* oocytes. Recent data show that these form a continuum of events involving liberation of varying amounts of calcium; probably as a result of stochastic recruitment of variable numbers of channels within functional clusters. Optical techniques thus provide a means to monitor activity of single calcium channels within intact cells, and to study their interactions to produce coordinated global signals.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**Gregory Smith** NIH Mathematical Research Branch, NIDDK	A Simple Numerical Model of Calcium Spark Formation and Detection in Cardiac Myocytes

Abstract: Ca^{2+} sparks, which arise from one or more ryanodine receptors in the sarcoplasmic reticulum (SR), are the elementary events of excitation-contraction coupling in heart muscle. I present a simple numerical model constructed to explore Ca^{2+} spark formation, detection, and interpretation in cardiac myocytes. This model includes Ca^{2+} release, cytosolic diffusion, resequestration by SR Ca^{2+}-ATPases, and the association and dissociation of Ca^{2+} with endogenous Ca^{2+}-binding sites and a diffusible indicator dye (fluo-3). Simulations in a homogeneous, isotropic cytosol reproduce the brightness and the time course of a typical cardiac Ca^{2+} spark, but underestimate its spatial size ($\tilde{1}$.1 mm vs. $\tilde{2}$.0 mm). Back-calculating $[Ca^{2+}]_i$ by assuming equilibrium with indicator fails to provide a good estimate of the free Ca^{2+} concentration even when using blur-free fluorescence data. A parameter sensitivity study reveals that the mobility, kinetics, and concentration of the indicator are essential determinants of the shape of Ca^{2+} sparks, whereas the stationary buffers and pumps are less influential. Using a geometrically more complex version of the model, we show that the asymmetric shape of Ca^{2+} sparks is better explained by anisotropic diffusion of Ca^{2+} ions and indicator dye rather than by sub-sarcomeric inhomogeneities of the Ca^{2+} buffer and transport system. In addition, we examine the contribution of off-center confocal sampling to the variance of spark statistics.

This is joint work with Joel E. Keizer, Michael D. Stern, W. Jonathan Lederer, and Heping Cheng.

Afternoon session: **Calcium Sparks and Calcium Waves.** Yue-Xian Li, chair

1:30 pm	**Hans Othmer** University of Utah	The Effect of Heterogeneously-Distributed RyR Channels on Calcium Dynamics in Cardiac Myocyte

Abstract: Calcium plays an essential role in excitation-contraction coupling in muscle, and derangements in calcium handling can produce a variety of potentially harmful conditions, especially in cardiac muscle. In cardiac tissue, periodic invaginations of the membrane penetrate deep into each sarcomere, and depolarization of the membrane leads to an influx of calcium through voltage-sensitive channels in these invaginations. This in turn triggers further calcium release from intracellular stores via ryanodine-sensitive calcium channels. Under certain conditions cardiac cells release calcium from the sarcoplasmic reticulum spontaneously, producing a calcium "spark" and propagating traveling waves of elevated calcium, without depolarization of the membrane. However, under normal resting conditions these potentially harmful waves seldom occur. In this talk we discuss analytical and computational results which shed light on the role of the periodic distribution of ryanodine-sensitive channels in determining whether a spark can trigger a wave. We show that the periodic spatial localization of these channels has a significant effect on both wave propagation and the onset of oscillations in this system.

2:15 pm	**John Pearson** Los Alamos National Lab.	Fire–Diffuse–Fire and the Dynamics of Intracellular Calcium Waves

Abstract: When calcium is released from internal stores in living cells the resulting wave of increased concentration can travel without deformation (continuous propagation) or with burst-like behavior, (saltatory propagation). We present the fire–diffuse–fire model in order to illuminate the differences between these two modes of propagation. We show that the calcium release wave in immature *Xenopus* oocytes is saltatory while the fertilization wave in mature oocytes is continuous. Whether the propagation is continuous or saltatory depends on the ratio of the time that a single site remains open to the time it takes for calcium to diffuse between neighboring release sites. If this ratio is large enough the propagation is continuous and if it is small enough the propagation is saltatory. In the continuous case the number of sites that release simultaneously is large while in the saltatory case only a single site releases at a time.

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

Calcium Gradients and Secretion, I

3:30 pm	**Robert Zucker** Univ. of Califonia, Berkeley	Presynaptic [Ca] Diffusion Simulations and Models of Synaptic Facilitation

Abstract: We are trying to understand the basis for a form of short-term synaptic plasticity called facilitation. During a train of presynaptic action potentials, successive postsynaptic responses increase due to an increase in transmitter release per spike. This effect rises with time constants of 30 and 300 ms, and decays with similar time constants after the last spike in the train (when measured by single test spikes at later intervals). Katz & Miledi (1968) showed that facilitation requires Ca entry, and proposed that it is a simple consequence of the highly cooperative action of 4 Ca ions binding at the site causing exocytosis combined with residual Ca remaining present during the facilitation period adding to the transient rise in [Ca] in an action potential. However, this simple model cannot account for the large magnitude of facilitation (several fold increase for a few spikes) in the face of a very small increase in the rate of secretion during the facilitation period. Yamada & Zucker (1992) and Bertram, Sherman & Stanley (1996) proposed that Ca acts at distinct facilitation sites, with slow unbinding kinetics determining the time constants of facilitation. However, Kamiya & Zucker (1994) found that rapid reduction of residual Ca by photolytic release of a presynaptic Ca buffer rapidly eliminated facilitation, implying that a small residual Ca (less than 1 μM) acts with fast kinetics and high affinity to strongly facilitate release elicited by local brief rises in [Ca] to about 100 μM. And Atluri & Regehr (1996) found that facilitation has intrinsic kinetics of tens of ms, and is normally rate limited by equilibrium reaction of low levels of residual Ca.

We are using simulations of Ca dynamics in the active zone and models of reaction schemes to search for possible models of facilitation. Ca enters presynaptic boutons through an array of Ca channels in active zones on the presynaptic surface, and diffuses in three dimensions into the bouton. Numerical simulations involve solution of the diffusion equation, with mobile and immobile presynaptic buffers, and surface extrusion of Ca by pumps, to produce a spatio-temporal profile of [Ca] during and after a short train of action potentials. A facilitation site with kinetics and affinities consistent with experimental results at the same location as the exocytosis binding site (20 nm from the nearest open Ca channel) is saturated by each action potential, and cannot cause facilitation. But such a site located 60 nm away produces facilitation similar to what is observed experimentally. This distance may reflect the mean free path of Ca ions from the nearest open Ca channel to a physically obscured binding site on the backside of the proteins that dock vesicles to release sites.

This is joint work with Thomas Schlumpberger.

4:15 pm	**Artie Sherman** NIH Mathematical Research Branch, NIDDK	Calcium Triggers Secretion, But Which Calcium and How?

Abstract: It is well established that calcium is the prime trigger for secretion, both in neurons (synaptic transmission) and in neuro-endocrine cells (hormone secretion). However, cell calcium is divided into multiple pools by buffering, spatial gradients, sequestration in internal organelles, and spatial co-localization of ion channels and calcium-binding effector sites. Differences in these features and consequent differences in the dynamics of neuro-transmitter and hormone secretion will be addressed.

6:00 pm	**Workshop Dinner** Campus Club	Fourth floor of Coffman Union

Reception at 6:00 with wine & cheese, dinner at 6:30.

Friday, February 13

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176

Morning session: **Calcium Gradients and Secretion, II.** Greg Smith, chair

9:00 am	**Illani Atwater** NIH	Calcium Stores and Calcium Influx: Interactions in the Control of Insulin Secretion
9:45 am	**Yue-Xian Li** Univ. of British Columbia	Sensing and Refilling Calcium Stores in an Excitable Gland Cell: Can math models make nontrivial predictions about biology?

Abstract: Mathematical models of important biological phenomena have provided insights about whether and how a verbally stated model can work in an accurate and quantitative sense. Biology has also given mathematicians a variety of challenging math problems that later live a more mathematical life with little biological consequences. However, it was the close combination of the two, in pursuing the unknown facts that would be difficult to achieve without the combination, which made the work of people like Hodgkin-Huxley a big success story. This talk will focus on the efforts of myself and coworkers to use math models, based on a large number of records, to make predictions on issues relevant to the real biological problem. The first part will be on how, by focusing on the whole dose-response scenario instead of a single record in pituitary gonadotrophs, the model predicts that the bell-shaped curve moves to the right as IP3 concentration increases. This prediction has been recently proved by experiments. The second part will be on what the model says about the communication between the cell surface and the endoplasmic reticulum (ER) calcium store in controlling Ca^{2+} entry and store refilling in gonadotrophs that are excitable and relatively small. Our study predicted some seemingly counterintuitive phenomena such as that store refilling occurs at lower than basal $[Ca^{2+}]_i$ levels and, most importantly, suggested that in excitable cells that do not express I_{crac}, $[Ca^{2+}]_i$ itself plays the role of a messenger between the ER and the plasma membrane. These results indicate that capacitative Ca^{2+} entry in such cells is likely to occur through Ca^{2+}-controlled Ca^{2+} entry.

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

Gradients, Sparks, and Secretion

11:00 am	**Informal Group Discussion** Joel Keizer, chair	Discussion Leaders: Artie Sherman; John Pearson, LANL; Gregory Smith, NIH; Hans Othmer, Utah

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Monday, February 16

Tuesday, February 17

IMA Postdoc Seminar:

2:30 pm	**Alexandra Milik** Techn. Univ. Vienna/IMA	Geometric singular perturbation theory at nonhyperbolic points of the slow manifold: A case study

Abstract: Until recently geometric singular perturbation theory only applied under the assumption of hyperbolicity of the slow manifold. By using the blow-up method also known as Arnold's sigma-process Dumortier and Roussarie first gave a purly geometric treatment of the Van der Pol oscillator including the nonhyperbolic points of its one-dimensional slow manifold. In a case study of a three- dimensional system of ODEs with a folded slow manifold we demonstrate that the method also works in higher dimensions.

Organizer: Kathleen Rogers

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, February 18

Math Department/IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**Gregory King** Warwick/IMA	On the onset of turbulence in the Taylor-Couette geometry: How important is symmetry?

Abstract: We consider the question of how important symmetry is on the transition to turbulence. Our approach is to use the much studied Taylor-Couette geometry (flow between two cylinders with inner cylinder rotating and outer cylinder fixed). There is a strong feeling that the SO(2) (rotational) symmetry of the concentric cylinder geometry causes difficulties in achieving a satisfactory mathematical explanation of the experimental observations thus far obtained.

Experiments designed to study the effects of breaking the rotational symmetry have been carried out by Mullin and co-workers and by me and Takeda (unpublished). Mullin and co-workers studied (i) the flow between a circular inner and a square outer cylinder, (ii) the flow in a triply connected domain and (iii) rotating flows in stadium-shaped domains. Hammer at al and Ning et al studied the effect of an external body force (Coriolis force). Takeda and I are investigating the flow between eccentric cylinders.

I will review these experiments and identify common features of the results, and then make my speculations. It is dearly hoped that the audience will make their own speculations, and offer their own suggestions for issues to be explored in future experiments.

Thursday, February 19

Geometry Center Seminar in room 409 Lind Hall:

11:00 am	**Javier A. Diez** Univ. Nac. del Centro, Tandil Argentina	Non-Circular Focussing Flow in Viscous Gravity Currents

Abstract: Experimental and numerical studies of the filling of a dry non-circular region (cavity) within a viscous liquid layer on a horizontal plane are reported. The flow is modelled within the lubrication approximation and the resulting two-dimensional, non-linear diffusion equation for the fluid height is numerically solved. The results show that cavities with discrete rotational symmetries (squares, equilateral triangles, etc.) close as circles, while those with elongated shapes (ellipses, rectangles, isosceles triangles, etc.) do not converge to a circular form, but become an elongated oval. The axes decrease following approximately power laws on (tc-t), where tc is the collapse time, the exponents being approximately 0.5 and 1 for the major and minor axes, respectively. This rather surprising behaviour cannot be attributed either to experimental or numerical effects. Surface tension cannot be responsable for the increasing aspect ratio (ratio of major to minor radius) of the collapsing cavity since, on the contrary, it tends to round the countours. However, the exact asymptotics of the non-circular collapse are beyond the range of our experimental or numerical results.

Friday, February 20

IMA Seminar on Industrial Problems

10:10 am	**Philip Fleming** Motorola	Diffusion Approximations of Join-the-Least-Loaded Infinite Server Station

Abstract: We consider models of multicarrier IS-95 Cellular CDMA System under a "Weighted Least-Load" load-balancing algorithm and describe diffusion approximations for the joint probability mass function of the number of calls on each (radio) carrier. The underlying queueing model consists of a finite number of stations each having an infinite number of servers. New arrivals are either dedicated to a given station or are allowed to join the (weighted) least loaded station. The approximation has a particularly simple form and is quite accurate as will be demonstated by comparisons with simulation.

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

Monday, February 23

Tuesday, February 24

IMA Postdoc Seminar:

2:30 pm **Kathleen Rogers**
Univ. of Maryland/IMA

Stability in Continuum Models of DNA Minicircles

Abstract: Stability results based on a constrained variational principle will be presented for rods loaded with varying amounts of imposed twist and force. The underlying variational structure is employed to predict exchanges of stability based on the shape of the branch in a 'distinguished bifurcation diagram'. The shapes of the solution branches in this distinguished diagram, and therefore the stability properties of equilibria, depend upon γ, the ratio of twisting stiffness to bending stiffness of the rod. Perturbation techniques are used to determine the critical value of γ at which bifurcating branches switch from subcritical to supercritical.

Stability results will also be presented for an elastic rod model of DNA with experimentally motivated parameters for bending stiffness, twisting stiffness, and a curved unstressed shape. Computations with the boundary value problem solver AUTO and a numerical implementation of a conjugate point test show that the number of negative eigenvalues of the appropriate operator changes as folds in the branches are traversed. The are at least two cyclized DNA configurations which are predicted to be stable using these techniques. Other cyclized DNA are unstable.

Organizer: Kathleen Rogers

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, February 25

Math Department/IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm **Michael Jolly**
Indiana University/IMA

What current estimates say about the dimensions of inertial manifolds for the Kuramoto-Sivashinsky equation over a moderate parameter range

Abstract: Estimates for the dimensions of inertial manifolds for the Kuramoto-Sivashinsky equation (KSE) typically take the form cL^b, L is the length of the spatial domain (in one-dimension), c is some constant independent of L, and b is an exponent which has been repeatedly improved in the literature. The actual value of c, however, is generally not explicitly provided. Since we wish to use inertial manifolds over a certain range in L, we seek estimates which can be completely evaluated. There are two main ingredients needed to derive such an estimate: the radius of an absorbing ball, and the Lipschitz constant for the nonlinear term after it is truncated outside that ball. In this talk, we rework portions of the analyses in [Collet et al.] and [Temam-Wang] to derive for these two quantities, expressions which can be completely evaluated. Several low-dimensional cases (3,4,5) for the manifold are then considered, with valid parameter ranges for L determined by a spectral gap condition. We also demonstrate to what extent truncation to a ball smaller than that rigorously known to be absorbing (for the full KSE) reduces the dimension for fixed L. The manifold so found, still captures within the smaller ball, the correct dynamic behavior for the full KSE.

Special MCIM Seminar in Vincent Hall 311:

2:30 pm **Steven Brams**
New York University

Fair Division: From Cake-Cutting to Dispute Resolution

Abstract: Cutting a cake, dividing up the property in an estate, determining the borders in an international dispute – such problems of fair division are ubiquitous. Fair division treats all these problems and many more through rigorous analysis

of a variety of procedures for allocating goods (or "bads" like chores), or deciding who wins on what issues, when there are disputes. Starting with an analysis of the well-known cake-cutting procedure, "I cut, you choose", the speaker shows how it has been adapted in a number of fields and then analyze fair-division procedures applicable to situations in which there are more than two parties, or there is more than one good to be divided. In particular, the speaker will focus on procedures which provide "envy-free" portion and hence does not envy anybody else. They also discuss the fairness of different auction and election procedures.

Thursday, February 26

Friday, February 27

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 260

March 1–31, 1998

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.

News and Notes

IMA Workshop:

Cardiac Dynamics

March 9–14, 1998
Organizers: Jim Collins (Boston)(chair), James Keener (Utah), Charles Peskin (Courant) and Rai Winslow (Johns Hopkins)

IMA Special Workshop: Knowledge and Distributed Intelligence (KDI) Opportunities in the Mathematical Sciences

Saturday, March 7, 1998

The National Science Foundation has just announced a new Foundation-wide activity, Knowledge and Distributed Intelligence (KDI), that builds on recent advances in computation and communications to make new thrusts in three focal areas: Knowledge Networking (KN), Learning and Intelligent Systems (LIS) and New Computational Challenges (NCC). Mathematics and statistics are intrinsic to KDI and mathematical scientists can participate at several levels. However, the proposal solicitation was posted only in February 1998 and proposals are due **May 8, 1998,** with letters of intent by **April 1.** Given the complexity and interdisciplinary nature of the solicitation and the short time for preparation of proposals, the IMA is offering a one-day workshop to describe in some detail to the mathematical

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

sciences community the scientific opportunities represented by KDI. Similar workshops will be hosted by MSRI in Berkeley February 27, by Rice in Houston March 2 and by NISS in Research Triangle Park March 9.

The IMA will hold the workshop from 10 am to 5 pm on Saturday, March 7, 1998. The purpose of the workshop is to inform mathematical scientists about the funding opportunities presented by KDI and, in particular, the mathematical research areas that are of greatest interest. Proposal preparation issues and issues of interdisciplinary collaboration will also be addressed. The workshop will begin with a 40-minute presentation by the NSF Division of Mathematical Sciences Program Director for KDI, Mike Steuerwalt, on the main issues of the workshop. It will be followed by three consecutive sessions on Knowledge Networking, Learning and Intelligent Systems and New Computational Challenges, respectively. Each session will feature three short talks by mathematical scientists working on projects that are highly relevant to KDI, followed by a panel discussion (with questions from the floor). Each panel will be composed of the speakers for the session and appropriate NSF representatives.

The workshop will be open to all, including researchers from industry, but no funding can be provided. IMA Participating Institutions can use IMA funds under their control to send faculty to the workshop.

Weekly IMA seminar list available by list server

The IMA offers an e-mail list service. This service is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to `imalists@@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@@ima.umn.edu`.

The current week's schedule is also available on request via `finger seminar@@ima.umn.edu`. An updated `.dvi` or `.ps` file of the IMA Newsletters (current and recent) is available by `ftp` or through the world-wide web.

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`.

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

Schedule for March 1–31, 1998

Monday, March 2

IMA Seminar on Industrial Problems

10:10 am	**Daniel R. Baker** GM Research & Design Center	The Role of Charge Separation in the Response of Electrochemical Systems

Abstract: Electrodes of microscopic dimensions play an increasingly important role in many electrochemical systems of industrial significance, e.g., thin-film batteries (with electrodes and electrolyte layers of micron dimensions), and microelectrodes (with micron or submicron dimensions) used as sensors or tools for electroanalytical studies. As the size of an electrode decreases, the thin charge layer adjacent to its surface, often on the order of angstroms, exerts an increasing influence on the current characteristics of the electrode. A mathematical model is used to study the impact of the charge layer on a microelectrode immersed in a dilute concentration of binary electrolyte. The transport-limited current density on

the electrode depends on a dimensionless parameter δ, corresponding to the quotient of the Debye length by the electrode radius. (The Debye length characterizes the charge-layer thickness.) As δ becomes small, the pde's describing charge transport become singularly perturbed, and numerical solution of the equations becomes increasingly difficult. Matched asymptotics were used to calculate the current in the limit $\delta << 1$, and the results were compared with numerical solutions for larger δ-values. This talk will focus mostly on the matched asymptotic procedure, with some discussion of how a knowledge of the boundary-layer structure can be used to aid in the numerical solution of the equations.

This is joint work with Mark W. Verbrugge.

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

Tuesday, March 3

IMA Postdoc Seminar:

2:30 pm	**Tony Varghese** Oxford University	Cardiac Electrophysiology and Pharmacology

Abstract: An introduction and overview of cardiac physiology and pharmacology will be presented. The ionic mechanisms underlying normal electrical activity in the heart will be discussed along with an overview of the mechanisms that disrupt the normal heart beat. A number of heart drugs can make things worse for some heart patients and an introduction to the effects of drugs will be presented.

Organizer: Kathleen Rogers

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, March 4

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**George R Sell** University of Minnesota	An introduction to the dynamics of fluid flows on thin domains

Abstract: In this lecture we present an introduction to the study of fluid flows on thin 3D domains. The objective is to show that the physics of the problem, namely that the fluid flow is "close to" some 2D problem, can lead to a good mathematical theory concerning the long-time dynamics of the solutions. This introductory lecture will form a basis for a subsequent lecture on global climate modeling, which be given later this spring.

Math Department Seminar on Partial Differential Equations in Vincent Hall 211:

3:35 pm	**Kiyoshi Mochizuki** Tokyo Metropolitan Univ.	Global existence and energy decay of small solutions to the Kirchhoff equation with a linear dispersion localized near infinity

Thursday, March 5

Friday, March 6

Saturday, March 7

Special IMA Workshop:

Knowledge and Distributed Intelligence (KDI)– Opportunities in the Mathematical Sciences

March 7, 1998

Organizers: Willard Miller (IMA) and Fadil Santosa (IMA)

Tentative schedule:

9:00 am	**Registration and Coffee**	Reception Room EE/CS 3-176
10:00 am	**Welcome and Orientation**	W. Miller, F. Santosa
10:10 am	**Mike Steuerwalt** NSF	Introduction to the KDI Initiative

Knowledge Networks (KN)

10:50 am	**George Cybenko** Dartmouth	Mathematical Aspects of Knowledge Networking

Abstract: To quote from the KDI program announcement, "Knowledge Networking (KN) focuses on the integration of knowledge from different sources and domains across space and time." This overview will survey aspects related to the quantitative representation of information and knowledge as well as what it means to integrate them over space and time and how such integrations can be supported by mathemtics and mathematical models.

11:05 am	**Kevin McCurley** IBM Almaden Research Center	Network Security: We have everything to fear including fear itself

Abstract: I will try to identify research questions regarding what is broadly called "network security" that address each of the four stated goals of the Knowledge Networking initiative. The emphasis will be on suggesting directions of investigation rather than solutions to problems. My personal interest is in cryptology, but there are other areas where mathematics can be brought to bear on the subject.

11:20 am	**Jon Kleinberg** Cornell Univ.	Analysis of Hypermedia

Abstract: The link structure of a hypermedia environment can be a rich source of information about the content of the environment, provided we have effective means for understanding it. This talk will survey settings in which an analysis of the underlying link structure has proved to be effective; we will also discuss connections between these analysis methods and some basic combinatorial and spectral properties of link structures.

11:35 am	**Panel discussion** Knowledge Networks	Cybenko, McCurley, Kleinberg *et al.*, NSF personnel
12:15 pm	**Workshop Luncheon**	

Learning & Information Systems (LIS)

2:00 pm	**Allen Tannenbaum** Univ. of Minnesota	Problems in Visual Grouping

Abstract: In this talk we will outline some of the key issues about our research program in visual grouping. This will include ideas from learning, adaptive control, and image segmentation.

2:15 pm	**Manfred Warmuth** Univ. of California, Santa Cruz	Simple on-line learning algorithms: multiplicative versus additive updates

Abstract: The goal is to design simple learning algorithms for the on-line estimation of parameters in non-stationary settings. An example would be to estimate the car rate at a traffic light.

Gradient descent is the standard heuristic for designing iterative learning algorithms with the aim of minimizing some loss function. In this heuristic the new value of a parameter equals the old value "plus" a constant times the derivative (gradient) of the loss function w. r. t. the parameters. We discuss new heuristics in which the gradients are used in a different way, leading to a "multiplicative" update of the parameters.

The multiplicative updates are good when the input dimension is large (data mining applications). They also can adapt quickly when the inputs are changing with time. Techniques from convex optimization, statistics, and control theory are used to derive and analyze the algorithms.

2:30 pm	**Neil Gershenfeld** MIT Media Lab	Machine Inference

Abstract: The spread of sensing, computing, and communications from traditional platforms to emerging environments presents significant new challenges and opportunities for data-driven inference. I will survey new algorithms and applications that integrate and act on such information.

2:45 pm	**Panel discussion** Learning & Information Systems	Gershenfeld, Tannenbaum, Warmuth *et al.*, NSF personnel

New Computational Challenges

3:15 pm	**Joe Greene** Univ. of Illinois, Urbana	Thin Film Growth Phenomena: Scaling from Ångstroms to Meters, Picoseconds to Hours

Abstract: Critical phenomena which determine nanoscale chemical reactions, together with microstructural and surface morphological evolution, during thin film growth, occur over vastly different distance and time scales. Continuum modeling, necessary for describing the structure and chemistry, and hence physical properties, of macroscopic thin film systems (typical dimensions of nm to microns thick by mm to several hundred cm in diameter, *i.e.* 10^{14} to 10^{22} atoms) requires input from kinetic equations which reliably predict surface and bulk mesoscopic-scale reactions (diffusion, surface roughening, island coalescence, grain growth, etc) that occur over times ranging from 10^{-9} secs. to hour. Understanding the basic physics governing these collective reactions requires probing and modeling atomic-scale interactions at surface and interfaces over times ranging from approximately 10^{-14} secs. to 10^{-6} secs. This, in turn, often necessitates *ab initio* or quantum chemical approaches. At all scales, experimental verification is essential.

In this talk, a few examples of microstructural and surface morphological evolution during both epitaxial and polycrystalline film growth will be briefly discussed to illustrate relationships (scaling laws) between atomic-scale interactions and macroscopic (bulk) behavior.

3:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
4:00 am	**Jon Kettenring** Bellcore	Massive Data Sets, Data Mining, and Cluster Analysis

Abstract: Practitioners are facing increasingly large amounts of data to analyze. Many standard approaches fall flat because they are in- appropriate or fail to scale. Computer scientists (and others) are promoting data mining as the answer. Is it? One of the basic techniques that is often listed as part of data mining is cluster analysis. Cluster analysis can help, in principle, to break large amounts of data down into manageable chunks. What are the important research issues involved in this particular setting and in the general massive data sets/data mining context? In this brief talk I will try to give a quick perspective on all of these topics.

4:15 am	**Terry Sejnowski** Salk Institute for Biological Studies	Independent Component Analysis

Abstract: Mixtures of several hundred signals can be blindly separated by Independent Components Analysis (ICA), an new unsupervised neural network learning algorithm that generalizes Principal Component Analysis to nongaussian signals that are nonorthogonal. This new technique can be applied to data at many different spatial and temporal scales and has many areas of application in signal processing and datamining. When applied to patches from natural images, ICA finds components that resemble localized and oriented Gabor filters, similar to responses of neurons in the primary visual cortex of primates. This suggests that the visual cortex preprocesses visual information into channels that are maximally independent. When applied to functional magnetic resonance imaging data (fMRI), which allows cognitive brain activity to be measured in humans noninvasively, the resulting ICA components consist of spatially-fixed 3-D maps of distributed activity and associated time courses of activation which identify spatially independent brain processing systems.

4:30–5:00	**Panel discussion** New Computational Challenges	Kettenring, Sejnowski *et al.*, NSF personnel

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IMA Workshop:

Cardiac Dynamics

March 9–14, 1998

Organizers: Jim Collins (Boston)(chair), James Keener (Utah), Charles Peskin (Courant) and Rai Winslow (Johns Hopkins)

Spatio-temporal patterns of electrical activity over the heart cause the muscle to contract. This workshop will consider the electrical activity of the heart, and the resulting mechanical events, in both health and disease. It will also review current understanding and modeling of drug action. Simplified models of the electrical activity show normal wave propagation, as well as arrhythmias such as spontaneous spiral wave generation. Complicating factors for electrical and mechanical modelers include differing nonlinear properties in different regions, anisotropy in the conduction pathways and in the fiber architecture of the heart, and branching in the Purkinje system which triggers the muscle electrical activity. Large scale 3-D computational models for electrical and mechanical activity of the heart as well as reduced electrical models based on singular perturbation descriptions and kinematics of spiral cores have led to insights into cardiac physiology, and for excitable media more generally.

Monday, March 9

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Dulles, J. Collins
9:30 am	**J. P. Keener** University of Utah	Introduction to the Electrophysiology of Cardiac Tissue, I

Abstract: The purpose of these three lectures (9:30 and 2:00 Monday and 11:00 Tuesday) is to give an introduction to and overview of the electrophysiology of the heart and the mathematical modelling thereof, with the goal of preparing participants for the workshop to follow. No previous background in cardiology will be assumed.

Topics will include an introduction to the electrocardiogram and vectorgrams (a quick survey of how to read an ecg), ionic models for single cells, modelling of intact cardiac tissue, propagation and propagation failure, cardiac arrhythmias (their initiation, dynamics and elimination or control), calcium dynamics and excitation-contraction coupling.

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

11:00 am	**Charles S. Peskin** Courant Institute, NYU	Introduction to Cardiac Mechanics, I: The Heart in the Circulation

Abstract: These three lectures (11:00 Monday, 9:30 and 2:00 Tuesday) will introduce the mechanics of the heart beginning with its role in the circulation and then concentrating on the heart itself.

Simple models will be used to explain how left and right sides of the heart are kept in balance, and how the cardiac output and its distribution are continually adjusted to the needs of the tissues. The fetal circulation and the changes in the circulation that happen at birth will also be discussed.

2:00 pm	**J. P. Keener** University of Utah	Introduction to the Electrophysiology of Cardiac Tissue, II
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, March 10

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Charles S. Peskin** Courant Institute, NYU	Introduction to Cardiac Mechanics, II: Cardiac Fluid and Tissue Mechanics

Abstract: Equations of motion for the heart will be presented in this lecture. These equations give a unified description of the muscular heart walls, the flexible heart valve leaflets, and the blood that flows in the cardiac chambers. The numerical solution of the equations of motion will also be briefly introduced, with further details in my talk on Thursday.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**J. P. Keener** University of Utah	Introduction to the Electrophysiology of Cardiac Tissue, III
2:00 pm	**Charles S. Peskin** Courant Institute, NYU	Introduction to Cardiac Mechanics, III: Fiber Architecture of the Heart and its Valves

Abstract: This lecture is an attempt at mathematical anatomy, the goal being to derive the anatomy of the heart, especially its fiber architecture, from first principles. This will be done for the left ventricle, and for the aortic valve.

Wednesday, March 11

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

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

Today's topic: Calcium Dynamics in Cardiac Cells

9:30 am	**Yoram Rudy** Case Western Reserve Univ.	Cardiac conduction: an interplay between membrane processes and structural properties

Abstract: Impulse propagation in the heart results from interaction between cellular ionic processes and passive structural properties of the myocardium. Using a multicellular theoretical fiber model, the interplay between membrane ionic processes and gap junction properties during action potential propagation will be explored. We will characterize the role of

different ion channels in normal and abnormal conduction. The robustness of conduction under a variety of conditions will be quantitatively characterized in terms of a "safety factor for conduction".

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Saleet Jafri** Johns Hopkins Univ. Sch. of Medicine	Modeling Cardiac Excitation-Contraction Coupling: New Insights into Interval-Force Relations

Abstract: We construct a detailed mathematical model for calcium (Ca) regulation in the ventricular myocyte that includes novel descriptions of subcellular mechanisms based on recent experimental findings: 1) the Keizer-Levine model for the sarcoplasmic reticulum (SR) Ca release channel, the ryanodine receptor (RyR), which displays adaptation at elevated Ca as observed by Gyorke and Fill; 2) a model for the L-type Ca channel that inactivates by mode switching, as suggested by Imredy and Yue; and 3) a restricted subspace into which the RyRs and L-type Ca channels empty and interact via Ca. We add membrane currents from the Luo-Rudy Phase II ventricular cell model and isometric force generation from the Rice-Hunter-Winslow model to our description of Ca handling to formulate a new model for ventricular action potentials, Ca regulation and force generation. The model can simulate Ca transients during an action potential similar to those seen experimentally. The subspace [Ca] rises more rapidly and reaches a higher level (10–30 μM) than the bulk myoplasmic Ca (peak [Cai] $\sim$ 1μM). Termination of SR Ca release is predominately due to emptying of the SR but is influenced by RyR adaptation. We explore the effects of pacing rate on force generation. The model reproduces transitions seen in force generation due to changes in pacing that cannot be simulated by previous models. Simulation of such complex phenomena requires an interplay of both RyR adaptation and the degree of SR Ca loading. This model, therefore, shows improved behavior over existing models that lack detailed descriptions of subcellular Ca regulatory mechanisms.

2:00 pm	**Chris Johnson** University of Utah	Bioelectric field modeling, simulation and visualization

Thursday, March 12

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

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

Today's topic: Cardiac Mechanics

9:30 am	**Charles Peskin & David McQueen** Courant Institute, NYU	Cardiac Mechanics by the Immersed Boundary Method

Abstract: The immersed boundary method was first introduced to study the fluid dynamics of heart valves. Around the valves has grown a computer model of the heart as a whole, including all four cardiac chambers, all four valves, and the great vessels that connect the heart to the rest of the circulation. This computer model employs a fiber-fluid representation of the heart. In each time step, forces are generated in elastic and contractile fibers. These forces are then allowed to act on a uniform cubic lattice, on which the equations of fluid dynamics are solved. Finally, the fibers move at the local fluid velocity. Neither the fluid motion nor the cardiac tissue motion is assumed known in advance. Instead, their simultaneous equations of motion are solved. For this reason, the immersed boundary method is particularly suitable for the computer simulation of diseases affecting the mechanical function of the heart or its valves, and also for the computer assisted design of devices such as prosthetic cardiac valves that interact with the heart and with the blood flow that occurs in the cardiac chambers.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00–11:45	**Andrew McCulloch** Univ. of California, San Diego	Three-Dimensional Electromechanical Interactions in the Heart

Abstract: Regional myocardial mechanical and electrical properties are dynamic and nonhomogeneous. Moreover they are coupled. Cardiac electrical excitation initiates mechanical contraction: excitation-contraction coupling. But mechanical

factors also modulate myocardial electrical activity: mechano-electric feedback. Since these processes are also governed by the three-dimensional geometry and fibrous anisotropy of the ventricular walls, we have developed a continuum model of the three-dimensional anatomy, mechanical and electrophysiology of the rabbit heart. The model analyses have shown that the nonuniformity of myofiber orientation and the anisotropy of the myocardium play an important role in governing the regional distributions of myocardial stress and strain, activation and recovery. Experimental studies of regional electromechanical interactions in isolated and intact hearts have been performed to validate and extend these models. The continuum models provide a convenient framework to analyze and interpret the experimental measurements.

Finally, to facilitate the integration of biological models across scales of organization and function, a new resource has recently been established. The goal of the BioNOME Resource (BIOlogy Network Of Modeling Efforts) at the San Diego Supercomputer is to provide a repository of computational models for biological scientists and the tools to help them integrate and share their modeling efforts. Initially the resource will focus on two major areas: signal transduction and cardiovascular physiology.

1:45 pm	**Giovanna Cacciola** Eindhoven Univ. of Technology	Numerical simulation of leaflet movement in a fiber-reinforced polymer heart valve prosthesis

Abstract: It is known that the stresses acting in the leaflets of a heart valve prosthesis, during the opening and closing phase, are responsible for most of their mechanical failure.

We postulate that bending and tensile stresses in the closed leaflets, can be significantly reduced by making a new type of synthetic valve prosthesis with fiber-reinforced leaflets, such that the fibers transmit the load from the leaflets to the aortic walls, similar to the natural valve. The fibers can be laid down with different patterns, reinforcing the structure in the areas where the highest stresses occur, such as in the commisures during the maximal systolic valve opening. Therefore it is very important to optimize the fiber layout in order to minimize the stresses.

In our laboratory we produce two types of valve prototypes: stented, where a rigid stent support the three leaflets, and stentless, where the leaflets are made within a piece of the aorta, which is flexible.

Using a finite element package (MARC), we simulated the opening and closing behavior of the fiber-reinforced valve prostheses, both stented and stentless. Only 1/6 of the whole valve is modelled, as the synthetic valve is symmetric. The leaflet was assumed to be of uniform thickness with an orthotropic linear-elastic behavior for the composite material, which closely follow that found in experiments. The geometry of the models is based on measurements on prototypes. The mesh consists of four-node thick shell elements, to include the bending stiffness of the leaflet. A contact algorithm is used to model the coaptation of two leaflets.

From a mechanical point of view, the opening and closing of the leaflets, which is coupled with the so-called 'snap through' behavior, is difficult to simulate. As it cannot be solved with a fixed loading step procedure, we must use variable load stepping, based upon the Riks arc length method. Full Newton-Raphson iteration and a large displacement procedure are used, the latter requiring the use of the total Lagrange method.

For different fiber layouts the resulting stresses are analyzed. The results show that in the fiber-reinforced structure the stresses are reduced with respect to the same structure without fibers by up to 60%. Moreover, the flexible leaflet attachment, in the stentless valve, reduces the stresses by up to 65%, with respect to a stented valve with the same type of reinforcement.

This is joint work with J. de Hart, G. W. M. Peters, P. J. G. Schreurs and F. P. T. Baaijens.

2:30 am	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**Larry A. Taber** Washington University	Modeling Strategies for Cardiac Development

Abstract: Cardiac development involves a dynamic interaction between the processes of growth (mass change), remodeling (property change), and morphogenesis (shape change). In this presentation, an overview of the primary events during development of the heart will be given. Then, techniques for modeling these processes will be discussed, with an emphasis on mechanical aspects. A general continuum theory will be presented for including the effects of large deformation, muscle activation, growth, and active cell shape change. Finally, the theory will be used to analyze relatively simple models of some developmental processes.

3:45–4:15	**Beth Feller Printz** Columbia University	Effects of Mitral Apparatus Geometry on Mitral Flow and Leaflet Motion: A Computer Study

Abstract: The two-dimensional computational heart model using the immersed boundary method is modified to explore the mechanisms of mitral valve prolapse, mitral valve regurgitation, and changes in diastolic transmitral flow patterns. This is just one example of the utility of computer modeling in exploring the pathophysiology of valve function.

6:00 pm	**Workshop Dinner** Jewel of India Restaurant	1427 Washington Ave. S., Minneapolis: a 15-minute walk across the Mississippi.

Friday, March 13

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

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

Today's topic: Control of Cardiac Arrhythmias

9:30 am	**Leon Glass** McGill University	Repetitive Paroxysmal Tachycardia — Mechanism and Control

Abstract: Repetitive parosxysmal tachycardia is a term used by Parkinson and Papp in 1947 to describe the repeated initiation and termination of short episodes of rapid heart beats. I describe three different experimental models that show repeated bursts of relatively rapid activity: a ball of pacemaker cells that is stimulated at a fixed delay after an action potential; an experimental model of accessory pathway created by stimulating the atria at a fixed delay after activation of the ventricles; a preparation of cultured heart cells that shows spontaneous initiation and termination of rotating waves. These three systems share common properties of intrinsic pacemaking activity, a reentrant loop, and loss of excitability as a consequence of rapid activation. Based on the above mechanism, methods to control or eliminate the rhythm are immediately suggested.

10:15 am	**Coffee Break**	Reception Room EE/CS 3-176
10:45–11:30	**Alain Karma** Northeastern University	Spatiotemporal control of reentrant tachycardias

Abstract: Reentrant tachycardias are abnormally fast cardiac rhythms produced by the circulation of electrical activity around some anatomical obstacle in the heart, or by spiral wave rotation around a phase singularity in homogeneous tissue. These arrhythmia are especially dangerous because they can become unstable and decay into fibrillation, a wave turbulent state that destroys the main pumping function of the heart if present in the ventricle. I will discuss the results of a modeling study aimed at controlling a known oscillatory instability of reentrant excitations in both one-dimensional rings and thin two-dimensional sheets of tissue. The good news is that control can be achieved, and the decay into turbulence prevented, with a relatively small number of spatially distributed pacing electrodes and a relatively simple control scheme. The bad news, however, is that ventricular fibrillation can also be produced by a distinct three-dimensional instability of scroll wave filaments that would require a completely different control strategy, yet to be developed.

1:30 pm	**Milton M. Morris** Guidant Corporation	Math Considerations in Detection and Classification of Cardiac Arrhythmias in a Dual Chamber Implantable Cardioverter Defibrillator: Robustness vs. Device Longevity
2:15 pm	**Coffee Break**	Reception Room EE/CS 3-176
2:45 pm	**Eddy Warman** Medtronic Inc.	The role of modeling in the design of antitachycardia implantable devices

Abstract: Despite the success of implantable devices in the termination of cardiac tachyarrhythmias, these devices have not met yet their full potential. Reliable pace termination of tachyarrhythmias is one of the most desired improvements for current devices. Today, many tachyarrhythmias are ultimately terminated by high current shocks that are not well tolerated by patients. Termination of tachyarrhythmias by unperceived low current pacing pulses is currently possible on highly periodic rhythms. Reliable pace termination of a wide class of rhythms remains one of the biggest challenges of today. Past experiments have been difficult to interpret due to high experimental variability and limited knowledge of the dynamic system. Presently, computer simulations have started to provide a framework to study basic and fundamental principles. New ideas and hypotheses can be first analyzed with the computer simulations to help plan and analyze experimental testing. The scope of the presentation will be to introduce current device technologies, review some experimental studies, and discuss how computer models can help in the design of better antitachycardia devices.

3:05 pm	**Shirley Xiaoyi Min** Medtronic, Inc.	Relationship between Anatomy and Ventricular Defibrillation Thresholds in Two Finite-Element Human Thorax Models

Abstract: Even though finite element human torso models have been increasingly used to study ventricular defibrillation field and to optimize defibrillation electrode systems, effect of human anatomical variation on defibrillation thresholds (DFTs) has not been well investigated. In order to investigate the anatomical variables that affect ventricular DFTs, finite element torso models were built from MRI and fast CT images of two patients. One patent had a dilated left ventricle (LV) and left atrium, and LV hypertrophy, 30% ejection fraction and a relatively small RV. The other patient had large cardiac dimensions (upper bound of normal) but no heart disease. The primary defibrillation electrode systems, *i.e.* SVC-RV, Can-RV and Can+SVC-RV, were analyzed and compared in the two models. The DFTs calculated based on 95% ventricular myocardium with voltage gradient greater than 5 V/cm were also compared with the clinical data. The FEA results show that anatomical variation can affect ventricular DFTs of certain lead configurations. Published clinical DFTs with these configurations correlate better with the normal heart model suggesting that it may be a better representation of an average ICD patient. The DFTs with Can+SVC-RV and Can-RV systems are robust and relatively insensitive to these anatomical differences.

This is joint work with Rahul Mehra.

3:25 pm	**Rahul Mehra** Medtronic, Inc.	Discussion session

Saturday, March 14

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

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

Today's topic: Modelling Drug Action on Cardiac Channels

9:30 am	**Dirk J. Snyders** Vanderbilt Univ. School of Medicine	K^+-channels as molecular targets for antiarrhythmic drugs. Molecular mechanisms of drug action

Abstract: Therapy of cardiac arrhythmias remains a challenge due to issues of efficiency, specificity and/or side effects. We will discuss antiarrhythmic drug action in relation to the molecular biology of cardiac ion channels, specifically potassium channels. Class III antiarrhythmic drugs increase cardiac refractoriness by prolonging the plateau duration of the action potential. While this can be achieved by increasing inward currents or blocking outward currents, most clinically used drugs act as K^+ channel blockers. Over the past decade a large number of Kv channel α and β subunits have been cloned. The basic properties (voltage-gating and selective pore permeation) reside in the α subunits; and can be modulated by accessory β-subunits. The molecular architecture of the native channel complexes is not fully understood, but the emerging pattern is that the different cardiac K^+ currents controlling the plateau phase are each encoded by subunits belonging to distinct subfamilies (I_{TO}: Kv4.2/3; I_{Kur}: Kv1.5; I_{Kr}: HERG; I_{Ks}: KvLQT1 + minK).

In principle, channel function can be altered by interfering with either permeation or gating. The cloned subunits have enabled us to identify binding sites and molecular determinants fro drug action. Quinidine and other local anesthetic type

drugs have been shown to act as open channel blockers. That is, they bind in the intracellular mouth of the (hydrophilic) permeation pathway, but binding is apparently stabilized by hydrophobic interactions. An obvious question is how much specificity can be expected with such rather generic mechanism. Fortunately, a reasonable degree of subfamily specificity has been demonstrated for several drugs, and small changes in side chains of amino acids in the proposed binding site can abolish stereoselective block. These findings support the view that more specific channel blocking drugs can be developed based on the emerging molecular information. However, an new challenge is posed by recent studies that have revealed down-regulation of some currents in cardiac disease (including long QT disease). Since block of near-absent currents is unlikely to be of therapeutic value, novel agents that up-regulate ion channels (agonists) could have a future role in the treatment of certain arrhythmias.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00–11:45	**Randall L. Rasmusson** Allegheny Univ. of the Health Sciences	Modeling Conformation-Specific Potassium Channel Block

Abstract: Recent advances in molecular biology and channel biophysics hold the promise of providing quantitative mechanisms for normal and abnormal cardiac electrical activity. However, the information from the new molecular technology has not been integrated into mathematical models of normal and abnormal electrical activity in the heart. This talk will examine the emerging problem of how to utilize data at the molecular and biophysical levels concerning the properties of K^+ channels, how their time dependent characteristics are modified by drug binding and how such information can be integrated into cellular models with predictive value to be used for rational drug design.

1:45 pm	**Lisa Irvine** Johns Hopkins University	A new cardiac sodium channel Markov model for describing drug action

Abstract: Several hypotheses of antiarrhythmic drug action have been proposed, but none provide a detailed quantitative description of drug effects on the cardiac sodium channel. The most widely accepted of these hypotheses is the modulated receptor hypothesis which states drug binds with different affinities to the resting, activated, and inactivated channel states. Using this hypothesis, we built a quantitative model of drug action on the cardiac sodium channel patterned after that of Hondeghem and Katzung (Biochim. Biophys. Acta **472**: 373–98). The model is unable to reproduce experimental data at multiple drug concentrations including the dose-response curve. We suggest that the model fails because it seeks only to represent phenomenologically a drug's effect instead of the mechanism by which the effect is generated.

A better model of antiarrhythmic drug action on the cardiac sodium channel would be more biophysically-detailed and would describe how drug binds to the channel and interacts with its gates. Building such a drug model requires the development of a biophysically-detailed cardiac sodium channel model. We have constructed a new Markov model of the cardiac sodium channel that not only is an improvement over existing Markov models, but is an improvement over existing Hodgkin-Huxley models as well. This model forms the basis of a model of lidocaine's action. Drug effect is the result of non-drug-bound channels gating as above and drug-bound channels gating with modified kinetics.

2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**Anthony Varghese** Oxford University	Block of Sodium Current and Cardiac Conduction

Abstract: Although drugs that block the fast sodium current in the heart have been in wide use for the last 40 years the actual mechanisms behind their therapeutic actions are not well understood. A new hypothesis for the action of such drugs will be presented in this talk. The effect of these drugs on isolated cells, represented by ordinary differential equations, will be compared to effects in a chain of cells. Predictions from numerical computations will be compared to experimental results. A theoretical basis for the propagation phenomena will be discussed.

Monday, March 16

Tuesday, March 17

IMA Postdoc Seminar:

2:30 pm **Miaohua Jiang** Spatial Averages of Chaotic Systems
Georgia Tech/IMA

Abstract: Both theoretical and numerical results will be presented concerning the dynamics of spatial averages of spatially extended dynamical systems. For systems with chaotic subsystems, we give numerical evidences to show that, asymptotically, the average either fluctuates periodically or converges to a constant.

Organizer: Kathleen Rogers

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, March 18

Thursday, March 19

Friday, March 20

IMA Seminar on Industrial Problems

10:10 am **David Ross** A PDE Model of Fluid Contact Lines
Kodak

Abstract: In the coating of thin fluid films, the curve along which the solid substrate, the fluid, and the air meet, is called the contact line. Understanding the shapes and stability of such lines is important for reliable manufacturing processes. Comparison of numerical simulations with experimental data suggest that a simple scalar conservation law model can predict the basic shapes of contact lines and their dependence on web speed. Further, a second-order hyperbolic equation, of which the scalar conservation law is a limiting form, appears to predict the transient wave structure on contact lines. In this talk, we will discuss these models and their underlying physical basis.

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

Monday, March 23

Tuesday, March 24

IMA Postdoc Seminar:

2:30 pm **Min Xie** Isochrons and Phase Response in Infinite-Dimensional Systems
University of Utah

Abstract: Periodically-forced oscillatory dynamics arise in many biological contexts. Isochrons are well defined in finite-dimensional oscillatory systems and the existence of isochrons enables one to study the asymptotic behavior of a forced oscillatory system by studying circle maps. The phase response behaviors of forced oscillators in finite-dimension were studied quite well. We show the existence of isochrons in infinite-dimensional oscillatory systems by different approaches in this talk. We show that the phase-locking structure in a infinite-dimensional system is analogous to that in finite-dimensional oscillatory systems.

Organizer: Kathleen Rogers

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, March 25

Thursday, March 26

Friday, March 27

Monday, March 30

Tuesday, March 31

IMA Postdoc Seminar:

2:30 pm	**Tony Shardlow** Stanford University/IMA	Long-time numerical approximation of stochastic differential equations

Abstract: I consider the numerical approximation of stochastic differential equations. I will review Ito stochastic differential equations, paying special attention to their finite time numerical approximation, before introducing new results that apply over a long time interval and that relate the numerical computations to the invariant measure of the underlying stochastic process. The theory was developed with A. Stuart (Stanford). The theory itself applies more generally, for example, to randomly impulsed differential equations and to stochastic PDEs.

Organizers: Ricardo Oliva & Warren Weckesser

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.

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IMA NEWSLETTER # 261

April 1–30, 1998

1997–98 Program

EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

See the Winter, Summer and Fall 1997 IMA Update or URL: http://www.ima.umn.edu/dynsys/ for a full description of the 1997–98 program on Emerging Applications of Dynamical Systems.

News and Notes

IMA and Institute of Technology Public Lecture:

Life's Other Secret: The New Mathematics of The Living World

April 23, 1998
Speaker: Ian Stewart, University of Warwick

Thursday, April 23, 1998

7:00 PM

Room 150, Tate Lab of Physics

116 Church Street S.E.

What is life? Why is the world of living creatures so different from the inorganic world? The discovery of the first secret of life, the molecular structure of DNA, in the middle of this century, showed that Life is a form of chemistry - but chemistry unlike any that ever graced a test tube. Some secrets, however, lie deeper that the genetic code. It is the mathematical law of physics and chemistry that control the growing organism's response to its genetic instructions.

That is Life's OTHER Secret.

Its full understanding will come only when we combine the mathematical and physical sciences with biochemistry, genetics, and developmental biology. One of the most exciting growth areas of twenty-first century science will be biomathematics. The next century will withness an explosion of new mathematical concepts, of new kinds of mathematics, brought into being by the need to understand the patterns of the living world.

IMA Workshop:

Nonlinear Identification and Control

April 27–May 1, 1998

Organizers: Yannis Kevrekidis (Princeton)(chair),Eric Ydstie (Carnegie-Mellon), P. S. Krishnaprasad (Maryland)

Co-sponsored by the Office of Naval Research

See also http://www.ima.umn.edu/dynsys/spring/dynsys8.html

The adaptive identification of nonlinear models, from both time series and spatial data, is an important component of modeling and controlling physical systems. Advances in nonlinear process control, and in image acquisition and processing techniques together with the low-dimensionality of the underlying fundamental dynamics set a new stage for the dialogue between modeling and control of nonlinear processes. This short workshop plans to study several aspects of this dialogue: time series processing, image compression and principal component analysis, adaptive and model predictive control, feedback in distributed systems as well as hybrid systems with continuous and discrete-time components. Industrial participation in this workshop will be especially encouraged and participants from industry have been invited.

This is a tentative schedule. There will be three one-hour talks every day (two in the morning and one in the afternoon); the afternoon talks will be followed by 20-minute presentations. There is a number of such invited presentations, but participants at the workshop and additional ones will also be scheduled at the workshop itself.

There will be three presentations from industry at the workshop; two will open on Monday, and one will close on Friday (in conjunction with the IMA Industrial Problems seminar).

IMA Workshop:

Pure, Applied and Industrial Mathematics: Strength through Connections

May 1–3, 1998

Organizers: Robert Gulliver (Minnesota),Naresh Jain (Minnesota), Willard Miller (Minnesota)

To Celebrate the 65th Birthday of Avner Friedman

Sponsored jointly with the University of Minnesota School of Mathematics

See also http://www.ima.umn.edu/dynsys/spring/friedman.html

Weekly IMA seminar list available by list server

The IMA offers an e-mail list service. This service is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to `imalists@@ima.umn.edu` whose first line is of the form

```
subscribe weekly
```

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

```
subscribe weekly you@@e.mail.address
```

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@@ima.umn.edu`.

The current week's schedule is also available on request via `finger seminar@@ima.umn.edu`. An updated `.dvi` or `.ps` file of the IMA Newsletters (current and recent) is available by `ftp` or through the world-wide web.

Improved IMA Home Page

The IMA has substantially improved its home page on the World-Wide Web, found 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`.

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

Schedule for April 1–31, 1998

Wednesday, April 1

Math Department Seminar on Partial Differential Equations in Vincent Hall 213:

3:35 pm	**Shari Moskow** MCIM	Identification of conductivity imperfections of small diameter by boundary measurments.

Thursday, April 2

Friday, April 3

Saturday, April 4

Rivière-Fabes Symposium on Analysis and PDE

Sponsored by the School of Mathematics

See http://www.math.umn.edu/arb/RFPoster.html

Talks today are in Lecture Hall Vincent Hall 16

9:00 am	**Refreshments**	Commons Room Vincent Hall 120
9:30 am	**Opening Remarks**	Naresh Jain, Dean H. Ted Davis, Walter Littman
10:00 am	**Mikhail Safonov** University of Minnesota	Estimates near the boundary for solutions of second order parabolic equations.
2:00 pm	**Zhongxin Zhao** University of Missouri	3G theorem and its applications.
5:30 pm	**Reception**	Campus Club, Coffman Union, 4th floor, West Wing

Sunday, April 5

Rivière-Fabes Symposium on Analysis and PDE

Talks today are in Lecture Hall Vincent Hall 16

9:00 am	**Refreshments**	Commons Room Vincent Hall 120
9:30 am	**Nicola Garofalo** Perdue University	Some recent progress in Carnot-Caratheodory geometry and in boundary value problems for subelliptic equations.
11:00 am	**Vladimir Sverak** University of Minnesota	On the notion of global ellipticity for nonlinear systems of partial differential equations.

Monday, April 6

Tuesday, April 7

IMA Postdoc Seminar:

2:30 pm	**Donald French** University of Cincinnati	A Posteriori Error Estimates for Adaptive Finite Element Approximations of the Obstacle Problem

Abstract: The obstacle problem is often considered a prototype for the class of problems that involve free boundaries and model many phenomenon such as phase transitions, jet flow, and gas expansion. These problems have solutions with discontinuities in their derivatives on the free boundary and in other areas depending on the given data. The finite element method is a thus a natural choice to solve them due to the ease with which this technique can handle mesh refinement.

A posteriori estimates are positive functions of computable quantities and in particular the approximate solution. They provide a rigorous upper bound for the error and give information that can be used to refine the mesh in a sensible way. Thus, they serve as an important part of a reliable adaptive algorithm.

In this talk we will describe the a posteriori estimates we have obtained, give the results of a simple implementation of an adaptive algorithm in one-dimension, and provide some background on finite element methods and a posteriori error analysis. This type of research has become a fundamental topic in the approximation of the solutions of partial differential equations.

The work presented is in collaboration with Ricardo Nochetto of the University of Maryland and Stig Larsson of Chalmers University of Technology.

Organizers: Ricardo Oliva & Warren Weckesser

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.

Math Department Seminar on Partial Differential Equations in Vincent Hall 570:

4:15 pm	**Songmu Zheng** Fudan University	Large-time behavior of solutions of a system of nonlinear PDEs arising in phase transition of shape-memory alloys

Wednesday, April 8

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**Ciprian Foias** Indiana University	The normal form of the Navier-Stokes equations and its applications and potential connections

Math Department Seminar on PDE's in room Vincent Hall 213:

3:35 pm	**Hiroshi Matano** University of Tokyo	Order Preserving Systems in the Presence of Symmetry.

Thursday, April 9

Mathematics Department Colloquium in room Vincent Hall 16:

3:30 pm	**V.S. Varadarajan** UCLA	Finite quantum systems and their continuum limits.

Friday, April 10

Monday, April 13

Tuesday, April 14

IMA Postdoc Seminar:

2:30 pm	**Mark E. Johnson** IMA	Interacting two-dimensional manifolds and global bifurcations for the Kuramoto-Sivashinsky Equation

Abstract: Elements of the global attractor for an approximate inertial form of the one-dimensional odd Kuramoto-Sivashinsky equation are studied in an attempt to classify global bifurcation phenomena involving the interaction of two-dimensional stable and unstable manifolds. Computer graphics plays a fundamental role in this investigation, which concludes with a conjecture connecting topological properties of periodic solutions and the creation of infinitely-many heteroclinic connections between steady states. This is work done in collaboration with M. Jolly and I. Kevrekidis.

Organizers: Ricardo Oliva & Warren Weckesser

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, April 15

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**Ciprian Foias** Indiana University	Beyond the Sobolev norms

Abstract: The use of Gevrey classes in the study of the Navier- Stokes equations promises to be a useful approach towards the study of the Leray problem on the global regularity of solutions in 3-dimensions. In this lecture, we will give some evidence for the fulfillment of this promise.

Math Department Seminar on Partial Differential Equations in Vincent Hall 211:

3:35 pm	**Joe Roseman** Tel Aviv University	Equilibria of the circular elastica under a uniform central force field

Thursday, April 16

Mathematics Department Colloquium in room Vincent Hall 16:

2:30 pm	**Paul Rabinowitz** University of Wisconsin	Heteroclinics for a Hamiltonian system on a 2–torus

Mathematics Department Colloquium in room Vincent Hall 16:

3:30 pm	**Jurgen Moser** ETH, Zurich	Stability in dynamical systems and viscosity solutions of the Hamilton–Jacobi equations

Friday, April 17

IMA Seminar on Industrial Problems

10:10 am	**David Runkle** Minneapolis Federal Reserve and Univ. of Minnesota Carlson School of Management	Are Credit-Risk Models Ready for Prime Time?

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**George Sell** University of Minnesota	Global Climate Modeling:The Grand Challenge to dynamicists

Abstract: In this lecture, we will present the basic physical and mathematical issues underlying the issue of global climate modeling. The objective here is to show that the dynamicists need to play a central role, in order to develop a good model of this phenomenon. We will also review some of the recent developments in the area of the longtime dynamics of oceanic models. As will be shown, these developments hold promise for the future.

Monday, April 20

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**Oscar Manley** Indiana University	An attractor for a simple model of combustion

Tuesday, April 21

IMA Postdoc Seminar:

2:30 pm	**Marina Osipchuk** IMA	Feedback control of nonlinear systems

Abstract: This talk will be a tutorial covering several aspects of nonlinear control. The topics covered will be selected from talks to be presented in the upcoming workshop on “Nonlinear Identification and Control.”

Organizers: Ricardo Oliva & Warren Weckesser

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, April 22

Math Department and IMA Seminar on Evolutionary Equations in Vincent Hall 570:

2:30 pm	**Edriss Titi** University of California, Irvine	On the connection between the Camassa-Holm equations and turbulence theory

Abstract: In this talk we will show the global well-posedness of the three dimensional viscous Camassa-Holm equations. The dimension of their global attractor will be esitmated and shown to be comparable with the number of degrees of freedom suggested by classical theory of turbulence. Furthermore, we will show that by using the Camassa-Holm equations as a closure model to the Reynolds averaged equations of the Navier-Stokes in an infinite channel one gets very good agreement with empirical and numerical data.

Thursday, April 23

School of Math Ordway Visitor Lecture in Vincent Hall 2

11:15 am	**Jurgen Moser** ETH, Zurich	A Lagrangian proof of the invariant curve theorem for twist maps.
6:00 pm	**Reception** Vincent Hall 502	In honor of Ian Stewart's Public Lecture

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IMA and Institute of Technology Public Lecture:

Life's Other Secret: The New Mathematics of The Living World

April 23, 1998
Speaker: Ian Stewart, University of Warwick

Thursday, April 23, 1998

7:00 PM

Room 150, Tate Lab of Physics

116 Church Street S.E.

Friday, April 24

IMA Seminar on Industrial Problems

10:10 am **Peter A. Blakey**
Motorola

Links Between The Nonlinear Behavior Of Transistors And The Spectral Characteristics Of Portable Wireless Power Amplifiers

Abstract: Cell phone technology is moving from analog systems to digital systems. Analog systems use simple modulation schemes that do not place stringent demands on the linearity of the transistor used as the final power amplifier (PA) in the transmitter. This makes it possible for circuit designers to achieve DC-to-RF conversion efficiencies that exceed 70%. Digital systems use more complicated modulation schemes that place very stringent demands on the linearity of the PA. As a result, the DC-to-RF conversion efficiencies of digital phones are quite low, typically around 40%.

The linearity of a PA is determined by several factors. These include the RF drive level, the nonlinear characteristics of the output transistor, and topology and element values associated with the surrounding circuit. Figures of merit that characterize the linearity of analog PA's, and links between these figures of merit and device nonlinearities, are well established. The figures of merit that characterize the linearity of PA's used in digital systems are quite different, and the relationships between these figures of merit and transistor nonlinearities are not well understood. However, it is known from experiments that there is little correlation between the figures of merit that are applicable to analog PA's and the figures of merit that are applicable to digital PA's.

The first part of this presentation will present an overview of analog modulation schemes and figures of merit that are used to characterize the linearity of analog PA's. The second part will cover the nonlinear characteristics of transistors and some approaches (such as Volterra series) that have been used to establish links between transistor nonlinearities and the figures of merit for analog PA linearity.. The third part of the presentation will describe digital modulation schemes and the linearity figures of merit applicable to digital PA's. The presentation ends with the question: Can we establish useful theoretical links between transistor nonlinearities and the spectral characteristics of digital power amplifiers?

A solution to this problem would assist both technology discrimination (determining what type of transistor is best suited for use in digital PA's) and device optimization (for a given type of transistor, determining what structural parameters lead to optimum performance).

IMA Workshop:

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Monday, April 27

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Dulles, Y. Kevrekidis
9:30 am	**Andrzej Banaszuk** United Technologies Research Center	A Survey of Dynamic Modeling, Analysis and Control Activities at UTRC: Focus on Nonlinear Dynamics and Future Research Opportunities.

This is research in collaboration with Clas A. Jacobson and Alexander I. Khibnik also of the United Technologies Research Center.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**A. Emami-Naeini** SC Solutions, Santa Clara, CA	Modeling and Control Problems in the Microelectronics Industry

Abstract: Processes to produce microelectronics devices are becoming more complex while global competition is demanding that these processes be brought to market more quickly and more reliably. The design of controlled microelectronics processing systems such as Rapid Thermal Processors (RTP), High Pressure Vertical Furnaces (HPV), Vapor Deposition Chambers, etc., involve a large design parameter space, and therefore trial-and-error process optimization is difficult and time consuming. With the imminent scaling to 300 mm diameter wafer size, the industry has realized that empirical approaches are not cost effective. In addition, the controller design of such systems is often separated from the equipment design, possibly resulting in a system operating far from its maximum capability. While detailed non-linear physical simulations, integrated with optimization and control design algorithms, have the potential to help explore the design space, the long turn-around time required to answer every "*What if . . . "* question makes this approach impractical at the present time.

Another difficulty is the inclusion of the feedback control for closed-loop performance evaluations. The dynamic and/or sampled-data requirements of the feedback control system are often very difficult to incorporate into existing finite element and dynamic analysis software packages. Furthermore, real-time robust feedback control design only requires models that are accurate enough to meet the performance tolerances, e.g., simplified or reduced-order models together with a measure of the model error. What is missing at the present time are mathematical methods that can operate on the detailed nonlinear physical models of these advanced chambers to derive reduced-order models, together with appropriate measures of model error. Ideally, such methods would be analytic and not require extensive simulations. Lack of appropriate sensors remains an impediment even though there is a major push toward sensor development. Also, there is a lack of purely nonlinear controller synthesis methods that are implementable.

Physical phenomena in microelectronics processing systems involve chemical reactions, heat transfer, fluid mechanics, species transport, and plasma physics. Integrated physical models are required to represent these systems. Hence, progress in solving these complex engineering problems requires an interdisciplinary approach involving close interaction between systems and control theorists and their counterparts in applied mathematics, physics, chemistry, and material science. Furthermore, physical models must be validated within the context of a carefully planned experimental program.

We will illustrate the above problems by describing our experience in designing a temperature feedback controller for a Rapid Thermal Processing (RTP) chamber, and the development of an integrated model for control of an RF diode sputtering chamber for the growing of Giant Magneto-resistive (GMR) thin-films.

2:00 pm	**Eric Ydstie** Carnegie-Mellon University	Foundations of Process Control

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

Short Presentations

3:15–3:35 pm	**Tariq Samad** Honeywell Technology Center	Nonlinear Control: Issues and Opportunities for Industrial Applications

Abstract: The intent of this talk is to impart to controls researchers in academia and industry an appreciation of application-oriented considerations for nonlinear control. I will pay specific attention to process industry applications, although other application domains will also be mentioned. Difficulties of identification, multivariable complications, some shortcomings of ”intelligent control”, and the lack of provable guarantees are discussed in this context. Yet if such challenges can successfully be met, exciting possibilities lie ahead. Multi-modeling architectures and randomized algorithms, among other topics, are key research topics to this end. Concepts for large-scale optimization, intelligent data analysis, and complex adaptive systems are outlined as potential breakthrough applications. I conclude by offering some reflections on defining ”nonlinear control”, in the hope of broadening the connotation of the term within the controls community.

3:35–3:55 pm	**Miroslav Krstic** University of California San Diego	Stochastic Nonlinear Disturbance Attenuation and Adaptive Stabilization

Abstract: The nonlinear (state) feedback theory has reached a level of generality where constructive methods (based on control Lyapunov functions) exist for all systems affine in the control and the disturbance. We present both the more widely known results for deterministic systems and very recent results for stochastic (continuous-time) systems. In the stochastic case, we work from scratch, starting with new definitions of equilibrium and input-output stability, new global Lyapunov theorems, to arrive at a new stochastic optimal control paradigm that is a more natural nonlinear extension of the standard LQG/H_2 than the widely studied risk-sensitive problem. Then we propose an adaptive approach to stabilization in the presence of unknown covariance and arrive at globally stabilizing controllers. In the linear case this result extends the ”multiplicative noise” results by Wonham and by Willems & Willems to a larger class of systems.

3:55–4:10 pm	**Jaroslav Stark** UCL	Imbedding for Stochastic and Spatio-temporal Dynamics

4:20 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, April 28

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**James B. Rawlings** University of Wisconsin, Madison	Current Issues in Model-Predictive Control

Model predictive control (MPC) is a form of control in which the current control action is obtained by solving on-line, perhaps approximately, an open-loop optimal control problem. An important advantage of this type of control is its ability to cope with hard constraints on the controls and states. Model predictive control has been widely applied in the petrochemical and related process industries where economic considerations demand operation near the boundary of the set of admissible states and controls. In this talk we first review some of the basics of MPC and overview the types of problems that have been solved. Next we describe an emerging consensus among researchers on the basic necessary components of model predictive control laws. This discussion focuses on the necessary ingredients to obtain closed-loop stability. Next we present one of the major unresolved problem for this control approach, which is receiving current attention, a practical on-line method for dealing with nonlinear dynamic models. A naive implementation of MPC for nonlinear models requires

the on-line global solution of non-convex optimization problems. We present a new method that requires less on-line computation and may ease implementation of MPC with nonlinear models.

The work presented was done in collaboration with Prof. D. Q. Mayne, UC Davis and Imperial College.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Roger Brockett** Harvard University	Putting the Feedback back into Automatic Control

Abstract: Fifty years ago it was more or less taken for granted that automatic control meant feedback control. Other fields, such as biology and economics, adopted the word feedback and, through these more popular disciplines, the word came into widespread use. However, as time evolved control theory, itself, largely ignored the idea of feedback, concentrating instead on technical issues associated with optimal control, estimation, modeling, etc. In fact, a quick examination of popular books on control fails to find any significant discussion of feedback or other conceptual issues associated with the implementation of control actions. This is in contrast with the literature in psychology, and neural science. In these fields there is a growing interest in the relationship between structure and function and this has motivated researchers to worry a great deal about the distinction between feedback and open loop implementations. For example, this distinction is particularly important when it comes to describing the role of learning in finding better ways to execute movements. In this talk I will layout a general mathematical formulation of the problem of implementing control policies leading to a new class of optimization problems in which the complexity of implementation is traded off against the quality of the trajectories. From a mathematical point of view the resulting theory is a field theory as opposed to a particle theory. One might say that it stands in relationship to optimal control in somewhat the same way that Maxwell's equations stand in relationship to the equations of motion for a charged particle. The resulting frame work, although technically more difficult, permits one to give a crisp definition of some slippery terms such as attention and practice.

2:00 pm	**I. Kanellakopoulos** UCLA	Active Identification for Discrete-Time Nonlinear Systems

Abstract: The problem of adaptive control design for discrete-time nonlinear systems with unknown parameters has been solved only for very special cases; in particular, to guarantee global stability, existing solutions impose growth restrictions on the nonlinearities. In this talk we propose a novel approach which removes this obstacle and yields global stability and tracking for systems in the strict-feedback form. Instead of the traditional structure of concurrent on-line estimation and control, we adopt a two-phase control strategy: First, in the active identification phase, we use the control input to drive the system state to points in the state space which provide us with information about the unknown parameters. We develop an algorithm which guarantees that the duration of this phase is finite and that at its end we will be able to compute future values of the system states. Then, in the look-ahead control phase, we use this prediction capability to treat the system as completely known and to drive it to its desired state in finite time.

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

Short Presentations

3:30–3:50 pm	**Edriss S. Titi** UC Irvine and LANL	Numerical Criterion for Stabilizing Steady State Solutions of the Navier–Stokes Equations.

Abstract: In this talk we show that by stabilizing a steady state solution to the Galerkin approximation of the Navier-Stokes equations, using certain linear feedback control, one in fact is stabilizing a nearby steady state solution to the fully three dimensional Navier-Stokes equations. Similar results also hold in the context of Nonlinear Galerkin method. It is worth mentioning that all our conditions are explicit and verified by the computed approximate Galerkin solution and that no a priori assumptions are made on the unknown exact solution of the Navier-Stokes equations.

4:13–4:50 pm	**L.M. Pismen** Technion-Israel Insitute of Technology	Wave Turing Resonance and Dynamics of Planforms

4:10–4:30 pm	**Yousef Saad** University of Minnesota	Krylov Subspace Methods for Solving Certain Matrix Problems in Control
3:50–4:10 pm	**Costas Kravaris** University of Michigan	Singular PDE's and the Single–step Formulation of Feedback Linearization With Pole Placement

Abstract: The present work proposes a new formulation to the feedback linearization problem. The problem under consideration is not treated within the context of geometric exact feedback linearization, where restrictive conditions arise, but is conveniently formulated in the context of singular PDE theory. In particular, the mathematical formulation of the problem is realized via a system of first-order quasi-linear singular PDE's and a rather general set of necessary and sufficient conditions for solvability is derived, by using Lyapunov's auxiliary theorem on singular PDE's. The solution to the above system of singular PDE's is locally analytic and this enables a series solution method, which is easily programmable with the aid of a symbolic software package. Under a simultaneous implementation of a nonlinear coordinate transformation and a nonlinear state feedback law computed through the solution of the system of PDE's, both feedback linearization and pole-placement design objectives are accomplished in one step, avoiding the restrictions of the other approaches.

Wednesday, April 29

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Iven Mareels** University of Melbourne	Estimating the control and identification effort for chaotic dynamics.

Abstract: In this talk we review the simple but effective OGY method for the control of chaotic dynamics from a control engineering perspective. An important ingredient in this method is to estimate the effort required to identify a sufficiently accurate local representation for the dynamics that need to be stabilised. Using ideas from linear system identification and ergodicity theory for chaotic dynamics we arrive at an estimate of the data complexity to achieve a deisred control result.

The estimates have implications for the reconstruction of low dimensional chaotic maps via local linear maps over tesselations.

A promising application area is in secure data communication.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Frank Doyle** University of Delaware	Input Sequence Design for Nonlinear Model Identification

Abstract: Recent advances in the application of advanced control methods in the chemical industry have increased interest in the identification of nonlinear dynamic models from process data. Two key issues that are relevant are model structure selection, and input sequence design. In this talk, results for finite Volterra series models will be reviewed in application to nonlinear model predictive control design. Two approaches to reducing the highly parametrized Volterra series will be covered, as will intelligent input sequence design. In particular, tailored input sequences will be derived from a weighted prediction error analysis. Furthermore, the engineering application of these sequences will be considered, resulting in the quantification of "plant-friendly" attributes.

2:00 pm	**Anthony Bloch** The University of Michigan	Isospectral Flows and Nonholonomic Stabilization

Abstract: In this talk, which presents joint work with S. Drakunov and M. Kinyon, I will discuss the stabilization of kinematic nonholonomic systems, and its relationship with the theory of isospectral matrix flows. In particular I shall

consider nonholonomic systems in the general canonical form suggested by Brockett. Nonholonomic systems are not stabilizable by smooth feedback and I will present an algorithm which uses discrete switching between smooth flows. The switching is essentially between flows which preserve eigenvalues of matrices (isospectral flows, similar to those found in the theory of integrable systems), and certain double bracket flows, similar to those found in gradient systems theory. Our double bracket flows are related to, but different from, those used by Brockett, the presenter, and others in least squares identification problems. I will discuss a generalization of these ideas to a class of systems based on the theory of Lie algebras.

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

Short Presentations

3:30–3:50 pm	**Dieter Armbruster** Arizona State University	Dynamics of re-entrant manufacturing systems.

Abstract: Motivated by re-entrant manufacturing processes in semiconductor wafer processing we model the queue changes associated with each step in the manufacturing process by a set of constant differential equations. A Poincare map reduces this to sets of piecewise linear maps. It is proved for a specific example of a 2–4 step–2 machine problem, that these maps do not show chaotic behavior but instead lead to periodic orbits of arbitrary period depending on the processing rates. A partly dissipative, partly conservative phase space is indentified and typical bifurcations are analyzed. This is contrasted with a switched arrival queuing system which shows chaotic behavior and where control of chaos ideas lead to the stabilization of unstable periodic orbits.

3:50–4:10 pm	**Thomas Co** Michigan Technological University	Parameter estimation of a certain class of nonlinear time varying systems

4:10–4:30 pm	**Raymond Adomaitis** University of Maryland	A Collocation-Based Approach to Model Reduction for a Tungsten Chemical Vapor Deposition

Abstract: We present a model of a tungsten chemical vapor deposition (CVD) system used to study the CVD system thermal dynamics and wafer temperature nonuniformities during a processing cycle. We develop a model for heat transfer in the system's wafer/susceptor/guard ring assembly and discretize the modeling equation with a multiple-grid, nonlinear collocation technique. This weighted residual method is based on the assumption that the system's dynamics are governed by a small number of modes and that the remaining modes are slaved to these slow modes. Our numerical technique produces a model that is effectively reduced in its dynamical dimension, while retaining the resolution required for the wafer assembly model. The numerical technique is implemented with only moderately more effort than the traditional collocation or pseudospectral techniques. Furthermore, by formulating the technique in terms of a collocation procedure, the relationship between temperature measurements made on the wafer and the simulator results produced with the reduced-order model remain clear.

4:30–4:50 pm	**Tryphon T Georgiou** University of Minnesota	Robustness of Non-Linear Control

Thursday, April 30

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

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

9:30 am	**John Baillieul** Boston University	The Geometry Of Second Order Control Systems

Abstract: In this talk I shall I shall present some recent work on a favorite topic— averaging theory for controlled mechanical systems with oscillatory inputs. Some particular points on which I hope to touch are:
1. The geometric distinction between veolicity controlled and acceleration controlled mechanical systems,
2. Geometric conditions for stable response to oscillatory forcing,
3. Interesting physical examples, and, time permitting,
4. Scale-invariance of the effects of oscillatory control.

I have chosen to emphasize these points because I believe they can be related in various ways to work of colleagues attending the workshop.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**P. Krishnaprasad** University of Maryland	From smart devices to smart systems

Actuators based on the interaction of electric and magnetic fields with materials (often referred to as smart actuators or smart structures), are of current interest at a variety of length scales. Arrays of electrostatic micro-actuators have found their way into applications in displays. For future applications involving interactions of such arrays with fluids it is likely that one needs to solve problems of communication and control in such arrays. One possible approach that is appealing in this context is the use of pattern-forming dynamical systems to realize control over large arrays. In this talk, based on joint work of Eric Justh and the speaker, we discuss the properties of a class of partial differential equations that have interesting pattern-formation characteristics. We analyze qualitative properties via suitable energy functionals. We also discuss some of the modeling aspects of individual actuators that lead us to this approach. This work is supported by Army Research Office under the ODDR&E MURI97 Program Grant No. DAAG55-97-1-0114 to the Center for Dynamics and Control of Smart Structures (through Harvard University), and an ARCS Fellowship awarded to Eric Justh.

2:10 pm	**Eduardo Sontag** Rutgers	Stabilization, Lyapunov-Like Functions, and the Effect of Disturbances

This expository talk describes several recent results in the areas of stability and stabilization of nonlinear control systems.

The first part will survey relationships between the existence of feedback stabilizers and control-Lyapunov functions (cLf's). The focus will be on correspondences between, respectively, (1) stabilizability and continuous cLf's, and (2) closed-loop robustness to "small" disturbances and smooth cLf's. In particular, the issue of discontinuous feedback stabilization leads one to a definition of "closed-loop behavior" which originates in the theory of differential games. Techniques from nonsmooth analysis (viscosity-like) are used in the construction of stabilizers.

Time permitting, the second part of the talk will shift into the effect of "large" disturbances, and notions of stability that take into account external perturbations. The concepts of input-to-state stability (ISS), as well as the more recently introduced integral input-to-state stability (IISS), provide a theoretical framework in which to analyze the issues that arise in this context. The focus will be on dissipation (Lyapunov-like) characterizations of these properties.

3:15 pm	**Coffee Break**	Reception Room EE/CS 3-176

Short Presentations

3:30–3:50 pm	**P. Daoutidis** University of Minnesota	Feedback Control of Nonlinear Differential Algebraic Equation Systems.

Abstract: Many engineering applications are naturally modeled by systems of coupled nonlinear differential and algebraic equations (DAEs) that cannot be directly reduced to ODEs. Such systems (also referred to as "high-index" DAEs, singular systems, descriptor systems etc.) behave fundamentally different from ODEs (they do not have a smooth solution for arbitrary initial conditions, the solution may depend on derivatives of the forcing input etc.) and have been studied extensively from the point of view of numerical simulation. In this talk, recent results on the feedback control of nonlinear

high-index DAEs will be presented. These rely on an algorithm for the derivation of state space realizations of the original DAE system or an equivalent feedback-modifed system. Connections with singular perturbations and chemical process applications will also be discussed.

3:50–4:10 pm	**Y. Kevrekidis** Princeton	Two bifurcation problems arising in a control setting

Abstract: I will briefly describe two bifurcation problems that arise (a) in discrete time model reference adaptive control and (b) in stabilizing infinite dimensional systems through truncations. In the first case noninvertible dynamics lead to new classes of instabilities and make the computation of basins of attraction difficult. In the second case, trying to relate open-loop to closed loop attractors via homotopy, give rise to broken (perturbed) transcritical bifurcations.

4:10–4:30 pm	**John Guckenheimer** Cornell	Recent Developments in Computing Periodic Orbits
6:00 pm	**Workshop Dinner**	Campus Club

Friday, May 1

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

8:30 am	**Coffee**	Reception Room EE/CS 3-176
8:45 am	**P. Kokotovic** University of California Santa Barbara	Constructive Nonlinear Control

This talk will survey recently developed tools and procedures for systematic design of stabilizing feedback controllers for classes of nonlinear systems. Among the tools are inverse optimality and passivity, while the procedures include backstepping and forwarding. A typical engine design application will also be discussed.

9:45 am	**Wolgang Kliemann** Iowa State University	Towards a Bifurcation Theory of Nonlinear Control Systems

Abstract: This talk deals with a structural aspect of control systems - their behavior under parameter variation with respect to local and global properies. Global properties include aspects of controllability and (practical) feedback stabilization, which may change as a parameter varies within a given set. We present persistence and continuity results for control and stabilization, which also give new insight into (uncontrolled) dynamical systems when applied to systems with small control range. The mathematical techniques are based on the study of transitivity of associated control flows. Local properties include aspects of robust stability and feedback stabilization. A control theoretic version of multiplicative ergodic theory shows that the spectrum of a control system consists of intervals. As the endpoints of these intervals pass through zero, the system changes its stability and stabilization behavior. Again, for small control range these results specialize to local bifurcation theory of dynamical systems.

10:45 am	**Coffee Break**	Reception Room EE/CS 3-176

Joint with IMA Seminar on Industrial Problems

11:15 am	**T. J. Burns** NIST	Modeling and Simulation of Some High-Speed Manufacturing Processes

Abstract: The most basic manufacturing processes involve the mechanical working of a material, resulting in a permanent alteration of its shape to produce a finished component. These *plastic deformation* processes can be classified according to

the order of magnitude of the rate of deformation, or *strain rate*, at which they are performed. Processes such as rolling, forming, and drawing are characterized by relatively low strain rates that do not exceed about $10^3\ s^{-1}$. On the other hand, operations such as stamping, punching, and machining can involve strain rates as high as $10^7\ s^{-1}$. *Annual expenditures on high-strain-rate manufacturing operations in the United States exceed* 3% *of the GDP.*

Trial-and-error prototyping is the current method used by industry to select process parameters. This method is expensive, and it often leads to sub-optimal parameter choices. For these reasons, and because of increasing international competition, U.S. industries are beginning to investigate more sophisticated approaches to the design and optimization of manufacturing processes. A necessary step towards improved process control is the development of better models of these operations. While considerable progress has been made in the development of predictive models for low-strain-rate processes, there is currently a need for improved predictive capabilities for high-rate processes.

In this talk, a survey will be given of some work in progress at NIST on the application of nonlinear dynamics to the modeling and simulation of two high-speed machining operations that are currently of considerable interest in industrial applications: high-speed turning and milling of metals. Unlike more conventional machining operations, which can be considered to be quasi-static, these more modern manufacturing processes are dynamic, and there are significant nonlinear effects which lead to complicated process dynamics.

IMA Workshop:

Pure, Applied and Industrial Mathematics: Strength through Connections

May 1–3, 1998

Organizers: Robert Gulliver (Minnesota),Naresh Jain (Minnesota), Willard Miller (Minnesota),

To Celebrate the 65th Birthday of Avner Friedman

Sponsored jointly with the University of Minnesota School of Mathematics

For the most current information about this workshop, see
http://www.ima.umn.edu/dynsys/spring/friedman.html

Friday, May 1

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

2:30 pm	**Registration and Coffee**	Reception Room EE/CS 3-176
3:00 pm	**Welcome and Orientation**	Naresh Jain
3:15–4:00 pm	**Luis Caffarelli** University of Texas	The Obstacle Problem Without Obstacle

Abstract: We will discuss the regularity theory and the geometry of the free boundary for free boundary problems of obstacle type, but without positivity assumptions, for instance the Pompeiu problem.

4:15–5:00 pm	**Wendell Fleming** Brown University	Risk Sensitive Stochastic Control

Abstract: Risk sensitive control provides a link between deterministic and stochastic modelling of disturbances in control systems. Connections with differential games, large deviations theory, parabolic partial differential equations and mathematical finance will be mentioned. The lecture is intended to be accessible to a rather broad audience.

5:30 pm	**Reception**	Radisson Hotel

Saturday, May 2

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

9:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:45–10:30 am	**Emanuelle DiBenedetto** Northwestern University	Stability Estimates for 2-dimensional Cracks in 3-Dimensional Bodies
10:40–11:25 am	**Peter Castro** Eastman Kodak	Industrial Mathematics - Benefits and Difficulties in Connecting to Academe
11:35–12:20 pm	**Hillary Ockendon** Oxford University Centre for Industrial and Applied Mathematics	Spinning and Weaving

Abstract: Many processes in the textile industry are just starting to be modelled mathematically. Typical configurations involve may thousands of fibres interacting with each other and with external forces.

The novel mathematics that can arise will be exemplified by two situations involving man-made fibres. The first concerns the dynamics of a wet tow modelled as an anisotropic deformable porous medium and the second involves the crimping of dry fibres, which leads to a delay integral equation.

Traditional processes involving carding and spinning of natural fibres seem to be especially hard to model mathematically, and some of the challenges will be discussed.

2:15–3:00 pm	**James Glimm** State Univ. of New York Stoneybrook	Stochastic Fluid Dymanics

Abstract: The practical computational and analytic modeling of stochastic fluid flow is a demanding challenge. We review several separate components of an integrated approach to this problem, drawing on recent results of the speaker, colleagues, and others.

Stochastic risk assessment of engineering systems motivates this study, as it requires stochastic fluid flow as an input. The use of multiple simulations to evaluate a stochastic ensemble places a strong premium on fast algorithms. Upscaling is a necessary approach to achieving fast algorithms in many cases. Upscaling can be understood as the opposite of multigrid methods in a multiscale problem: Finely gridded data is used to condition a coarsely gridded solution. Analytic, numerical, and experimental studies are needed to validate upscaling methodologies. Massively parallel computing based on a locally-assembled supercomputer with commodity components and public domain software is a cost effective solution for the still remaining large computational problems.

In combination, these methods appear to be capable of solving previously intractible stochastic fluid flow problems.

3:10–3:55 pm	**Zalman Usiskin** University of Chicago	What Can We Learn from International Comparisons in School Mathematics?

Abstract: Noticeably absent from the official reports and media summaries of the Third International Mathematics and Science Study (TIMSS) results are any references to what happened in the first and second studies. Yet, if we ignore earlier studies when a new one appears, we will learn very little, and in fact, the evidence is that much of what was considered new in TIMSS reports was known from earlier studies. This talk summarizes some of what we have learned from international studies to date.

4:05–4:50 pm	**Shmuel Winograd** IBM, Research Division	Factorization of Polynomials Over Fields of Characteristics 2

Abstract: Decoding Reed-Solomon codes calls for finding the roots of polynomials over a field of characteristic 2. This talk will describe a new method for factorizing such polynomials which is particularly efficient for polynomials of small

degree.

6:00–7:00 pm	**Reception**	Radisson Hotel
7:00–8:15 pm	**Dinner**	Radisson Hotel
8:15 pm	**After Dinner Speeches**	Radisson Hotel

After dinner speeches by various participants including Lynn Friedman and Avner Friedman.

Sunday, May 3

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

:w 8:30 am	**Coffee**	Reception Room EE/CS 3-176
9:00–10:45 am	**John Ockendon** Oxford University Centre for Industrial and Applied Mathematics	Stimulating Mathematics in Industry

Abstract: Two recent examples will be given of how industrial stimulus can lead to new ways of thinking about problems in partial differential equations. The first shows how models for capacitor manufacturing can pose interesting new questions for the Laplace-Young equation; the second describes how the quest for more acute radar systems motivates the construction of a systematic theory of complex rays for the Helmholtz equation.

For various reasons, the academic mathematics community has been deluged with industrial problems in recent years. The talk will conclude with a transparency to demonstrate the current mismatch between supply and demand for mathematical expertise in this area.

10:00–10:45 am	**Juan Velazquez** Universidad Complutense de Madrid	Singularities for the Stefan Problem

Abstract: An overview will be given concerning different singularity mechanisms that have been found for the Stefan problem in classical and undercooled situations using either rigourous techniques or formal asymptotic expansions. In particular different mechanisms of shrinking of the free boundaries to points, as well as cusp formation and corner formation mechanims will be discussed.

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Abstract: For several years the speaker has taught a course in Industrial Mathematics at Minnesota, using the book coauthored with Avner Friedman. The history, the many unique features of this course, as well many helpful hints on how to succeed in this course will be offered. This course has been a source of great gratification both for the students and the speaker.

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IMA NEWSLETTER # 262

May 1–31, 1998

1997–98 Program

EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

See the Winter, Summer and Fall 1997 IMA Update or http://www.ima.umn.edu/dynsys/ for a full description of the 1997–98 program on Emerging Applications of Dynamical Systems and see http://www.ima.umn.edu/ seminar/sched and http://www.ima.umn.edu/newsltrs/ for the latest scheduling information.

News and Notes

IMA and University of Minnesota School of Math Workshop:

Pure, Applied and Industrial Mathematics: Strength through Connections

May 1–3, 1998

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To Celebrate the 65th Birthdays of Avner & Lynn Friedman

See also http://www.ima.umn.edu/dynsys/spring/friedman.html

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.

PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

IMA Workshop:

Dynamical Systems Techniques in Oceanography: Chaotic Advection in Ocean Mesoscale Structure

May 7–9, 1998
Organizers: Chris Jones (Brown)

Co-sponsored by the Office of Naval Research

See also http://www.ima.umn.edu/dynsys/spring/ocean.html

IMA Workshop:

Pattern Formation in Continuous and Coupled Systems

May 11–15, 1998
Organizers: Martin Golubitsky (University of Houston), Dan Luss (University of Houston), Steve Strogatz (Cornell)

See also http://www.ima.umn.edu/dynsys/spring/dynsys9.html

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

`webmaster@@ima.umn.edu`.

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

Schedule for May 1–31, 1998

IMA Workshop:

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See IMA Newsletter 261 (April 1998) for the concluding events on the morning of May 1 of the IMA workshop on Nonlinear Identification and Control

Friday, May 1

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

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Wednesday, May 6

IMA Postdoc Seminar:

2:30 pm	**Ian Stewart** University of Warwick	Symmetry Methods for Collisionless N-Body Problems

Abstract: Hamiltonian Dynamics of a system of N identical particles can, under certain conditions, be treated as a perturbation of the non-physical state in which all particles coincide (and are stationary.) Symmetry methods can then be used to prove the existence of certain periodic configurations that are physically realizeable.

Organizers: Ricardo Oliva & Warren Weckesser

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.

IMA Workshop:

Dynamical Systems Techniques in Oceanography: Chaotic Advection in Ocean Mesoscale Structure

May 7–9, 1998
Organizers: Chris Jones (Brown)

Partially supported by the Office of Naval Research.

Co-sponsored by the Office of Naval Research

The following is a preliminary schedule, for more current information see also
http://www.ima.umn.edu/dynsys/spring/ocean.html

Assessing the transport of fluid across such ocean structures as the Gulf Stream, and the exchange of fluid between its constituent parts, is essential for a clear understanding of the distribution of fluid properties, such as temperature and salinity in the Ocean. There have been significant advances recently in applying the techniques of dynamical systems to numerical models and assessing the significance of the fluid exchange resulting from the mechanism known as "chaotic advection." A major hurdle has been overcome in adapting the techniques previously developed for periodic systems to aperiodic flows. However, to make effective applications to realistic flows, and in particular numerical models of real ocean situations, further devlopment is needed as the output of the models extends over only finite times. An efficient operational strategy for determining the extent of chaotic mixing in realistic models promises important applications in both oceanography and atmospheric sciences. A key to this development is a close working relationship between applied dynamicists and oceanographers. This workshop would bring together researchers from both areas and give an opportunity to share the recent advances in the different fields as well as provide a forum for setting an agenda for future activity.

Thursday, May 7

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

8:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
8:45 am	**Welcome and Orientation**	W. Miller, F. Dulles, C. Jones
9:00 am	**P. Miller & L. Pratt** Stevens Institute of Technology & Woods Hole Oceanographic Institute (respectively)	Transport and Stirring in Meandering Jets and Recirculations

Abstract: Geometric methods from dynamical systems are used to study Lagrangian transport in numerically-generated, time-dependent, two-dimensional (2D) flow fields. The first calculation involves an idealized model of the Gulf Stream consisting of an unstable jet. The instability has been allowed to develop to the point of saturation, leading to a nearly-periodic, meandering state. Calculation of the stable and unstable manifolds of hyperbolic trajectories allows a lobe analysis showing fluid passing between regions of predominantly retrograde, prograde, and recirculating motion. The volume transports are comparable to those observed for Gulf Stream rings, implying that this type of transport may be important for the mixing of the Gulf Stream with its surroundings. A similar analysis is carried out in connection with a wobbling recirculation gyre located on the eastern edge of an island. Here the object is to compare the lobe transport into and out of the gyre to the transport produced by the Ekman layer. A laboratory experiment will be presented in which the unstable manifold of the gyre is visualized with dye.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Roger Samelson** COAS Oregon State University	Quasi-geostrophic instabilities of planetary geostrophic circulation

Abstract: Instabilities of the large-scale mean flow are one likely source of mesoscale ocean variability. In general, however, the coupling of the fluctuating, mesoscale flow to the large-scale circulation remains poorly understood. One approach to this problem is through a multiple scale technique that explicitly recognizes the existence of two different types of geostrophic motion. In this picture, the large-scale flow is described by planetary geostrophic equations, and the mesocale flow by quasi-geostrophic equations. The quasi-geostrophic instabilities of solutions of an idealized planetary geostrophic model circulation may then be examined directly. In the present study, linear plane-wave quasi-geostrophic normal-mode instabilities are calculated numerically for vertical profiles of density and horizontal velocity extracted from the subtropical gyre of a planetary geostrophic circulation model. All of the profiles support growing modes. The most rapidly growing modes have e-folding times less than 1 month and horizontal wavelengths less than 10 km. These modes have vertical scales of 500 m and are centered at a shallow thermostad that may be identified as subtropical mode water. They may be interpreted in terms of a baroclinic 'defect' instability, in which a linear vertical shear of horizontal geostrophic velocity is destabilized by an arbitrarily small but sufficiently sharp local decrease in buoyancy frequency. An analytic dispersion relationship may be obtained asymptotically for the defect instabilities. Instabilities with larger vertical scales and horizontal wavelengths of 30-300 km have smaller growth rates, similar to previous estimates for mid-ocean baroclinic instability.

12:00–12:30 pm	**Discussion**	
2:00 pm	**Andrew Majda** Courant Institute–NYU	Mesoscale Coherent Structures and Crude Closure via Statistical Theories
3:00–3:30 pm	**Discussion**	
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Friday, May 8

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Steve Meacham** Florida State University	Multiple Dynamical Regimes, Low Frequency Variability, and Their Influence on Particle Transport in the Upper Ocean.
10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30 am	**Igor Mezic** University of California Santa Barbara	Mixing in Three-Dimensional Flows

Abstract: We discuss the kinematics of three-dimensional, time-dependent and time-independent fluid flows in geometrical and statistical terms. Two types of flows arise as typical: those that can be reduced to action-action-angle maps and action-angle-angle maps. A study of transport and mixing in these two types of flows will be presented: existence and non-existence of invariant objects, statistical quantities such as dispersion, and the relationship between the two. Similarities and differences with the behavior of two-dimensional, time dependent flows will be emphasized.

11:30–12:30 pm	**Discussion**	
2:00 pm	**James McWilliams** UCLA	Material Transport and Mixing by Coherent Spatial Patterns in Wind-Driven Gyres

Abstract: The Lagrangian transport and mixing of material are explored in a geographically idealized numerical model of mid-latitude wind-driven gyres. Equilibrium solutions at low (just beyond the primary Hopf bifurcation) and relatively high Reynolds number are analyzed and compared from the Lagrangian viewpoint. The character of the time variability in these solutions differs considerably, from a geographically confined limit cycle, in the former case, to geographically extensive, broad-band fluctuations with considerable power at interannual periods in the latter. It is shown that a substantial part of the intergyre transport is done by coherent patterns, which trap fluid and carry it across the time-mean streamlines, and that the domain may be qualitatively partitioned into several regions characterized by distinct mixing scenarios and statistical distribution functions (PDFs). Techniques applied include ensemble analysis of particle trajectories and particle PDFs, calculation of invariant manifolds attached to certain hyperbolic points, dispersion, finite-time Lyapunov exponents,

correlation dimension, and velocity spectra and PDFs. Consideration is also given to devising a stochastic trajectory model that mimics the transport in transient gyre solutions.

3:00 pm	**Coffee**	Reception Room EE/CS 3-176
3:30–4:30 pm	**Chad Couliette** California Institute of Technology	A Dynamical Systems Approach to Lagrangian Transport in a Double-Gyre

Abstract: We study the flow obtained from a 3-layer, eddy-resolving quasi-geostrophic circulation model subject to an applied wind stress curl. For this model we will consider transport between the northern and southern "gyres" separated by a jet. We will focus on the importance of invariant manifolds in forming geometric structures that govern transport. By "govern", we mean they can be used to compute Lagrangian transport quantities, such as the flux across the jet. We will consider periodic, quasi-periodic, and chaotic velocity fields, and thus assess the effectiveness of dynamical systems techniques in flows with progressively more spatio-temporal complexity. The numerical methods necessary to implement the dynamical systems techniques and the significance of invariant manifolds as signatures of specific "events", such as rings pinching off from a meandering jet, will also be discussed.

4:30–5:00 pm	**Kayo Ide** UCLA	Transport in Midlattitude's Oceanic Circulation: Variability and Dynamical Processes.

Abstract:

6:00 pm	**Workshop Dinner** Jewel of India Restaurant	

The Jewel of India Restaurant is located within walking distance of the IMA, in between the West bank campus and Interstate 35W in the Seven corners section of Minneapolis on Washington Avenue.

Saturday, May 9

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Gyorgy Haller & Andrew Poje** Brown University (both)	Finite-time mixing theory and its applications

Abstract: Dynamical systems offers a geometric point of view in which to study Lagrangian particle dynamics. While the geometric theory of mixing has a solid foundation for two-dimensional flows with regular time-dependence, such techniques fall short in applications to aperiodic velocity fields. We discuss recent results that enable one to study mixing in finite-time numerical or experimental velocity fields with general time dependence. We also discuss applications to oceanic and atmospheric problems, including mixing in a double-gyre ocean model and near the arctic ozone hole.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Darryl Holm** Los Alamos National Laboratory	Reduced Models for the Ocean's 'Climate'

Abstract: One might suppose the ocean's mean circulation, or 'climate,' should be described by some sort of mean of the primitive equations (PE). (The PE describe an incompressible stratified fluid in hydrostatic balance in a rotating frame.) We will discuss various candidates for these mean PE.

The nonlinear, nondissipative part of each model is obtained by applying asymptotic expansions, two-timing, Taylor expansions and (sometimes) Lagrangian mean averaging in Hamilton's principle for the primitive equations. Before adding

viscosity, we shall discuss some of the nondissipative properties of these mean PE, such as their Kelvin circulation theorems and their related potential vorticity conservation laws. We also compare the results of numerical simulations for some of these models with the PE solution for an unstable baroclinic jet.

Their linear, viscous part is obtained by identifying the appropriate momentum that should be diffused by viscosity. For one of these mean equations, called the "alpha model," we test the natural candidate for the viscous term by using it to derive a new closure model for the mean velocity and Reynolds stress in channel turbulence. Agreeably, the analytical solution of this model compares well with experimental data.

12:00–12:30 pm	**Diego del-Castillo-Negrete** Scrips Institute of Oceanography	Statistics of Passive Traces in the Presence of Coherent Structures
2:00 pm	**Shouhong Wang** Indiana University	Structure analysis of two-dimensional incompressible flows and applications to the double gyre ocean circulation

Abstract: I shall present in this talk a joint work with T. Ma on structure analysis of 2D incompressible flows and its applications to ocean dynamics. The main motivation is to understand the topological and geometrical structure of the Lagrange dynamics of two-dimensional incompressible fluid flows. On the theoretical side, I shall address 1). the global structural classification of divergence-free vector fields, 2). structural and block stability of divergence-free vector fields, 3) structural bifurcation of the solutions of the 2D Navier-Stokes equations. Then I shall apply the dynamical systems theory to the structure analysis of a wind-driven, double gyre, quasi-geostrophic ocean model, and the relavant numerical simulation is also given.

IMA Workshop:

Pattern Formation in Continuous and Coupled Systems

May 11–15, 1998

Organizers: Martin Golubitsky (University of Houston), Dan Luss (University of Houston), Steve Strogatz (Cornell)

See also http://www.ima.umn.edu/dynsys/spring/dynsys9.html

Pattern formation in spatially extended systems has been observed recently in a number of experimental systems. These include surface reactions on catalytic ribbons and homogeneous chemical reactions in gels. These patterns do not resemble the spatially periodic structure of Turing patterns but have spatially localized patterns and spatially differentiated dynamics. Moreover, these patterns appear in both PDE systems and in systems of coupled cells. The basis of these new patterns appears to be in non-local non-diffusive coupling. In another direction regular patterns have been observed in the time-averages of spatio-temporally chaotic regimes in the Faraday surface wave experiment and in rotating convection experiments. It is the purpose of this workshop to delve into the mathematical origin of these new types of pattern and the kinds of (numerical and physical) experiments that may exhibit such patterns.

We describe briefly some of the mathematical issues. In recent years, starting with the work of Field and the examples of Guckenheimer and Holmes, it has been seen that the dynamics of systems with symmetry has different structurally stable dynamics than does systems without symmetry. These differences include heteroclinic cycles, drifting along group orbits, symmetric chaos, instant chaos and issues of forced symmetry breaking.

Heteroclinic cycles give one mathematical formulation for intermittency and can be formed in two different ways. The first is through standard bifurcations where saddle-sink connections are formed in invariant (symmetry) planes. The second method involves system symmetry breaking where a perturbation parameter in the equations leads to equations with less symmetry. In this case an orbitally stable group orbit of equilibria is perturbed to a dynamically invariant manifold with

less symmetry and more complicated dynamics. In another direction symmetry of attractors has been shown to lead to group invariant time-averages and patterns in time-averages in experiments with spatio-temporal chaos.

Monday, May 11

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

8:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
8:45 am	**Welcome and Orientation**	W. Miller, F. Dulles, M. Golubitsky
9:00 am	**Harry L. Swinney** University of Texas	Meandering and resonant spirals in a reaction-diffusion system

Abstract: We examine spiral patterns in a reaction-diffusion system for two cases: the autonomous system and the system driven by external periodic perturbations. Experiments are performed in a reactor consisting of a thin gel layer sandwiched between two continuously refreshed reservoirs of chemicals; the layer is thin compared to the spiral wavelength so the patterns are quasi-two-dimensional. In the absence of external perturbations, for a wide range of control parameters the spirals are found to simply rotate – the spirals are stationary in a co-rotating frame. Variation of two control parameters reveals a critical curve at which there is a transition from the simple rotating (temporally periodic) spirals to meandering (quasiperiodic) spirals. There are two types of trajectories of the tips of the meandering spirals: inward-petal (epicycloid) trajectories and outward-petal (hypocycloid) trajectories. These two types of meandering regimes are separated in the phase diagram by a line of traveling spirals that terminates at a codimension-2 point [1]. The observed unfolding of the bifurcation about a codimension-2 point is in accord with theory [2]. The rates of the chemical reaction can be changed by shining light on the gel layer since the reaction (a ruthenium-catalyzed Belousov-Zhabotinsky system) is photosensitive. We examine the effect of periodically modulating the intensity of light incident on a pattern of simple rotating spirals. The modulation frequency is varied from one to four times the intrinsic frequency of the chemical system. As the modulation frequency is varied, the system passes through resonant regimes in which it becomes locked to the driving frequency (that is, the ratio of the driving frequency to the natural frequency is given by a ratio of small integers). These frequency-locked regimes are like the Arnold tongues of periodically forced low dimensional systems. However, in the spatially extended system, bifurcations can also occur between different spatial patterns that lie within the same frequency-locked region [3]. Some aspects of the observations are found in a periodically forced reaction-diffusion model with two species (Brusselator kinetics) [4].

Acknowledgments: This research was conducted with V. Petrov, Q. Ouyang, G. Li, and M. Gustafsson, and was supported by DOE.

[1] G. Li, Q. Ouyang, V. Petrov, and H. L. Swinney, Phys. Rev. Lett. 77, 2105 (1996).

[2] D. Barkley, Phys. Rev. Letter 72, 164 (1994); M. Golubitsky, V. LeBlanc, and I. Melbourne, to appear; C. Wulff, to appear.

[3] V. Petrov, Q. Ouyang, and H. L. Swinney, Nature 388, 655 (1997).

[4] V. Petrov, M. Gustafsson, and H. L. Swinney, to appear.

9:45 am	**H. H. Rotermund** Fritz-Haber Institut	Pattern formation in a surface reactions with global coupling.

Abstract: Dynamic processes on surfaces, like the Pt - catalyzed CO-oxidation, can be described by a set of simple reaction-diffusion equations. For a certain range of the control parameters which are the partial pressures of the reactants and the temperature of the sample pattern formation like spiral waves, target patterns or solitary waves can be observed. When global coupling via the gas phase is introduced strong temporal oscillations may occur, sometimes exhibiting spatio-temporal patterns like standing waves, their period doubling and chaotic behavior. The mentioned patterns were found under isothermal conditions. Of course, when increasing the reaction pressure, due to the exothermic nature of the CO-oxidation, also temperature patterns can be explored, observable with a sensitive InfraRed (IR) camera. A short video will demonstrate the great richness of spatio-temporal pattern formation for a simple surface reaction.

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

11:00-11:45 am	**Bjorn Sandstede** Ohio State University	Meandering and Drifting of Spiral Waves

Abstract: Meandering and drifting spiral waves has been observed in many experiments, and also in numerical simulations of reaction-diffusion systems. Numerical evidence shows that these spiral waves can be created in Hopf bifurcations of rigidly-rotating spiral waves. Barkley explained the transition from meandering to drifting as a resonance phenomenon which involves the Euclidean symmetry group of the plane. In this talk, a geometric center-manifold approach is presented which corroborates Barkley's conclusions. In fact, it allows us to describe bifurcations of spiral waves by finite-dimensional ODEs. Some examples of such bifurcations are given. Finally, the limitations of our result are explained. This is joint work with B. Fiedler, A. Scheel and C. Wulff.

2:00 pm	**Michael J. Gorman** University of Houston	Pattern Formation in Cellular Flames

Abstract: A uniform, circular, flat flame front stabilized on a porous plug burner at low pressures can undergo bifurcations to an ordered pattern of concentric rings of brighter, hotter cells demarked by darker, cooler cusps and folds that extend away from the burner. As the control parameters of total gas flow rate and equivalence ratio are varied, bifurcations to dynamic states are observed: rotating states in which rings of cells rotate uniformly or nonuniformly; hopping states in which individual cells abruptly change their angular position; ratcheting states in which one or more rings of cells rotate (very) slowly and nonuniformly, speeding up and slowing down in a manner charatericistic to each particular state; and intermittently ordered states in which ordered patterns of concentric rings appear and disappear at irregular intervals. Each of these states raises its own significant theoretical issues, such as bifurcations with symmetry and numerical solutions of the 2-d KuramotouSivashinsky equation, and its own experimental issues, such as precise measurments of the position, size, and shape of each cell. The relevance of these experimental results to other pattern-forming systems and also to controlling instabilities in other combustion systems will be discussed.

2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00-3:45 pm	**Bernard Matkowsky** Northwestern University	Coupled KS-CGL and Coupled Burgers-CGL Equations for Flames Governed by a Sequential Reaction

Abstract: We consider the nonlinear evolution of the coupled long scale oscillatory and monotonic instabilities of a uniformly propagating combustion wave governed by a sequential chemical reaction, having two flame fronts corresponding to two reaction zones with a finite separation distance between them. We derive a system of coupled complex Ginzburg-Landau and Kuramoto-Sivashinsky equations that describes the interaction between the excited monotonic mode and the excited or damped oscillatory mode, as well as a system of complex Ginzburg-Landau and Burgers equations describing the interaction of the excited oscillatory mode and the damped monotonic mode. The coupled systems are then studied, both analytically and numerically. The solutions of the coupled equations exhibit a rich variety of spatiotemporal behavior in the form of modulated standing and traveling waves, blinking states, traveling blinking states, intermittent states, heteroclinic cycles, localized chaotic structures, etc.

The talk is based on joint work with A. Golovin, A. Bayliss and A. Nepomnyashchy.

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

A variety of appetizers and beverages will be served.

Tuesday, May 12

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Edgar Knobloch** University of California Berkeley	A New Mechanism for Bursting

Abstract: The interaction of two unstable oscillatory modes of opposite parity can produce periodic or irregular *bursting*

close to threshold (A.S. Landsberg and E. Knobloch, *Phys. Rev. E* **53**, 3579, 1996). These bursts take the form of large amplitude events separated by long periods of stasis. This talk will describe joint work with Jeff Moehlis to understand the essence of this behavior using the Hopf bifurcation with broken D_4 symmetry. The bursts are found to be associated with global bifurcations involving fixed points and limit cycles "at infinity". This approach allows us to identify the conditions for the presence of repeated bursts and to elucidate the origin of chaotic bursting. The results enable us to interpret experiments on the so-called "repeated transients" observed in binary fluid convection.

9:45 am	**Herre van der Zant** T. U. Delft	Dynamics of Josephson-junction arrays

Abstract: We present experimental results on the dynamics of Josephson arrays. One-dimensional arrays of Josephson junctions connected in parallel by superconducting wires are model systems for the discrete, damped sine-Gordon equation. Excellent agreement between theory and experiment is obtained. Resonant steps in the current-voltage characteristics indicate the appearance of phase-locking between small-amplitude linear waves and moving kinks. Other resonant steps occur at higher voltages and are caused by a parametric destabilization of a high-velocity whirling mode. The influence of boundary conditions and the coupling between two discrete sine-Gordon systems have also been investigated. In Josephson ladders, superconducting islands are connected to other islands by three Josephson junctions. Their dynamics is more complicated than that of the 1D sine-Gordon systems. The Josephson ladders are an interesting model system intermediate between the purely 1D systems and 2D Josephson arrays.

Work done in collaboration with M. Barahona, A. E. Duwel, E. Trías, T. P. Orlando, Shinya Watanabe and Steven Strogatz.
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10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00–11:45 am	**Kurt Wiesenfeld** Georgia Institute of Technology	Josephson Arrays: Puzzles and Prospects

Abstract: Josephson junction arrays have become an archtype in the study of mutual synchronization of coupled oscillators. After briefly recapping some recent theoretical progress, I'll turn to open problems and future prospects for these superconducting systems. These new directions include the role of disorder, modulated spatial patterns, and even intermittent avalanching dynamics which manifests itself experimentally in magnetic "flux creep". I'll also discuss how progress on Josephson arrays may help us tackle other systems of interest in applied physics, specifically laser arrays and quasioptical semiconductor arrays.

2:00 pm	**Guenter Ahlers** University of California Santa Barbara	Pattern formation in Rayleigh-Bénard convection at small Prandtl numbers and with rotation about a vertical axis

This talk will discuss results from and future prospects for experimental studies of Rayleigh-Bénard convection with rotation about a vertical axis. At dimensionless rotation rates $0 \leq \Omega \leq 20$ and for Prandtl numbers $\sigma \simeq 1$, measurements of Küppers-Lortz-unstable patterns have offered a unique opportunity to study spatio-temporal chaos immediately above a supercritical bifurcation. However, for $\Omega \stackrel{\sim}{>} 70$ and $\sigma \simeq 1$ patterns were found to be cellular near onset with local four-fold coordination. They differ from the theoretically expected Küppers-Lortz-unstable state. Stable as well as intermittent defect-free rotating square lattices exist in this parameter range.

Smaller Prandtl numbers ($0.16 \stackrel{\sim}{<} \sigma \stackrel{\sim}{<} 0.7$) can only be reached in mixtures of gases. These fluids are expected to offer rich future opportunities for the study of a line of tricritical bifurcations, of supercritical Hopf bifurcations, of a line of codimension-two points, and of a codimension-three point.

2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**Eberhard Bodenschatz** Cornell University	Bistability with Spiral Defect Chaos and Rolls
3:30 pm	**Alastair Rucklidge** University of Cambridge	Bifurcations of Periodic Orbits with Spatio-Temporal Symmetries

Abstract: Motivated by recent analytical and numerical work on two- and three-dimensional convection with imposed spatial periodicity, we analyse examples of bifurcations from a continuous group orbit of spatio-temporally symmetric periodic solutions of partial differential equations. The presence of spatial symmetries can lead to a doubling of the marginal Floquet multiplier and to bifurcation to drifting patterns. We propose a systematic way of analysing bifurcations of periodic orbits with discrete spatio-temporal symmetries, which is relevant to other pattern formation problems, and contributes to our understanding of the transition from ordered to disordered behaviour in pattern-forming systems.

4:00–4:30 pm	**Jeroen Lamb** University of Warwick	Bifurcations of Discrete Rotating Waves

Wednesday, May 13

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Rajarshi Roy** Georgia Institute of Technology	Temporal Patterns in Coupled Laser Systems: Coherence, Chaos and Communication

Abstract: The emission of light by coupled lasers is a fascinating scientific problem involving the fundamental concepts of coherence and chaos [1]. Such coupled nonlinear systems also lead naturally to new possibilities for optical communications [2]. Experimental and theoretical developments that show how one may utilize coupled chaotic systems for communication will be described [3].

References:

1. L. Fabiny et al., Phys. Rev. A47, 4287 (1993); K.S. Thornburg et al., Phys. Rev. E 55, 3865 (1997).

2. R. Roy and K.S. Thornburg, Phys. Rev. Lett. 72, 2009 (1994); P. Colet and R. Roy, Opt. Lett. 19, 2056 (1994).

3. Q. L. Williams, J. Garcia-Ojalvo and R. Roy, Phys. Rev. A55, 2376 (1997); G. D. VanWiggeren and R. Roy, Science 279, 1198 (1998); J-P. Goedgebuer, L. Larger and H. Porte, Phys. Rev. Lett. 80, 2249 (1998); H. Abarbanel and M. Kennel, Phys. Rev. Lett. 80, 3153 (1998).

9:45-10:30 am	**Peter Ashwin** University of Surrey	Chaotic Intermittency of Patterns in Symmetric Systems

Abstract: I will discuss some recent work looking at generic dynamics and bifurcations of systems with symmetries, or more generally, with invariant subspaces. On varying system parameters it is possible for chaotic states in invariant subspaced to lose stability through various types of blowout bifurcation. Although classification of such blowouts is only partially understood, they do seem to provide a good framework to describe breakdown to spatio-temporal intermittency in physical systems with symmetries. This talk will discuss examples of such intermittent patterns formed in physical systems and also some open problems in the theory.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00-11:45 am	**Katarina Krischer** Fritz-Haber Institute	Pattern Formation at the Electrode/Electrolyte Interface

Abstract: In many electrochemical systems, patterns were observed that cannot be understood in the framework of 'traditional' reaction-diffusion systems. These experiments will be reviewed. In general, the patterns result from the interaction of reaction term, non-local coupling through the electrolyte and (positive or negative) global coupling originating from the operation mode (constant voltage or constant current condition). Different combinations of these three 'ingredients' give rise to a variety of dispersion relations, and thus divers dynamic behaviors. The interplay of the different coupling types explains the experimental observations.

2:00-2:45 pm	**H.G. Purwins** Universitat Münster	Pattern Formation in Lateral Gas Discharge Systems: Quasiparticles and Other Structures in Reaction-Diffusion-Systems

Abstract: Lateral DC and AC gas-discharge-systems exhibit a large variety of self-organized current density patterns. These patterns are experimentally observed in one- and two-dimensional systems and can be stationary or nonstationary and spatially extended or well localized. Examples are domains, hexagons, stripes, spirals, targets, zigzag-patterns, strings, filaments, and clusters of filaments. In this talk the main emphasis is layed on filaments that behave experimentally like quasiparticles.

The experimental results are discussed qualitatively in terms of a three-component reaction-diffusion-model. Numerical solutions of the corresponding partial differential equation are discussed, in particular those representing well-localized solitary filaments that again can be referred to as quasiparticles. These particles can undergo interactions thereby being generated, annihilated, captured, reflected or scattered. The interaction of quasiparticles can also lead to the formation of quasimolecules and large clusters. The experimental work suggests that lateral gas discharge devices can serve as model systems for the investigation of pattern formation in dissipative systems of reaction-diffusion type. The model equation is complex enough to exhibit a rich variety of fundamental patterns at the same time the structure is sufficiently simple to obtain deep insight into the mechanisms that lead to patterns in reaction-diffusion-systems.

2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**F. H. Busse** Universitat Bayreuth	Formation of Structures Far from Criticality in Isotropic Fluid Layers and the Emergence of Patterns in Chaotic States.
3:30 pm	**Ronald Imbihl** Institut für Physikalische Chemie	Pattern Formation in Systems with Memory Effects
4:00–4:30 pm	**Hermann Riecke** Northwestern University	Localized Patterns Related to Experiments in Liquid-Crystal Convection and Granular Media.

Thursday, May 14

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Jerry Gollub** Haverford College	Ordered Patterns and Spatiotemporal Chaos in Parametrically Forced Surface Waves

An experimental survey will be presented of both the primary patterns and the secondary instabilities of parametrically forced surface waves (Faraday waves) in the large system limit. The symmetry of the primary pattern (stripes, squares, or hexagons) depends on viscosity n and driving frequency fo. Hexagons are observed at low fo over the whole viscosity range despite the subharmonic symmetry that tends to suppress them. Possible mechanisms for the occurrence of hexagons for single frequency forcing are discussed. Phase defects occur between hexagonal domains differing in temporal phase by p (with respect to the forcing). Patterns of different symmetry coexist in certain parameter ranges. Some of our observations have been explained theoretically by Chen and Vi=F1als using systematically derived amplitude equations. The basic physics governing the relative stability of the different ordered states can be explained qualitatively in terms of nonlinear wave interactions.

The transition to spatiotemporal chaos (STC) depends on the symmetry of the primary patterns. The Hexagonal patterns undergo a order/disorder transition in which the angular anisotropy in Fourier space declines continuously to zero. Striped patterns at high viscosity become unstable via transverse amplitude modulations in regions of high curvature; this instability results in a spatially nonuniform mixed state in which domains of STC coexist with stripes. This phenomenon may be

understood in terms of a critical curvature that depends on the acceleration. An oscillatory zig-zag secondary instability of the striped pattern is also observed at intermediate viscosities. At smaller aspect ratios, we find that the onset of spatiotemporal chaos is strongly affected by the pattern's symmetry, with symmetric patterns being more stable.

When forced at two different frequencies, a variety of additional wave patterns are realized, including twelve-fold quasicrystalline patterns composed of two hexagonal lattices aligned at 30 degrees relative to each other. Interactions between hexagonal lattices at other angles gives rise to striking "superlattice" patterns. In some cases the resulting patterns are neither simple standing nor traveling waves.

9:45 am	**Mary Silber** Northwestern University	Superlattice Turing Patterns: Why Not?

Abstract: "Superlattice patterns" are characterized as having spatial structure on two disparate length scales; they are spatially-periodic on the large scale, and have beautiful intricate structure on the smaller scale. Such patterns were recently observed in experiments on parametrically-excited surface waves by Kudrolli, Pier and Gollub. I will review results of equivariant bifurcation theory that show that patterns similar to those seen in the experiments arise in a generic symmetry-breaking bifurcation of a spatially-uniform state. These bifurcation results will then be applied to a general two-component reaction-diffusion system in the vicinity of a Turing instability. By considering a particular degenerate bifurcation problem we are able to show that the transitions observed in the hydrodynamic problem cannot be reproduced in the chemical reaction-diffusion system.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Moshe Sheintuch** Technion	Pattern Selection in a Diffusion-Reaction System With Global or Long-Range Interaction

Abstract: We review recent results on pattern selection in the reaction-diffusion one- or two-dimensional system $xt - Dx = f(x, y, l)$, $yt = eg(x, y)$, subject to global ($< x > i = xs$) or long-range interaction; the source functions may be realistic kinetic functions or simple cubic or quintic f(x) functions for which the system admits inversion symmetry. The talk will discuss

(i) physical sources of such interactions and experimental observations in catalytic and electrochemical systems;

(ii) the main emerging patterns and their classification according to their symmetry;

(iii) the bifurcation between patterns;

(iv) approximate solutions based on front-motion and front-interaction, and

(v) patterns when f(x)=0 is tristable and can sustain several fronts.

The rich class of patterns simulated in a ribbon can be classified as stationary-front solutions (including oscillating fronts and antiphase oscillations) and moving pulse solutions (unidirectional, back-and-forth and source-points). Patterns on a disk may be classified as circular (including oscillatory or moving target patterns), rotating (stationary or moving spiral wave) and other patterns.

2:00 pm	**Michael Field** University of Houston	Dynamics of symmetrically coupled systems of identical cells.

We describe recent work, some joint with P Ashwin (Surrey), on the dynamics of symmetrically coupled systems of cells, with particular reference to heteroclinic cycles and cycling chaos.

2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00 pm	**Stephan van Gils** Universiteit Twente	The Homoclinic Twist Bifurcation in Josephson Junction Series Arrays
3:30 pm	**M. Gabriela M. Gomes** University of Porto	Sliced planforms: a representation of three-dimensional symmetries in thin domains

Abstract: Problems described by PDEs in thin domains are often formulated as planar problems (see for example Gunaratne, Ouyang & Swinney [1] for a reaction-diffusion problem and Golubitsky, Swift & Knobloch [2] for the Rayleigh-Bénard convection problem). In particular for problems with Euclidean symmetry (which reaction-diffusion equations satisfy), the expected solutions are often described as planforms which are doubly periodic with respect to a certain two-dimensional lattice. Here we show that some nontrivial symmetries may be missed by this assumption. We consider the thin domain as a slice of a fully three-dimensional problem whose symmetry is described by a lattice in three dimensions. The corresponding *sliced planforms* have now a three-dimensional characterization and different planforms may have different structure along the thin direction. As a result we find symmetries that are not expect in planar systems. In particular, we find that two planar planforms with different wavelength may extend to planforms with the same wavelenght in the three dimensional space.

References

[1] Gunaratne, G.H., Ouyang, Q. & Swinney, H.L. (1994) Pattern formation in the presence of symmetries. *Phys. Rev. E*, **50**(4), 2802-2820.

[2] Golubitsky, M., Swift, J.W. & Knobloch, E. (1984) Symmetries and Pattern Selection in Rayleigh-Bénard Convection. *Physica* **10**D, 249-276.

4:00–4:30 pm	**Dieter Armbruster** Arizona State University	Multi-frequency oscillations in (almost) symmetrically coupled oscillators.

Abstract: Coupled nonlinear oscillators that lead to oscillations where one oscillator oscillates with a multiple of the frequency of the other oscillators are analyzed. Systems with n identical and symmetrically coupled oscillators lead to oscillations with an n-1 fold frequency. Systems with n identical oscillators coupled symmetrically to one different one lead to oscillations with n-fold frequency.

6:00 pm	**Workshop Dinner** Campus Club	

Friday, May 15

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

8:45 am	**Coffee**	Reception Room EE/CS 3-176
9:00 am	**Dwight Barkley** University of Warwick	Bifurcations, Computations, and Open questions in Excitable Media.

Abstract: The dynamics of spiral waves in excitable media has led to interesting developments in bifurcation theory for systems with Euclidean symmetry. I will review the relevant computational studies and show why Euclidean symmetry is important for spiral waves. I will demonstrate a fast simulation code (EZ-Scroll) for real-time interactive simulations of waves in three dimensions. Finally, I will describe two intriguing open mathematical questions motivated by the dynamics of spiral and scroll waves.

9:45 am	**Paul Umbanhowar** University of Pennsylvania	Wave patterns in shaken sand

Abstract: Experiments on vertically vibrated granular layers reveal, at a critical acceleration amplitude (about 2.5 g's), a well-defined hysteretic transition from a flat surface to standing wave patterns oscillating at half the drive frequency. At low frequencies, the hysteresis is large and the patterns are squares, while at high frequencies, the hysteresis is small and the patterns are stripes. For frequencies in the middle of this transition regime, and at acceleration amplitudes below the onset

of planar wave patterns, highly localized, non-propagating, standing waves appear. These localized excitations, which we term ”oscillons”, come in two “flavors”. Like oscillons repel, while opposites attract and bind to form diatoms, tetramers, and polymer-like chains. Near onset, planar patterns of squares and hexagons can be interpreted as oscillon composites.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Ian Stewart** University of Warwick	Belousov and Zhabotinskii meet Bessel and Robin

Abstract: It is well known from numerical simulations and other approaches that reaction-diffusion equations possess solutions of ‘target pattern’ and ‘spiral’ form, similar to phenomena observed in the BZ reaction. The talk will outline joint work in progress with Marty Golubitsky and Edgar Knobloch, which — in a particular abstraction — view such patterns as examples of symmetric Hopf bifurcation. For this purpose we work in a circular domain. In order to prove the existence of such solutions, it turns out that boundary conditions are crucial. With the usual Neumann or Dirichlet boundary conditions, for example, spirals do not occur. Robin boundary conditions, in contrast, lead to spirals and target patterns as the generic Hopf bifurcations. The geometry is closely related to Bessel functions evaluated along radial lines in the complex plane that do not coincide with either the real or imaginary axis. The talk will also indicate the current limitations of this approach. In particular the occurrence of such bifurcations in realistic model equations remains to be demonstrated, and several other important issues remain unresolved.

Tuesday, May 19

IMA Postdoc Seminar:

2:30 pm	**Steven H. Strogatz** Cornell University	A stability problem in the Kuramoto model of coupled oscillators

Abstract: This talk will give a tutorial introduction to the Kuramoto model of coupled nonlinear oscillators. I’ll focus on a linear stability calculation for the continuum limit of this system. The problem involves the continuous spectrum of a linearized integro-differential operator, with some subtle features related to Landau damping in plasmas. Specifically, a certain quantity appears to decay exponentially, even though there are no eigenvalues in the left half plane. (If that sounds mysterious, it is meant to!)

Organizers: Ricardo Oliva & Warren Weckesser

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.

Thursday, May 21

School of Math and IT Public Lecture in 125 Willey Hall

7:30 pm	**Tony DeRose** Pixar Studios	How Geometry is Changing Hollywood

Abstract: Filmmaking is undergoing a digital revolution brought on by advances in computer technology, computational physics, and geometry.

Tony DeRose of Pixar Studios will provide a behind the scenes look at how fully digital films like Pixar’s TOY STORY are made, with particular emphasis on the role that geometry plays in the revolution. He will use the Academy Award-winning short film GERI’S GAME to highlight two technical advances: the use of subdivision surfaces for geometric modeling and the use of simulated cloth dynamics.

DeRose, joined Pixar Studios in 1996. He has developed the primary software tools that allow for seamless integration of animated subdivision surfaces like cloth and skin. He has written more than 50 papers and eight patent applications.

The lecture is sponsored by the IT Alumni Society and the School of Mathematics.

Friday, May 22

IMA Seminar on Industrial Problems

10:10 am	**Todd Salamon** Bell Laboratories	Interfacial Flow

Abstract: Interfacial flows, where two fluid phases are separated by an interface, arise in a variety of applications ranging from the coating of photographic film to the phase separation of oil and water. Some of the outstanding issues related to these flow problems include: (1) describing flows where there are large changes in interfacial topology; (2) developing macroscale models that accurately predict the flow physics at the juncture of two fluid phases and a solid phase, commonly known as a contact line; and (3) determining the flow when surface tension forces become small relative to either viscous or inertial forces. I will highlight these issues by considering examples including the flow of a fluid down an inclined plane and the coating of an optical fiber, and discuss approaches that address the aforementioned issues.

Monday, May 25

Memorial Day (observed), a University of Minnesota holiday. IMA offices will be closed.

Tuesday, May 26

IMA Postdoc Seminar:

2:30 pm	**Marty Golubitsky** University of Houston	TBA

Organizers: Ricardo Oliva & Warren Weckesser

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.

Friday, May 29

IMA Seminar on Industrial Problems

10:10 am	**Mrdjan Jankovic** Ford Research Laboratories	Robust Nonlinear Controller Design: Application to Diesel Engines

Abstract: A method of designing robust controllers for nonlinear systems is applied to a turbocharged diesel engine equipped with a variable geometry turbocharger (VGT) and an exhaust gas recirculation (EGR) valve. VGT varies the turbine flow area as a function of the engine operating condition thus providing faster torque response. EGR valve allows controlled recirculation of the exhaust gas into the intake manifold to reduce NOx emissions. However, simultaneous operation of the two actuators results in significant interactions between them. The control design problem is additionally complicated by inherently nonlinear nature of the diesel engine.

For this design problem we propose a recently developed robust control design method which applies to multi-input nonlinear systems with a known control Lyapunov function (CLF). The robustness achieved by the design is the nonlinear equivalent of that guaranteed by the theory for linear optimal regulators: infinite gain margin and 60 degrees phase margin. A CLF is constructed by employing the tools of geometric control theory. Simplicity of the resulting controller is achieved by judiciously choosing the control oriented model and the CLF. Performance will be illustrated by simulations on a detailed model of a diesel engine and by experimental data.

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IMA NEWSLETTER # 263

June 1–30, 1998

1997–98 Program

EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS

See the Winter, Summer and Fall 1997 IMA Update or http://www.ima.umn.edu/dynsys/ for a full description of the 1997–98 program on Emerging Applications of Dynamical Systems. IMA schedules are subject to revision, particularly during workshops. See http://www.ima.umn.edu/~seminar/sched and http://www.ima.umn.edu/newsltrs/ for the latest scheduling information.

News and Notes

IMA Workshop:

Animal Locomotion and Robotics

June 1–5, 1998
Organizers: James Collins (Boston University) (Chair), Martin Golubitsky, University of Houston, Daniel Koditschek, University of Michigan

See also http://www.ima.umn.edu/dynsys/spring/dynsys10.html

Legged animals typically employ multiple gaits, i.e., phase-locked patterns of limb movements, for terrestrial locomotion. The control of animal locomotion involves a central pattern generator (CPG), which is an intraspinal network of neurons capable of producing rhythmic output. Over the past few decades, mathematicians and engineers have become increasingly interested in animal gaits and locomotor CPGs. This interest has largely been motivated by the need for developing control systems for multi-legged robots. Machines capable of legged locomotion are an attractive option, because they can be used to explore rough and uneven terrain, which is often inaccessible to wheeled vehicles. However, the control of such devices, and in particular the coordination of a large number of legs, poses a difficult technical problem. Engineers and mathematicians have increasingly turned to biology

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, Mississippi 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 Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Wisconsin, Wayne State University.
PARTICIPATING CORPORATIONS: Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Medtronic, Motorola, Siemens, Telcordia Technologies, 3M.

for inspiration, on the assumption that biological evolution has led to optimally-designed control mechanisms for legged locomotion. In this area, contemporary topics of interest include:

1. The role of symmetry and symmetry-breaking in the generation and control of gait patterns
2. The relationship between gait transitions and bifurcations of various kinds
3. Coupled nonlinear oscillators and locomotor CPGs
4. The stability of various gait patterns and their associated phase-locked oscillation patterns
5. Design and control issues for "statically-stable" versus "dynamically-stable" legged robots
6. The effects of noise, feedback gains, and control-loop time delays on the stability of gait patterns
7. Emergent dynamics arising from the interactions between neural (electronic) elements, mechanical elements, and the environment
8. Design and control issues for microrobots
9. "Top-down" versus "bottom-up" approaches to the control of legged robots
10. "Passive" versus "active" control of legged robots
11. Hierarchical control of locomotion

Special IMA Workshop:

Continuum Mechanics and Non-linear Partial Differential Equations

June 8–12, 1998

Organizers: Richard James (University of Minnesota), Stefan Mueller (MPI for Mathematics in the Sciences), Vladimir Šverák, (University of Minnesota)

The workshop is organized in honor of the 50th birthday of Professor John Ball.

See also http://www.ima.umn.edu/dynsys/spring/dynsys13.html

Improved IMA Home Page

The IMA has substantially improved its home page on the World-Wide Web, accessible through web browsers at

`http://www.ima.umn.edu/`

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

`webmaster@@ima.umn.edu`.

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

Schedule for June 1–30, 1998

IMA Workshop:

Animal Locomotion and Robotics

June 1–5, 1998

Organizers: James Collins (Boston University) (Chair), Martin Golubitsky, University of Houston, Daniel Koditschek, University of Michigan

See also http://www.ima.umn.edu/dynsys/spring/dynsys10.html

Monday, June 1

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Dulles, J. Collins

CPG/Oscillators

9:30 am	**Sten Grillner** Nobel Institute for Neurophysiology	The Neuronal Network Underlying Locomotion in Lamprey - Intrinsic Function and Forebrain Control

Abstract: The lamprey is a primitive vertebrate with a nervous system that has the same basic plans as that of more advanced vertebrates. This nervous system can be maintained in vitro (isolated) for several days, and under these conditions the network underlying the locomotor behavior can be activated. This has permitted a detailed analysis of the network that generates the motor pattern and the structures that control the initiation and maintenance of the locomotor activity, as well as the sensory feedback control. The pattern generating part of the network is comprised of excitatory glutamatergic neurons and inhibitory glycinergic neurons. The network on the left and right sides of a segment are coupled with reciprocal inhibition. The membrane properties providing spike frequency adaptation and also post burst hyperpolarisation are important components in the control system. The knowledge has been developed through an interaction between experiments and detailed biophysical modelling. Recently the forebrain control system for goal-directed locomotor activity has been investigated, as well as the control of turning and maintenance of body orientation during movement.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Philip Holmes** Princeton University	Simple Models of Excitable Oscillators And CPGs

Abstract: Chains of coupled oscillators of simple "rotator" type have been used to model the central pattern generator (CPG) for locomotion in lamprey, among numerous applications in biology and elsewhere, where the details of neural architecture are yet unknown. One would like to include more than simple rhythmic oscillations in such models, without going to the full complexity of Hodgkin-Huxley type models.

I will describe a class of flows on tori which capture key features of excitable and oscillatory neural networks of CPGs. The model is motivated by experiments of A. Cohen *et al.* on lamprey CPG with brainstem attached, but may have wider applicability. The analysis involves pairs of coupled oscillators with both excitatory and inhibitory "synaptic" coupling, derived from a Fitzhugh-Nagumo type reduction of the Hodgkin-Huxley equations, and includes bifurcations describing locomotion onset and cessation. I will also discuss traveling wave patterns arising from chains of oscillators, including simulations of "body shapes" generated by a double chain providing input to a kinematic musculature model.

The talk will be based on joint work with D.A. Taylor (Iomega Corporation) and A.H. Cohen (University of Maryland).

2:00 pm	**P. S. Krishnaprasad** University of Maryland	Oscillations and Motion On Lie Groups

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15 pm	**Panel Discussion** James Collins (Boston Univ.), Chair	CPG/Oscillators

Panel discussions will begin with a 10 minute presentation by each of the panel members of either their own work or commentary on the day's talks. The remainder of the hour will be devoted to discussion including participation from the audience.

Panel members today will be Matt Berkemeier (Boston Univesity), Carmen Canavier (University of New Orleans), Judy Schotland (Boston University), and Paul Stein (Washington University).

4:15 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, June 2

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

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

Symmetry/Bifurcation

9:30 am	**Joel Burdick** California Institute of Technology	Controllability and Trajectory Planning for Biomimetic Locomotion

Abstract: "Biomimetic locomotion" is the movement of robotic mechanisms in ways that are analogous to the patterns of movement found in nature. Practically speaking, it is movement that does not rely upon wheels, jets, thrusters, or propellers. Biomimetic locomotion is typically generated by a coupling of periodic internal body deformations to an external constraint. In order to establish notation and key ideas, the talk will begin with a review of the basic mechanics underlying biomimetic locomotion. In particular, the role of principal fiber bundles and connections will be stressed.

A biomimetic locomotion mechanism is "controllable" if there exists an admissible set of controls which drives the system from its current configuration to any nearby configuration. Controllability is a key issue that must be addressed by any comprehensive theory of biomimetic locomotion engineering. Unfortunately, standard controllability methods from nonlinear control theory, such as Chow's theorem, are not well suited to the analysis of biomimetic locomotors. For example, in the case of legged robot mechanisms, the governing mechanics of foot placement are discontinuous. However, conventional controllability tests rely upon differentiation. In order to overcome this difficulty, we present an extension of Chow's theorem to the case of "stratified" configuration spaces, which can be used to model the discontinuous nature of legged locomotion. Even in the cases where the governing mechanics are smooth, standard controllability results are inefficient because they do not take advantage of the inherent structure in biomimetic locomotion configuration spaces. We also present a version of Chow's theory that is adapted to biomimetic locomotion systems.

While controllability is a key issue in the design and analysis of biomimetic locomotion systems, trajectory generation is a primary practical problem for the deployment of complex biomimetic locomotors. Using the controllability framework established in the first part of the talk, the second part of the talk will described trajectory generation methods.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Ian Stewart** University of Warwick	Legged Locomotion from the Symmetry Viewpoint

Abstract: This talk is on joint work with Marty Golubitsky, Luciano Buono, and Jim Collins.

Legged locomotion involves many different gait patterns — for example the horse can walk, trot, canter, or gallop. A key feature of these patterns is phase-locking: each leg moves periodically, with the same period for all legs, with a fixed

pattern of phase relationships. For instance the walk gait has the phase pattern

$$\begin{array}{lll} 1/4 & 3/4 & front \\ 0 & 1/2 & back \\ left & right & \end{array}$$

where the phases are stated as fractions of one complete period.

For many gaits (but not all) the phases are simple fractions of a full period. Moreover, many gaits exhibit spatio-temporal symmetries, and their phase patterns can be derived from those symmetries.

It is believed that the basic rhythms of legged gaits are set up by neural circuits known as Central Pattern Generators (CPGs). The above facts suggest that CPG architecture is symmetric, and that the phase patterns are 'universal' patterns of symmetry-breaking oscillations.

Early work by Collins and Stewart (also Kelso and Schöner) showed that a small number of circuits can generate all the symmetric quadruped gaits. However, these authors did not identify a single circuit that could generate *all* quadruped gaits. Another difficulty was 'spurious conjugacy': for instance any 4-oscillator network that can generate walk and pace can also generate trot, *and* trot and pace have identical dynamical characteristics.

These difficulties disappear if a suitable 8-oscillator network (schematic) is employed. This network has a simple architecture that relates sensibly to known physiology. A generalisation to $2n$ oscillators applies to n-legged animals. The circuit has a tidy 'modular' structure that may make it easily applicable to legged robots. Moreover, the 8-oscillator circuit can exhibit 'mixed mode' patterns corresponding to the rotary and transverse gallops, and to the canter. This appears to be the first model that includes a natural canter.

2:00 pm	**Jill Whitall** University of Maryland at Baltimore	Symmetry, Asymmetry, Bifurcations and Intention in Human Locomotion

Abstract: In the case of bipedal walking, the adoption of a symmetrical anti-phase relationship between the legs is supported from a mechanical modeling perspective. The robustness of this solution is seen in its ready adoption by newly walking infants. However, walking *per se* is rather limiting as the only mode of locomotion and infants soon learn to be more adaptable in their environment by acquiring other forms such as running (also symmetrical and anti-phase) and galloping (asymmetrical). In the first half of the talk I will discuss characteristics of these gaits both as steady state behaviors and when taken through speed-related transitions. Kinematic and kinetic descriptions of these gait patterns will be related to the properties of coupled nonlinear oscillatory systems. In particular, I will concentrate on the bipedal gallop which, unlike the gallop of quadrupeds, appears to be almost always initiated with the "intention" of changing the phasing relationship between the legs.

The second half of the talk also will address the interface of intention with gait, but in this case the focus will be on humans who crawl on their hands and feet to purposefully adopt quadrupedal gait form. Rather than requiring them to change phasing, we asked for a change of direction (forwards/backwards) and postural orientation (prone/supine). The resulting consequences to their coordination (phasing) reflected both mechanical and non-mechanical influences. Overall it is suggested that mechanical constraints have a powerful influence on human locomotion patterns, but they provide only a part of the picture with respect to how the interlimb coordination emerges. The general theme across both sets of data is to question whether the existing models of animal locomotion can accommodate these data, and/or suggest that models seeking to represent (human) gait should incorporate intentional variables along with the necessary mechanical/dynamical variables.

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

3:30–4:30 pm	**Panel Discussion** James Collins (Boston Univ.), Chair	Symmetry/Bifurcation

Panel discussions will begin with a 10 minute presentation by each of the panel members of either their own work or commentary on the day's talks. The remainder of the hour will be devoted to discussion including participation from the audience.

Panel members today will be Martin Golubitsky (University of Houston), S. V. Shastri (SRI International) Steven Strogatz

(Cornell University), and Jill Whitall (University of Maryland at Baltimore)

Wednesday, June 3

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

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

Neuro-mechanical Issues

9:30 am	**Martin Buehler** McGill University	Robots with Simple Legs

Abstract: The purpose of this presentation is to introduce a novel approach to robot design and control for walking. The advantage of the design is, besides its mechanical simplicity, the resulting modeling simplicity and the subsequent potential for mathematical analysis. Walking and running robots are well known for the analytical challenges caused by the high dimensionality of the model, as well as the intermittent nature of the dynamics. The proposed robot designs offer the potential for a practical platform which is also amenable to mathematical analysis.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Fred Delcomyn** University of Illinois	Hexapod walking: From Reality to Simulation

Abstract: Most insects walk using a stereotyped alternating tripod gait in which two triplets of legs, front, rear, and opposite middle, step alternately. Experiments involving perturbations of the locomotor system suggest that sensory feedback aids coordination by providing critical timing cues and ensuring gait stability during walking. Nevertheless, exactly how the nervous systems orchestrates coordination during locomotion is still not entirely clear.

Simulation can in principle be a useful tool to study neural mechanisms of locomotor control because it allows rapid testing of hypotheses about how the nervous system generates patterned motor output. Here, a system for the simulation of an insect, including sense organs, muscles, body, and legs, will be introduced. The simulation system, written in C++, allows users to study elements ranging from isolated leg segments to whole animals with multi-jointed legs. The program assembles the object to be simulated according to information provided in separate, user-prepared configuration files, placing muscles and sense organs where desired. A user may then test hypotheses about how coordinated movements are generated by encapsulating these hypotheses in control algorithms that operate the simulated elements. Because the specification of the input and output variables to which control algorithms have access is made in configuration files rather than in the simulation code itself, algorithms for the control of movements can be written by users who have no knowledge of the simulation code.

The system was developed for the study of neural mechanisms of coordination during walking in insects, but by specifying in configuration files the physical parameters of a hexapod robot and the performance characteristics of its actuators and sensors, it is possible to investigate control mechanisms for these devices as well.

2:00 pm	**S. Epstein & N. Kopell** Boston University (both)	Resonance Tuning Revisited

Abstract: Central pattern generators (CPGs) are often observed to drive motor rhythms at frequencies that differ from the endogenous CPG frequency, but lie close to a principal resonance of the musculoskeletal plant. Such CPGs are said to exhibit 'resonance tuning.' Owing to changes in posture, load, muscle properties, and so on, resonant frequencies can change significantly over time scales as short as a single period. A CPG must therefore be able to adapt its output quickly and robustly in response to sensory feedback if it is to match the resonant frequency of the plant. Previously proposed solutions to this problem are neither quick nor robust. We present a solution in the case of a very simple, four-dimensional 'neuromechanical' model, consisting of a relaxation oscillator reciprocally coupled to a linear oscillator. We show how our feedback scheme works and why some other schemes do not.

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

3:30–4:30 pm	**Panel Discussion** James Collins (Boston Univ.), Chair	Neuro-mechanical Issues

Panel discussions will begin with a 10 minute presentation by each of the panel members of either their own work or commentary on the day's talks. The remainder of the hour will be devoted to discussion including participation from the audience.

Panel members today will be Avis Cohen (University of Maryland), Fred Delcomyn (University of Illinois), John Guckenheimer (Cornell University), and Mark Tilden (Los Alamos National Laboratory).

Thursday, June 4

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

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

Mechanics

9:30 am	**Robert Full** University of California Berkeley	Neuromechanics of Self-Stabilization and Maneuverability in Polypeds

During slow terrestrial locomotion, a wide base of support and a low center of mass allow many-legged, sprawled postured animals to be highly statically stable. By contrast, at faster speeds, we found that even these animals use dynamic gaits. They can operate like spring-mass systems during running. We have shown that many extraordinarily diverse morphological solutions appear to be adequate for running. To understand the importance of sprawled postured morphology during running, we made a simple two dimensional dynamic model that focuses on the horizontal plane instead of the vertical. Sprawled posture animals produce substantial lateral forces in the horizontal plane that have been ignored. To test whether this model was robust to perturbations, we changed the momentum of its center of mass during running. We speculated that the model could not recover from a velocity perturbation, since it has an extremely simple control system with no explicit feedback circuitry. The horizontal plane model was extremely stable to velocity perturbations. Dynamic coupling of body orientation, leg moment arms and leg force production produced remarkable self-stabilization. To understand the influence of posture on stability, we varied morphology from an upright posture to a more sprawled posture and increased the amount of the lateral force proportionally. Wider stances, and therefore greater lateral forces, resulted in faster recovery to perturbations. Our two dimensional model tells us that control can reside in the mechanical design of the system and can be simple. The control algorithms can be embedded in the form of the animal itself. Data from climbing, turning and negotiation of irregular terrain show that maneuverability can result from minor adjustments in the feedforward pattern used during straight-ahead locomotion. Three dimensional dynamic models and direct muscle measurements reveal that the musculo-skeletal complexes act as an important determinant of the system's behavior that can't be predicted from the neural signal alone.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**A. Ruina & A Kuo** Cornell & U. of Michigan	Passive Walking and Pendual: What Can You Do With Mechanics and Feedback, and Why Do You Need a Clock?
2:00 pm	**Jerry Marsden** California Institute of Technology	Lagrangian Reduction and the Falling Cat Theorem

Abstract: We will present a new proof of Richard Montgomery's beautiful "Falling Cat Theorem" which relates optimal reorientation of the falling cat to the dynamics of particles in Yang-Mills fields (governed by Wong's equations). We will begin by putting the theorem in the general context of optimal control problems as studied by Brockett. The new proof

involves ideas of Lagrangian reduction for which there has been much activity lately (Scheurle, Weinstein, Koon, Ratiu, Bloch, Krishnaprasad, Murray, Cendra, Holm, etc. etc.). We shall also present generalizations of the Falling Cat Theorem to the context of nonholonomic locomotion problems.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30–4:30 pm	**Panel Discussion** James Collins (Boston Univ.), Chair	Mechanics

Panel discussions will begin with a 10 minute presentation by each of the panel members of either their own work or commentary on the day's talks. The remainder of the hour will be devoted to discussion including participation from the audience.

Panel members today will be Andy Ruina (Cornell University), Claire Farley, (University of California Berkeley), Arthur Kuo (University of Michigan), and Stefan Schaal (University of Southern California)

6:00 pm	**Workshop Dinner** Campus Club	

Friday, June 5

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

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

Control

9:30 am	**Randall D. Beer** Case Western Reserve University	Design, Evolution and Analysis of Biologically-Inspired Control Systems for Walking

Abstract: Animals are remarkably effective and robust in complex real-world environments. For this reason, they are increasingly serving as a source of inspiration for autonomous robots. Unfortunately, many of the very same properties of biological nervous systems that are responsible for these impressive behavioral capabilites can also make them very difficult to understand and design. This talk will survey a variety of ongoing projects attempting to grapple with some of these difficulties. First, I will briefly describe a series of legged robots whose control is based on Pearson's flexor-burst generator model of cockroach walking and Cruse's model of stick insect walking. Next, I will briefly describe the use of genetic algorithms to evolve dynamical neural controllers for legged locomotion. One of the interesting results of these experiments is that chain reflex, central or "mixed" pattern generation architectures consistently evolve depending on the availability of sensory feedback during evolution. Finally, I will present an analysis of the general principles of operation of a large population of evolved single-leg central pattern generators, as well as a preliminary analysis of phase-locking in Cruse's model of stick insect walking.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10:45 am	**Trevor Drew** University of Montreal	Supraspinal Control Mechanisms Responsible for the Regulation of Locomotion in the Cat.

Abstract: Locomotion is the result of a complex interplay between a centrally generated rhythmic pattern of activity and a host of feedback and feedforward modulatory signals that arise in pathways from the periphery and from the brain. In my presentation, I will discuss how the central structures that give rise to the major descending pathways in the cat may participate in ensuring that the basic locomotor rhythm, generated in the spinal cord, is adapted to the vagaries of the environment and the goals of the organism. I will concentrate on two structures and on two aspects of locomotor control. In the initial part of the presentation, I will concentrate on the role of the brainstem reticular formation in modifying the level of electromyographic (EMG) activity in flexor and extensor muscles of each of the four limbs of the cat. I will present data that suggest this structure is organised to produce coordinated modifications of the EMG activity in each of the four

limbs of the cat. I will further suggest that the PMRF acts through the central pattern generator (CPG) in the spinal cord to ensure that the modifications of gait are appropriately incorporated into the base rhythm. Consideration of the anatomy and physiology of this pathway suggests that relatively simple descending signals may result in complex modifications of gait. In the second part of the presentation, I will concentrate on the role of the motor cortex in producing the fine control of limb trajectory and foot placement that is required in a normal, cluttered environment. I will show that the command signal descending from the motor cortex to the spinal cord contains detailed information about the modification of EMG activity that is required to step over an obstacle in one's path. I will further suggest that the final transformation of this command signal into the resultant pattern of EMG activity depends on the excitability of interneurones that either form part of, or that are influenced by, the CPG.

11:45 pm	**Daniel Koditschek** University of Michigan	Workshop Summary

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Special IMA Workshop:

Continuum Mechanics and Non-linear Partial Differential Equations

June 8–12, 1998

Organizers: Richard James (University of Minnesota), Stefan Mueller (MPI for Mathematics in the Sciences), Vladimir Šverák, (University of Minnesota)

The workshop is organized in honor of the 50th birthday of Professor John Ball.

See also http://www.ima.umn.edu/dynsys/spring/dynsys13.html

This meeting will bring together leading experts in nonlinear PDE and Continuum Mechanics.

The workshop is supported in part by the Max Planck Research Award from the Humboldt foundation, by the School of Mathematics of the University of Minnesota and by the IMA.

Monday, June 8

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Dulles, R. James
9:30 am	**Jerry Marsden** California Institute of Technology	Computational Mechanics and Collision Algorithms.

Abstract: We discuss algorithms and simulations for the collision of rigid and elastic bodies. The algorithms are discussed in the context of variational integration algorithms (in the sense of Veselov) for mechanical systems (both ode's and pde's) with constraints and symmetry. A broader context, including phenomena such as cracking and fragmentation processes, in which complex collision sequences occur, will also be presented.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Felix Otto** Univ. of California Santa Barbara	Fingering instability of fluid flow down an inclined plane: an intrinsic linear stability analysis

Abstract: We consider the flow of a thin film of a viscous fluid down an inclined plane. Experiments show that the initially horizontal front of the thin film breaks into fingers. The emerging finger pattern has a characteristic wave length. Our goal is to recover the instability with characteristic wave length within the standard model of this flow problem.

The standard model is the lubrication approximation of the quasi stationary Stokes flow within the thin flow domain limited by the free surface, driven by gravity and surface tension. Mathematically speaking, it comes in form of a degenerate parabolic (second and forth order) equation for the height h of the free surface. The goal is to establish the instability of its 1-dimensional traveling wave solution and to show that the wave length of the fastest growing perturbation is finite. The standard proceeding is to analyze the linearization of the equation around the traveling wave solution in the moving frame.

The conventional way to analyze the linearization is to consider the eigenvalue problem related to the differential operator T defining the linearization, as done by Troian et al. But Bertozzi and Brenner pointed out that there is a parameter regime where all eigenvalues of T have negative real part, although instabilities are observed experimentally. Bertozzi and Brenner also observed transient growth in numerical simulations of the linearized equation. This is not unconsistent with the theoretical result since T is not normal with respect to, say, L^2.

We propose an analysis of the linearized equation which recovers the instability with characteristic wave number. It is based on the "energy method" applied by Spaid and Homsy. They consider the transient decay or increase of the L^2–norm of solutions to the linearized equation. This amounts to analyzing the spectrum of the symmetric part $Sym_{L^2}(T)$ of T w. r. t. L^2.

2:00 pm	**Weinan E** Courant Institute	Pattern Formation During Liquid Crystal Phase Transition
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15 pm	**Philip Holmes** Princeton University	Two Models From Nonlinear Optics

Abstract: I will discuss recent joint work with J. Nathan Kutz, Alex Mielke, and others in which variants and derivatives of the nonlinear Schroedinger equation (NLS), describing the propagation of light in optical fibers, are studied. In the first, we study a model of a broadband laser in the form of an NLS with non-local terms describing the averaged properties of a quantum mirror, the saturable Bragg reflector. We prove existence-uniqueness results and study the bifurcations and stability of certain "chirped soliton" solutions, comparing them with experimental results from W. Knox's group at Lucent Technologies. In the second, we derive a planar mapping approximating variations in amplitude and phase of a pulse propagating in a lossless optical fiber with periodically varying dispersion. The map's behavior agrees well with simulations of the periodically switched NLS due to S. Evangelides. We analyse the bifurcations of fixed points and global dynamics with a view to describing pulse modulation properties.

4:15 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, June 9

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

9:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:30 am	**Constantine Dafermos** Brown University	Genuinely Nonlinear Hyperbolic Systems of Two Conservation Laws
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

11:00 am	**Louis Nirenberg** Courant Institute	On poperties of solutions of second order elliptic equations
2:00 pm	**Igor Kukavica** University of Chicago	Analyticity for the Navier-Stokes Equations

Abstract: We will review some recent results concerning spatial analyticity of solutions of the Navier-Stokes system. More particularly, we will be interested in estimating the size of the analyticity domain in terms of the physical parameters and address implications related to the minimal scale, decay of the Fourier spectrum, and the size of nodal sets.

3:00 pm	**Coffee Break**	Vincent Hall 502
3:30–4:30 pm	**Maria Esteban** Université Paris Dauphine	About the Evolution of Solid Bodies in an Incompressible Fluid.

Wednesday, June 10

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

9:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:30 am	**François Murat** Université Paris 6	TBA
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**L. C. Young**	Nature & Applications of Young Measures

Abstract: Historical Background. Probability and duality aspects. The reformulation of boundary conditions. Relation to Schwartz distributions, de Rham currents, non-standard analysis and a great variety of applications, notably non-linearity.

Thursday, June 11

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

9:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:30 am	**David Kinderlehrer** Carnegie Mellon University	Remarks about the dynamics of the Fokker-Planck Equation

Abstract: Nonlinear systems which are active across disparate length and time scales are among the most intriguing ones we encounter in nature. Moreover, many of these systems, although persistent for long times, reside in metastable states and their evolution is poorly understood. We are, thus, presented with difficult scientific challenges, both in the derivation of appropriate frameworks for modeling and in the effective use of large scale simulation techniques for their execution. We focus here on a mechanism we believe to be deeply intertwined with these properties. This is the competition between the thermodynamic energy and nearness in the appropriate sense for the distribution of microscopic variables, the 'averages' that describe the evolution of the macroscopic system. The result is a new derivation of the Fokker-Planck Equation as the gradient flux or steepest descent of the ordinary thermodynamic energy (e.g., minus the entropy in the case of ordinary diffusion or Brownian motion.).

This is joint work with Richard Jordan and Felix Otto.

10:30 am	**Coffee Break**	Vincent Hall 502

11:00 am	**Gero Friesecke** University of Oxford	Existence and Nonexistence of Minimizers in the Calculus of Variations

Abstract: We will discuss central examples of variational problems exhibiting a transition from existence to nonexistence of minimizers. The examples share the following two features: a) they are of physical origin (nonconvex elasticity, quantum chemistry, BCS theory of superconductivity), b) traditional lower semicontinuity methods fail to shed light on why, or at which threshold, the transition occurs.

2:00 pm	**Zhouping Xin** Courant Institute	TBA
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**Bernard Dacorogna** EPFL-Lausanne	Some Geometric Restrictions for the Existence of Viscosity Solutions

Abstract: We consider the following Dirichlet problem

$$\begin{cases} F\left(Du\left(x\right)\right)=0, \text{ a.e. } x\in\Omega \\ u\left(x\right)=\varphi\left(x\right), x\in\partial\Omega. \end{cases} \tag{1}$$

where $\Omega\subset\mathbb{R}^n$ is open, $u:\Omega\to\mathbb{R}$, $F:\mathbb{R}^n\to\mathbb{R}$ and $\varphi\in C^1\left(\overline{\Omega}\right)$.

If we let $E=\left\{\xi\in\mathbb{R}^n : F\left(\xi\right)=0\right\}$ then the problem (1) has a (dense set of) solution $u\in W^{1,\infty}\left(\Omega\right)$, under the sole compatibility condition $D\varphi\left(x\right)\in E\cup intcoE$, $x\in\Omega$, where $intcoE$ stands for the interior of the convex hull of E.

We will see that the existence of Lipschitz viscosity solutions under the above assumption, is however far from being guaranteed. Only strong compatibility conditions on the geometry of Ω, on E and on φ ensure the existence of such solutions.

Friday, June 12

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

9:15 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:30 am	**Stuart Anman** University of Maryland	Quasilinear Parabolic-Hyperbolic Systems from Solid Mechanics

Abstract: This lecture surveys recent advances and open problems in the analysis of nonlinear evolution equations of solid mechanics, especially those describing the dynamics of viscoelastic and viscoplastic materials. The governing equations studied here form systems of quasilinear partial differential equations of "parabolic-hyperbolic" type involving singular differential operators of monotone type. Since the unknown in these equations represents a deformation of a body in Euclidean space, it should be locally one-to-one. This requirement is the source of severe analytical difficulties, the treatment of which surprisingly depends on the nature of the dissipation. The role of dissipation is likewise central in dealing with nonlinear effects due to rotation and with the behavior of the spectrum for Hopf bifurcation problems. The general theory is illustrated with a variety of concrete problems.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**K. Bhattacharya** California Institute of Technology	TBA
2:00 pm	**Mitch Luskin** University of Minnesota	On the Stability of Crystal Microstructure

Abstract: Microstructure is a feature of crystals with multiple symmetry-related energy-minimizing states. In the geometrically nonlinear theory of martensite, martensitic crystals are modeled by a non-convex energy density with multiple,

symmetry-related, rotationally invariant energy wells. For this model, the elastic energy of a deformation can generally be lowered as much as possible only by the fine scale mixing of the martensitic variants to form a microstructure. We have developed a theory for the stability of macroscopic variables with respect to small energy perturbations of a simply laminated microstructure. We have applied this theory to analyze the stability and numerical approximation of martensitic and ferromagnetic microstructure.

In joint work with Bo Li, we have applied our stability theory to martensitic crystals that can undergo an orthorhombic to monoclinic (two well) transformation or a cubic to tetragonal (three-well) transformation. Recently, in joint work with Kaushik Bhattacharya and Bo Li, we have applied this theory to the cubic to orthorhombic (six-well) transformation. The fact that the energy density for the cubic to orthorhombic transformation has six wells makes this transformation significantly more difficult to analyze than the two and three-well transformations since the additional wells give the crystal more freedom to deform without the cost of additional energy. The uniqueness of the microstructure for the cubic to orthorhombic transformation, which had been an open problem, is a consequence of this stability analysis.

3:00 pm	**Coffee Break**	Vincent Hall 502
3:30–4:30 pm	**Peter Constantin** University of Chicago	Variational Bounds in Turbulence

Tuesday, June 16

IMA Postdoc Seminar:

2:30 pm	**Marco Antonio Fontelos** Universidad Complutense de Madrid	Break-up of Thin Fluid Tubes

Abstract: Abstract: A classical analysis due to Lord Rayleigh shows that an infinitely long fluid cylinder is unstable and tends to break into drops. Some models have been proposed in order to understand the break-up process. The so-called one-dimensional model may be obtained from Navier-Stokes equations under the ”infinite slenderness” assumption. We study the system that one obtains when considering perfect fluids, Stokes fluids and fluids without surface tension. Finally, some considerations concerning the full Navier-Stokes system will be made.

Organizers: Ricardo Oliva & Warren Weckesser

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, June 17

IMA Picnic

The picnic will be at the Wabun Picnic Area “A” at Minnehaha Falls in Minneapolis. Maps are available in the IMA main office or online at `http://twincities.sidewalk.com/map?EID=17120` . The picnic begins at 4:00 pm. IMA staff, postdocs and visitors and their families are encouraged to come! Please sign up in the IMA main office, 514 Vincent Hall by Monday, June 15.

Tuesday, June 23

IMA Postdoc Seminar:

2:30 pm	**Steve Strogatz** Cornell University	TBA

Organizers: Ricardo Oliva & Warren Weckesser

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.

VIII. DETAILED DESCRIPTION OF 1998 SUMMER PROGRAMS

1. CODING AND CRYPTOGRAPHY

From July 6 – 18, the IMA held a Summer Program on Coding and Cryptography. The organizers were:
Ian Blake, Hewlett-Packard Laboratories
Robert Calderbank, AT&T Laboratories
Andrew Odlyzko, AT&T Laboratories
Vera Pless, University of Illinois-Chicago
The aim of the workshop was to bring together mathematicians, computer scientists, and electrical engineers involved in two disciplines, coding and cryptography, so that the techniques from one area could be applied to problems in the other area. One major goal was be to utilize knowledge from coding to construct good cryptographic schemes.

Both coding theory and cryptography originated with the seminal work of Claude Shannon in 1948. During and before World War II, the main applications of cryptography were military. With the spread of computers and electronic communications after the war, the use of cryptographic schemes for passwords, banking transactions and various aspects of computer security proliferated. So did the uses of error-correcting codes in radio based communication systems, satellite communications and for high fidelity on CD's. These uses and the evolving mathematical theory of codes generated much mathematical activity.

The program consisted of three parts and took place over a period of two weeks:

Week 1: Codes, Design, and Cryptography , July 6-10, 1998

Week 2: Coding, Complexity and Cryptography Sequences, July 13-18, 1998

This part of the program will concentrate on finite geometries, designs, secret sharing schemes, schemes to detect deception and authentication, secret broadcasting schemes, and the construction of cryptographic schemes related to discrete objects. Both finite geometries and more generally combinatorial designs have been used in the analysis and construction of error correcting codes and secret sharing schemes. These uses will be explored to see if they can be utilized in other areas.

Week 1: Codes, Design, and Cryptography July 6–10

Monday, July 6

Monday, July 6

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	F. Dulles
9:20 am	**Vera Pless** University of Illinois at Chicago	Some Connections Between Coding Theory and Cryptography

Abstract: Abstract: This talk will explore some common areas between coding theory and cryptography and attempt to evaluate their status and impact on these disciplines. Views on this vary widely. One answer is that both draw on common subject areas of mathematics, such as number theory, finite fields, algebraic geometry, combinatorial designs and sequences. We review some specific long standing connections including the public key McEliece scheme, cyclic codes and linear feed-back shift registers, MDS codes and threshold schemes, and wiretappers with limited resourses and generalized Hamming weights. We give all the relevant definitions.

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

11:00 am **Gustavus J. Simmons** Keyed Permutation Generators
University of New Mexico

Abstract: Keyed permutation generators are essential components in many information integrity protocols. The generator described in this paper is the simplest instance in a family of such devices which lend themselves to simple high speed VLSI implementation.

Differentiation of n-bit binary sequences defines a family of digraphs in which the vertices are labeled with the sequences in a natural way. When n is a prime, the even Hamming weight sequences are all labels for vertices in simple cycles and the odd weight sequences are labels for vertices in simple cycles and the odd weight sequences are labels for vertices in isomorphic trees rooted on these cycles. The digraphs for composite n are easily derived from the digraphs for the prime factors of n. A simple alteration of the differentiation operation preserves the digraph structure but interchanges – and permutes – the odd and even labels. The 2-graph which results from combining these two digraphs is a surprisingly familiar structure in which every k-bit sequence can be caused to define a permutation on the n-bit sequences; i.e. the k-bit sequences "key" the generation of the permutations. The operation is invertible in the sense that given the key and an input sequence, the output sequence can be easily calculated, or given the key and the output sequence, the input sequence can be equally easily recovered.

The cycle structure for this keyed generation of permutations is shown to be isomorphic to the cycle structure for the iterative parity encoding of binary sequences – a result that is both counterintuitive and the key to the analysis of the generators.

2:00 pm **A. R. Calderbank** Orthogonal Geometry and Quantum Error Correction
AT&T

Abstract: The unreasonable effectiveness of quantum computing is founded on coherent quantum superposition or entanglement which allows a large number of calculations to be performed simultaneously. This coherence is lost as a quantum system interacts with its environment.

In classical computing one can assemble computers that are much more reliable than any of their individual components by exploiting error correcting codes. In quantum computing this was thought to be precluded by the Heisenberg Uncertainty Principle as recently as 2 years ago. But the development of quantum error correcting codes has completely turned this around.

This talk will describe a beautiful group theoretic framework that simplifies the presentation of known quantum error correcting codes and greatly facilitates the construction of new examples.

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

A variety of appetizers and beverages will be served.

Tuesday, July 7

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

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

9:30 am **Pascale Charpin** The Weights of Primitive Cyclic Codes With Two Zeros
INRIA

Abstract: We consider binary primitive cyclic codes generated by a product of two minimal generators. We first present the links between these codes and other objects appearing in cryptography, mainly sequences and boolean functions.

Although these objects, and their "good" properties, have been known for a long time, many problems remain open. We next explain recent results which are concerned with the classification of such cyclic codes by means of their minimal distance.

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

11:00 am **G. A. Kabatianski** — Hash Distances of Codes
INRIA-Rocquencourt

Abstract: The well-known definition of Hamming distance between two vectors is generalized to the case of s vectors. This produces a new notion, hash distances of a code. The second hash distance coincides with the usual minimal (Hamming) distance of a code. The so-called sets of perfect hash functions, widely studied in combinatorics and computer science, are, in fact, the same as codes with the s-th hash distance at least 1.

We study hash distances of codes by coding-theoretic methods trying to obtain good upper and lower bounds on the maximal cardinality of codes with given s-th distance.

Among the new results let us mention an upper bound, which is better than the celebrated Friedman-Komlos bound for the size of sets of perfect hash functions, and an application of linear codes with large hash distance to constructing sets of perfect hash functions with "simple realization". We also discuss one nice combinatorial problem arising from the question when linear codes with nonzero hash distance exist. Many open problems will be set.

This talk is based on a joint paper of L.Bassalygo, M.Burmester, A.Dyachkov, and the speaker.

Wednesday, July 8

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

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

9:30 am **Juriaan Simonis** — Codes and Projective Multisets.
Technical University of Delft

Abstract: The purpose of the talk is to give a matrix-free presentation of the correspondence between linear codes and projective multisets. We generalize the Hill-Brouwer-Van Eupen construction that transforms projective codes into two-weight codes. Remarkably short proofs of known theorems are obtained. A new notion of self-duality in coding theory is introduced.

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

11:00 am **Neil J. A. Sloane** — The Grand Tour in Four Dimensions and Other Mysteries
AT&T

Abstract: How should you choose a nice set of planes in four (or more) dimensions? Or more generally how do you find packings in Grassmannian manifolds? The answers turn out to be connected in a mysterious way with error-correcting codes for quantum computing.

This is based on joint work with Calderbank, Conway, Hardin, Rains, and Shor.

2:00 pm **Alexei Ashikhmin** — Upper Bounds on the Size of Quantum Codes
Los Alamos National Laboratory

Abstract: The paper is concerned with bounds for the quantum error correcting codes. Using the quantum MacWilliams identities, we generalize the linear programming approach from classical coding theory to the quantum case. Using this approach, we obtain Singleton type, Hamming type, and the first linear programming type bounds for quantum codes. We demonstrate that classical Singleton bound is valid for quantum error correcting codes despite the relaxation in the definition of the minimum distance of a quantum code. We also show that Hamming and first linear programming type bounds are also valid for quantum codes practically on all interval $0 < \log K/n < 1$.

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

3:30–4:10 pm	**Gary McGuire** Colorado State University	Characterization of Certain Cinimal Rank Designs

Abstract: In 1987 Dillon and Schatz proved a theorem relating difference sets in elementary abelian 2-groups and designs with the symmetric difference property. As a corollary, they characterized designs with Hadamard parameters (where $v = 2^{2m}$) whose codes have dimension $2m + 2$ and contain the all-1 vector, in terms of difference sets. Dillon, and later Assmus, asked whether the assumption on the all-1 vector could be removed. We show that the answer is yes.

Thursday, July 9

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Kevin Phelps** Auburn University	Perfect codes

Abstract: We will review recent research on combinatorial problems in perfect 1-error-correcting (non-linear) binary codes. This will include recent work on rank and kernals of such codes, nonsystematic codes and the connection to resilient functions, equivalence classes and methods for determining them, and partitions of n-space by perfect codes.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**S. S. Magliveras** University of Nebraska	A Public Key Cryptosystem From Logarithmic Signatures of Finite Permutation Groups

Abstract: A secret key cryptosystem based on certain factorization bases (called *logarithmic signatures*) for finite permutation groups was described by Magliveras in the late 1970's and its algebraic properties were studied by Magliveras and Memon in 1989. We presently announce a new method whereby logarithmic signatures can be used to construct a new type of public key cryptosystem. The new system relies on the fact that there exist *non-transversal* logarithmic signatures which (loosely speaking) can be written as the (functional) *composition* of a small number (usually two) *transversal* logarithmic signatures. Since transversal logarithmic signatures can be inverted efficiently, while non-transversal ones can not, such a factorization can be used as a trap door for a public key cryptosystem. Examples are constructed in the smallest carrier group where this is possible, and algorithms for constructing such trap doors in the general case are discussed.

2:00 pm	**Emanuel Knill** Los Alamos National Laboratory	A Mathematician's Adventures in Experimental Quantum Error-Correction

Abstract: About two years ago, it was realized that standard Nuclear Magnetic Resonance (NMR) equipment could be used to experimentally try out small quantum computations. Last year, we decided to embark on a project to try out the simplest [3,1] quantum phase error-correcting code on an NMR spectrometer available at our laboratory. To our surprise, the experiments were successful. I will describe our experiments and discuss the theoretical questions that arose from our involvement in this work.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30-4:10 pm	**Vladimir D. Tonchev** Michigan Technological University	Linear Perfect Codes and a Characterization of the Classical Designs

Abstract: A new definition for the dimension of a combinatorial t-(v, k, λ) design over a finite field is proposed. The complementary designs of the hyperplanes in a finite projective or affine geometry, and the finite Desarguesian planes in particular, are characterized as the unique (up to isomorphism) designs with the given parameters and minimum dimension.

This generalizes a well-known characterization of the binary hyperplane designs in terms of their minimum 2-rank. The proof utilizes the q-ary analogue of the Hamming code, and a group-theoretic characterization of the classical designs.

6:00 pm	**Workshop Dinner** TBA	

Friday, July 10

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Jack van Lint** Eindhoven University of Technology	Codes with the Identifiable Parent Property

Abstract: If C is a q-ary code of length n and $\mathbf{a}$ and $\mathbf{b}$ are two codewords, then $\mathbf{c}$ is called a descendant of $\mathbf{a}$ and $\mathbf{b}$ if $c_i \in \{a_i, b_i\}$ for $i = 1, 2, \ldots, n$. We are interested in codes C with the property that, given any descendant $\mathbf{c}$, one can always identify at least one of the "parent" codewords in C. We study bounds on $F(n, q)$, the maximal cardinality of a code C with this property, which we call the *identifiable parent property*.

Multimedia publishers can "fingerprint" images by changing perceptually insignificant aspects in order to be able to trace violation of copyright restrictions. Our codes have the property that if the codewords are used as fingerprints and two users create a new image by combining parts of their images, then the new image reveals the identity of at least one of the source images.

Typical results of this paper are of the type

$$3q - 12\sqrt{q} \leq F(n, q) \leq 3q - 1$$

and

$$F(n, q) \geq c \left(\frac{q}{4}\right)^{\frac{n}{3}}.$$

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00–11:40 am	**Gilles Zemor** ENTS	Uniquely Decodable Codes

Abstract: A Uniquely Decodable (UD) Code is a code such that any vector of the ambiant space has a unique closest codeword. This definition seems to have appeared for the first time in the book of Van Lint (Introduction to Coding theory), but although UD codes are appealing combinatorial objects, no systematic search for them has been attempted since. Perfect codes are obvious instances of UD codes : so are direct sums of perfect codes. Are there any other UD codes ? In the nonlinear case, the answer is yes. In the linear case, the question is still open. We have focused on the linear case, and begun a study of their structure. In particular we can show that a linear UD code must have 'nested' perfect subcodes. By using these perfect subcodes, identifying related designs, and applying Llyod theorems together with some nonexistence results for codes we can solve the existence problem of linear UD codes in some cases. In particular, all UD codes of covering radius 2 can be found.

This is joint work with G. Cohen, J. Rifa and J. Tena.

2:00 pm	**Nicolas Sendrier** INRIA-Rocquencourt	The Support Splitting Algorithm and Some of Its Applications

Abstract: We define a signature as a property of a code and of one of its positions which is invariant when the support is permuted ; for instance the weight distribution of the code punctured in the position is a signature. The discriminancy of a signature is measured by how often it will be different for two distinct positions of the same code. We designed an algorithm, using a signature, able to split the support of a code into the orbits of its permutation group. In particular, if

the permutation group is trivial, we can distinguish any two positions of a code. For this algorithm to be practical, we need a signature both discriminant an easy to compute. This is the case of the weight enumerator of the hull (intersection of code with its dual). We will present some applications of the support splitting algorithm in the binary case: the "code equivalence problem", the characterization of weak keys in McEliece's cryptosystem and the computation of permutation groups.

2:40 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00–3:40 pm	**Oscar Moreno** University of Puerto Rico	Codes, Communication Science, Expander Graphs and Exponential Sums

Exponential sums are of importance in algebraic number theory. We retrace the concept of an exponential sum in applied areas such as coding, communication science, and interconnection networks. In this way we transfer knowledge from the applications and improve results by Chevalley-Warning, Ax, Weil and Deligne.

Week 2: Coding, Complexity and Cryptography July 13–18

Monday, July 13

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Dulles, I. Blake
9:30 am	**Tor Helleseth** University of Bergen	On the Crosscorrelation of m-Sequences and Related Topics

Abstract: The crosscorrelation function between two m-sequences of period $p^m - 1$, that differ by a decimation d is defined as

$$C_d(\tau) = \sum_{t=0}^{p^m-2} \omega^{s(t+\tau)-s(dt)},$$

where ω is a primitive pth root of unity. We give a survey of known results on the crosscorrelation function of m-sequences.

Let $f(x)$ be a mapping $f : GF(p^m) \to GF(p^m)$. Let $N(a, b)$ denote the number of solutions $x \in GF(p^m)$ of $f(x + a) - f(x) = b$ where $a, b \in GF(p^m)$ and let

$$\Delta_f = \max\{N(a, b) \mid a, b \in GF(p^m),\ a \neq 0\}.$$

The mapping f is said to be differentially k-uniform if $\Delta_f = k$. This concept is of interest in cryptography since differential and linear cryptanalysis exploit weaknesses of the uniformity of the functions which are used in DES and in several other block ciphers. We show how to consruct sequences with optimal correlation properties from 1-differential power mappings. We also survey results on known results on 2-uniform mappings (called almost perfect nonlinear (APN)).

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**P. Vijay Kumar** University of Southern California	Sequences With Low Correlation and Large Linear Span

The linear span of a sequence is the smallest degree of a linear recursion satisfied by the sequence. An overview of some of the techniques that have been used in the past to construct single or families of sequences having desirable correlation properties will be provided, with an emphasis on those sequences that also have large linear span. It is planned to discuss

bent functions and sequences, GMW, No sequences and their generalizations, sequences derived using Galois rings as well as those arising from hyperovals.

2:00 pm	**Yvo Desmedt** University of Wisconsin-Milwaukee	Computational Complexity and Covert Aspects of Secret Sharing and Their Applications

Abstract: A t-out-of-l threshold scheme is a generalization of a an erasure code. A $(l+1, t)$ erasure code can correct up to $l+1-t$ erasures. In a threshold scheme one also has up to $l+1-t$ erasures. However, the first entry, called the secret key, is always one of these $l+1-t$ erasures and one is not interested in correcting the other erasures, called shares. Secret sharing schemes, which are a generalization of threshold schemes, have mainly been studied from an information theoretical and combinatorial viewpoint.

In many applications the entropy of the secret key is zero, and an information theoretical treatment makes then no sense. We therefore discuss a computational complexity treatment of secret sharing. A way to address this issue is to develop threshold schemes that work over any (Abelian) group. One method presented to achieve this is a generalization of the Reed-Solomon codes. The erasure code and error-correcting properties of this generalized code are discussed in detail. Other methods to achieve group independent threshold schemes have been presented. These rely on combinatorics, e.g., on Vandermonde's convolution and on families of perfect hash functions. We briefly discuss the importance and applications of group independent threshold schemes.

In many threshold schemes, $t-1$ shares have been chosen uniformly. A new research goal is to develop secret sharing schemes in which the shares are not uniform, but corresponds to ordinary pictures, sound, etc. Methods to achieve this are briefly discussed. Such secret sharing schemes may be used towards watermarking.

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

A variety of appetizers and beverages will be served.

Tuesday, July 14

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Ben Smeets** Lund University	Performance of Information Set Decoding in a Correlation Attack on Certain Stream Ciphers

Abstract: This contributions contains a brief overview of methods used for the recovery of the initial state of a linear feedback shift register from a noisy version of the output sequence. Among others a probabilistic recovery algorithm is described where it is assumed that the length of the observed output sequence is close to the unicity distance which is the theoretical lower bound on the average length when recovery is still possible. The presented algorithm makes use of information set decoding of a random linear code. A deterministic algorithm with the same asymptotical complexity is also presented.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Alexander Barg** Bell Labs, Lucent Technologies	Minimum Distance Decoding Algorithms for Linear Codes

Abstract: Let C be a linear code of length n. We examine the following general problem: given a vector y, find the closest code vector to y. We focus on the algorithmic aspects of this problem. We discuss two groups of algorithms: gradient-like decoding and information set decoding. Together this covers most known general decoding methods.

This talk is partly based on joint works with A. Ashikhmin, and with E. Krouk and H.C.A. van Tilborg.

2:00 pm	**Markus Breitbach** University of Tokyo	Digital Watermarking of Still Images - An Application of Communications Theory

Abstract: When compared with analog data, digital data has the advantage to be much more resistant to noise during its transmission or storage. However, this advantage also allows the errorfree copying of information. At the beginning of the information age, where informations are to be sold to multiple customers, this turns out to be a severe drawback.

In order to cope with this problem varios methods of embedding imperceptible watermarks into digital still images have been proposed so that by revealing the existence of the watermark the proprietor of the image could prove his ownership.

We think that communications theory is a suitable basis for the analysis of watermarking schemes. In our contribution we will present a watermarking scheme that generalizes many of today's known watermarking methods, and we will describe it as communications system. Analysis starts from the channel. We distinguish between two channel models: A honest customer applying standard image processing methods on one hand and an offender trying to destroy the watermark on the other. Standard image processing methods include lossy image compression, in particular according to JPEG. This limits the achievable data rate for the watermark. Since JPEG is based on the DCT transform, we analyze the DCT coefficients to obtain limits on the achievable data rate. Further we propose coding schemes to efficiently use the available data rate at a high reliability of the watermark data.

This work was done jointly with Hideki Imai

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30–4:10 pm	**Vladimir Levenshtein** Keldysh Inst. for Applied Mathematics	An Algorithm for Fast Reconstruction of Sequences Using Their Subsequences

Abstract: The problem of reconstruction of an unknown sequence using the minimum number of its subsequences is considered. A number $N(n,t)$ was found that has the following properties: (i) there exist two binary sequences of length n which have the same set from $N(n,t)$ distinct their subsequences of length $n-t$, (ii) any binary sequence of length n can be uniquely defined using any subset from $N(n,t)+1$ its subsequences of length $n-t$. A simple algorithm was also found which reconsruct an arbitrary sequence of length n using any set from $N(n,t)+1$ its subsequences of length $n-t$ (if such a set exists). This algorithm is based on a combination of majority and threshold principles.

Wednesday, July 15

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Gui-Liang Feng** University of Southwestern Louisiana	Improved Geometric Goppa Codes

Abstract: The most important development in the theory of error-correcting codes in recent 20 years has been the introduction of methods from algebraic geometric curves for the construction of linear codes. These so-called *algebraic-geometric codes (AG codes)* were introduced by Goppa. In this talk, we present a new construction of linear codes called improved geometric Goppa codes, and also present a method to determine the designed minimum distances for the codes using only linear algebra. These improved geometric Goppa codes are more efficient than the traditional geometric Goppa codes derived from some varieties, which include algebraic curves, hyperplanes, surfaces, and other varieties. For these improved geometric Goppa codes any $\lfloor \frac{d-1}{2} \rfloor$ or less errors can be corrected by the majority voting scheme decoding procedure. As Goppa codes can be used in cryptography, we believe that the improved geometric Goppa codes can also be used in cryptography.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Andrew Odlyzko** AT&T	Search for Extremal Sequences and Polynomials

Abstract: Many aplications in acoustics, communication theory, and analysis require finite sequences of 0s and 1s or ± 1s that have special autocorrelation properties. These properties are often equivalent to conditions on the polynomials

with that sequence as coefficients. While there are many constructions and theorems known, some of the most intriguing problems remain wide open, and extensive computer searches with special algorithms are often used to search for the best sequences.

2:00 pm	**Kenny Paterson** Hewlett-Packard Laboratories	Reed-Muller Codes, Golay Complementary Sets and Power Control in OFDM

Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation technique that employs frequency diversity to overcome the noise inherent in typical radio channels. The principal barrier to the widespread acceptance of OFDM has been the high power of uncoded OFDM transmissions: the peak power can be as much as n times the mean power, where n is the number of carriers. This results in inefficient amplifier usage and undesirable spectral characteristics.

It is known that using a codeword taken from a Golay complementary set of size k to modulate the carriers results in an OFDM signal with peak-to-mean power ratio at most k. But to obtain a high code rate, a large number of such OFDM codewords are needed. Recently, J.A. Davis and J. Jedwab have shown a striking connection between Golay complementary pairs of sequences ($k = 2$) and Reed-Muller codes. They exhibited $m!/2$ cosets of the binary code $RM(1, m)$ lying in $RM(2, m)$ which consist entirely of binary Golay complementary pairs. These cosets yield $m!2^m$ binary OFDM codewords for $n = 2^m$ carriers which have a peak-to-mean power ratio of only 2 and which enjoy (as a consequence of the code structure) good error-correcting capability and efficient encoding and decoding. They also generalised this result to 2^h-ary pairs, introducing along the way generalisations of the binary Reed-Muller code that are closely related to the now famous quaternary codes of Hammons et al.

We show how these results fit into a larger theoretical picture. We prove that *any* second order coset of an appropriate q-ary generalisation of the first order Reed-Muller code can be partitioned into Golay complementary sets of a certain size. It turns out that the set size depends on a property of the graph associated with the quadratic form defining the coset; the previous results of Davis and Jedwab are then easy corollaries. As well as shedding new light on existing constructions for Golay pairs, the proof of this result answers a long-standing open problem of Tseng and Liu concerning the explicit construction of Golay complementary sets. It also leads to a number of fascinating open questions concerning Golay complementary sets and Reed-Muller codes.

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

3:30 pm	**Andrew Klapper** University of Kentucky	Multicovering Radii of Reed-Muller Codes and the Security of Stream Ciphers

The covering radius of an error correcting code C is the smallest integer r such that every vector is within Hamming distance r of at least one codeword. This concept is closely related to various basic properties of codes. It has been extensively studied for decades by coding theorists.

This talk will concern a new generalization, the multicovering radius. For any integer m, the m-covering radius is the smallest integer r such that every set $v_1, ..., v_m$ of m vectors is within Hamming distance r of a single codeword. That is, for all $v_1, ..., v_m$, there exists a $u in C such that for each i, dist(v_i, u) is at most r$. When m is 1, this is the ordinary covering radius. This concept arose in a recent study of the existence of secure cryptosystems of a certain type. It was shown that cryptosystems of this type that resist a very general type of cryptanalytic attack exist if there is a code with small multicovering radius whose codewords can be efficiently generated.

We describe the basic properties of the multicovering radii of codes, including a variety of general upper and lower bounds. We derive bounds on the multi-covering radii of Reed-Muller codes that can be used to solve the cryptanalytic question mentioned above. In particular we show that there exist families of sequence $B^1, B^2, ...$ that is secure against every cryptanalytic algorithm that attempts to predict $p + p^e$ bits of a sequence $(e > 1/2)$ given a short prefix.

Some of this work is joint with Iiro Honkala.

Thursday, July 16

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

9:15 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Bob Blakley** Texas A&M University	A General Theory of Codes

Abstract: Two 1998 papers [ISBN 3-540-64382-6, pp. 1-31, and ISBN 3-85366-890-9, pp. 1-29] of Itshak Borosh and myself outline the general theory of codes. It is a set-theoretic formulation which embraces essentially all known codes. The idea is that the composition d e consisting of the decode relation d following the encode relation e must never lead away from the plaintext symbol which was originally encoded. In other words the composite relation d e must be an identity partial function whose domain is a subset of the set of all plaintext symbols.

This extremely economical definition is framed to avoid any mention of origin, application, content, context, phenomenology or finiteness. It is meant to be a theory of all codes, and so must not exhibit features distinctive of any one type of code, however important it may be. Yet this general theory contains many results. Also, it leads naturally to several topics in group theory, graph theory, Boolean matrix theory and other areas. Perhaps its most significant aspect so far is the fact that a code is an object within universal algebra. And there are very natural homomorphisms of codes which cause the general theory of codes to obey the three standard isomorphism theorems of universal algebra.

The talk will capsule the two papers. It will also discuss further progress in the theory, as well as in applications of the theory to cryptography, error control, biology and other fields.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Torleiv Kløve** University of Bergen	On the Newton Radius

Abstract: An error $\mathbf{e}$ is (uniquely) correctable by an $[n, k]$ code $\mathcal{C}$ if and only if it is the unique coset leader in its coset. The **Newton radius** $\nu(\mathcal{C})$ of $\mathcal{C}$ is the largest weight of a uniquely correctable error (it was introduced in T. Helleseth and T. Kløve, "The Newton radius of codes", *IEEE Trans. Inf. Theory*, vol. 43, Nov. 1997).

We will discuss some problems on the Newton radius:

- Methods to determine $\nu(\mathcal{C})$.
- The value of (or bounds on) $\nu(\mathcal{C})$ for some codes.
- How are the Newton radius and the covering radius related?

2:00 pm	**Harald Niederreiter** Inst. of Information Processing(Austria)	Beating the Gilbert-Varshamov Bound: The Asymptotics of Algebraic-Geometry Codes

Abstract: Goppa's algebraic-geometry codes over a finite field GF(q) are based on algebraic curves over GF(q) with many rational points. This leads to a well-known connection between the asymptotic behavior of good algebraic-geometry codes and the asymptotics of the number of rational points on algebraic curves with growing genus. In the seminal paper of Tsfasman, Vladut, and Zink from 1982 this was used to beat the asymptotic form of the Gilbert-Varshamov bound in the case where q is a sufficiently large square.

The talk will report on recent joint work of the speaker and C.P. Xing which has produced significant advances in the asymptotic theory of the number of rational points on algebraic curves. The results allow us to beat the asymptotic Gilbert-Varshamov bound in the case where q is a sufficiently large composite nonsquare. Tools from function field theory such as Drinfeld modules and class field towers are important in our approach.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30–4:10 pm	**Bernhard Schmidt** California Institute of Technology	Projective two-intersection sets and Gauss sums

Abstract: We present a classification of the subgroups U of prime index in the Singer cycle G of $PG(n-1,q)$ which are projective $(|U|, n, h_1, h_2)$ sets in $PG(n-1,q)$, i.e. sets of points that meet every hyperplane in h_1 or h_2 points. Our result is that subject to a conjecture on a number theoretic equation there are exactly 15 sporadic examples besides the known ones. We show that the problem of deciding whether U is a projective two-intersection set can be reduced to the evaluation of certain Gauss sums. In virtually all relevant cases, we are are able to reduce this problem further to the determination of all solutions of a number theoretic equation involving a parameter describing the minimum number occuring as an exponent of a prime ideal in Stickelberger's theorem on the factorization of Gauss sums. Assuming the generalized Riemann hypothesis for imaginary quadratic fields, this approach leads to a complete classification in some important cases. We present a table of our new and the previously known examples of subgroups of prime index in G which are projective two-intersection sets. Based on several theoretical results and computer searches, we conjecture that this table is complete.

6:00 pm **Workshop Dinner**
TBA

Friday, July 17

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

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

9:30 am **Agnes Hui Chan**
Northeastern University
Generation of Ultrafast Pseudorandom Sequences

Abstract: Transfer of large, bursty files has been made possible by the advancement of technology in ultrafast optical TDM networks. Such transfers require ultrafast encryption using pseudorandom key streams. However, the implementation of logic at 100 Gbps rate, whether it is electronic or optical, is often limited in scope and extremely expensive. In this talk, we will review the various traditional approaches of generating complex pseudorandom sequences and discuss their limitations in ultrafast networks. We propose a new sequence generator, based on both optical logic and electronic Feedback Shift Registers, that generates sequences at optical rates. We will show that the complexity of the sequence depends on that of the electronic controller.

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

11:00 am **Qing Xiang**
University of Delaware
Gauss sums, Jacobi sums and p-ranks of cyclic difference sets

Abstract: Let F_{2^d} denote a finite field of 2^d elements, with $d \geq 2$. Examples of $(2^d-1, 2^{d-1}-1, 2^{d-2}-1)$ cyclic difference sets in $F_{2^d}^*$ include quadratic residue difference sets, GMW difference sets, and difference sets from monomial hyperovals. We show that, except for a few cases with small d, these difference sets are pairwise inequivalent. This is accomplished in part by examining their 2-ranks. The 2-ranks of all these difference sets were previously known, except for those connected with the Segre and Glynn hyperovals. We determine the 2-ranks of the difference sets arising from the Segre and Glynn hyperovals, in the following way. Stickelberger's theorem for Gauss sums is used to reduce the computation of these 2-ranks to a problem of counting certain cyclic binary strings of length d. This counting problem is then solved combinatorially, with the aid of the transfer matrix method. We give further applications of the 2-rank results, including the determination of the nonzeros of certain binary cyclic codes, and a criterion in terms of the trace function to decide for which β in $F_{2^d}^*$ the polynomial $x^6 + x + \beta$ has a zero in $F_{2^d}^*$, when d is odd.

This work was done in collaboration with Ronald Evans, Henk Hollmann, and Christian Krattenthaler

2:00 pm **W. J. Martin**
University of Winnipeg
A Coding-Theoretic Approach to Ordered Orthogonal Arrays

Abstract: In 1987, Niederreiter introduced the idea of a (T, M, S)-net in base b. A (T, M, S)-net is a collection of points

in the S-dimensional Euclidean unit cube satisfying certain uniformity properties which are useful for applications such as pseudo-random number generation and numerical integration.

A recent result of Schmid and Lawrence generalised the concept of an orthogonal array in order to cast (T, M, S)-nets in a combinatorial framework. An *ordered orthogonal array* $OOA_\lambda(t, s, \ell, v)$ is an array with $s\ell$ columns — partitioned into s groups of size ℓ — having entries from an alphabet of v symbols and satisfying the following condition: in any t columns which are left-justified within their respective groups, each t-tuple of symbols occurs exactly λ times.

In this talk, we construct a family of association schemes similar to the Hamming schemes (but not P-polynomial) which afford a context in which we may extend standard results from the theory of orthogonal arrays and error-correcting codes to the case of ordered orthogonal arrays and *ordered codes*. In particular, we present a generalised Rao bound, a linear programming bound and a MacWilliams-type theorem for the linear case.

This is joint work with D. R. Stinson at the University of Waterloo.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm	**Ian F. Blake** Hewlett-Packard Laboratories	Point Counting on Elliptic Curves

Abstract: Elliptic curves are of interest in both coding and cryptography. As curves of genus one, they yield codes with a minimum distance one less than allowed by the Singleton bound. In cryptography, the additive group of points on the curve serves as the underlying group for the implementation of protocols such as key exchange and digital signature. In either case it is of importance to determine precisely the number of points on the curve. This number, by the Hasse-Weil theorem, is within $2\sqrt{q}$ of $q + 1$, where q is the field size. In cryptography, the field size might be on the order of 10^{150} or greater and it is a mathematically challenging problem to determine computationally effective algorithms to achieve this point counting. The talk will review some of the recent work on this problem.

Organizer's Assessment of Coding and Cryptography Summer Program-July 6-18,1998

One goal of the workshop was to explore the connections between the two areas so that techniques in one area could be brought to bear on the other area. Participants included mathematicians, computer scientists and electrical engineers from academia and industry. They came from many different countries. Many worked in either coding or cryptography ,but some were from related areas. The workshop was quite successful in bringing together many different points of view, presenting new results in the separate areas, and giving diverse connections between the two areas.

The first week featured a sequence of talks on the new area of quantum computing. If quantum computing is successful, it will change cryptography radically as it will be possible to factor in polynomial time. It turns out that the use of quantum error-correcting codes, whose theory parallels that of classical error-correcting codes, are necessary for the success of quantum computing.

An emphasis of the workshop was on issues of complexity and combinatorial designs and their relation to coding and cryptography. The talks proceeded at a leisurely pace with much time for quesions and discussion. Indeed, there was quite a bit of discussion after most talks. Several paricipants told me that it was the best conference that they had ever attended. I think that the workshop stimulated many new ideas and approaches.

-Vera Pless

2. Mathematical Modeling in Industry - A Workshop for Graduate Students

July 22 to July 31, 1998

Fadil Santosa and Fernando Reitich, Organizers

The IMA held a 10-day workshop on Mathematical Modeling in Industry. The workshop is designed to provide graduate students and qualified advanced undergraduates with first hand experience in industrial research.

Format

Students worked in teams of up to 6 students under the guidance of a tutor from industry. The tutor will help guide the students in the modeling process, analysis and computational work associated with a real-world industrial problem. Each team will be expected to make a public oral presentation and submit a written report at the end of the 10-day period.

Projects and Industry Mentors

There were be 6 teams participating in the workshop. The following industry scientists served as mentors:

Participant	Affiliation	Topic
Len Borucki	Motorola	Chemical/Mechanical Planarization in Semiconductor Manufacturing
John Hoffman	Secure Computing	Problems in Computer Security
Shirley Min	Medtronic	Computer Simulation of Intracardiac Electrogram Sensing
David Misemer	3M	Modeling crystal growth
Craig Poling	Lockheed Martin	Mathematics in GPS
Samer Takriti	IBM Watson Research Ctr	A Pricing Problem in the Energy Industry

RESULTS

Detailed reports from each of the teams are available on the web at
`http://www.ima.umn.edu/preprints/october98/october98.html`
and also in the IMA Preprint series as preprint #1589.

PROGRAM SCHEDULE

Wednesday, July 22

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

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	W. Miller, F. Santosa & F. Reitich
9:30 am	**David Misemer** 3M	Modeling Crystal Growth

Abstract: Growing a population of small crystals from solution is an important process for several industries, particularly those engaged in the production of photographic, agricultural and pharmaceutical chemicals. The properties that need to be controlled range from the shape and type of individual crystals to the distribution of sizes in the final population. All of the properties are determined, at least in part, by the availability of the crystal constituents in the surrounding solution.

In this activity, we will concentrate on the distribution of crystal sizes in the population. Two processes are important in determining the distribution: nucleation, the creation of new crystals, and growth, the addition of material to existing crystals.

We will developing numerical simulations that predict the evolution of the crystal population.

10:10 am	**John Hoffman** Secure Computing	Problems in Computer Security

Abstract: The area of mathematics/computer security that the problem will be from is an area known as Non-Interference. For the development of highly secure systems, it is crucial that all information flows through the system are understood. In particular, covert channels or unexpected information flows can be particularily damaging to a secure system which is attempting to maintain a high level of confidentiality. (For example, a top secret process should not under normal situations be able to send or otherwise signal any information to a secret process.) Non-Interference is a mathematical technique that

allows a system model to be analyzed for these kinds of information. Traditionally these non-interference techniques or theorems have been stated in a hierarchical (POSet based) fashion. That is, they have emphasized a military approach where information is labelled "top secret" or "secret" and no information from "top secret" is allowed to flow to "secret". Recently there have been attempts to generalize this approach, to allow information to flow between processes in a non-hierarchical (non partially ordered set) way. The problem will be to examine this new framework, and to work some small examples to gain an understanding of this approach and to validate whether or not in can be used to actually analyze real systems.

10:50 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Samer Takriti** IBM Watson Research Ctr	A Pricing Problem in the Energy Industry

Abstract: The electric power industry is going through deregulation. The current picture of a single utility controlling the market in a specific region will soon disappear. Instead, there will be power producers who sell their production to a power pool; and power suppliers who will buy power from the pool and sell it to their customers. As a result, generating companies are faced with increasing demand uncertainty and must consider volatile electricity prices in their operations. We study scheduling the generating units in the presence of uncertainty. The resulting models are large-scale mixed-integer programs. We investigate solving these models using branch-and-bound (CPLEX) and using Lagrangian relaxation.

1:30 pm	**Shirley Min** Medtronic	Computer Simulation of Intracardiac Electrogram Sensing

Abstract: The project will lead students step by step from understanding the electrogram sensing problems to mathematical formulation and solution. At the beginning of the workshop, an overview of the mathematical modeling and the importance in tachyarrhythmia research of implantable cardioverter and defibrillator industries will be given. Then the background and the existing models of the sensing will be reviewed. Mathematical description of the problem will be developed and the surface integral equations will solved by numerical methods i.e. Method of Moment. Other alternative approaches such as Finite Element Analysis will also be discussed. Students are required to develop the computer code by using Matlab or other tools and to obtain the solutions to a few simple geometries of pacing/sensing leads. On the last day of the workshop, students need to give a presentation on their findings and submit a written report.

2:10 pm	**Len Borucki** Motorola	Chemical/Mechanical Planarization in Semiconductor Manufacturing

Abstract: Chemical/mechanical polishing utilizes a liquid slurry containing very fine particles to planarize the surface of a wafer. The slurry coats the top of the wafer and is pressed between the wafer and a flexible circular rotating pad. The surface of the pad in contact with the slurry is not smooth, but contains grooves and is "conditioned" so that the entire surface contains small scratches. The conditioning process greatly affects the polishing performance. So does the pressure applied to the pad.

The liquid in the slurry is formulated to have a slight etching effect. As the slurry flows over the wafer surface, the suspended particles abrade the surface and the liquid in the slurry etches the abraded area. The process is somewhat like using a rotary buffer to polish the finish on a car. The overall objective is to understand how the achievable flatness is related to the many variables that might be controlled in the process, for example the pressure on the pad, the rotation speed, the sizes of the particles in the slurry, the pad conditioning, the chemistry of the liquid used in the slurry, etc.

2:50 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:10 pm	**Craig Poling** Lockheed Martin	Mathematics in GPS

Abstract: On day 1, 7/22/98, we will briefly survey the wide range of commercial, defense and scientific applications where the Global Satellite Positioning System GPS has had a major impact. Following the introduction we will develop the mathematical notation, definitions and framework necessary to describe: 1) conventional, 2) differential and 3) interferometric,

or real time kinematic, positioning and attitude determination. Following the development of the mathematical framework necessary to understand GPS we will pose selected challenging mathematical problems which arise from attempts to determine ultra high precision interferometic position and attitude. GPS workshop participants will then be given selected reading material to aid in the mathematical modeling and solution of the problems that are posed.

During the course of the workshop GPS antenna and receivers will be used to collect pseudorange and integrated carrier phase data. This data can be used by the workshop participants to evaluate their mathematics models and approaches to achieving high precision position and attitude estimates. Some exposure to classical mechanics, numerical analysis, and stochastic processes would be helpful, although the workshop is designed to be self-contained.

By the end of the GPS workshop, participants will have learned how to resolve positions anywhere on the earth to sub-centimeter accuracy and to determine orientation in space with accuracy comparable to that achieved byVLBI methods using quasars (e.g. 1.4 x 10-8 degrees). In addition, workshop participants will have been exposed to some of the principal research questions which arise in high precision GPS position and attitude applications.

Recommended GPS reference:

Global Positioning System: Theory and Applications; Volumes 1 and 2, edited by Bradford W. Parkenson, James J. Spilker Jr., Associate Editors, Penina Axelrod and Per Enge, Volume 164; Progress in Astronautics and Aeronautics, Paul Zarchan Editor-in-chief, published by AIAA 1996.

4:00 pm	**IMA Tea++**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Friday, July 31

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

Presentation of Final Reports

8:15 am	**Coffee**	Reception Room EE/CS 3-176
8:30 am	**Group 1**	Modeling Crystal Growth
9:30 am	**Group 2**	Problems in Computer Security
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10:45 am	**Group 3**	A Pricing Problem in the Energy Industry
11:45 am	**Lunch** Pizza Party	Reception Room EE/CS 3-176
12:45 pm	**Group 4**	Computer Simulation of Intracardiac Electrogram Sensing
1:45 pm	**Group 5**	Chemical/Mechanical Planarization in Semiconductor Manufacturing
2:45 pm	**Coffee Break**	Reception Room EE/CS 3-176

PROGRAM PARTICIPANTS

NAME	INSTITUTION	DATES
ABHYANKAR, KASHI	Univ. of California - Berkeley (Mathematics)	JUL 21 – AUG 1
ALFORD, JOHN	Univ. of Houston (Mathematics)	JUL 21 – 31
AMBROSE, DAVID	Duke Univ. (Mathematics)	JUL 21 – 31
ARNOLD, JON	St. Charles, MN 55972 (RR2 Box 219A)	JUL 22 – 24
AUERBACH, RUTH LYNN	University Maryland	JUL 21 – 31
BAER, NAOMI	Central High School	JUL 22 – 24
BELTUKOV, ALEKSEI	Tufts Univ. (Mathematics)	JUL 21 – AUG 1
BORUCKI, LEN	Motorola Inc	JUL 21 – 31
CHOI, JONGHO	Univ. of Wisconsin - Madison (Mathematics)	JUL 21 – 31
COGAN, NICK	Montana State Univ. (Mathematical Sciences)	JUL 21 – 31
CONNELL, CAMERON	New York Univ. (Courant)	JUL 21 – 31
CUTLER, ARNIE	(University Minnesota)	JUL 22 – 31
DOBSON, DAVID	Texas A&M Univ. (Math)	JUL 21 – 31
FOGARTY, TIERNAN	Univ. of Washington (Applied Mathematics)	JUL 20 – AUG 1
FOURNELLE, CONNIE GERADS	Univ. of Kentucky (Mathematics)	JUL 21 – AUG 1
GULDBERG, NANCY	17185 Valley View Rd (Eden Prairie High School)	JUL 22 – 24
GURSKI, KATHARINE F.	Univ. of Maryland (Applied Mathematics)	JUL 21 – AUG 1
HOFFMAN, JOHN	Secure Computing Corporation	JUL 5 – 31
HOFFNUNG, LEONARD	Univ. of Kentucky (Mathematics)	JUL 21 – AUG 1
JADALLAH, HALA	Indiana Univ. (Mathematics)	JUL 21 – AUG 1
KERBEL, NATALIYA	Univ. of Minnesota (Mathematics)	JUL 22 – 31
KIEBER, JAN	200 East 10th Ave (Shakopee High School)	JUL 22 – 24
KIMBER, JENNIFER LEIGH	Kent State Univ. (Math and Computer Science)	JUL 21 – 31
LI, JIANBO	Univ. of Kentucky (Mathematics)	JUL 21 – 31
LIN, ANHUA	The Johns Hopkins Univ. (Mathematical Sciences)	JUL 20 – AUG 1
LITTMAN, WALTER	Univ. of Minnesota (Mathematics)	SEP 1 – AUG 31
MEGRAW, MOLLY	The Johns Hopkins Univ. (Mathematical Sciences)	JUL 20 – AUG 1
MILLER, CHARLES	Univ. of Notre Dame (Mathematics)	JUL 22 – 31
MIN, SHIRLEY	Medtronic, Inc	JUL 21 – 31
MISEMER, DAVID	3M	JUL 21 – 31
NELSON, JENNIFER	17185 Valley View Rd (Eden Prairie High School)	JUL 22 – 24
NIGAM, NILIMA	Univ. of Delaware (Mathematical Sciences)	JUL 21 – AUG 1
OSBURN, ROBERT	Louisiana State Univ. (Mathematics)	JUL 21 – AUG 1
PARK, PETER J.	Caltech (Applied Mathematics)	JUL 22 – 31
PATINKIN, SETH	Indiana Univ. (Mathematics)	JUL 7 – 31
PEERCY, BRADFORD E.	Univ. of Utah (Mathematics)	JUL 21 – 31
PENG, DANPING	UCLA (Mathematics)	JUL 21 – 31
PETRACOVICI, BORIS	Univ. of Illinois at Urbana (Mathematics)	JUL 21 – AUG 1
POLING, CRAIG	Lockheed Martin	JUL 21 – 31
ROSENBERG, NOAH	Stanford Univ. (Mathematics)	JUL 21 – AUG 1
SEO, SEUNG SUK	Univ. of Minnesota (Mathematics)	JUL 22 – 31
SHEKHAR, VIVEK	Univ. of Cincinnati (Mathematical Sciences)	JUL 21 – 31
SHETTY, SACHINDEV	Arizona State Univ. (Mathematics)	JUL 21 – AUG 2
STERLING, DAVID	Univ. of Colorado (Applied Mathematics)	JUL 21 – 31

TAKRITI, SAMER	IBM Research (Thomas Watson Research Center)	JUL 21 – 31
TUPPER, PAUL	Stanford Univ. (Scientific Computing and Computational)	JUL 21 – AUG 1
ZEIGLER, DAVID	Texas A&M Univ. (Mathematics)	JUL 21 – AUG 1

IX. PUBLICATIONS

1. IMA PREPRINT SERIES.

The following is a list of papers which appeared in the IMA Preprint Series during the period of September 1, 1997 to August 31, 1998.

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 # Author/s Title

1511 **Tuncay Aktosun and Paul E. Sacks**, Inverse Problem on the Line without Phase Information

1512 **Susanne C. Brenner and Li-yeng Sung**, Balancing Domain Decomposition for Nonconforming Plate Elements

1513 **Amadeu Delshams and Tere M. Seara**, Splitting of Separatrices in Hamiltonian Systems with one and a half Degrees of Freedom

1514 **David E. Keyes, Dinesh K. Kaushik and Barry F. Smith**, Prospects for CFD on Petaflops Systems

1515 **Jens Lorenz, Steven Jackett and Wangguo Qin**, Self–Organized Criticality: Analysis and Simulation of a 1D Sandpile

1516 **Gary Hatfield and Peter J. Olver**, Canonical Forms and Conservation Laws in Linear Elastostatics

1517 **Bernd Krauskopf and Hinke Osinga**, Growing Unstable Manifolds of Planar Maps

1518 **Kazufumi Ito and Fernando Reitich**, A High–Order Perturbation Approach to Profile Reconstruction. I: Perfectly Conducting Gratings

1519 **Brian J. Suchomel, Benito M. Chen and Myron B. Allen III**, Network Model of Flow, Transport and Biofilm Effects in Porous Media

1520 **Avner Friedman, Bei Hu and Juan J.L. Velazquez**, Asymptotics for the Biharmonic Equation near the tip of a Crack

1521 **Avner Friedman, Bei Hu, and Juan J.L. Velazquez**, Propagation of cracks in elastic media

1522 **M.J. Friedman and J.W. Demmel**, An efficient algorithm for locating and continuing connecting orbits

1523 **Matti Lassas, Margaret Cheney, and Gunther Uhlmann**, Uniqueness for a wave propagation inverse problem in a half space

1524 **Amadeu Delshams and Rafael Ramírez-Ros**, Singular separatrix splitting and Melnikov method: an experimental study

1525 **Miaohua Jiang and Yakov B. Pesin**, Equilibrium measures for coupled map lattices: existence, uniqueness and finite-dimensional approximations

1526 **Christopher K.R.T. Jones**, A geometric approach to systems with multiple time scales

1527 **Yi A. Li and Peter J. Olver**, Well-posedness and blow-up solutions for an integrable nonlinearly dispersive model wave equation

1528 **Brian J. Suchomel, Benito M. Chen, and Myron B. Allen**, Macroscale properties of porous media from a network model of biofilm processes

1529 **Àngel Jorba**, A methodology for the numerical computation of normal forms, centre manifolds and first integrals of Hamiltonian systems

1530 **Bennett Chow and Robert Gulliver**, Aleksandrov reflection and nonlinear evolution equations, I: the n-sphere and n-ball

1531 **A. Litman, D. Lesselier, and F. Santosa**, Reconstruction of a 2-D binary obstacle by controlled evolution of a level-set

1532 **George Avalos**, Exact controllability of a thermoelastic system with control in the thermal component only

1533 **Susanne C. Brenner**, The condition number of the Schur complement in domain decomposition

1534 **Avner Friedman and Bei Hu**, A Stefan problem for a protocell model

1535 **Laurent O. Jay and Thierry Braconnier**, A parallelizable preconditioner for the iterative solution of implicit Runge-Kutta type methods

1536 **Kurt Lust and Dirk Roose**, Computation and bifurcation analysis of periodic solutions of large-scale systems

1537 **Brian T. Nguyen**, On comparisons of time-domain scattering schemes

1538 **Yi A. Li, Brian Nguyen, and Peter J. Olver**, Solitary waves in the critical surface tension model

1539 **Matthias K. Gobbert and Andreas Prohl**, A discontinuous finite element method for solving a multi-well problem

1540 **Andreas Prohl**, A first order projection-based time-splitting scheme for computing chemically reacting flows

1541 **Andreas Prohl**, A second order projection based time-splitting scheme for computing chemically reacting flows

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Fire

X. COMPUTING AND CONFERENCE FACILITIES AT THE IMA

Workstations

The IMA's basic computer facilities consist of a network of two SGI Indigo^2 IMPACT 10000 workstations, an SGI O2 R5000, an SGI Indigo^2 and a POWER Indigo^2, an SGI Challenge S, and three SGI Indigo workstations running IRIX; two 300 MHz Pentium II workstations, twelve 200 MHz Pentium Pro workstations, and a dual-processor 200 MHz Pentium Pro workstation running Linux; and four Sun Microsystems SPARCstation 10 workstations. A four-processor SGI Challenge L with two gigabytes of memory for intensively computational jobs is connected by an ATM fiber optic link to the network. In addition, we have five Pentium-class or better machines running Windows NT, over thirty X-terminals, and twelve Apple PowerMacintoshes.

Programming languages which are available include several versions of Fortran (HPF, Fortran 90, Fortran 77), C++ and C, Common Lisp, Pascal, and Java, among others. The MPI parallel programming system is also available, as is the mathematics package MATLAB, the statistical program S-PLUS, and the symbolic-manipulation programs Maple and Mathematica. The IMA has adopted LaTeX as its standard text formatting program. The X Window System is available on most machines.

Communication between our network and the Internet is provided by an ATM switch communicating at 155 Mbps over a fiber optic link to the University backbone. As the University is a charter member of Internet2, we can maintain this high data rate with other institutions connected by the vBNS. Our main servers and three high-end workstations are directly connected by this ATM switch. Many of our remaining workstations are connected to the switch through 100 Mbps Fast Ethernet connections, and all of our computational resources have access to the local network and the Internet.

Supercomputers

Researchers at the IMA also have access to the high-performance computing resources of the University of Minnesota Supercomputing Institute (MSI). These resources currently include:

- A Cray C90 with 12 processors and 512 megawords of memory
- A Cray T3E-900 with 272 nodes and 512 megawords of memory per node
- An IBM SP with 56 processors and a total of 25.6 gigabytes of memory
- An SGI Origin 2000 with 32 processors and 8 gigabytes of memory, and a four-processor SGI Origin 200

In addition, IMA researchers have access to several other MSI laboratories around campus equipped with high-performance SGI workstations and visualization equipment.

Conference Facilities

The IMA Conference Hall and adjoining reception room were originally completed in winter 1989, but it has recently been substantially upgraded. The Conference Hall seats 130 in soft chairs, is air-conditioned and sound-proofed, and is equipped with a control booth, six video cameras, and a projection system for display of computer and video output. The conference hall is on the building ATM network so that real-time output from a remote computer on the Internet or from a local laptop computer can be easily displayed. A white board, overhead projector, workstation, slide projector, and VCR are standard equipment, and a movie projector may be provided readily on request. Teleconferencing capability is also available.

XI. PARTICIPATION OF WOMEN AND MINORITIES IN IMA PROGRAMS

The following figures may be smaller than actual numbers for several reasons:

1. Except for the hiring of postdocs, the IMA has no formal mechanisms for determining whether our participants are members of a minority group. Thus the figures for long and short term visitors are based primarily on the lists of participant names and their home institutions. This may lead to an undercounting of some minorities.
2. The figures include only visitors who registered with the IMA and were supplied with office space. A considerable number of local participants in our workshops do not bother to register with us.
3. Submission of the requested information is not mandatory and is not a precondition of future acceptance to the IMA workshops. Consequently, there are times when participants simply decline to provide information.

	Total	*Women*	*Hispanics*	*African-American*	*Asians*
Emerging Applications of - Dynamical Systems (Sept, 1997 – June, 1998)					
Postdocs (12 months)	11	2	2	–	2
Long-term visitors (4 weeks to 1 year)	73	13	–	–	5
Short-term visitors (less than 4 weeks)	896	104	10	2	88
Coding and Cryptography July 6–August 18, 1998	109	12	1	–	6
Mathematical Modeling In Industry July 6–August 18, 1998	46	11	–	–	8

XII. RELATIONS WITH THE UNIVERSITY OF MINNESOTA

There is a continuing exchange of scientific and technical expertise between the IMA and several departments of the University of Minnesota. Faculty members in mathematics, chemical engineering, aerospace engineering, electrical engineering, chemistry, computer science, physics, and economics have been particularly active in this regard. Three specific aspects of the academic life at the University of Minnesota have been especially useful in facilitating these exchanges:

1. The first feature, which appears to be unique to Minnesota, is the administrative structure of the Institute of Technology (IT). This institute is a collegiate level body which consists of the departments of mathematics, computer science, physics, chemistry, earth sciences, architecture, and five engineering departments.
2. The second feature concerns the physical plan of the University of Minnesota. The departments and libraries in IT are very close to each other. All these facilities are within a five-minute walk of Vincent Hall.
3. The third feature is the long-standing tradition of interdisciplinary research among mathematicians, scientists, and engineers at the University.

The administrative structure of IT, the physical proximity of the facilities, and the tradition of interdisciplinary research at the University create a healthy scientific milieu for an applied mathematics institute. The IMA has flourished in this environment. In this part we give a very brief description of the many interactions between the scientists at the IMA and the scholars at the University.

The response of the IMA visitors to the scientific environment at the University has been uniformly high. Special mention should be made of favorable comments of many visitors for the easy access to the resources in the Mathematics Library in Vincent Hall.

1. SCHOOL OF MATHEMATICS

The IMA and the School of Mathematics and the Mathematics Library are housed in Vincent Hall on the main campus at the University of Minnesota. This proximity offers many efficiencies and conveniences for the research activities of visitors to the IMA. It is easy for IMA visitors to frequent the seminars and colloquia in the School of Mathematics. Indeed, dozens of IMA visitors have presented seminar and/or colloquium lectures in the School of Mathematics (and in other departments at the University). In addition, faculty members and graduate students from the School of Mathematics have given dozens of lectures in the IMA. This interchange continues at an increasing rate.

The faculty in the School of Mathematics shares its expertise with the IMA visitors in a number of ways. Doors are open in Vincent Hall, and Minnesota has a tradition of being a friendly place. Several faculty members including

Donald Aronson	Albert Marden	Steven Orey
Jerry Ericksen	Larry Markus	David Sattinger
Eugene Fabes	Richard McGehee	George Sell
Dennis Hejhal	Wei-Ming Ni	James Serrin
David Kinderlehrer	Johannes Nitsche	Dennis Stanton
Walter Littman	Peter Olver	Hans Weinberger
Mitchell Luskin		

have contributed significantly to the planning and coordination of the IMA programs.

Don Aronson	Leon Green	Peter Olver
John Baxter	Robert Gulliver	Marian Pour-El
Bernardo Cockburn	Naresh Jain	Peter Rejto
Jack Eagon	Harvey Keynes	Joel Roberts
Paul Edelman	David Kinderlehrer	Yasutaka Sibuya
Robert Ellis	Walter Littman	Dennis Stanton
Eugene Fabes	Larry Markus	James Thompson
Mark Feshbach	Charles A. McCarthy	Hans Weinberger
Lisl Gaal	Richard Moeckel	Dennis White
Larry Gray		

were involved as participants in the 1989–90 program.

Don Aronson
Bernardo Cockburn
Jerald Ericksen
Eugene Fabes
Steven Gaal
Robert Gulliver
Satyanad Kichenessamy
David Kinderlehrer
Walter Littman
Mitchell Luskin
Norman Meyers
Wei-Ming Ni
Johannes Nitsche
Peter Olver
James Serrin
John Sullivan
Hans Weinberger

participated in the 1990–91 program.

Matthew Brahm
Bernardo Cockburn
Jack Eagon
Paul Edelman
Eugene Fabes
Steven Gaal
Robert Gulliver
Max Jodeit
Satyanad Kichenassamy
Walter Littman
Mitchell Luskin
Charles McCarthy
Richard McGehee
William Messing
Peter Olver
Peter Rejto
Steve Sperber
Dennis Stanton
John Sullivan
Peter Webb
Hans Weinberger
Dennis White

participated in the 1991–92 program.

Bernardo Cockburn
Paul Edelman
Eugene Fabes
Robert Gulliver
Naresh Jain
Max Jodeit
Satyanad Kichenessamy
Nicolai Krylov
Walter Littman
John Lowengrub
Mitchell Luskin
Larry Markus
Wei-Ming Ni
Peter Rejto
John Sullivan
Hans Weinberger

participated in the 1992–93 program.

John Baxter
Bernardo Cockburn
Panagiota Daskalopoulos
Paul Edelman
Eugene Fabes
Bert Fristedt
Jay Goldman
Larry Gray
Mary Ann Horn
Naresh Jain
Nicolai Krylov
Walter Littman
Jeffrey Rosenthal
Dennis Stanton

participated in the 1993–94 program.

Eugene Fabes
Satyanad Kichenassamy
Nicolai Krylov
Boris M. Levitan
Walter Littman
Peter Rejto
David Sattinger

participated in the 1994–95 program.

Eugene Fabes
Naresh Jain
Walter Littman
Mitchell Luskin
Wei-Ming Ni
Sam Northshield
Peter Olver
John Sullivan
Vladimir Sverak

participated in the 1995-96 program.

Alfred Aeppli	Satyanad Kichenassamy	Claudia Neuhauser
Donald Aronson	Michael Kouritzin	Karel Prikry
John Baxter	Walter Littman	Peter Rejto
Maury Bramson	John Lowengrub	Michail Safonov
George Brauer	Mitchell Luskin	David Sattinger
Yi-Ju Chao	Albert Marsden	George Sell
Bernardo Cockburn	Lawrence Markus	James Serrin
Dennish Hejhal	Richard McGehee	Vladimir Sverak
Naresh Jain	Max A. Jodeit	Richard Moeckel
		Hans Weinberger

participated in the 1996-97 program; and.

Donald Aronson	John Baxter	Bernardo Cockburn
Paul Garrett	Jay Goldman	Naresh Jain
Donald Kahn	Nicolai Krylov	Walter Littman
Mitchell Luskin	Lawrence Markus	Charles McCarthy
Richard McGehee	Richard Moeckel	Wei-Ming Ni
Peter Olver	Marian Pour-El	Karel Prikry
Fernando Reitich	Michail Safonov	David Sattinger
George Sell	Vladimir Sverak	Hans Weinberger

particiapted in the 1997-98 program.

The relationship between the IMA and the School of Mathematics is quite harmonious. Sharing of resources and financial aid for visitors are frequently given by the School of Mathematics.

The Ordway Visiting Professorship program within the School of Mathematics has added substantially to the scientific milieu of the IMA. The following mathematicians have or will have spent a significant period at the IMA under this program:

1982–83:	Haim Brezis	Saunders MacLane
	Charles Conley	
1983–84:	Shmuel Agmon	Daniel Kleitman
	Robert Aumann	
1984–85:	Felix Browder	Joseph Keller
	Constantine Dafermos	Jean Louis Lions
1985–86:	Kiyoshi Ito	
1986–87:	Jim Douglas	
1987–88:	George Andrews	Richard Askey
1988–89:	Richard Beals	James Glimm
1989–90:	Ciprian Foias	Jürgen Moser
	Michael Herman	
1990–91:	John Ball	Bernard Malgrange
	Luis Caffarelli	Hiroshi Matano
	Morton Gurtin	
1991–92:	Gene Golub	Jerrold Marsden

	Victor Klee	
1992–93:	Wendell Fleming	Robert Liptser
1993–94:	Persi Diaconis	S.R.S. Varadhan
1994–95:	George Papanicolaou	
1995–96:	John Ball	
1996–97:	Rolf Rannacher	Ridgway Scott
1997–98:	Jürgen Moser	

2. OTHER DEPARTMENTS

The IMA receives strong and enthusiastic support of many other faculty members at the University of Minnesota. As noted above, the interaction between mathematicians, engineers, and scientists from a multitude of departments is a part of a long tradition of interdisciplinary research. The University of Minnesota is well known for nurturing such activities.

Professors from several departments participated actively in several of the workshops given at the IMA. These included (Partial listing):

DEPARTMENT OF ACCOUNTING:

John Dickhaut

DEPARTMENT OF AEROSPACE ENGINEERING AND MECHANICS:

Adair Aguiar	Heath Johnson	Perry Leo
Garry Balas	Ellen Longmire	Thomas Lundgren
Jerry Ericksen	T. Posberg	P.R. Sethna
Roger Fosdick	T. Tezduyar	Lev Truskinovsky
Richard James	William Warner	Y. Zhao
Daniel Joseph		

DEPARTMENT OF BIOSCIENCE:

Todd Thoresen

DEPARTMENT OF BIOSTATISTICS:

Bradley P. Carlin	Chap Le
Li Chen	Thomas Louis
Anne Goldman	Lance Waller
Patricia Grambsch	

DEPARTMENT OF BIOCHEMISTRY:

Leonard J. Banaszak	Douglas H. Ohlendorf
Renhao Li	Alexander Watters
Dimitry Makhailov	

DEPARTMENT OF CHEMICAL ENGINEERING:

Rutherford Aris
Frank Bates
John Dahler
H. Ted Davis
Prodromos Daoutidis
Jeff Derby
Barry Hughes
Hanchul Kim
Chris Macosko
Mohammed Sahimi
L.E. Scriven
Ilja Siepmann
Matthew Tirrell

DEPARTMENT OF CHEMISTRY:

Tom Allison
Jan Almlöf
Xavier Assfeld
Yao-Yuan Chuang
Laura Coitino
Jose C. Corchado
Christopher J. Cramer
John Dahler
Jiabo Li
Tiqing Liu
Timothy Lodge
Marcus Martin
C. Alden Mead
Bongjin Moon
Albert Moscowitz
William C. Necoechea
Eric Patterson
Maria Planas
Steven Prager
Ivan Rossi
Bradley Smith
Jay Srinivasan
Maria Toplar
Donald Truhlar
Jianhu Xing
Tianhai Zhu

DEPARTMENT OF CIVIL AND MINERAL ENGINEERING:

Efie Foufoula-Georgio
Walter J. Maier
Henryk Stolarski

ELECTROCHEMICAL ENGINEERING:

Philip Cheung

DEPARTMENT OF COMPUTER SCIENCE:

Rahul Aggarwal
Dan Boley
A. Borchers
Feng Cao
Anthony Chronopoulos
Robert Cooley
Du Ding-Zhu
David Fox
M.L. Gini
Tara Gustafson
Eui-Wong Han
L. Jay
V. Kumar
Dalvinder Malhotra
Haesun Park
Chang Peng
Doug Perrin
Linda Petzold
J. Ben Rosen
Y. Saad
Ahmed Sameh
Ben Schafer
E. Shragowitz
Jaideep Srivastava
Andreas Stathopoulos
Shang-Hua Teng
Anand Tripathi
Jun Zhang

DEPARTMENT OF ECONOMICS:

John Chipman
Hulya Eraslan
John Geweke
Leonid Hurwicz
James Jordan
J. Kareken
Andrew McLennan
Edward Prescott
Marcel K. Richter
Christopher Sims
Michihiro Ohyama
Neil Wallace

DEPARTMENT OF ELECTRICAL ENGINEERING:

Mosoud Alghoniemy
Fred Bailey
Kevin Buckley
Enis Cetin
Ed H. Chi
T. Georgiou
Anand Gopinath
Khaied Hamdy
J.E. Holte
Mos Kaveh
Pat Kumar
Vipin Kumar
Bruce E. Lee
Mohammed Nafie
Nikmil Sarpotdar
Jeff Shamma
Sameh Sowelam
Allen Tannenbaum
Andrew Teel
Ahmed Tewfik
Lan Tse-Hue

DEPARTMENT OF FINANCE AND INSURANCE:

John Kareken David Runkle

DEPARTMENT OF GEOLOGY:

Kaushik Bhattacharya Tine Larsen David Yuen
Peter Huddleston H.O. Pfannkuch

DEPARTMENT OF MECHANICAL ENGINEERING:

Max Donath Francis Kulacki
Richard Goldstein E.M. Sparrow

DEPARTMENT OF OPERATIONS AND MANAGEMENT SCIENCE:

M. Taaffe

SCHOOL OF PHYSICS AND ASTRONOMY:

Dan Dahlberg James Kaklios M. Shifman
Allen Goldman Walter H. Johnson Oriol Valls
J. Woods Halley Thomas Jones Thomas Walsh
Morton Hamermesh Gautmam Khera Paul Woodward
Russell Hobbie Shlomo Marianer William Zimmermann

DEPARTMENT OF RADIOLOGY

Xiaoping P Hu

POLITICAL SCIENCE DEPARTMENT:

John Aldrich Robert Holt

SCHOOL OF SOIL SCIENCE:

Satish C. Gupta

DEPARTMENT OF PHYSIOLOGY

John N Eian Matha Flanders

SCHOOL OF STATISTICS:

Kathryn Chaloner Charles Geyer Luke Tierney
Dennis Cook Bret Musse Ming-Dauh Wang
E. Funo Gary W. Oehlert Sandy Weisberg
Seymour Geisser William Sudderth

DEPARTMENT OF MEDICINAL CHEMISTRY:

David Ferguson Philip Portoghese
Kenneth E. Lind William C. Stevens
Germana Paterlini

BELL MUSEAUM OF NATURAL HISTORY:

Phillip Regal

VA MEDICAL CENTER:

Stephen Strother

MINNESOTA SUPERCOMPUTER CENTER:

Barry Bolding
Dave Doherty
Barry Rackner
Shepard Smithline
Rogene M. Eichler West

LABORATORY MEDICINE AND PATHOLOGY:

Pilar Forns

DEPARTMENT OF COMPUTER SCIENCE (Duluth Campus):

Carolyn Crouch
Donald Crouch
Douglas Dunham

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING (Duluth Campus):

Marian Stachowicz

DEPARTMENT OF NATURAL RESOURCES RESEARCH (Duluth Campus):

Zhuangyi Lui

MATHEMATICS AND STATISTICS (Duluth Campus):

Bruce Peckham
Harlan Stech

GORTNER LABORATORY:

Jim Hem

CENTER FOR MAGNETIC RESONANCE RESEARCH:

Eric Ray Cohen
Kamil Ugurbil

INSTITUTE OF TECHNOLOGY (DEAN'S OFFICE):

Willard Miller, Jr. (during his term as Associate Dean for Finance & Planning, 1994–1997)

Several of the scientists mentioned above have taken an active role in the planning of IMA workshops. These include J. Aldrich, J. Chipman, H.T. Davis, J. Ericksen, R. Fosdick, A. Goldman, B. Hughes, L. Hurwicz, R. James, J. Jordan, J. Kareken, T. Lodge, S. Prager, M.K. Richter, L.E. Scriven, M. Tirrell, Donald Truhlar, N. Wallace and D. Yuen. Also, P. Khargonekar, M. Kaveh and, A. Tannenbaum of the Department of Electrical Engineering were involved in planning for the 1988 Summer program on Signal Processing; Sanford Weisberg and Luke Tierney were organizers for the 1989 Summer program on Applied Statistics; and T. Tezduyar of the Department of Aerospace Engineering and Mechanics helped to plan the 1993 Summer program on Mesh generation. Seymour Geisser, Patricia Grambsch, and Sandy Weisberg were co-organizers of the 1997 Summer program on Statistics in the Health Sciences.

Rutherford Aris (Chemical Engineering) and L.E. Scriven were on the Advisory Committee for the 1986–1987 program on Scientific Computation. In addition to Jerry Ericksen, who is mentioned above, Leonid Hurwicz has served as a program coordinator at the IMA. Dan Joseph (Mechanics) was a member of the Organizing Committee for the program on Nonlinear Waves. Richard James (Aerospace Engineering and Mechanics) was Chair of the Organizing Committee for the 1995–96 program on Materials Science.

Several departments, in addition to the School of Mathematics, have jointly sponsored some of the IMA programs and short-term visitors. This includes the Departments of Aerospace Engineering, Chemical Engineering, Operations and

Management Science, Chemistry, Finance and Insurance, Political Science, Statistics and Physics and the Carlson School of Management. In addition the Departments of Aerospace Engineering and Chemical Engineering have made some joint appointments of senior scientists with the IMA.

PUBLIC HEALTH

Mindy Geisser George Maldonado

GEOMETRY CENTER

John Sullivan

3. OTHER UNIVERSITY OF MINNESOTA CENTERS

The IMA has jointly sponsored three workshops with the Minnesota Supercomputer Institute and cosponsored two workshops with the Center for Interfacial Engineering. Two workshops have had added sessions hosted by the Geometry Center. IMA participants have been cosponsored by the Army High Performance Computing Research Center (AHPCRC), the Corrosion Center, the Center for Control Theory and Dynamical Systems, the Institute for Theoretical Physics, The Geometry Center and (most notably) the Minnesota Supercomputer Institute. The Geometry Center and the IMA have held joint programming which made use of The Geometry Center's graphics, computing facilities and technical staff and the IMA's conference facilities and expertise to offer workshops on computer graphics and visualization.

XIII. THE IMA PARTICIPATING INSTITUTIONS PROGRAM

The Institute for Mathematics and its Applications was established by the National Science Foundation in 1982. The IMA brings mathematicians together with engineers and scientists in order to stimulate the flow of interesting and relevant problems and to encourage the development of means of solving them. It seeks to provide an atmosphere conducive to collaboration and the creation of new ideas.

From its inception, the IMA has been supported by a consortium of universities known as the IMA Participating Institutions. In addition to the IMA programs which take place in Minnesota, the IMA runs programs with the Participating Institutions. An annual contribution of $10,000 is requested from each PI. Here are some of the main aspects of this program.

1. The IMA contributes $30,000 per year as seed money for IMA Participating Institution Conferences, which are held on the campuses of the Participating Institutions. This seed money can be (and often is) supplemented by funds from other sources.

   During 1997–98, there were six Participating Institution Conferences: **Topics in Number Theory** at Pennslyvania State University on July 30– August 3 1997. **Workshop on Superconductivity** at Purdue University in the Spring of 98 **Global Analysis 30 Years Later** at the University of Cincinnati on March 25–28 1998. **Waves & ContinuationMethods in Biology & Related Areas** at the University of Pittsburgh on September 26–28 1998. **Stochastic Control and Nonlinear Filtering** at the University of Southern California on December 14–16 1997. **7th Conference of the International Linear Algebra Society (ILAS)** at the University of Wisconsin on June 3–6 1998.

2. The IMA conducts Summer Program for Graduate Students. Each year the program brings together for four weeks in the summer, two selected students from each Participating Institution. The students live in a dormitory on one of the PI campuses; the location of the campus changes from year to year. During the four weeks, there is a series of (related) lectures given by four senior mathematicians. Funding for the lecturers and the student living expenses is assumed by the IMA. The total support is approximately $55,000.

   The summer 1990 program, on **ALGEBRA**, was held at the University of Michigan, Ann Arbor. The summer 1991 program, **TOPOLOGY**, was held at Northwestern University; the summer 1992 program, **PARTIAL DIFFERENTIAL EQUATIONS**, was at Indiana University; the summer 1993 program was **PROBABILITY** at Ohio State University; in the summer of 1994 the program was **COMPLEX ANALYSIS**, held at the University of Pittsburgh. The program chosen for the summer of 1995 was **DIFFERENTIAL GEOMETRY**, held at the University of Illinois, Urbana. For the summer of 1996, the program was **HARMONIC ANALYSIS**, at the University of Wisconsin, Madison. The program for the summer of 1997 was **SELECTED TOPICS IN ALGEBRAIC TOPOLOGY**, and will be held at the University of Chicago. The 1998 program will be **TOPOLOGY OF MANIFOLDS** at the University of Iowa in Iowa city.

3. The IMA conducts programs aimed at bringing Participating Institutions and industry together.

   (a) Industry Day. On December 5, 1989 the IMA held its first Industry Day at the University of Chicago, with speakers from Industry and audience from PI's. Other Industry Days are being organized at other PI campuses, and initiated locally. The IMA will support 50% of all expenses involved.

   (b) The IMA holds in Minnesota more extended workshops for industry and PI's. Thus on October 12–13, 1990 there was a two day workshop "Connecting to Industry"; on October 7–11, 1991 a workshop "Transfer of Mathematics to Industry in the US and France"; and on May 22–23, 1993 a tutorial workshop "How to Start an Industrial Postdoc Program". The purpose of these events is to enhance contact between industrial and academic mathematical scientists. The IMA supports all PI participants in such events at the level of at least 50%.

   (c) The IMA runs an industrial postdoctoral member program. An industrial postdoc is supported 50% by industry and 50% by NSF. It is hoped that the IMA experience and impact of this program will prove useful for Participating Institutions who wish to build on this model.

4. Mathematics Department Heads of Participating Institutions hold annual meetings at O'Hare Airport to discuss both the IMA and PI programs, as well as issues of common interest. The IMA covers the costs of these meetings.

5. A portion ($3,000 per year) of the contribution from each Participating Institution is set aside for the direct benefit of the faculty and graduate students of the Participating Institution. These funds can be used in any of the following ways:

(a) To pay expenses for faculty members, including faculty members from other departments, or graduate students who wish to participate in IMA programs.

(b) To pay expenses for IMA visitors who are invited to lecture on the campus of the Participating Institution.

(c) To supplement other IMA funds for the support of long-term participation of faculty members in IMA activities.

(d) To provide complementary support for the workshops which are already partially supported, see (1), (3a).

6. Participating Institutions receive:

   (a) Information about annual programs

   (b) A monthly newsletter specifying activities at the IMA

   (c) IMA Update, which appears quarterly

   (d) IMA Preprints

   (e) IMA Abstracts

   (f) IMA Volumes (approximately 8 volumes per year)

   The IMA Newsletter is routinely sent to the heads of the science and engineering departments at the Participating Institutions.

7. Finally, faculty and graduate students from the PI's get preferential treatment in terms of local support when they wish to participate in IMA programs.

Because of the interdisciplinary nature of the IMA mission and programs, many university faculties, in addition to the mathematical sciences departments, benefit from a Participating Institution membership.

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.

XV. THE IMA PARTICIPATING CORPORATIONS PROGRAM

A major part of the mission of the Institute for Mathematics and its Applications is to bring mathematicians together with engineers and scientists in order to stimulate the flow of interesting and relevant problems and to develop the means of solving them. Interaction with and input from industrial scientists and engineers is vital to this mission.

For this reason the IMA is actively seeking industrial firms who are interested in establishing ties between their scientists and engineers and the participants in the various IMA programs. We have found that the resulting scientific interaction coming from such ties to be of great value to all parties involved.

Participating Corporations will receive:

- Information about annual programs
- Access to IMA activities, including participation in the Seminar on Industrial Problems
- IMA Consulting Services
  The Director will make regular visits to the Corporation to increase interaction on scientific problems.
- IMA Update, a quarterly publication listing upcoming activities
- Monthly Newsletter specifying titles, abstracts and visitors at the IMA
- Abstracts of Research Publications
- IMA Volumes
- IMA Annual Report
- Participating Corporations will be listed on the IMA stationery

A Participating Corporation is asked to commit itself to provide strong encouragement to its scientists and engineers to participate in the workshops, Seminar on Industrial Problems, and other activities of the IMA. These visits provide opportunities to meet and establish scientific ties with both junior and senior researchers. They are therefore very important to the success of the IMA.

Participating Corporations will be invited to serve on the Industrial Advisory Committee of the IMA, which is a source of programmatic and other ideas to the Institute.

An annual contribution of $10,000 is requested from a Participating Corporation.

PARTICIPATING CORPORATIONS:

Bellcore, Eastman Kodak, EPRI, Ford, Fujitsu, General Motors, Honeywell, IBM, Lockheed Martin, Lucent Technologies, Motorola, Siemens, 3M.

XIV. RELATIONS WITH INDUSTRY AND GOVERNMENT LABS

The IMA mission is broad-ranging and multifaceted. It is seeking meaningful scientific interactions between mathematicians, engineers and other scientists. Since a need for new mathematical ideas and a source of new mathematical problems both can be found in the research of many persons from various organizations (e.g., academia, industry and government labs) the IMA invites scientists from all these places to participate in its programs. For example, the following individuals from corporations and laboratories participated in IMA workshops, seminars and other meetings during the 1997–97 program on Emerging Applications of Dynamical Systems and in the 1998 summer programs on Coding and Cryptography and Mathematical Modeling in Industry :

AMIN, MASSOUD	Electric Power Research Institute (EPRI)	MAR 5 - 7
ANDERSH, JONATHAN	3M	APR 27 - MAY 1
ANDERSON, MEREDITH	American Express Financial Advisors	MAR 7 - 7
ANDERSON, ROGER	3M	MAY 1 - 3
APTE, CHID	IBM T.J. Watson Research Center	MAR 6 - 8
ASHIKHMIN, ALEXEI	Los Alamos National Laboratory	JUL 5 - 12
AXELROD, ANTHONY	3M	APR 26 - MAY 1
BAKER, DANNY	General Motors Corporation	MAR 1 - 3
BANASZUK, ANDRZEJ	United Technologies Research Center	APR 26 - 29
BARG, ALEXANDER	Bell Laboratories	JUL 12 - 18
BAUM, HOWARD	NIST	FEB 28 - MAR 1
BELL, TONY	Interval Research Corporation	JAN 14 - 18
BLAKE, IAN	Hewlett Packard	JUL 11 - 18
BLAKEY, PETER A.	Motorola	APR 23 - 24
BORUCKI, LEN	Motorola Inc.	JUL 21 - 31
BURNS, TIM	NIST	SEP 14 - 19
BUTERA, ROB	NIH	JAN 17 - 23
CALDERBANK, ROBERT	AT&T Labs	JUL 4 - 10
CARMEIN, DAVID	Minnesota Virtual Simulations	MAR 7 - 7
CASTRO, PETER	Eastman Kodak Co.	MAY 1 - 3
CHANG, ROSEMARY	Silicon Graphics Computer Systems	NOV 8 - 9
CHIPROUT, ELI	IBM Austin Research Lab	NOV 23 - 25
CHOCK, DAVID	Ford Motor Company	JUN 27 - 28
COWSAR, LAWRENCE	Bell Labs, Lucent Technologies	JUL 7 - 8
DAI, LONG	NIH	FEB 8 - 13
DAVIS, MICHAEL J.	Argonne National Laboratory	OCT 26 - 31
DINH, THOMAS	Medtronic	MAR 12 - 14
ELFADEL, ABE	IBM T.J. Watson Research	NOV 22 - 25
EMAMI-NAEINI, ABBAS	SC Solutions, Inc.	APR 26 - 28
FELDMANN, PETER	Bell Labs Innovations	NOV 23 - 25
FLEMING, PHILIP	Motorola	FEB 19 - 20
FREUND, ROLAND	Bell Laboratories	NOV 22 - 26
ARRETT, DAVID	Lockheed Martin	JUL 8 - 8
GEISLER, CHARLES	Minnesota Technology Incorp.	JUL 8 - 8
GILLBERG, JEFFREY	Medtronic	MAR 9 - 13
GUNNEY, BRIAN	Medtronic	MAR 9 - 14
HAMLEN, CUSHING	Medtronic	MAR 9 - 14
HOFFMAN, JOHN	Secure Computing Corporation	JUL 5 - 31
JANKOVIC, MRDJAN	Ford Research Laboratory	MAY 28 - 30
JENISON, TROY	Medtronic	MAR 13 - 13
KAHLERT, MARTIN	Siemens AG	NOV 22 - 26
KETTENRING, JON	Bell Communications Research	MAR 6 - 8
KNILL, EMANUEL	Los Alamos National Laboratory	JUL 5 - 10
KUNDERT, KEN	Cadence	NOV 23 - 25

LULING, MARTIN	Schlumberger-Doll Research	JAN 8 - 11
MANRODT, CHRIS	Medtronic	MAR 9 - 14
MAY, STEVE	Medtronic Inc.	MAR 9 - 14
MCCURLEY, KEVIN	IBM Research	MAR 6 - 7
MCKENNA, JAMES	Bell Comm. Research	NOV 8 - 9
MCMAHON, CATHY	Medtronic	MAR 9 - 12
MEARS, DAVID	NIH	FEB 10 - 14
MEHDI, KHAWAR	Medtronic	MAR 9 - 13
MIN, SHIRLEY	Medtronic, Inc.	MAR 9 - 14
MISEMER, DAVID	3M	JUL 21 - 31
MIURA, ROBERT	NIH	FEB 4 - 13
MORISSETTE, JOSEE	Medtronic, Inc.	MAR 9 - 14
MORRIS, MILTON	Guidant Corporation	MAR 9 - 14
MULIER, FILIP	3M	MAR 7 - 7
NGUYEN, TUYEN	IBM	NOV 23 - 25
NUMRICH, ROBERT	Cray Research, Inc.	JUL 7 - 8
ODLYZKO, ANDREW	A.T.&T. Laboratories	JUL 12 - 16
OLSON, WALTER	Medtronic, Inc.	MAR 9 - 14
ORAN, ELAINE	NRL	FEB 28 - MAR 1
OSINGA, HINKE	California Institute of Technology	SEP 1 - AUG 31
PATERSON, KENNETH	Hewlett Packard Laboratories	JUL 5 - 18
PERCHAK, DENNIS	Eastman Kodak	OCT 30 - 31
PHILLIPS, JOEL	Cadence	NOV 23 - 25
POLING, CRAIG	Lockheed Martin	JUL 21 - 31
PULLEYBLANK, WILLIAM	IBM Corporation	NOV 8 - 9
REICHELT, MARK	The MathWorks, Inc	SEP 4 - 6
ROJAS, EDUARDO E.	NIH	FEB 8 - 13
ROSE, TODD	Donaldson Co. Inc.	JUN 1 - 5
ROSS, DAVID	Kodak	MAR 20 - 21
ROYCHOWDHURY, JAIJEET	Bell Laboratories	NOV 23 - 25
RUEHLI, ALBERT	IBM	NOV 23 - 25
RUSSELL, JAMES T.	NIH	FEB 8 - 13
SALAMON, TODD	Lucent Technologies	MAY 20 - 24
SAMAD, TARIQ	Honeywell	APR 26 - MAY 1
SHERMAN, ARTHUR	NIH	FEB 4 - 13
SHUB, MICHAEL	IBM Watson Res Ctr	NOV 18 - 21
SIMMONS, GUS	Sandia	JUL 5 - 10
SLOANE, NEIL	A. T. & T. Research Labs	JUL 5 - 10
SMITH, GREGORY D.	NIDDK, National Institutes of Health	FEB 8 - 13
SOLJANIN, EMINA	Bell Labs-Lucent	JUL 5 - 19
STOJIKOVIC, STANKO	NICHD, NIH	FEB 8 - 12
SWELDENS, WIM	Lucent Tech Bell Labs	NOV 13 - 14
TAKRITI, SAMER	IBM Research	JUL 21 - 31
TAUBIN, GABRIEL	IBM T. J. Watson Research Center	OCT 2 - 4
THALER, AL	NSF	MAR 6 - 8
TUFILLARO, NICK	Hewlett-Packard Company	SEP 25 - 28
VOTH, ERIC	Endocardial Solutions, Inc.	MAR 13 - 13
WAGNER, ROB	Ansoft	NOV 22 - 25
WARMAN, EDUARDO	Medtronic, Inc.	MAR 8 - 15
YU, WEIPING	Medtronic Inc.	MAR 9 - 14
ZHAO, YONG	Medtronic	MAR 9 - 14
ZIMLIKI, CHARLES	NIH	FEB 10 - 14

The IMA seeks advice on programmatic issues from a wide variety of persons. A very useful source for this advice is

the IMA Industrial Advisory Committee. The panel consists of scientific and engineering managers and researchers from national corporations; it meets once a year at the IMA. The 1997-98 membership was:

Debasis Mitra	AT&T Bell Laboratories
James McKenna	Bell Communications Research
Peter Castro	Eastman Kodak Company (Computational Science Laboratory)
David Chock	Ford Motor Company (Chemistry Department)
A. Martin Wildberger	EPRI (Exploratory & Applied Research)
Sam Marin	General Motors Research Laboratories
Gunter Stein	Honeywell, Inc.
Bernard Rudin	IBM Austin Laboratory
William Pulleyblank	IBM Corporation (Thomas J. Watson Research Center)
Blaise Morton	Honeywell , Inc. (Systems and Research Center)
Leonard Borucki	Motorola Inc.
Knut Merten	Siemens Corporate Research, Inc.
Charles Geisler	Minnesota Technology Incorp.
David Garrett	Lockheed Martin
T. Craig Poling	Lockheed Martin
David Misemer	3M General Offices
Yoshio Tago	Fujitsu Limited (Research Center for Computational Science)
Robert Numrich	Cray Research, Inc.
Albert Gilg	Siemens AG/ZT AN2 (Corporate Technology)

The IMA is proceeding aggressively to expand its industrial interactions. Our most visible programs are the Seminar on Industrial Problems and the Postdoctorates in Industrial Mathematics program.