News & Events

PACM Colloquium

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This is an archive of past PACM Colloquiums.

2012-2013 Collapse/Expand

Date: February 6
Speaker: Fan Chung, University of California, San Diego
Title: Graph gauge theory and vector diffusion maps

Abstract: We consider a generalization of graph Laplacian which acts on the space of functions which assign to each vertex a point in d-dimensional space. The eigenvalues of such connection Laplacian are useful for examining vibrational spectra of molecules as well as vector diffusion maps for analyzing high dimensional data. We will discuss algebraic, probabilistic and algorithmic methods in the study of the connection spectra. For example, if the graph is highly symmetric and the connection Laplacian is invariant under the symmetry of the graph, then its eigenvalues can be deduced by using irreducible representations. In addition, by using matrix concentration inequalities, the eigenvalues of random connection Laplacians can be approximated by the eigenvalues of the expected matrices under appropriate conditions. Furthermore, graph sparsification algorithms can be generalized to approximate and extract the global structure of information networks arising in signal and data processing.

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Date: February 13
Speaker: Mark Braverman, Princeton University, Computer Science
Title: Computability and Complexity of Julia Sets
Abstract: Studying dynamical systems is key to understanding a wide range of phenomena ranging from planetary movement to climate patterns to market dynamics. Various computational and numerical tools have been developed to address specific questions about dynamical systems, such as predicting the weather or planning the trajectory of a satellite. However, the theory of computation behind these problems appears to be very difficult to develop. In fact, little is known about computability of even the most natural problems arising from dynamical systems. In this talk I will survey the recent study of the computational properties of dynamical systems that arise from iterating quadratic polynomials on the complex plane. These give rise to the amazing variety of fractals known as Julia sets, and are closely connected to the Mandelbrot set. Julia sets are perhaps the most drawn objects in Mathematics due to their fascinating fractal structure. The theory behind them is even more fascinating, and the dynamical systems generating them are in many ways archetypal. I will present both positive and negative results on the computability and computational complexity of Julia sets.

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Date: February 20
Speaker: Francois Meyer, University of Colorado Boulder
Title: A Random Walk on Image Patches
Abstract: Algorithms that analyze patches extracted from time series or images have led to state-of-the art techniques for classification, denoising, and the study of nonlinear dynamics. In the first part of the talk we describe two examples of such algorithms: a novel method to estimate the arrival-times of seismic waves from a seismogram, and a new patch-based method to denoise images. Both approaches combines the following two ingredients: the signals (times series or images) are

first lifted into a high-dimensional space using time/space-delay embedding; the resulting phase space is then parametrized using a nonlinear method based on the eigenvectors of the graph Laplacian. Both algorithms outperform existing gold standards. In the second part of the talk we provide a theoretical explanation for the success of algorithms that organize patches according to graph-based metrics. Our approach relies on a detailed analysis of the commute time on prototypical graph models that epitomize the geometry observed in general patch-graphs.

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Date: February 27
Speaker: Eric Vanden-Eijnden, Courant NYU
Title: Dimension reduction, coarse-graining and data assimilation in high-dimensional dynamical systems
Abstract: Modern computing technologies, such as massively parallel simulation, special-purpose high-performance computers, and high-performance GPUs permit to simulate complex high-dimensional dynamical systems and generate time-series in amounts too large to be grasped by traditional "look and see" analyses. This calls for robust and automated methods to extract the essential structural and dynamical properties from these data in a manner that is little or not depending on human subjectivity. To this end, a decade of work has led to the development of analysis techniques which rely on the partitioning of the conformation space into discrete substates and reduce the dynamics to transitions between these states. A particular successful class of methods of this type are Markov state models (MSMs), in which the transitions between the states in the partition are assumed to be memoryless jumps. The accuracy of these models crucially depends on the choice of these states. In this talk, I will discuss systematic strategies that permit to identify these states and quantify the error of the resulting approximation. These methods will be illustrated on examples arising from molecular dynamics simulations of biomolecules.

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Date: March 5
Speaker: Yuan Yao, Peking University
Title: Topological Landscape of Networks
Abstract: We will discuss how one can endow a network with a landscape in a very simple and natural way. Critical point analysis is introduced for functions defined on networks. The concept of local minima/maxima and saddle points of different indices are defined, by extending the notion of gradient flows and minimum energy path to the network setting. Persistent homology is used to design efficient numerical algorithms for performing such analysis. Applications to some examples of social and biological networks (LAO protein binding network) are demonstrated. These examples show that the critical nodes play important roles in the structure and dynamics of such networks. This is a joint work with Weinan E and Jianfeng Lu.

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Date: March 26
Speaker: Sayan Mukherjee, Duke University
Title: Geometry and Topology in Dimension Reduction
Abstract: In the first part of the talk we describe how learning the gradient of a regression function can be used for supervised dimension reduction (SDR). We provide an algorithm for learning gradients in high-dimensional data, provide theoretical guarantees for the algorithm, and provide a statistical interpretation. Comparisons to other methods on real and simulated data are presented. In the second part of the talk we present preliminary results on using the Laplacian on forms for dimension reduction. This involves understanding higher-order versions of the isoperimetric inequality for both manfifolds and abstract simplicial complexes.

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Date: April 2
Speaker: Lek-Heng Lim, University of Chicago

Title: Mathematics of the Human Brain Connectome
Abstract: The human brain connectome is an ambitious project to provide a complete map of neural connectivity and a recent source of excitement in the neuroscience community. Just as the human genome is a triumph of marrying technology (high throughput sequencers) with theory (dynamic programming for sequence alignment), the human connectome is a result of a similar union. The technology in question is that of diffusion magnetic resonance imaging (dMRI) while the requisite theory, we shall argue, comes from three areas: PDE, harmonic analysis, and algebraic geometry. The underlying mathematical model in dMRI is the Bloch-Torrey PDE but we will approach the 3-dimensional imaging problem directly. The main problems are (i) to reconstruct a homogeneous polynomial representing a real-valued function on a sphere from dMRI data; and (ii) to analyze the homogeneous polynomial via a decomosition into a sum of powers of linear forms. We will discuss the algebraic geometry associated with (ii) and discuss a technique that combines (i) and (ii) for mapping neural fibers. This is joint work with T. Schultz of MPI Tubingen.

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Date: April 9
Speakers: Prof. David Donoho, Stanford
Title: Optimal Phase Transitions in Compressed Sensing
Abstract: "Compressed Sensing" is an active research area which touches on harmonic analysis, geometric functional analysis, applied mathematics, computer science electrical engineering and information theory. Concrete achievements, such as speeding up pediatric MRI acquistion times from several minutes to under a minute, are now entering daily use. In my talk I will discuss the notion of phase transitions in combinatorial geometry, describe how they precisely demarcate the situations where a popular algorithm in compressed sensing -- ell_1 minimization -- can succeed. Then I will discuss the issue: what is the best possible phase transition of any algorithm? We get different answers depending on the assumptions we make. If we assume the distribution of the coefficients is known/unknown, we get different answers; in each case I describe novel algorithms precisely achieving the optimal phase transition, converging to the answer at an expoential rate depending only on distance from phase transition. Both algorithms are applications of the Approximate Message Passing algorithm introduced by Maleki, Montanari and myself. This talk surveys joint work with several authors, including Andrea Montanari and Jared Tanner, as well as Adel Javanmard, Iain Johnstone and Arian Maleki.

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Date: April 16
Speakers: Dustin Mixon, Afonso Bandeira

Title: Special PACM Student Colloquium!

Abstracts:
Dustin Mixon - "Phaseless recovery with polarization": In many applications, an unknown vector is measured according to the magnitude of its inner product with some known vector. It is desirable to design an ensemble of vectors for which any unknown vector can be recovered from such measurements (up to a global phase factor). In 2006, Balan et al. demonstrated that this measurement process is injective for generic M-dimensional vector ensembles of size at least 4M-2. Recently, Candes et al. used semidefinite programming to stably reconstruct from measurements with random ensembles of size O(MlogM). In this talk, we use the polarization identity and expander graphs to efficiently recover from measurements with specific deterministic ensembles of size O(M). We then observe how the theory of synchronization can be leveraged to demonstrate stability in this method.

Afonso Bandeira - "Cheeger Inequality for the Graph Connection Laplacian": The $O(d)$ Synchronization problem consists of estimating a set of unknown orthogonal transformations O_i from noisy measurements of a subset of the pairwise ratios $O_iO_j^{-1}$. We formulate and prove a Cheeger-type inequality that relates a measure of how well it is possible to solve the $O(d)$ synchronization problem with the spectra of an operator, the graph Connection Laplacian. We also show how this inequality provides a worst case performance guarantee for a spectral method to solve this problem. This is joint work with Amit Singer (Princeton) and Daniel Spielman (Yale).

2011-2012 Collapse/Expand

Date: February 7
Speaker: Xiao-Jing Wang, Yale University
Title: High-dimensional reservoir neural dynamics: rules and memories
Abstract: Neural activity recorded in behaving animals is highly variable and heterogeneous, which is especially true for neurons in the prefrontal cortex (PFC), the so called `CEO of the brain' of central importance to many cognitive functions. In this talk, I will present a reservoir-type model of randomly connected neurons to account for the diversity of neural signals in the prefrontal cortex. Specifically, I will show that such a network gives rise to mixed-selectivity of neurons that can encode task rules underlying flexible behaviors, and a broad range of time constants for short-term memory.

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Date: February 14
Speaker: Lin-Wang Wang, Lawrence Berkeley National Lab
Title: A few computational and applied math problems in density functional theory related calculations
Abstract: Density functional theory (DFT) has become the most widely used quantum mechanical method in material science simulations. Due to the change of computer architectures, and the corresponding change in the scope of problems amenable by the DFT method, the algorithms used in the DFT calculations are also changing. In this talk, I will discuss a few commonly used ground state based algorithms for large scale DFT calculations. I will also discuss what it will take to speed up the DFT molecular dynamics simulations by a thousand times, and the self-consistent problems often encountered in large system simulations. Some of our recent effort in implementing our planewave DFT code in GPU will also be discussed. Finally, I will present a method using auxiliary periodic boundary conditions to solve an open boundary condition scattering state problem in quantum transport calculations.

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Date: February 21
Speaker: Robert Ghrist, University of Pennsylvania
Title: Euler calculus and Data Aggregation over Networks
Abstract: This talk concerns an ingenious integral calculus based on Euler characteristic, stemming from work on sheaves due to MacPherson and Kashiwara in the 1970s, and connecting back further to classical integral geometry. I will emphasize its novel utility in data management, particularly in aggregation of redundant data and inverse problems over sensor networks. Applications to target counting, localization, and shape detection will be given. Issues of numerical analysis & integral transforms in Euler calculus are particularly interesting open problems.

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Date: February 28
Speaker: Roman Vershynin, University of Michigan **(Joint PACM/Analysis Colloquium)**
Title: Invertibility of random matrices and applications
Abstract: Consider an n by n random matrix H with independent entries. As the dimension grows to infinity, how likely is H to be invertible? And what is the typical norm of the inverse? These questions can be traced back to P. Erdos (for matrices with +1,-1 entries) and von Neumann and his collaborators (motivated by the analysis of numerical algorithms). For both matrices with all independent entries and for symmetric random matrices, there was a considerable progress on the invertibility problem in the last few years. The methods come from different areas, including classical random matrix theory, mathematical physics, geometrical functional analysis, and additive combinatorics. A related problem for rectangular random matrices is motivated by statistical applications (covariance estimation). We will discuss recent progress and several conjectures.

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Date: March 7
Speaker: Joshua Plotkin, University of Pennsylvania
Title: Generalized Markov models in population genetics
Abstract: Population geneticists study the dynamics of alternative genetic types in a replicating population. Most theoretical works rests on a simple Markov chain, called the Wright-Fisher model, to describe how an allele's frequency changes from one generation to the next. We have introduced a broad class of Markov models that share the same mean and variance as the Wright-Fisher model, but may otherwise differ. Even though these models all have the same variance effective population size, they encode a rich diversity of alternative forms of genetic drift, with significant consequences for allele dynamics. We have characterized the behavior of standard population-genetic quantities across this family of generalized models. The generalized population models can produce startling phenomena that differ qualitatively from classical behavior -- such as assured fixation of a new mutant despite the presence of genetic drift. We have derived the forward-time continuum limits of the generalized processes, analogous to Kimura's diffusion limit of the Wright-Fisher process. Finally, we have shown that some of these exotic models are more likely than the Wright-Fisher model itself, given empirical data on genetic variation in Drosophila populations. Joint work with Ricky Der and Charlie Epstein.

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Date: March 21
Speaker: Philip Rosenau, Tel Aviv University
Title: Brother, can you spare a compacton?
Abstract: Unlike certain personal or national tragedies which may extend indefinitely, patterns observed in nature are of finite extent. Yet, as a rule, the solitary patterns predicted by almost all existing mathematical models extend indefinitely with their tails being a by product of their analytical nature. Rather then viewing such tails as a manifestation of the inherent limitation of math to model physics in detail, we adopt the opposite view: the persistence of tails in a large variety of solitary patterns points to a missing mechanism capable to constrain the pattern. Clearly, to induce a compact pattern one has to escape the curse of analyticity. Differently stated, one has to supplement the existing models with a mechanism(s) which may beget a local singularity. When this is done the resulting local loss of solution's uniqueness enables to connect a smooth part of the solution with the trivial ground state and thus to form an entity with a compact support: the compacton. We shall describe a variety of singularity inducing mechanisms that beget compact solutions of dispersive or dissipative uni and multi-dimensional phenomena. Compactified variants of the K-dV, Klein-Gordon and Schroedinger equations will be surveyed. In Part two of the lecture we shall discuss the intriguing nature of these (weakly strong or strongly weak) solutions, the underlying singularities and their relation with a discrete antecedent where a sharp fronts are replaced with tails decaying at a doubly exponential rate.

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Date: March 28 **(Special Seminar!)**
Time/Location: 4:00 p.m., 214 Fine Hall
Speaker: Graduate Students of PACM
Title: see below
Abstract: We will have the following short presentations:
Lin Lin: "Can the state of the electrons be discontinuous?"
Gaurav Thakur: "Instantaneous Frequency Estimation from Nonuniform Samples"
Lanhui Wang: "Wavelet-regularized Direct Fourier Reconstruction of cryo-EM images"

Refreshments and snacks will be served at 3:30 pm in 214 Fine Hall

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Date: April 4 **(joint PACM/Analysis seminar)**
Speaker: Peter Jones, Yale University
Title: Product Formulas for Measures and Applications to Analysis

Abstract: We will discuss elementary product formalisms for positive measures. These appeared in analysis for purposes of examining "harmonic measures" related to elliptic equations (work of R. Fefferman, J. Pipher, C. Kenig). We will discuss three topics where product formulas appear: applied projects related to signal processing; SLE; and Geometric measure theory. For the first topic we will explain some work arising in analysis of network failures. For the second topic (SLE) we will show the relations between some models of random measures, and relations to SLE. The third topic (geometric measure theory) will be a discussion of joint work with Marianna Csörnyei. The main point here is how product formulas can detect directionality in sets. The new result concerns Lebesgue measurable sets E of finite measure in the unit cube (in any dimension). The set E can be decomposed into a bounded number of sets with the property that each (sub)set has a nice "tangent cone". This yields strong results on points of non- differentiability for Lipschitz functions. The main technical result needed is a d dimensional, measure theoretic version of (a geometric form of) the Erdös-Szekeres theorem, which holds when d = 2. In what is perhaps a small surprise, certain ideas from random measures can be used effectively in the deterministic setting.

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Date: April 6 **(Distinguished Lecture Seminar)**
Time/Location: 8:00 p.m., A02 McDonnell Hall
Speaker: Ray Goldstein, University of Cambridge
Title: Stirring Tails of Evolution
Abstract: One of the most fundamental issues in biology is the nature of evolutionary transitions from single cell organisms to multicellular ones. Not surprisingly for microscopic life in a fluid environment, many of the processes involved are related to transport and locomotion, for efficient exchange of chemical species with the environment is one of the most basic features of life. This is particularly so in the case of flagellated eukaryotes such as green algae, whose members serve as model organisms for the study of transitions to multicellularity. In this talk I will focus on recent experimental and theoretical studies of the stochastic nonlinear dynamics of these flagella, whose coordinated beating leads to graceful locomotion but also to fluid flows that can out-compete diffusion. A synthesis of high-speed imaging, micromanipulation, and three-dimensional tracking has quantified the underlying stochastic dynamics of flagellar beating, allowed for tests of the hydrodynamic origins of flagellar synchronization, and revealed a eukaryotic equivalent of the run-and-tumble locomotion of peritrichously flagellated bacteria. Challenging problems in applied mathematics, fluid dynamics, and biological physics that arise from these findings will be highlighted.

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Date: April 11
Speaker: Antonin Chambolle, CMAP -- Ecole Polytechnique
Title: From (basic) image denoising to surface evolution
Abstract: it is relatively easy to make a connection between the implicit time-discrete approaches for the mean curvature flow and the "Rudin-Osher-Fatemi" total variation based approach for image denoising. This connection has interesting consequences, allowing to build explicit solutions for the flow of the total variation or study regularity issues, up to showing the existence of the crystalline curvature flow of convex sets or building up efficient algorithms. The talk will explain the relationship between all these problems. *(Joint works with V. Caselles, M. Novaga, J. Darbon, T. Pock, D. Cremers)*

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Date: April 18
Speaker: Gregory Rempala -- Medical College of Georgia
Title: Likelihood and algebraic maps for stochastic biochemical network models
Abstract: With the development of new sequencing technologies of modern molecular biology, it is increasingly common to collect time-series data on the abundance of molecular species encoded within the genomes. This presentation shall illustrate how such data may be used to infer the parameters as well as the structure of the biochemical network under mass-action kinetics. Given certain constraints on the geometry of the stoichiometric space, we use algebraic methods as an alternative to conventional hierarchical graphical models, to carry out network structure inference by identifying reaction rate constants

which are significantly different from zero.

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Date: April 25
Speaker: Boaz Nadler, Weizmann Institute -- Israel
Title: Learning from Labeled and Unlabeled Data: Global vs. Multiple Approaches
Abstract: In recent years there is increasing interest in learning from both labeled and unlabeled data (a.k.a. semi-supervised learning, or SSL). The key assumption in SSL, under which an abundance of unlabeled data may help, is that there is some relation between the unknown response function to be learned and the marginal density of the predictor variables. In the first part of this talk I'll present a statistical analysis of two popular graph based SSL algorithms: Laplacian regularization method and Laplacian eigenmaps. In the second part I'll present a novel multiscale approach for SSL as well as supporting theory. Some intimate connections to harmonic analysis on abstract data sets will be discussed. Joint work with Nati Srebro (TTI), Xueyuan Zhou (Chicago), Matan Gavish (WIS/Stanford) and Ronald Coifman (Yale).

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ate: September 26
Speaker: Leonidas Guibas, Stanford University
Title: Understanding 3D Shapes Jointly
Abstract: The use of 3D models in our economy and life is becoming more prevalent, in applications ranging from design and custom manufacturing, to prosthetics and rehabilitation, to games and entertainment. Although the large-scale creation of 3D content remains a challenging problem, there has been much recent progress in design software tools, like Google SketchUp for buildings or Spore for creatures, or in low cost 3D acquisition hardware, like the Microsoft Kinect scanner. As a result, large commercial 3D shape libraries, such as the Google 3D Warehouse, already contain millions of models. These libraries, however, can be unwieldy, when the need arises to efficiently incorporate models into various workflows. Mathematical formulations, efficient algorithms, and software tools are required to support navigation and search over 3D model repositories. In this talk we examine the problem of facilitating these navigation and search tasks by automatically extracting relationships between shapes in a collection and understanding their common or shared structure. By effectively organizing the collection into (possibly overlapping) groups of related shapes, by separating what is common from what is variable within each group and across groups, and by understanding the main axes of variability, we can facilitate a whole slew of operations that make large 3D repositories much more navigable, searchable, compressible, and visualizable. We will present a quick summary of tools for efficiently computing informative shape descriptors as well as structure preserving maps between shapes at different levels of resolution. The main part of the talk, however, is aimed beyond pairwise relationships, to the study and analysis of many shapes jointly, looking at networks of maps between shapes in order to extract joint structure, derive consistent segmentations, infer phenotypic relationships, etc. This is preliminary work on what we believe to be a large open area for research -- the joint understanding of collections of related geometric data sets.

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Date: October 3
Speaker: Don Saari, University of California - Irvine
Title: Complexity theory applied to voting theory
Abstract: As it will be shown with results and examples, the paradoxes associated with standard voting rules are surprisingly likely and are so complex that one must worry about the legitimacy of election outcomes. To extract an understanding of what can happen and why, it is shown how lessons from complexity theory, where complicated behavior is due to a combination of simple interactions, explain many mysteries both in this area and for related topics such as nonparametric statistics, etc. Indeed, all paradoxes of standard rules, including Arrow's seminal "Impossibility Theorem," reflect simple but hidden symmetry structures connecting the preferences of voters.

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Date: October 10
Speaker: Eitan Tadmor, University of Maryland
Title: A new model for self-organized dynamics: From particle to hydrodynamic descriptions
Abstract: Self-organized dynamics is driven by “rules of engagement", which describe how each agent interacts with its neighbors. They consist of long-term attraction, mid-range alignment and short-range repulsion. Many self-propelled models are driven by the balance between these three forces, which yield emerging structures of interest. Examples range from consensus of voters and traffic flows to the formation of flocks of birds or school of fish, tumor growth etc. We introduce a new particle-based model, driven by self-alignment, which addresses several drawbacks of existing models for self-organized dynamics. The model is independent of the number of agents: only their geometry in phase space is involved. We will explain the emerging flocking behavior of the proposed model in the presence of non-symmetric interactions which decay sufficiently slow, and discuss the difficulties of tracing graph connectivity otherwise. The methodology is based on the new notion of active sets, which carries over from particle to kinetic and hydrodynamic descriptions, and we discuss the unconditional flocking at the level of hydrodynamic description.

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Date: October 17
Speaker: Michael L. Overton, Courant Institute of Mathematical Sciences, NYU
Title: Optimization of Polynomial Roots, Eigenvalues and Pseudospectra
Abstract: The root radius and root abscissa of a monic polynomial are respectively the maximum modulus and the maximum real part of its roots; both these functions are nonconvex and are non-Lipschitz near polynomials with multiple roots. We begin the talk by giving constructive methods for efficiently minimizing these nonconvex functions in the case that there is just one affine constraint on the polynomial's coefficients. We then turn to the spectral radius and spectral abscissa functions of a matrix, which are analogously defined in terms of eigenvalues. We explain how to use nonsmooth optimization methods to find local minimizers and how to use nonsmooth analysis to study local optimality conditions for these nonconvex, non-Lipschitz functions. Finally, the pseudospectral radius and abscissa of a matrix A are respectively the maximum modulus or maximum real part of elements of its pseudospectrum (the union of eigenvalues of all matrices within a specified distance of A). These functions are also nonconvex but, it turns out, locally Lipschitz, although the pseudospectrum itself is not a Lipschitz set-valued map. We discuss applications from control and from Markov chain Monte Carlo as examples throughout the talk. Coauthors of relevant papers include Vincent Blondel, Jim Burke, Kranthi Gade, Mert Gurbuzbalaban, Adrian Lewis and Alexandre Megretski.

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Date: October 24
Speaker: Charles Epstein, UPenn
Title: Existence and regularity for a class of degenerate diffusions arising in population genetics
Abstract: Infinite population limits of standard Markov chain models lead to Markov processes on polyhedral domains that are formally generated by degenerate elliptic operators. These operators are characterized, in part, by the first order vanishing, along the boundary, of the coefficient of the second normal derivative term. This fact places these operators beyond those which have thus far been successfully analyzed using methods of geometric analysis. I will present an approach to these operators, which I have been pursuing with Rafe Mazzeo, based on an-isotropic Holder spaces, which leads to a rather complete existence, uniqueness and regularity theory.

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Date: November 7
Speaker: Arjen Doelman, University of Leiden / Lorentz Center
Title: The mathematics of desertification: searching for early warning signals
Abstract: The process of desertification can be modeled by systems of reaction-diffusion equations. Numerical simulations of these models agree remarkably well with field observations: both show that `vegetation patterns' -- i.e. regions in which the vegetation only survives in localized `patches' -- naturally appear as the transition between a healthy homogeneously

vegetated state and the (non-vegetated) desert state. Desertification is a catastrophic and non-reversible event during which huge patterned vegetation areas `collapse' into the desert state at a fast time scale -- for instance as a consequence of a slow decrease of yearly rainfall, or through an increased grazing pressure. It is crucial to be able to recognize whether a patterned state is close to collapse (or not), ecologists are thus searching for `early warning signals'. In this talk, we will translate the issues raised by the desertification process into mathematical terms and relate these to recent developments in the field of pattern formation. It will be shown that the process of desertification poses fundamental mathematical questions and that it already has led to the development of novel mathematical theory.

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Date: November 14
Speaker: Vladimir Rokhlin, Yale University
Title: Accurate Randomized Algorithms of Numerical Analysis
Abstract: Randomized algorithms are ubiqutous in computer science and computer engineering. Many problems that are intractable when viewed deterministi- cally can be effectively solved with probabilistic techniques. Perhaps the most important aspect of most randomized procedures in current use is the fact that they produce the correct result with (practically speaking) 100% reliabil- ity, and with (essentially) machine precision. Historically, randomized techniques have been less popular in numerical analysis. Most of them trade accuracy for speed, and in many numerical environments one does not want to add yet another source of inaccuracy to the calculation that is already sufficiently inaccurate. One could say that in numerical analysis probabilistic methods are an approach of last resort. I will discuss several probabilistic algorithms of numerical linear algebra that are never less accurate than their deterministic counterparts, and in fact tend to produce better accuracy. In many situations, the new schemes have lower CPU time requirements than existing methods, both asymptotically and in terms of actual timings. I will illustrate the approach with several numerical examples, and discuss possible extensions.

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Date: November 21
Speaker: Frederik Simons, Princeton University
Title: Prolates on the sphere, Extensions and Applications: Slepian functions for geophysical and cosmological signal estimation and spectral analysis
Abstract: Functions that are timelimited (or spacelimited) cannot be simultaneously bandlimited (in frequency). Yet the finite precision of measurement and computation unavoidably bandlimits our observation and modeling scientific data, and we often only have access to, or are only interested in, a study area that is temporally or spatially bounded. In the geosciences we may be interested in spectrally modeling a time series defined only on a certain interval, or we may want to characterize a specific geographical area observed using an effectively bandlimited measurement device. In cosmology we may wish to compute the power spectral density of the cosmic microwave background radiation without the contaminating effect of the galactic plane. Analyzing and representing scientific data of this kind is facilitated in a basis of functions that are spatiospectrally concentrated, i.e. localized in both domains at the same time. Here, we give a theoretical overview of the approach to this concentration problem that was proposed for time series by Slepian and coworkers, in the 1960s. We show how this framework leads to practical algorithms and statistically performant methods for the analysis of signals and their power spectra in one and two dimensions, and on the surface of a sphere. "Spherical Slepian functions" are now widely applied to the study of inverse problems with (potential-field) satellite data, including such problems whose solutions are linear (source estimation), and quadratic (spectral estimation), in the data. Among the applications that I will discuss are the analysis of the time-variable gravity field for the recovery of coseismic gravity perturbations, the sparse analysis and representation of the lithospheric magnetic field, the recovery of the power spectral density of the cosmic microwave background radiation, and so on.

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Date: November 28
Speaker: Andrea Montanari, Stanford University

Title: Sharp Thresholds in Statistical Estimation
Abstract: Sharp thresholds are ubiquitous high-dimensional combinatorial structures. The oldest example is probably the sudden emergence of the giant component in random graphs, first discovered by Erdos an Renyi. More recently, threshold phenomena have started to play an important role in some statistical learning and statistical signal processing problems, in part because of the interest in 'compressed sensing'. The basic setting is one in which a large number of noisy observations of a high-dimensional object are made. As the ratio of the number of observations to the number of `hidden dimensions' crosses a threshold, our ability to reconstruct the object increases dramatically. I will discuss several examples of this phenomenon, and some algorithmic and mathematical ideas that allow to characterize these threshold phenomena. [based on joint work with Mohsen Bayati, David Donoho, Iain Johnstone, Arian Maleki]

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Date: December 5
Speaker: Peter Constantin, Princeton University
Title: Nonlocal Evolution Equations
Abstract: Nonlocal evolution equations have been around for a long time, but in recent years there have been some nice new developments. The presence of nonlocal terms might originate from modeling physical, biological or social phenomena (incompressibility, Ekman pumping, chemotaxis, micro-micro interactions in complex fluids, collective behavior in social aggregation) or simply from inverting local operators in the analysis of systems of PDE. I will brifly present some regularity results for hydrodynamic models with singular constitutive laws. The main part of the talk will present a nonlinear maximum principle for linear nonlocal dissipative operators and applications.

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Date: February 8 **(Joint w/Mathematics)**
Speaker: Artur Avila, Director of Research, IMPA
Title: Dynamics of renormalization operators
Abstract: It is a remarkable characteristic of some classes of low-dimensional dynamical systems that their long time behavior at a short spatial scale is described by an induced dynamical system in the same class. The renormalization operator that relates the original and the induced transformations can then be iterated. We will discuss how features (such as hyperbolicity) of this "dynamics in parameter space" impact the underlying systems, especially in the case of typical parameters.

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Date: February 15
Speaker: Konstantin Mischaikow, Mathematics and BioMaPS Institute, Rutgers University
Title: A Database Schema for the Global Dynamics of Multiparameter Nonlinear Systems
Abstract: Prof. Mischaikow will discuss new computational tools based on topological methods that extracts coarse, but rigorous, combinatorial descriptions of global dynamics of multiparameter nonlinear systems. This techniques are motivated by several observations which we claim can, at least in part, be addressed:
1. In many applications there are models for the dynamics, but specific parameters are unknown or not directly computable. To identify the parameters one needs to be able to match dynamics produced by the model against that which is observed experimentally.
2. It is well established that nonlinear dynamical systems can produce extremely complicated dynamics, e.g. chaos, however experimental measurements
are often too crude to identify such fine structure.
3. Often the models themselves are based on heuristics as opposed to being derived from first principles and thus the fine structure of the dynamics produced by the models may be of little interest for the applications in mind.

To make the above mentioned comments concrete, Prof. Mischaikow will describe the techniques in the context of a simple model arising in population biology.

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Date: February 22
Speaker: Ronen Basri, Weizmann Institute of Science in Israel, Computer Science & Applied Math Dept.
Title: Detection of Faint Edges in Noisy Images
Abstract: One of the most intensively studied problems in image processing concerns how to detect edges in images. Edges are important since they mark the locations of discontinuities in depth, surface orientation, or reflectance, and their detection can facilitate a variety of applications including image segmentation and object recognition. Accurate detection of faint, low-**contrast edges in noisy images is challenging. Optimal detection of such edges can potentially be achieved if we use filters that match the shapes, lengths, and orientations of the sought edges. This however requires search in the space of continuous curves. In this talk we explore the limits of detectability, taking into account the lengths of edges and their combinatorics. We further construct two efficient multi-level algorithms for edge detection. The first algorithm uses a family of rectangular filters of variable lengths and orientations. The second algorithm uses a family of curved filters constructed through a dynamic-**programming-like procedure using a modified beamlet transform. We demonstrate the power of these algorithms in applications to both noisy and natural images, showing state-of-the-art results. Joint work with Meirav Galun, Achi Brandt, and Sharon Alpert.

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Date: March 1
Speaker: Yosi Keller, School of Electrical Engineering, Bar-Ilan University (Israel)
Title: Probabilistic approach to high order assignment problems/td>
Abstract: A variety of computer vision and engineering problems can be cast as high order matching problems, where one considers the affinity of two or more assignments simultaneously. The spectral matching approach of Leordeanu and Hebert (2005) was shown to provide an approximate solution of this np-hard problem. It this talk we present a probabilistic interpretation of spectral matching and derive a new probabilistic matching scheme. We show how our approach can be extended to high order matching scheme, via a dual tensor marginalization-decomposition. Last, we present an Integer Least Squares algorithm and apply it to the decoding of MIMO channels and the solution of Suduko puzzles. Joint work with Amir Egozi, Michael Chertok and Amir Leshem

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Date: March 29
Event: PACM Student Colloquium
Refreshments will be served at 3:30 p.m.

Presentations: Mihai Cucuringu: "Sensor network localization by eigenvector synchronization over the Euclidean group"
Lin Lin: "Nuclear quantum effects of hydrogen bonded systems"
Jesus Puente: "Surface comparison with mass transportation"
Michael Sekora: "A Hybrid Godunov Method for Radiation Hydrodynamics"

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Date: April 5
Speaker: Peter Winkler, Mathematics and Computer Science, Darthmouth College
Title: Combinatorial Phase Transition
Abstract: The past fifteen years have seen a huge boom in work at the interface of statistical physics, combinatorics, probability, and the theory of computing. A unifying objective has been understanding phase transition, especially in

discrete models with hard constraints. We will give some indication of why the notion is so interesting to diverse groups of researchers, and some examples where there has been recent progress.

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Date: April 12
Speaker: Walter Willinger, AT&T Labs Research, Florham Park NJ
Title: Internet Traffic Matrices and Compressive Sensing
Abstract: Internet traffic matrices (TMs) specify the traffic volumes between origins and destinations in a network over some time period. For example, origins and destinations can be individual IP addresses, prefixes, routers, points-of-presence (PoPs), or entire networks or Autonomous Systems (ASes). Past work on TMs has almost exclusively focused on large ASes such as AS7018 (AT&T) and their router- or PoP-level TMs, mainly because the latter are critical inputs to many basic network engineering tasks, and the thrust of much of this work has been on measurement and inference of TMs. A key remaining challenge in this area is how to cope with missing values that frequently arise in real-world TMs. This problem brings TM research into the realm of compressive sensing, a generic technique for dealing with missing observations that exploits the presence of structure or redundancy in data from many real-world systems. In particular, since real-world TMs have been found to be of low rank, the concept of compressive sensing is directly applicable, at least in theory. In this talk, I will report on novel applications of compressive sensing to TM interpolation and inference and discuss how the resulting techniques work in practice. I will end by describing some challenging open problems concerning measuring and inferring the completely unknown Internet-wide AS-level TM. (This is joint work with Y. Zhang and L. Qiu (Univ. of Texas) and M. Roughan (Univ. od Adelaide).)

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Date: April 26
Speaker: Jonathan Weare, Courant Institute for Mathematics, NYC
Title: Toward practical rare event simulation in high dimensions
Abstract: Prof. Weare will discuss an importance sampling method for certain rare event problems involving small noise diffusions. Standard Monte Carlo schemes for these problems behave exponentially poorly in the small noise limit. Previous work in rare event simulation has focused on developing, in specific situations, estimators with optimal exponential variance decay rates. He will introduce an estimator related to a deterministic control problem that not only has an optimal variance decay rate under certain conditions, but that can even have vanishingly small statistical relative error in the small noise limit. The method can be seen as the limit of a well known zero variance importance sampling scheme for diffusions which requires the solution of a second order partial differential equation.

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Date: May 3
Speaker: Stephen Howard, University of Melbourne, Australia
Title: Sensor Registration and Synchronisation in Networks
Abstract: An important problem in distributed and networked sensing is registration of coordinate systems or synchronisation of clocks across the network. The main problem discussed in this talk is as follows. We have a network of sensors each with its own local coordinate system. We are given noisy measurements of the transformations connecting the coordinate systems of certain pairs of sensor in the network. The goal is to find local algorithms which will, in a optimal statistical sense, align the coordinate systems across the network. The talk will show how this problem can be formulated as a gauge invariant statistical estimation problem, how it is related to the homology of graphs, and how statistical optimal local estimators can be constructed in a number of cases.

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Date: May 17
Speaker: Anthony Peirce, University of British Columbia

Title: Hydraulic Fractures: multiscale phenomena, asymptotic and numerical solutions
Abstract: Hydraulic fractures (HF) are a class of tensile fractures that propagate in brittle materials by the injection of a pressurized viscous fluid. In this talk I provide examples of natural HF and situations in which HF are used in industrial problems. Natural examples of HF include the formation of dykes by the intrusion of pressurized magma from deep chambers. They are also used in a multiplicity of engineering applications, including: the deliberate formation of fracture surfaces in granite quarries; waste disposal; remediation of contaminated soils; cave inducement in mining; and fracturing of hydrocarbon bearing rocks in order to enhance production of oil and gas wells. Novel and emerging applications of this technology include CO2 sequestration and the enhancement of fracture networks to capture geothermal energy. I describe the governing equations in 1-2D as well as 2-3D models of HF, which involve a coupled system of degenerate nonlinear integro-partial differential equations as well as a free boundary. I demonstrate, via re-scaling the 1-2D model, how the active physical processes manifest themselves in the HF model and show how a balance between the dominant physical processes leads to special solutions. I discuss the challenges for efficient and robust numerical modeling of the 2-3D HF problem and some techniques recently developed to resolve these problems: including robust iterative techniques to solve the extremely stiff coupled equations and a novel Implicit Level Set Algorithm (ILSA) to resolve the free boundary problem. The efficacy of these techniques is demonstrated with numerical results.
Relevant papers can be found at: http://www.math.ubc.ca/~peirce

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Date: August 20, 11 a.m., 214 Fine Hall **(Special PACM Colloquium)**
Speaker: Volkan Cevher, EPFL
Title: An ALPS' view of Compressive Sensing
Abstract: Compressive sensing (CS) is an alternative to Shannon/Nyquist sampling for acquisition of sparse or compressible signals that can be well approximated by just K<< N elements from an N-dimensional basis. Instead of taking periodic samples, we measure inner products with M<N random vectors and then recover the signal via a sparsity-seeking optimization or greedy algorithm. The standard CS theory dictates that robust signal recovery is possible from M=O(K log(N/K)) measurements. The implications are promising for many applications and enable the design of new kinds of analog-to-digital converters, cameras and imaging systems, and sensor networks.
In this talk, we introduce three first-order, iterative CS recovery algorithms, collectively dubbed algebraic pursuits (ALPS), and derive their theoretical convergence and estimation guarantees. We empirically demonstrate that ALPS outperforms the Donoho-Tanner phase transition bounds for sparse recovery using Gaussian, Fourier, and sparse measurement matrices. We then describe how to use ALPS for CS recovery in redundant dictionaries. Finally, we discuss how ALPS can also incorporate union-of-subspaces-based sparsity models in recovery with provable guarantees to make CS better, stronger, and faster.

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Date: September 20 **(Joint PACM/Analysis Colloquium)**
Speaker: Felix Otto, Max-Planck Institute for Mathematical Sciences
Title: Optimal Error Estimates in Stochastic Homogenization
Abstract: Click here to view

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Date: September 27
Speaker: Philip Holmes, Princeton University
Title: Still running! Recent work on the neuromechanics of insect locomotion
Abstract:I will describe several models for running insects, from an energy-conserving biped with passively-sprung legs to a muscle-actuated hexapod driven by a neural central pattern generator(CPG). Phase reduction and averaging theory collapses some 300 differential equations that describe this neuromechanical model to 24 one-dimensional oscillators that track motoneuron phases. The reduced model accurately captures the dynamics of unperturbed gaits and the effects of impulsive perturbations, and phase response and coupling functions provide improved understanding of reflexive feedback

mechanisms. Specifically, piecewise-holonomic constraints due to intermittent foot contacts confers asymptotic stability on the CPG-driven feedforward system, the natural dynamics features a slow subspace that permits maneuverability, and leg force sensors modulate firing patterns to mitigate large perturbations. More generally, I will argue that both simple models and large simulations are necessary to understand such complex systems. The talk will draw on joint work with Einat Fuchs, Robert Full, Raffaele Ghigliazza, Raghu Kukillaya, Josh Proctor, John Schmitt, Justin Seipel and Manoj Srinivasan. Research supported by NSF and the J. Insley Blair Pyne Fund of Princeton University.

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Date: October 4
Speaker: Maria Chudnovsky, Columbia University
Title: Vertex-disjoint paths in tournaments
Abstract: The question of linking pairs of terminals by disjoint paths is a standard and well-studied question in graph theory. The setup is: given vertices s1,..,sk and t1,..,tk, is there a set of disjoint path P1,..,Pk such that Pi is a path from si to ti? This question makes sense in both directed and undirected graphs, and the paths may be required to be edge- or vertex-disjoint. For undirected graphs, a polynomial-time algorithm for solving both the edge-disjoint and the vertex-disjoint version of the problem (where the number k of terminals is fixed) was first found by Robertson and Seymour, and is a part of their well-known Graph Minors project. For directed graphs, both problems are NP-complete, even when k=2 (by a result of Fortune, Hopcroft and Wyllie). However, if we restrict our attention to tournaments (these are directed graphs with exactly one arc between every two vertices), the situation improves. Polynomial time algorithms for solving the edge-disjoint and the vertex-disjoint paths problems when k=2 have been known for a while(these are results of Bang-Jensen, and Bang-Jensen and Thomassen, respectively). Last year, Fradkin and Seymour were able to design a polynomial-time algorithm to solve the edge-disjoint paths problem in tournaments for general(fixed) k, using a new parameter for tournaments, developed by Seymour and the speaker, called "cut-width". However, the vertex-disjoint paths problem seemed to be resistant to similar methods. This talk will focus on the polynomial-time algorithm to solve the vertex-disjoint paths problem in tournaments for general (fixed) k, that we have recently obtained in joint work with Scott and Seymour.

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Date: October 11
Speaker: David Levin, Tel Aviv University
Title: Extrapolation Models
Abstract: Click here to view

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Date: October 18
Speaker: Ali Jadbabaie, University of Pennsylvania
Title: Information Aggregation in Complex Networks
Abstract: Over the past few years there has been a rapidly growing interest in analysis, design and optimization of various types of collective behaviors in networked dynamic systems. Collective phenomena (such as flocking, schooling, rendezvous, synchronization, and formation flight) have been studied in a diverse set of disciplines, ranging from computer graphics and statistical physics to distributed computation, and from robotics and control theory to ecology, evolutionary biology, social sciences and economics. A common underlying goal in such studies is to understand the emergence of some global phenomena from local rules and interactions.

In this talk, I will expand on such developments and present and analyze new models of consensus and agreement in random networks as well as new algorithms for information aggregation tailored to opinions and beliefs in social networks. Specifically, I will present a model of social learning in which an agent acts as rational and Bayesian with respect to her own observations, but exhibits a bias towards the average belief of its neighbors to reflect the "network effect". When the underlying social network is strongly connected all agents reach consensus in there beliefs. Moreover, I will show that when each agent's observed signal is independent from others, agents will "learn" like a Bayesian who has access to global

information, hence information is correctly aggregated.

Joint work with Pooya Molavi, Alireza Tahbaz-Salehi, Alvaro Sandroni and Victor Preciado

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Date: October 25
Speaker: John Lowengrub, University of California - Irvine
Title: Feedback, Lineages and Cancer
Abstract: A multispecies continuum model is developed to simulate the dynamics of cell lineages in solid tumors. The model accounts for spatiotemporally varying cell proliferation and death mediated by the heterogeneous distribution of oxygen and soluble chemical factors. Together, these regulate the rates of self-renewal and differentiation of the different cells within the lineages. As demonstrated in the talk, the feedback processes are found to play a critical role in tumor progression and the development of morphological instability.

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Date: November 8
Speaker: Michael Shelley, Courant Institute
Title: Novel Phenomena and Models of Active Fluids
Abstract: Fluids with suspended microstructure - complex fluids - are common actors in micro- and biofluidics applications and can have fascinating dynamical behaviors. A new area of complex fluid dynamics concerns "active fluids" which are internally driven by having dynamic microstructure such as swimming bacteria. Such motile suspensions are important to biology, and are candidate systems for tasks such as microfluidic mixing and pumping. To understand these systems, we have developed both first-principles particle and continuum kinetic models for studying the collective dynamics of hydrodynamically interacting microswimmers. The kinetic model couples together the dynamics of a Stokesian fluid with that of an evolving "active" stress field. It has a very interesting analytical and dynamical structure, and predicts critical conditions for the emergence of hydrodynamic instabilities and fluid mixing. These predictions are verified in our detailed particle simulations, and are consistent with current experimental observation.

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Date: November 15
Speaker: Leslie Greengard, Courant Institute, NYU
Title: A New Formalism for Electromagnetic Scattering in Complex Geometry
Abstract: We will describe some recent, elementary results in the theory of electromagnetic scattering in R3. There are two classical approaches that we will review - one based on the vector and scalar potential and applicable in arbitrary geometry, and one based on two scalar potentials, due to Lorenz, Debye and Mie, valid only in the exterior (or interior) of a sphere. In extending the Lorenz-Debye-Mie approach to arbitrary geometry, we have encountered some new mathematical questions involving differential geometry, partial differential equations and numerical analysis. This is joint work with Charlie Epstein.

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Date: November 22
Speaker: Zuowei Shen, National University of Singapore
Title: Wavelet Frames and Applications
Abstract: One of the major driving forces in the area of applied and computational harmonic analysis during the last two decades is the development and the analysis of redundant systems that produce sparse approximations for classes of functions of interest. Such redundant systems include wavelet frames, ridgelets, curvelets and shearlets, to name a few. This talk focuses on tight wavelet frames that are derived from multiresolution analysis and their applications in imaging. The pillar of this theory is the unitary extension principle and its various generalizations, hence we will first give a brief survey

on the development of extension principles. The extension principles allow for systematic constructions of wavelet frames that can be tailored to, and effectively used in, various problems in imaging science. We will discuss some of these applications of wavelet frames. The discussion will include frame-based image analysis and restorations, image inpainting, image denosing, image deblurring and blind deblurring, image decomposition, and image segmentation.

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Date: December 6
Speaker: Ioannis Karatzas, Columbia University
Title: Diffusions Interacting Through Their Ranks, and the Stability of Large Equity Markets
Abstract: We introduce and study ergodic multidimensional diusion processes interacting through their ranks. These interactions give rise to invariant measures which are in broad agreement with stability properties observed in large equity markets over long time-periods. The models we develop assign growth rates and variances that depend on both the name (identity) and the rank (according to capitalization) of each individual asset. Such models are able realistically to capture critical features of the observed stability of capital distribution over the past century, all the while being simple enough to allow for rather detailed analytical study. The methodologies used in this study touch upon the question of triple points for systems of interacting diusions; in particular, some choices of parameters may permit triple (or higher-order) collisions to occur. We show, however, that such multiple collisions have no eect on any of the stability properties of the resulting system. This is accomplished through a detailed analysis of intersection local times. The theory we develop has connections with the analysis of Queueing Networks in heavy traffic, as well as with models of competing particle systems in Statistical Mechanics, such as the Sherrington-Kirkpatrick model for spin-glasses.

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Date: December 13
Speaker: Sal Torquato, Princeton University
Title: Reformulation of the Covering and Quantizer Problems as Ground States of Interacting Particles
Abstract: I reformulate the covering and quantizer problems, well-known problems in discrete geometry, as the determination of the ground states of interacting particles in d-dimensional Euclidean space that generally involve single-body, two-body, three-body, and higher-body interactions. This is done by linking the covering and quantizer problems to certain optimization problems involving the "void" nearest-neighbor functions that arise in the theory of random media and statistical mechanics. These reformulations, which again exemplifies the deep interplay between geometry and physics, allow one now to employ optimization techniques to analyze and solve these energy minimization problems. The covering and quantizer problems have relevance in numerous applications, including wireless communication network layouts, the search of high-dimensional data parameter spaces, stereotactic radiation therapy, data compression, digital communications, meshing of space for numerical analysis, and coding and cryptography, among other examples. The connections between the covering and quantizer problems and the sphere-packing and number-variance problems (related to problems in number theory) are discussed. I also show that disordered saturated sphere packings provide relatively thin (economical) coverings and may yield thinner coverings than the best known lattice coverings in sufficiently large dimensions. I derive improved upper bounds on the quantizer error using sphere-packing solutions, which are generally substantially sharper than an existing upper bound in low to moderately large dimensions. I demonstrate that disordered saturated sphere packings yield relatively good quantizers. Finally, I remark on possible applications of the results to the detection of gravitational waves.

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2009-2010 Collapse/Expand

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Date: February 2
Speaker: Iven Mareels, Biomedical , University of Melbourne

Title: Systems Engineering for Water Management
Abstract: It is estimated that we harvest and utilize about 65% of the readily available fresh water resources of the world. In general, perhaps because water is perceived as an abundantly available resource, we use water rather poorly. Typically less than half the water taken from the environment serves the objective for which it was intended. The UNESCO World Water reports 2003 and 2005 identify in no uncertain terms a water crisis.

In this lecture we provide an overview of a 10 year collaborative research and development effort, between the University of Melbourne and a local company Rubicon Systems Australia, and more recently with National ICT Australia.

The programme called Water Information Networks (WIN) is a systems engineering approach to water management in irrigation systems. Because irrigation accounts for 70% of the total water consumption, this is a logical place to start. The ultimate goal is to manage water at the level of an entire water catchment basin, accounting for surface and ground water and providing for the needs of all users, including the environment. WIN has developed a sensor/actuator network and a systems engineering approach to water management. The patented technology (commercialized as Total Channel Control™) is now being deployed in Australia's largest irrigation district Goulburn Murray Water (GMW), consisting of 6800km of open irrigation canals servicing over 22,000 farms.

The objective for the open canal system is to deliver water on demand (in as much this may be feasible) with maximal overall efficiency meeting the competing demands.

We review the research work, including open questions, and discuss the WIN outcomes from a number of substantial pilot and commercial projects in Australia that have realized significant gains in either water efficiency or water productivity in irrigation.

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Date: February 9
Speaker: Jennifer Rexford, Computer Science, Princeton University
Title: Stable Internet Routing Without Global Coordination
Abstract: Global Internet connectivity results from a competitive cooperation of tens of thousands of independently-administered networks (called Autonomous Systems), each with their own preferences for how traffic should flow. The responsibility for reconciling these preferences falls to interdomain routing, realized today by the Border Gateway Protocol (BGP). However, BGP allows ASes to express conflicting local policies that can lead to global routing instability. This talk proposes a set of guidelines for an AS to follow in setting its routing policies, without requiring coordination with other ASes. Our approach exploits the Internet's hierarchical structure and the commercial relationships between ASes to impose a partial order on the set of routes to each destination. The guidelines conform to conventional traffic-engineering practices of ISPs, and provide each AS with significant flexibility in selecting its local policies. Furthermore, the guidelines ensure route convergence even under changes in the topology and routing policies. Drawing on a formal model of BGP, we prove that following our proposed policy guidelines guarantees route convergence. We also describe how our methodology can be applied to new types of relationships between ASes, how to verify the hierarchical AS relationships, and how to realize our policy guidelines. Our approach has significant practical value since it preserves the ability of each AS to apply complex local policies without divulging its BGP configurations to others.

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Date: February 16
Speaker: Salvatore Torquato, Chemistry, PMI, PACM, and PCTP
Title:"Unusual Classical Ground States of Matter"
Abstract:A classical ground-state configuration of a system of interacting particles is one that minimizes the system potential energy. In the laboratory, such states are produced by slowly cooling a liquid to a temperature of absolute zero, and usually the ground states are crystal structures. However, our theoretical understanding of ground states is far from complete. For example, it is difficult to prove what are the ground states for realistic interactions. I discuss recent

theoretical/computational methods that we have formulated to identify unusual crystal ground states as well as disordered ground state
[1,2,3,4]. Although the latter possibility is counterintuitive, there
is no fundamental reason why classical ground states cannot be aperiodic
or disordered.

1) M. Rechtsman, F. H. Stillinger and S. Torquato, Synthetic Diamond and Wurtzite Structures Self-Assemble with Isotropic Pair Interactions , Physical Review E, vol. 75, 031403 (2007).

2) S. Torquato and F. H. Stillinger, "New Duality Relations for Classical Ground States," Physical Review Letters, vol. 100, 020602 (2008).

3) R. D. Batten, F. H. Stillinger and S. Torquato, "Classical Disordered Ground States: Super-Ideal Gases, and Stealth and Equi-Luminous Materials," Journal of Applied Physics, vol. 104, 033504, (2008).

4) A. Scardicchio, F. H. Stillinger and S. Torquato, "Estimates of the Optimal Density of Sphere Packings in High Dimensions, Journal of Mathematical Physics, vol. 49, 043301 (2008).

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Date: March 2
Speaker: Jonathan Mattingly, Duke University, Mathematics Department
Title: Trouble with a chain of stochastic oscillators
Abstract: I will discuss some recent (but modest) results showing the existence and slow mixing of a stationary chain of Hamiltonian oscillators subject to a heat bath. Such systems are used as simple models of heat conduction or energy transfer. Though the unlimite goal might be seen to under stand the "fourier" like law in this setting, I will be less ambitious. I will show that under some hypotheses, the chain posses a unique stationary state. Surprisingly, even these simple results require some delicate stochastic averaging. Furthermore, it is the existence of a stationary measure (not the uniquness) which is difficult. This is joint work with Martin Hairer .

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Date: March 9
Speaker: Rebecca Willett, Electrical and Computer Engineering, Duke University
Title: High-Dimensional Co-Occurrence Density Estimation
Abstract: Co-occurrence data can represent critical information in a variety of contexts, such as meetings in a social network, routers in a communication network, or genes, proteins, and metabolites in biological research. In this talk, I will present two novel approaches to conducting inference from high-dimensional co-occurrence training observations. First, I will describe an efficient recursive algorithm for computing an orthogonal series density estimate in the Walsh basis, which allows for a flexible trade-off between estimation error and computational complexity. In particular, even when there are 2^d coefficients to estimate and d is very large, we can achieve near- minimax error decay rates with a computational complexity which is polynomial in d and depends on the density's sparsity in the Walsh basis. Second, I will present an online convex programming approach to estimating the likelihood of sequentially observed co-occurrences. We will see that this approach is minimax optimal relative to an oracle estimator and that the optimization at each time can be computed very efficiently in terms of both time and memory.

Rebecca Willett is an assistant professor in the Electrical and Computer Engineering Department at Duke University. She completed her PhD in Electrical and Computer Engineering at Rice University. She received the National Science Foundation CAREER Award in 2007 and is a member of the DARPA Computer Science Study Panel. In addition to studying at Rice, Prof. Willett has worked as a Fellow of the Institute for Pure and Applied Mathematics at UCLA, as a visiting researcher at the University of Wisconsin-Madison and the French National Institute for Research in Computer Science and Control (INRIA), and as a member of the Applied Science Research and Development Laboratory at GE

Medical Systems (now GE Healthcare). Her research interests include signal processing and communications with applications in medical imaging, astrophysics, and networks. Additional information, including publications and software, are available online at http://www.ee.duke.edu/~willett/.

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Date: March 23
Speaker: Zhaohua Wu, Department of Meteorology & Center for Ocean-Atmospheric Prediction Studies, Florida State University
Title: The Empirical Mode Decomposition: the method, its progress, and open questions
Abstract: The Empirical Mode Decomposition (EMD) was an empirical one-dimensional data decomposition method invented by Dr. Norden Huang about ten years ago and has been used with great success in many fields of science and engineering. In this talk, I will introduce, from the perspective of a physical scientist, the thinking behind and the algorithm of EMD; and its most recent developments, especially the Ensemble EMD (EEMD), a noise-assisted data analysis method, and the multi-dimensional EMD based on EEMD. I will also outline some open questions that we currently do not have answers, or even clues to the answers, such as how to optimize EMD algorithm, what is the mathematical nature of EMD. To a significant degree, this is a talk intended for obtaining helps from mathematicians.

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Date: March 30
Speaker: Olgica Milenkovic, Electrical & Computer Engrg, University of Illinois - Urbana-Champaign
Title: On the interplay between coding theory and compressed sensing
Olgica Milenkovic, ECE Department, UIUC
Abstract: Compressed sensing (CS) is a signal processing technique that allows for accurate, polynomial time recovery of sparse data-vectors based on a small number of linear measurements. In its most basic form, robust CS can be viewed as a specialized error-control coding scheme in which the data alphabet does not necessarily have the structure of a finite field and where the notion of a “parity-check” is replaced by a more general functionality. It is therefore possible to combine and extend classical CS and coding-theoretic paradigms in terms of introducing new minimum distance, reconstructions complexity, and quantization precision constraints. In this setting, we derive fundamental lower and upper bounds on the achievable compression rate for such constrained compressed sensing (CCS) schemes, and also demonstrate that sparse reconstruction in the presence of noise can be performed via low-complexity correlation-maximization algorithms that operate based on belief propagation iterations.
Our problem analysis is motivated by a myriad of applications ranging from compressed sensing microarray designs, reliability-reordering decoding of linear block-codes, identification in multi-user communication systems, and fault tolerant computing.

This is a joint work with Wei Dai and Vin Pham Hoa from the ECE Department at UIUC.

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Date: April 13
Speaker: Yaron Lipman, PACM/Computer Science
Title: Surface Correspondence via Discrete Uniformization
Abstract: Many applied-science fields like medical imaging, computer graphics and biology use meshes to model surfaces. It is a challenging problem to determine whether, how and to what extent such surfaces correspond to each other, e.g. to see whether they are differently parametrized views of one object, or whether they indicate movement of part of an object with respect to its other parts. In this talk we will show how the Uniformization theory can be used to establish correspondences between simply-connected surfaces. We will present an algorithm for automatically finding corresponding points between two discrete surfaces (meshes). The algorithm is based on the observation that the correspondence problem between nearly

isometric surfaces is a low dimensional problem in practice, which is well characterized by the Mobius group of fractional linear transformations.

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Date: April 20
Speaker: Jennifer Chayes, Microsoft Corporation
Title: Interdisciplinarity in the Age of Networks
Abstract: Everywhere we turn these days, we find that networks have become increasing appropriate descriptions of relevant interactions. In the high tech world, we see the Internet, the World Wide Web, mobile phone networks, and a variety of online social networks. In economics, we are increasingly experiencing both the positive and negative effects of a global networked economy. In epidemiology, we find disease spreading over our ever growing social networks, complicated by mutation of the disease agents. In problems of world health, distribution of limited resources, such as water resources, quickly becomes a problem of finding the optimal network for resource allocation. In biomedical research, we are beginning to understand the structure of gene regulatory networks, with the prospect of using this understanding to manage the many diseases caused by gene mis-regulation. In this talk, I look quite generally at some of the models we are using to describe these networks, processes we are studying on the networks, algorithms we have devised for the networks, and finally, methods we are developing to indirectly infer network structure from measured data. In particular, I will discuss models and techniques which cut across many disciplinary boundaries.

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Date: April 27
Speaker: Adam Burrows, Astrophysics, Princeton University
Title: State-of-the-art Computer Simulations of Supernova Explosions
Abstract: To simulate supernova explosions, one must solve simultaneously the non-linear, coupled partial differential equations of radiation hydrodynamics. What's more, due to a variety of instabilities and asymmetries, this must eventually be accomplished in 3D. The current state-of-the-art is 2D, plus rotation and magnetic fields (assuming axisymmetry). Nevertheless, with the current suite of codes, we have been able to explore the evolution of the high-density, high-temperature, high-speed environment at the core of a massive star at death. It is in this core that the supernova explosion is launched. However, the complexity of the problem has to date obscured the essential physics and mechanisms of the phenomenon, making it indeed one of the "Grand Challenges" of 21st century astrophysics. Requiring forefront numerical algorithms and massive computational resources, the resolution of this puzzle awaits the advent of peta- and exa-scale architectures and the software to efficiently use them. In this talk, I will review the current state of the science and simulations as we plan for the fully 3D, multi-physics capabilities that promise credibly to crack open this obdurate astrophysical nut.

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Date: September 29
Speaker: Kevin Drummey, NSA
Title: NSA Summer Program Opportunity
Abstract: In this seminar, we provide an overview of NSA and its Summer Program for Operations Research Technology (SPORT), which is a 12-week internship for graduate students enrolled in an M.S. or Ph.D. program who also have experience in computer programming. The goal of SPORT is to offer top graduate students, who have highly developed operations research and applied math skills, a unique opportunity to apply their knowledge to actual problems that are encountered at NSA in one of the most advanced intelligence gathering environments in the world. Specific areas of technical interest include: Operations Research, Modeling and Simulation, Industrial/Systems Engineering, Probability and Statistics, and Management Science.
More Information: Talk begins at 4:30 p.m. in room 101, Sherrerd Hall

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Date: October 5
Speaker: Robert Eisenberg, Rush Medical Center/Chicago and Argonne National Labs
Title: Self-organized selectivity in Calcium and Sodium Channels: important biology ready for mathematical analysis
Abstract: Ion channels are irresistible objects for biological study because they are the [nano] 'valves of life' controlling an enormous range of biological function, much as transistors control computers. Ion channels are appealing objects for physical investigation because conformation changes are not involved in channel function, once the channel is open. Open channels are interesting objects for chemical study because they effectively select among chemically similar ions, under unfavorable circumstances. Channels are interesting objects for physical study because they contain an enormous density of charge, fixed, mobile, and induced. Direct simulation of channel behavior in atomic detail is difficult if not impossible, because ion transit takes ~ 10-8 sec compared to a simulation calculation time step of 10-16 sec and a biological time scale beginning at 10-4 sec. Direct simulation must deal with concentrations of 10-7 to 55 M in a single calculation, and macroscopic electric fields and concentration gradients produce substantial flows which are the function of the channel, making equilibrium analysis unhelpful.

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Date: October 12
Speaker: Raphy Coifman, Yale University **(joint w/analysis seminar)**
Title: Harmonic Analysis and Geometries of Digital Data Bases
Abstract: Given a matrix (of Data) we describe methodologies to build two multiscale (inference) Geometries/Harmonic Analysis one on the rows , the other on the columns . The geometries are designed to simplify the representation of the data base . We will provide a number of examples including; matrices of operators , psychological questionnaires, vector valued images, scientific articles, etc.
In all these cases tensor Haar orthogonal bases play a crucial role in organizing the data base viewed as a function of two variables (row, column) in the case of potential operators we relate to Calderon Zugmund decompositions , while for other data this is a "data agnostic analytic learning tool"
For the example of the matrix of eigenfunctions of a discretized Laplace operator (say, on a compact manifold) we obtain both the Geometry of the domain of the Laplace operator as well as a dual multiscale Geometry of the eigenvectors.

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Date: October 26
Speaker: Howard Stone, Mechanical and Aerospace Engineering
Title: Some variants on the flows of suspensions: Diffusion, dispersion, and biofilms
Abstract: In this talk I will present several fluid mechanics problems that concern the flow of particles and suspensions. This topic has many variants, which I will introduce to provide breadth and perspective for the listener (most of you) who has not studied the topic. After the introduction I will highlight (i) shear-enhanced diffusion, as studied in a microfluidic device, (ii) axial dispersion due to shear-enhanced diffusion, and (iii) unusual structures formed when bacteria flow, and biofilms grow, in curved channels. Some answers will be given and open questions will be indicated.

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Date: November 9
Speaker: Mauro Maggioni, Duke University
Title: Geometry and Analysis of point sets in high dimensions
Abstract: The analysis of high dimensional data sets is useful in a large variety of applications, from machine learning to dynamical systems: data sets are often modeled as low-dimensional, noisy data sets embedded in high-dimensional spaces; dynamical systems often have very high-dimensional state spaces but sometimes interesting dynamics occurs on low-dimensional sets. We discuss several problems associated with the analysis of the geometry of such sets, and with the

approximation of functions on such sets, together with some solutions: in particular we discuss how to construct random walks on such data sets and perform multiscale analysis of them and their applications (especially to machine learning); how to construct robust coordinate systems for data sets; how to estimate reliably the intrinsic dimensionality of the data when only few noisy samples are available.

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Date: November 16
Speaker: Erik Vanmarcke, Civil and Environmental Engineering
Title: Testable New Theory about Early-Universe Density Fluctuations and Origins of Solar Systems: Applied-Probability and Quantum-Physics Aspects
Abstract: The talk will summarize, with a focus on applied-probability aspects, the main findings, testable predictions and research opportunities stemming from a new probabilistic model of how complex patterns of energy-density fluctuations may have arisen during the inflation phase of the Big Bang. Based on first (quantum-physical) principles and requiring a minimum number of (observationally-accessible) parameters, the "embryonic inflation model" yields a coherent set of testable (hence falsifiable) hypotheses about the formation, evolution, composition, internal structure and cosmic environment of galaxies, stars and planets, and is consistent with key findings from observations of the Cosmic Microwave Background (CMB). Implying a robust alternative (and challenge) to the dual paradigm of spatially-uniform light-element primordial nucleosynthesis and stellar "recycling" of matter as the sole mechanism of heavy-element production, the theory holds the promise of integrating astrophysical and planetary sciences with cosmology and galaxy formation in a coherent evolutionary framework. Observations indicating overall cosmic flatness, the existence of an accelerating component, dark matter and dark energy all fit, in quantifiable and testable ways, into the framework of the theory.

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Date: November 23
Speaker: Warren Powell, ORFE
Title: Solving High-Dimensional Stochastic Optimization Problems using Approximate Dynamic Programming
Abstract: There are many stochastic resource allocation problems arising in transportation, energy and health that involve high-dimensional state and action variables in the presence of dierent forms of uncertainty. These might involve discrete or continuous resources, and generally involve vectors of random variables that preclude exact computation of expectations. I will also describe our research into the important \exploration vs. exploitation" problem that arises in approximate dynamic programming, where we have the ability to choose the next state we will visit.

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Date: November 30
Speaker: Joris Dik, Delft University of Technology, Netherlands
Title: Looking over the painter's shoulder
Abstract: Just microns below their paint surface lies a wealth of information on Old Master Paintings. Hidden layers can include the underdrawing, the underpainting or compositional alterations by the artist. All too often artists simply re-used their canvases and painted a new composition on top. Thus, a look /through /the paint layer provides a look /over/ the painter's shoulder. I will discuss case different subsurface imaging techniques and present case studies from the work of Vincent van Gogh and Rembrandt.

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Date: December 7
Speaker: Roy S. Berns, Munsell Color Science Laboratory, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, USA
Title: Imaging Techniques and the Rejuvenation of Artwork

Abstract: Advances in digital imaging within the visible spectrum enable the accurate color rendering of artwork. It is possible to generate a colorimetric image with high spatial resolution and high image quality (appropriate sharpness and low noise). When the number of sensor channels exceeds three, it is also possible to generate spectral images. Spectral images can be used to calculate colorimetric images for any illuminant and observer pair, to evaluate color inconstancy, as an aid in retouching (i.e., “restorative inpainting”), for pigment mapping, and to improve printed reproductions. These digital images, of course, record the color and spectra of the artwork in its current condition. Depending on how the artwork has aged, its color may bear little resemblance to its appearance when first executed. This can dramatically affect the analysis of the painting in terms of its historical context and understanding the artist’s working methods. A variety of techniques can be used to determine such color changes including analysing cross-sections, finding protected areas and identical materials that retain their color, early photographic records, and descriptions by art critics and connoisseurs at the time of creation. Having determined that a color change has occurred, it is possible to “rejuvenate” the colors of a digital image by using the principles of instrumental-based color matching. These principles are used to determine pigments and their concentrations that when mixed, match a particular color. This is equivalent to pigment mapping. The digital rejuvenation is performed by either replacing the spectral properties of the changed pigment with one that hasn’t changed or increasing the concentration of a pigment that has faded. These rejuvenated images, while speculative, provide important and interesting new insights. This presentation will review research by the author in digital rejuvenation using examples by Vincent Van Gogh and Georges Seurat.

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Date: September 4
Speaker: Shiwei Zhang, College of William and Mary
Title: First-principles electronic structure computations by random walks in Slater determinant space
Abstract: Accurate first-principles calculations of materials remain an outstanding theoretical and computational challenge. The "standard model" is an independent-electron approach in the framework of density-functional theory (DFT). In materials with strong electron interaction effects, such as high-temperature superconductors and spintronic materials, this approach is often inadequate. Several alternatives are being actively pursued. Among these, we have been developing a many-body, non-perturbative method using random walks in the space of Slater determinants. I will discuss the basic framework, its connection with DFT, the "sign problem" in this context, and how it can be controlled with an approximate constraint on the random walks. Results will be presented on atoms, molecules, bulk solids, and the Hubbard model for cuprate superconductors.

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Date: October 6
Speaker: Amit Singer, PACM & Mathematics, Princeton University
Title: Structure Determination through Eigenvectors of Sparse Operators

Abstract: In many applications, the main goal is to obtain a global low dimensional representation of the data, given some local noisy geometric constraints. In this talk we will show how the problems listed below can be efficiently solved by constructing suitable operators on their data and computing a few eigenvectors of sparse matrices corresponding to the data operators.

- **Cryo Electron Microscopy for protein structuring:** reconstructing the three-dimensional structure of a molecule from projection images taken at random unknown orientations (unlike classical tomography, where orientations are known).
- **NMR spectroscopy for protein structuring:** finding the global positioning of all hydrogen atoms in a molecule from their local distances. Distances between neighboring hydrogen atoms are estimated from the spectral lines corresponding to the short ranged spin-spin interaction.
- **Sensor networks:** finding the global positioning from noisy local distances.

Joint work with Ronald Coifman, Yoel Shkolnisky (Yale Applied Math) and Fred Sigworth (Yale School of Medicine).

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Date: October 13
Speaker: Greg Hammett, Princeton Plasma Physics Lab
Title: Simulations of 5-D Plasma Turbulence in Fusion Energy Devices
Abstract: This talk will start with a brief status report on magnetic fusion energy research. One of the key challenges in fusion has been the occurrence of fine-scale turbulent fluctuations, which cause plasma to leak out of a magnetic trap, so we would like to be able to predict and reduce this turbulence. A major advance in this field has been the recent development of codes for comprehensive 5-D gyrokinetic simulations of microturbulence in the core region of fusion devices. These simulations have been made feasible by significant advances not only in raw computer power, but also in asymptotic simplification of the problem formulation, and in algorithmic development. Remaining challenges and some opportunities for contributions from applied and computational mathematics will be described.

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Date: October 20
Speaker: Shamgar Gurevich, Mathematics, University of California, Berkeley and Ronny Hadani, Mathematics, University of Chicago
Title: Group representation patterns in digital signal processing
Abstract: In the lecture we will explain how various fundamental structures from group representation theory appear naturally in the context of discrete harmonic analysis and can be applied to solve concrete problems from digital signal processing. We will begin the lecture by describing our solution to the problem of finding a canonical orthonormal basis of eigenfunctions of the discrete Fourier transform (DFT). Then we will explain how to generalize the construction to obtain a larger collection of functions that we call "The oscillator dictionary." Functions in the oscillator dictionary admit many interesting properties, in particular, we will explain several of these properties which arise in the context of problems of current interest in areas such as communication and radar.

Joint work with **Nir Sochen (Tel Aviv)**.

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Date: November 3
Speaker: Jeroen Tromp, PACM & Geosciences, Princeton University
Title: Spectral-element and adjoint methods in computational seismology
Abstract: We provide an introduction to the use of spectral-element and adjoint methods in seismology. Following a brief review of the basic equations that govern seismic wave propagation, we discuss how these equations may be solved numerically based upon the spectral-element method (SEM) to address the *forward* problem in seismology. Examples of

synthetic seismograms calculated based upon the SEM are compared to data recorded by global and regional seismographic networks. We also discuss the challenge of using the remaining differences between the data and the synthetic seismograms to constrain better Earth models and source descriptions. This leads naturally to adjoint methods, which provide a practical approach to this formidable computational challenge and enables seismologists to tackle the *inverse* problem.

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Date: November 10
Speaker: Pierre-Louis Lions, Collége de France, Ecole Polytechnique and and University Paris-Dauphine
Title: Symmetric functions of a large number of variables

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Date: November 17
Speaker: Aleksandar Donev, Lawrence Livermore National Laboratory
Title: Multiscale Methods for Hydrodynamics of Polymer Chains in Solution
Abstract: The hydrodynamics of complex fluids, such as polymer solutions and colloidal suspensions, has attracted great interest due to recent advances in fabrication of micro- and nano-fluidic devices. I will first review recent advances in mesoscopic numerical methods for simulating the interaction between complex fluid flow and suspended macro molecules and structures. Computational issues at play include coarse-graining to bridge the large gap in timescales and length scales, coupling between disparate methods such as molecular dynamics and Navier-Stokes solvers, the inclusion of thermal fluctuations.

I will then present my recent work at LLNL to develop novel particle methods for modeling polymer chains in flow. Typically, Molecular Dynamics (MD) is used for the polymer chains, and the solvent is modeled with a mesoscopic method. In our algorithm, termed Stochastic Event-Driven Molecular Dynamics (SEDMD) [A. Donev and A. L. Garcia and B. J. Alder, J. Comp. Phys., 227(4), 2644-2665, 2008], polymers are modeled as chains of hard spheres and the solvent is modeled using a dense-fluid generalization of the Direct Simulation Monte Carlo (DSMC) method [Phys. Rev. Lett., 101, 075902, 2008]. Even with all of the speedup compared to brute-force MD the algorithm is still time-consuming due to the large number of solvent particles necessary to fill the computational domain. It is natural to restrict the particle model only to regions close to a polymer chain and use a lower-resolution continuum model elsewhere. I will present a hybrid method that couples an explicit fluctuating compressible Navier-Stokes solver with the particle method. The coupling is flux-based and generalizes previous work [J. B. Bell and A. L. Garcia and S. A. Williams, SIAM Multiscale Modeling and Simulation, 6, 1256-1280, 2008] to dense fluids as appropriate for polymer problems.

I will conclude with a look into the challenges of developing a simulation methodology capable of simulating macroscopic flows of complex fluids with atomistic fidelity.

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Date: November 24
Speaker: René Carmona, PACM & ORFE, Princeton University
Title: Emissions Market Models
Abstract: The main goal of the talk is to introduce a new cap-and-trade scheme design for the control and the reduction of atmospheric pollution. The tools developed for the purpose of the study are intended to help policy makers and regulators understand the pros and cons of the emissions markets at a quantitative level.

We propose a model for an economy where risk neutral firms produce goods to satisfy an inelastic demand and are endowed with permits by the regulator in order to offset their pollution at compliance time and avoid having to pay a penalty. Firms that can easily reduce emissions do so, while those for which it is harder buy permits from those firms anticipating that they will not need them, creating a financial market for pollution credits.

Our model captures most of the features of the European Union Emissions Trading Scheme. We show existence of an equilibrium and uniqueness of emissions credit prices. We also characterize the equilibrium prices of goods and the optimal production and trading strategies of the firms. We choose the electricity market in Texas to illustrate numerically the qualitative properties observed during the implementation of the first phase of the European Union cap-and-trade CO_2 emissions scheme, comparing the results of cap-and-trade schemes to the Business As Usual benchmark. In particular, we confirm the presence of windfall profits criticized by the opponents of these markets. We also demonstrate the shortcomings of tax and subsidy alternatives. Finally we introduce a relative allocation scheme which, despite its ease of implementation, leads to smaller windfall profits than the standard scheme.

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Date: December 1
Speaker: Ingrid Daubechies, PACM & Mathematics, Princeton University
Title: Report on the PACM Van Gogh project
Abstract: Stimulated by the workshops for "Imaging Scientists and Art Historians" organized by Rick Johnson at the Van Gogh Museum in Amsterdam in 2007 and 2008, a team of graduate students in Princeton studied several aspects of Van Gogh's paintings, based on high resolution digital representations. The talk will report on the results, the interactions with the Museum, and the further plans of the team.

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Date: December 8
Speaker: James M. Stone, PACM & Astrophysical Sciences
Title: Computational Astrophysics and the Dynamics of Accretion Disks
Abstract: The ever increasing performance of computer hardware and improvements to the accuracy of numerical algorithms are revolutionizing scientific research in many disciplines, but perhaps none more so than astrophysics. I will begin by describing why computation is crucial for the solution of a variety of problems at the forefront of research in astronomy and astrophysics, with particular emphasis on understanding accretion flows onto black holes. I will outline the challenge of developing, testing, and implementing numerical algorithms for the investigation of these problems. Finally, I will present results that demonstrate how computation can help us understand the basic physics of magnetized accretion disks.

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Date: March 9
Speaker: Rebecca Willett, Electrical and Computer Engineering, Duke University
Title: High-Dimensional Co-Occurrence Density Estimation
Abstract: Co-occurrence data can represent critical information in a variety of contexts, such as meetings in a social network, routers in a communication network, or genes, proteins, and metabolites in biological research. In this talk, I will present two novel approaches to conducting inference from high-dimensional co-occurrence training observations. First, I will describe an efficient recursive algorithm for computing an orthogonal series density estimate in the Walsh basis, which allows for a flexible trade-off between estimation error and computational complexity. In particular, even when there are 2^d coefficients to estimate and d is very large, we can achieve near- minimax error decay rates with a computational complexity which is polynomial in d and depends on the density's sparsity in the Walsh basis. Second, I will present an online convex programming approach to estimating the likelihood of sequentially observed co-occurrences. We will see that this approach is minimax optimal relative to an oracle estimator and that the optimization at each time can be computed very efficiently in terms of both time and memory.

Rebecca Willett is an assistant professor in the Electrical and Computer Engineering Department at Duke University. She completed her PhD in Electrical and Computer Engineering at Rice University. She received the National Science Foundation CAREER Award in 2007 and is a member of the DARPA Computer Science Study Panel. In addition to studying at Rice, Prof. Willett has worked as a Fellow of the Institute for Pure and Applied Mathematics at UCLA, as a visiting researcher at the University of Wisconsin-Madison and the French National Institute for Research in Computer Science and Control (INRIA), and as a member of the Applied Science Research and Development Laboratory at GE Medical Systems (now GE Healthcare). Her research interests include signal processing and communications with applications in medical imaging, astrophysics, and networks. Additional information, including publications and software, are available online at http://www.ee.duke.edu/~willett/.

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Date: March 23
Speaker: Zhaohua Wu, Department of Meteorology & Center for Ocean-Atmospheric Prediction Studies, Florida State University
Title: The Empirical Mode Decomposition: the method, its progress, and open questions
Abstract: The Empirical Mode Decomposition (EMD) was an empirical one-dimensional data decomposition method invented by Dr. Norden Huang about ten years ago and has been used with great success in many fields of science and engineering. In this talk, I will introduce, from the perspective of a physical scientist, the thinking behind and the algorithm of EMD; and its most recent developments, especially the Ensemble EMD (EEMD), a noise-assisted data analysis method, and the multi-dimensional EMD based on EEMD. I will also outline some open questions that we currently do not have answers, or even clues to the answers, such as how to optimize EMD algorithm, what is the mathematical nature of EMD. To a significant degree, this is a talk intended for obtaining helps from mathematicians.

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Date: March 30
Speaker: Olgica Milenkovic, Electrical & Computer Engrg, University of Illinois - Urbana-Champaign
Title: On the interplay between coding theory and compressed sensing
Olgica Milenkovic, ECE Department, UIUC
Abstract: Compressed sensing (CS) is a signal processing technique that allows for accurate, polynomial time recovery of sparse data-vectors based on a small number of linear measurements. In its most basic form, robust CS can be viewed as a specialized error-control coding scheme in which the data alphabet does not necessarily have the structure of a finite field and where the notion of a “parity-check” is replaced by a more general functionality. It is therefore possible to combine and extend classical CS and coding-theoretic paradigms in terms of introducing new minimum distance, reconstructions complexity, and quantization precision constraints. In this setting, we derive fundamental lower and upper bounds on the achievable compression rate for such constrained compressed sensing (CCS) schemes, and also demonstrate that sparse reconstruction in the presence of noise can be performed via low-complexity correlation-maximization algorithms that operate based on belief propagation iterations.
Our problem analysis is motivated by a myriad of applications ranging from compressed sensing microarray designs, reliability-reordering decoding of linear block-codes, identification in multi-user communication systems, and fault tolerant computing.

This is a joint work with Wei Dai and Vin Pham Hoa from the ECE Department at UIUC.

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Date: April 13
Speaker: Yaron Lipman, PACM/Computer Science
Title: Surface Correspondence via Discrete Uniformization
Abstract: Many applied-science fields like medical imaging, computer graphics and biology use meshes to model surfaces. It is a challenging problem to determine whether, how and to what extent such surfaces correspond to each other, e.g. to see whether they are differently parametrized views of one object, or whether they indicate movement of part of an object with respect to its other parts. In this talk we will show how the Uniformization theory can be used to establish correspondences

between simply-connected surfaces. We will present an algorithm for automatically finding corresponding points between two discrete surfaces (meshes). The algorithm is based on the observation that the correspondence problem between nearly isometric surfaces is a low dimensional problem in practice, which is well characterized by the Mobius group of fractional linear transformations.

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Date: April 20
Speaker: Jennifer Chayes, Microsoft Corporation
Title: Interdisciplinarity in the Age of Networks
Abstract: Everywhere we turn these days, we find that networks have become increasing appropriate descriptions of relevant interactions. In the high tech world, we see the Internet, the World Wide Web, mobile phone networks, and a variety of online social networks. In economics, we are increasingly experiencing both the positive and negative effects of a global networked economy. In epidemiology, we find disease spreading over our ever growing social networks, complicated by mutation of the disease agents. In problems of world health, distribution of limited resources, such as water resources, quickly becomes a problem of finding the optimal network for resource allocation. In biomedical research, we are beginning to understand the structure of gene regulatory networks, with the prospect of using this understanding to manage the many diseases caused by gene mis-regulation. In this talk, I look quite generally at some of the models we are using to describe these networks, processes we are studying on the networks, algorithms we have devised for the networks, and finally, methods we are developing to indirectly infer network structure from measured data. In particular, I will discuss models and techniques which cut across many disciplinary boundaries.

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Date: April 27
Speaker: Adam Burrows, Astrophysics, Princeton University
Title: State-of-the-art Computer Simulations of Supernova Explosions
Abstract: To simulate supernova explosions, one must solve simultaneously the non-linear, coupled partial differential equations of radiation hydrodynamics. What's more, due to a variety of instabilities and asymmetries, this must eventually be accomplished in 3D. The current state-of-the-art is 2D, plus rotation and magnetic fields (assuming axisymmetry). Nevertheless, with the current suite of codes, we have been able to explore the evolution of the high-density, high-temperature, high-speed environment at the core of a massive star at death. It is in this core that the supernova explosion is launched. However, the complexity of the problem has to date obscured the essential physics and mechanisms of the phenomenon, making it indeed one of the "Grand Challenges" of 21st century astrophysics. Requiring forefront numerical algorithms and massive computational resources, the resolution of this puzzle awaits the advent of peta- and exa-scale architectures and the software to efficiently use them. In this talk, I will review the current state of the science and simulations as we plan for the fully 3D, multi-physics capabilities that promise credibly to crack open this obdurate astrophysical nut.

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Date: September 24
Speaker: Janos Csirik, D E Shaw
Title: *My experiences with mathematics outside academia*
Abstract: The speaker attended the Berkeley Math PhD program from 1995 to 1999, completing his magnum opus "The kernel of the Eisenstein ideal" in algebraic number theory under the direction of Ken Ribet. He is currently a quantitative analyst at D. E. Shaw & Co, one of the largest hedge funds in the world.
In this very informal seminar he will aim to provide some information that he would have found interesting and/or useful back when he was a graduate student. He will comment on his various experiences including an internship in cryptography

with Arjen Lenstra at Citibank, being a researcher at two major industrial research labs (HP and AT&T), and being a quant at D. E. Shaw & Co.
The speaker will be available for Q&A after the seminar.
There will be a recruiting presentation by D. E. Shaw & Co. at 6:30pm on the same day at the Nassau Inn, which the speaker whole-heartedly recommends to all who are interested in finding out about a career in finance.

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Date: October 1
Speaker: Panos Papadopoulos, Mechanical Engineering, University of California, Berkeley
Title: *A Critical Look at Mesh-Tying and Contact Algorithms in Computational Mechanics*
Abstract: The solution of boundary-value problems in solid and fluid mechanics often involves interfaces between similar or dissimilar domains. On such interfaces, the underlying physics dictates that certain conditions be enforced. The enforcement of such conditions, in turn, poses numerical challenges arising from the choice of approximation spaces, as well as from the geometry and discrete character of the associated computational grids. In this talk, a mathematical framework for the analysis of a class of such interface problems involving contact between deformable solids will be reviewed and certain convergent dual algorithms will be discussed within the context of the finite element method.

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Date: October 8
Speaker: Carlos Brody, Molecular Biology, Princeton University
Title: *Modeling complex brain dynamics*
Abstract: It is thought that the neural activity in specific, specialized structures of the brain is responsible for what we experience as "cognition." I will describe recordings from the brains of awake primates, performing a cognitive task, that show that the relevant neural activity has a very complex and heterogeneous dynamical pattern. In these recordings, only a few neurons (less than 10) are recorded from at a time, and only a few hundreds of neurons are recorded from in the course of an entire experiment. Yet the number of neurons in the relevant brain areas is in the tens of millions. We aim to build dynamical systems models that describe the mechanisms responsible for the observed patterns in the data. How can we build models that are faithful to the complexity of the data, and faithful to the very large number of neurons involved, yet simple enough that we can understand their principles of operation?

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Date: October 22
Speaker: Lai-Sang Young, Courant Institute, New York University
Title: *Shear-induced Mixing*
Abstract: I will discuss the phenomenon of shear-induced mixing in driven dynamical systems. The unforced system is assumed to have certain simple underlying structures, such as attracting periodic solutions or equilibria undergoing Hopf bifurcations. Specifics of the defining equations are unimportant. A geometric mechanism for producing chaos - or equivalently promoting mixing - is proposed. In the case of periodic kicks followed by long periods of relaxation, rigorous results establishing the presence of strange attractors with SRB measures are presented. These attractors belong in a class of chaotic systems that can be modeled (roughly) by countable-state Markov chains. From this I deduce information on their statistical properties. In the last part of this talk, I will explore numerically the range of validity of the geometric ideas discussed. Examples including stochastically forced coupled oscillators will be presented.

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Date: November 5
Speaker: John Lafferty, Computer Science, Carnegie Mellon University
Title: *Functional Sparsity*

Abstract: Substantial progress has recently been made on understanding the behavior of sparse linear models in the high dimensional setting, where the number the variables can greatly exceed the number of samples. This problem has attracted the interest of multiple communities, including applied mathematics, signal processing, statistics, and machine learning. But linear models often rely on unrealistically strong assumptions, made more by convenience than conviction. Can we understand the properties of high dimensional nonlinear functions that enable them to be estimated accurately from sparse data? In this talk we present some progress on this problem, showing that many of the recent results for sparse linear models can be extended to the infinite dimensional setting of nonparametric function estimation. In particular, we present some theory for estimating sparse additive models, together with algorithms that are scalable to high dimensions. We illustrate these ideas with an application to functional sparse coding of natural images. This is joint work with Han Liu, Pradeep Ravikumar, and Larry Wasserman.

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Date: November 12
Speaker: Patrick Cheridito, Operations Res & Financial Eng, Princeton University
Title: *Coherent and convex risk measures: representation results and dynamic consistency conditions*
Abstract: Coherent and convex risk measures were introduced to address drawbacks of traditional risk measures such as variance, value-at-risk or default probability. After a short introduction I will give representation results for static risk measures. Then I will discuss dynamic risk measures and conditions for time-consistency.

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Date: November 19
Speaker: Dargan Frierson, Atmospheric Sciences, University of Washington
Title: *A Hierarchy of Mathematical Models for Studying the Earth's Climate*
Abstract: The Earth's climate is a remarkably complex physical system; constructing models to study it is a difficult task which requires parameterization of a multitude of physical processes. Not surprisingly, such models quickly become difficult to understand due to the vast number of nonlinear processes that are active in them.
Therefore, an important line of work in atmospheric science involves the development and use of intelligently chosen idealized models, designed to better understand the results of comprehensive climate models as well as the fundamental dynamics of atmospheric circulations. These models are simpler to interpret than the full climate models, but hopefully can still provide insight into the dynamics of their more complex cousins.
In this talk, we give a summary of some topical problems in climate dynamics, and the hierarchical modeling approach we have used to study them. We will discuss physical problems such as the predicted poleward shift of the midlatitude jet stream with global warming, and changes in energy fluxes and temperature gradients in the atmosphere. Focusing on the effect of moist convection on these issues, we present a variety of idealized models that we have used to study these problems. These range from models of 3-D fluid motion on a rotating sphere in the presence of condensation, to highly idealized 1-D PDE models of diffusive energy transport.

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Date: December 3
Speaker: Marsha Berger, Courant Institute, New York University
Title: *Cartesian Cut Cell Methods: Where Do Things Stand?*
Abstract: We discuss some of the steps involved in preparing for and carrying out a fluid flow simulation in complicated geometry. Our goal is to automate this process as much as possible to enable high quality inviscid flow calculations. We use multilevel Cartesian meshes with irregular cells only in the region intersecting a solid object. We present some of the technical issues involved in this approach, including the special discretizations needed to avoid loss of accuracy and stability at irregular boundary cells, as well as how we obtain highly scalable parallel performance. This method is in routine use for aerodynamic calculations in several organizations, including NASA Ames Research Center. Many open problems are discussed.

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Date: December 10
Speaker: Iain Couzin, Ecology & Evolutionary Biology, Princeton University
Title: *Collective motion and decision-making in animal groups*
Abstract: Animal groups such as bird flocks, insect swarms and fish schools are spectacular, ecologically important and sometimes devastating features of the biology of various species. Outbreaks of the desert locust, for example, can invade approximately one fifth of the Earth's land surface and are estimated to affect the livelihood of one in ten people on the planet.
Using a combined theoretical and experimental approach involving insect and vertebrate groups I will address how, and why, individuals move in unison and investigate the principals of information transfer in these groups, particularly focusing on leadership and collective consensus decision-making.
For very large animal groups, despite huge differences in the size and cognitive abilities of group members, recent models from theoretical physics ('self-propelled particle', SPP, models) have suggested that general principles underlie collective motion. Such models demonstrate that some group-level properties may be largely independent of the types of animals involved. I shall present recent experimental work on locusts that validates some of the predictions of simple mechanistic models including a density-dependent "phase transition" from disordered to ordered motion.
Details of the mechanism by which individuals interact, however, also provide important biological insights into swarm behaviour. Using laboratory studies involving nerve manipulation and field experiments we demonstrate that some swarming insects are in effect on a "forced march" driven by cannibalism.
These results will be discussed in the context of the evolution of functional complexity and pattern formation in biological systems.

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Date: February 4
Speaker: John Storey, Lewis-Sigler Institute & Molecular Biology, Princeton University
Title: *New Methods for Quantitative Genomics*
Abstract: It is now possible to simultaneously measure thousands of genomic features from a given biological sample, most notably variations in the DNA at hundreds of thousands of locations and RNA transcriptional levels for every known gene. One of the main goals in utilizing this information is to understand the genetic and molecular basis of variation in higher-order traits (such as disease status or a quantitative trait) at the genome-wide scale. I will describe our recent efforts in developing a quantitative framework for tackling this problem, which involves new concepts and methods for experimental design, statistical significance, and causal network modeling. Applications to recent experiments will be discussed.

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Date: February 11
Speaker: Moses Charikar, Computer Science, Princeton University
Title: *New Insights into Semidefinite Programming for Combinatorial Optimization*
Abstract: Beginning with the seminal work of Goemans and Williamson on Max-Cut, semidefinite programming (SDP) has firmly established itself as an important ingredient in the toolkit for designing approximation algorithms for NP-hard problems. Algorithms designed using this approach produce configurations of vectors in high dimensions which are then converted into actual solutions.
In recent years, we have made several strides in understanding the power as well as the limitations of of such SDP approaches. New insights into the geometry of these vector configurations have led to breakthroughs for several basic optimization problems. At the same time, a sequence of recent results seems to suggest the tantalizing possibility that, for several optimization problems including Max-Cut, SDP approaches may indeed be the best possible. In this talk, I will present a glimpse of some of this recent excitement around SDP-based methods and explain some of the new insights we have developed about the strengths and weaknesses of this sophisticated tool.

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Date: February 18
Speaker: David G. Stork, Ricoh Innovations and Stanford University
Title: *Did the great masters 'cheat' using optics? Computer vision and graphics addresses a bold theory in art history*
Abstract: In 2001, artist David Hockney and scientist Charles Falco stunned the art world with a controversial theory that, if correct, would profoundly alter our view of the development of image making. They claimed that as early as 1420, Renaissance artists employed optical devices such as concave mirrors to project images onto their canvases, which they then traced or painted over. In this way, the theory attempts to explain the newfound heightened naturalism or "opticality" of painters such as Jan van Eyck, Robert Campin, Hans Holbein the Younger, and many others.
This talk will describe the application of rigorous computer image analysis to masterpieces adduced as evidence for this theory. It covers basic geometrical optics of image projection, the analysis of perspective, curved surface reflections, shadows, lighting and color. While there remain some loose ends, such analysis of the paintings, infra-red reflectograms, modern reenactments, internal consistency of the theory, and alternate explanations allows us to judge with high confidence the plausibility of this bold theory. You may never see Renaissance paintings the same way again (http://www.diatrope.com/stork/FAQs.html).

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Date: March 3
Speaker: Brendan Frey, Electrical & Computer Engineering, University of Toronto
Title: *Closing the optimality gap using affinity propagation*
Abstract: An important problem in science and engineering is how to find and associate constituent patterns or motifs in large amounts of high-dimensional data. Examples include the identification and modeling of object parts in images, and the detection and association of RNA motifs that regulate tissue-dependent gene splicing in mammals. One approach is to identify a subset of representative data exemplars that are used to summarize and model the data. This is an NP-hard problem that is traditionally solved approximately by randomly choosing an initial subset of data points and then iteratively refining it. I'll describe a method called 'affinity propagation', which takes as input measures of similarity between pairs of data points. Real-valued messages are exchanged between data points until a high-quality set of exemplars and corresponding clusters gradually emerges. Affinity propagation is a general-purpose method and has been applied in a variety of areas, including digital communications, genomics, transcriptomics and document analysis. I'll outline open problems and possible future directions of research.

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Date: March 10
Speaker: Peter Winkler, Mathematics, Dartmouth College
Title: *Branched Polymers*
Abstract: A branched polymer is a finite, connected set of non-overlapping unit balls in space. The powerful "dimension reduction" theorem of Brydges and Imbrie permits computation of the volume of the space of branched polymers of size N in dimensions 2 or 3. We will show how these and some related computations can be done using elementary calculus and combinatorics.
New results include methods for random generation, asymptotic diameter in 3-space, and a combinatorial proof of the notorious "random flight" problem of Rayleigh and Spitzer. Joint work with Rick Kenyon (Brown).

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Date: March 24
Speaker: Blaise Aguera y Arcas, Microsoft Live Labs
Title: *A worldwide web of images*
Abstract: In this talk we'll explore the emerging potential of computer vision to transform the way we think about the interconnectedness of digital imagery and the Web, and how these relate to our physical environment. We'll begin with an introduction to the foundations of "3D computer vision", a bag of tricks which has been developing steadily for three decades, combining classical photogrammetry with machine vision. We'll then dive specifically into Photosynth, based on a combination of the Photo Tourism project (a collaboration between Microsoft Research and the University of Washington) and Seadragon, a multiresolution networked platform allowing one to play with arbitrarily many arbitrary large visual objects using only constant-time and constant-bandwidth operations. The aim of Photosynth is to allow meaningful 3D navigation within real-world environments reconstructed entirely from the photos. Interesting social dimensions are added to this application when one considers that the source photos can be mined from the existing Web, aggregated from user communities, and actively contributed to and interconnected. We'll end with some preliminary findings about the latent graph structure of Internet photography, and a glimpse of where we're heading next.

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Date: March 31
Speaker: Joyce McLaughlin, Mathematical Sciences, Rensselaer Polytechnic Institute
Title: *Mathematical and Computational Challenges in Shear Stiffness Imaging of Tissue: Can cancerous and benign lesions be distinguished?*
Abstract: For centuries doctors have palpated tissue to detect abnormalities. We target imaging the stiffness the doctor feels in the palpation exam, including imaging deeper than what can be felt in this exam and distinguishing between benign and cancerous lesions. Current applications include breast and prostate cancer. Current experimentalists with whom we collaborate are: Dr. Richard Ehman, Mayo Clinic; Mathias Fink, ESPCI, Paris; and Dr. Kevin Parker at the University of Rochester. We describe the challenges and opportunities for imaging, including mathematical modeling and algorithmic development, with the data from the individual experiments.

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Date: CANCELLED - April 7
Speaker: Iven Mareels, Electrical & Electronic Engineering, The University of Melbourne
Title: *Water Information Networks & Efficiency in Irrigation Systems*
Abstract: The world's sustainable water supply is heavily used (it is estimated that annually 65% of the available water resources are extracted), and with very poor efficiency (typically less than half the water taken from the environment serves the objective for which it was intended). The UNESCO World Water reports 2003/2005 identify management as one of the main issues to be addressed in order to avoid a water catastrophe. Australia is in a particularly critical situation, where management has to deal with significant climate change effects.
In this lecture we outline a sensor networks and systems engineering approach to underpin the management of an entire water catchment basin. The technology exists to construct a sensor network to monitor at a global scale the water resource and manage in closed loop the resource through the distribution infrastructure using the data derived from the sensor network. The control objective is to deliver water on demand with maximal overall efficiency. Such technology would provide the necessary data to implement a sustainable water policy in an adaptive way, where economic, environmental and social issues are properly taken into account.
We review the results from a number of substantial pilot projects in Victoria and New South Whales Australia in which, where Rubicon Systems Australia Pty. Ltd., who commercialise the technology, have realized significant gains in water efficiency in irrigation distribution. We show how this experience may lead to substantial gains in water management overall, and leads to better on farm practices, building further water savings. At present the state government of Victoria is backing this technoly with a 1 billion dollar investment to create significant water savings across the state. We discuss

aspects of modeling of water dynamics followed by the control aspects enabled in the present and envisaged hardware upgrades.

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Date: April 14
Speaker: Eitan Bachmat, Computer Science, Ben-Gurion University and Brandeis University
Title: *Airplane boarding and space-time geometry*
Abstract: It is hard to think of a process that is more boring than boarding an airplane. In the hope of relieving, or at least shortening, some of the pain, airlines have devised various boarding strategies such as back-to-front, window to aisle, boarding by zones or even unassigned seating. In the talk we will try to overturn the negative image that airplane boarding has and will try to portray it as a very exciting process which is modeled via space-time (a.k.a Lorentzian) geometry with a touch of random matrix theory. Using the model we will try to figure out what are the better strategies. If time permits, we will use insights from the airplane borading process to suggest an interpretation for Einstein's law of motion in which god plays the ultimate dice game. The talk is entirely self contained. Partly based on joint works with D. Berend, L. Sapir, S. Skiena, M. Elkin and V. Khachaturov.

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Date: April 28
Speaker: Rob Nowak, Electrical and Computer Engineering, University of Wisconsin-Madison
Title: *Active and Semi-Supervised Learning Theory*
Abstract: Science is arguably the pinnacle of human intellectual achievement, yet the scientific discovery process itself remains an art. Human intuition and experience is still the driving force of the high-level discovery process: we determine which hypotheses and theories to entertain, which experiments to conduct, how data should be interpreted, when hypotheses should be abandoned, and so on. Meanwhile machines are limited to low-level tasks such as gathering and processing data. A grand challenge for scientific discovery in the 21st century is to devise machines that directly participate in the high-level discovery process. Towards this grand challenge, we must formally characterize the limits of machine learning. Statistical learning theory is usually based on supervised training, wherein a learning algorithm is presented with a finite set of i.i.d. labeled training examples. However, modern experimental methods often generate incredibly large numbers of unlabeled data for very little expense, while the task of labeling data is often painstaking and costly. Machine learning methods must leverage the abundance of unlabeled data in scientific problem domains. Active learning (AL) and semi-supervised learing (SSL) are two well known approaches to exploit unlabeled data. In both paradigms one has access to a large pool of unlabeled examples, and only a few labeled examples are provided or selected. AL is a sequential feedback process. Unlabeled examples that are predicted to have very informative labels, based on previously gathered labeled and unlabeled data, are selected for labeling. In SSL, labeled examples are randomly provided, without regard to potential informativeness. Today, little is known about theoretical limits of AL and SSL performance. Sparsity and complexity of the underlying data-generating distributions appear to play a central role in the performance of AL and SSL, and this talk will discuss some of the known theoretical results.
This work is joint with Rui Castro, Aarti Singh and Jerry Zhu.

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Date: September 18
Speaker: J. Nathan Kutz, Applied Mathematics, University of Washington
Title: Soliton Lasers
Abstract: A comprehensive treatment is given for the formation of mode-locked soliton pulses in optical fiber and solid state lasers. The pulse dynamics is dominated by the interaction of the cubic Kerr nonlinearity and chromatic dispersion with an intensity dependent perturbation provided by the mode-locking element in the laser cavity. The intensity dependent

perturbation preferentially attenuates low intensity electromagnetic radiation which makes the mode-locked pulses attractors of the laser cavity. A review of the broad spectrum of mode-locked laser models, both qualitative and quantitative, are considered with the basic pulse formation phenomena highlighted. Although the numerous mode-locking models are considerably different, they are unified by the fact that stable solitons are exhibited in each case due to the intensity discrimination perturbation in the laser cavity.

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Date: September 25
Speaker: Peter Winkler, Mathematics, Dartmouth College
Title: Maximum Overharng
Abstract: How far can a stack of n bricks hang over the edge of a table? It took 5 mathematicians (Mike Paterson, Yuval Peres, Mikkel Thorup, Uri Zwick and the speaker) to solve this classic problem---and the answer is not what most people thought.

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Date: October 9
Speaker: C. Richard Johnson, Jr., Electrical and Computer Engineering, Cornell University
Title: Vincent Van Gogh and Imitators in Greyscale: An Experiment in Cross-Disciplinary Stimulation
Abstract: This seminar describes a recently initiated project intended to accelerate the interaction of art historians and image processors in artist identification. The collection of digital images of artwork has been underway for over twenty years. Subsequently, in the last ten years image processors have initiated projects to process digitized images of paintings and drawings to assist art historians in artist identification. A key issue in the advance of this emerging technology, which is poised to expand rapidly over the next ten years, is bridging the gap between the two cultures of image processor system developers and art historian users. Four teams presently creating image processing schemes to assist the art historian in artist identification have agreed to prepare a daylong program for art historians to introduce them to the potential of this technology. The Van Gogh Museum in Amsterdam and the Kr¨oller-M¨uller Museum in Otterloo have agreed to provide these four teams access to a common database of digitized paintings by Vincent Van Gogh and his imitators. The Van Gogh Museum plans to host a workshop on May 18, 2007, to be attended by art historians to whom the four teams will make presentations on brushstroke analysis in assistance of artist identification. The genesis of this pioneering experiment in cross-disciplinary stimulation raises a number of interesting issues about research between one field suffused with mathematics, models, and algorithms and another where such intellectual tools are practically absent and conceivably considered intellectually inappropriate.

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Date: October 16
Speaker: Anna Gilbert, Mathematics, University of Michigan
Title: One sketch for all: a sublinear approximation scheme for heavy hitters
Abstract: The heavy hitters problem elicits a list of the m largest-magnitude components in a signal of length d. Although this problem is easy when the signal is presented explicitly, it becomes much more challenging in the setting of streaming data, where the signal is presented implicitly as a sequence of additive updates. One approach maintains a small sketch of the data that can be used to approximate the heavy hitters quickly. In previous work, this sketch is essentially a random linear projection of the data that fails with small probability for each signal. It is often desirable that the sketch succeed simultaneously for ALL signals from a given class, a requirement that may be called uniform heavy hitters. It arises, for example, when the signal is queried a large number of times or when the signal updates are stochastically dependent.
This talk describes a random linear sketch for uniform heavy hitters that succeeds with high probability. The recovery algorithm produces a list of heavy hitters that approximates the input signal with an l2 error that is optimal, except for an additive term that depends on the optimal l1 error and a controllable parameter e. The recovery algorithm requires space m*poly(log(d)/e) and time m2*poly(log(d)/e) to produce the list of heavy hitters. Up to logarithmic factors, the performance of this algorithm is the best possible with respect to several resources.

Joint work with Martin Strauss, Joel Tropp, and Roman Vershynin.

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Date: October 23
Speaker: Margaret Wright, Computer Science Department, CIMS, New York University
Title: Solving Nasty Optimization Problems in Science and Engineering
Abstract: Many important optimization problems in science and engineering involve functions that can fairly be described as "nasty", which can mean any or all of wildly nonlinear, nonsmooth, noisy, and defined through complex black-box simulation or error-prone experimental data. Because it is often impossible or impractical to calculate derivatives of these functions, non-derivative methods are the only feasible choice. These methods are in the midst of a renaissance involving research on their theoretical and computational properties, as well as investigation of which methods are best suited for which applications. This talk will include examples of challenging problems along with the speaker's assessment of the state of the art in non-derivative optimization methods.

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Date: November 6
Speaker: Alon Orlitsky, ECE and CSE, University of California, San Diego
Title: Information Theory and Probability Estimation: From Shannon to Shakespeare via Laplace, Good, Turing, Hardy, Ramanujan, and Fisher
Abstract: Standard information-theoretic results show that data over small, typically binary, alphabets can be compressed to Shannon's entropy limit. Yet most practical sources, such as text, audio, or video, have essentially infinite support. Compressing such sources requires estimating probabilities of unlikely, even unseen, events, a problem considered by Laplace. Of existing estimators, an ingenious if cryptic one derived by Good and Turing while deciphering the Enigma code works best yet not optimally. Hardy and Ramanujan's celebrated results on the number of integer partitions yield an asymptotically optimal estimator that compresses arbitrary-alphabet data patterns to their entropy. The same approach generalizes Fisher's seminal work estimating the number of butterfly species and its extension authenticating a poem purportedly written by The Bard. The talk covers these topics and is self contained.
Joint work with Prasad Santhanam, Krishna Viswanathan, and Junan Zhang

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Date: November 13
Speaker: Yang Wang, Mathematics, Georgia Institute of Technology
Title: Denoising Color Images
Abstract: Natural color images captured by digital cameras often exhibit noticeable noise, particularly when the pictures are taken under low lighting or artificial lighting conditions. Traditional denoising techniques, which are often tested for removing artificial noise in monochromatic images, often do not work well for noisy color images.
In this talk, we present an overview of some of the traditional methods for denoising. We discuss a new strategy, which we call the cross-channel principle, that can be applied for very effective denoising of color images. In particular we show how this principle can be applied to the total variation denoising scheme and an ENO type denoising scheme.

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Date: November 20
Speaker: Massimo Fornasier, PACM, Princeton University
Title: Faithful recovery of vectorr valued functions from incomplete data. Recolorization and art restoration
Abstract: On March 11, 1944, the famous Eremitani's Church in Padua (Italy) was destroyed in an Allied bombing together with the inestimable frescoes by Andrea Mantegna et al. contained in the Ovetari Chapel. In the last 60 years, several attempts have been made to restore the fresco fragments by traditional methods, but without much success. We have developed a fast, robust, and efficient pattern recognition algorithm in order to map the original position and orientation of

the fragments, based on comparisons with an old gray level image of the fresco prior to the damage. This innovative technique allowed for the partial reconstruction of the frescoes. Unfortunately, the surface covered by the fragments is only 77 m^2, while the original area was of several hundreds. This means that we can currently reconstruct only a fraction (less than 8%) of this inestimable artwork. In particular the original color of the blanks is not known. This begs the question of whether it is possible to estimate mathematically the original colors of the frescoes by making use of the potential information given by the available fragments and the gray level of the pictures taken before the damage. Can one estimate how faithful such restoration is?
In this talk we retrace the development of the recovery of the frescoes as an inspiring and challenging real-life problem for the development of new mathematical methods. We introduce two models for the recovery of vector valued functions from incomplete data, with applications to the fresco recolorization problem. The models are based on the minimization of a functional which is formed by the discrepancy with respect to the data and additional regularization constraints. The latter refer to joint sparsity measures with respect to frame expansions for the first functional and functional total variation for the second. We establish the relations between these two models. As a byproduct we develop the basis of a theory of fidelity in color recovery, which is a crucial issue in art restoration.

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Date: November 27
Speaker: Charles Epstein, Mathematics, University of Pennsylvania
Title: Inverse scattering in nuclear magnetic resonance
Abstract: Selective excitation is an essential ingredient of any application of nuclear magnetic resonance, e.g. MR-imaging or spectroscopy. I will explain how the problem of selective excitation of 2-level quantum systems leads directly to the classical inverse scattering problem for the 2x2 AKNS system. We discuss the analysis of the inverse scattering transform and the role of non-linearity. I then show how a viable numerical algorithm, based on the hard pulse approximation, allows for the practical and accurate solution of this problem.

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Date: December 1, 8pm, A02 McDonnell Hall
Speaker: *Distinguished Lecture Series* Eric S. Lander, Broad Institute, Massachusetts Institute of Technology
Title: Genomic Information: Biology and Medicine in the 21st Century
Abstract: The Human Genome Project was just an early step in a decades-long scientific program aimed at achieving a systematic and comprehensive view of biology and medicine. This program involves deep collaboration among biologists, chemists, physicians, engineers and – importantly – mathematicians and computer scientists. The lecture will describe current projects in genomic medicine, including comparative genomics, human genetics, cancer genetics and chemical biology. Along the way, it will highlight analytical issues that arise from the massive amounts of genomic information that are rapidly becoming available.

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Date: December 4
Speaker: Graduate Student Short Talks:
Title: An Overview of Research in PACM

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Date: February 5
Speaker: Philip Holmes, PACM & MAE, Princeton University
Title: 122+ Years of Nonlinear Dynamics: More is Different and Less is More
Abstract: As I was completing my PhD in Engineering in the early 1970's, dynamical systems theory was reapproaching earth after a 70-year sojourn in the mathematical stratosphere. Catastrophe theory was hot (if controversial), complexity was yet to come, and some prominent mechanicians and applied mathematicians told me that chaos didn't exist, or would be

irrelevant if it did.
I will review some developments in nonlinear dynamics since that time, traveling back to check its origins in the works of Poincare, Birkhoff, Cartwright, Littlewood, Kolmogorov, Arnold, Moser and Smale, and returning to current frontiers in hybrid systems and stochastic models. These will illustrate the first subtitle, drawn from an article by Philip Anderson (Science 177: 393, 1972). I will also emphasize the central ideas of dimension reduction via invariant manifolds, normal forms, and the role of simple canonical examples such as Smale's horseshoe, thus justifying the second subtitle (due to Mies van der Rohe). I will close by speculating on future directions, and, in doing so, probably repeat the lack of foresight to which I alluded at the beginning.

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Date: February 12, 4:30pm
Speaker: Ron Weiss, Electrical Engineering, Princeton University
Title: Synthetic Biology: from Bacteria to Stem Cells
Abstract: With recent advances in our understanding of cellular processes and improvements in DNA synthesis methods, we can now regard cells as "programmable matter." Through genetic engineering, we are equipping cells with new sophisticated capabilities for gene regulation, information processing, and communication. These new capabilities serve as catalysts for Synthetic Biology, an emerging engineering discipline to program cell behaviors as easily as we program computers. Synthetic biology will improve our quantitative understanding of natural biological processes and will also have biotechnology applications in areas such as biosensing, synthesis of pharmaceutical products, molecular fabrication of biomaterials and nanostructures, and tissue engineering.
In this talk, I will describe the use of computer engineering principles of abstraction, composition, and interface specifications to program cells with sensors and actuators precisely controlled by analog and digital logic circuitry. I will present theoretical and experimental results from synthetic systems implemented in bacteria and higher order organisms. I will begin by describing how information flows through synthetic transcriptional cascades in single cells by examining noise propagation, ultrasensitivity, and impedance matching. Understanding these issues is critical for the analysis and de novo engineering of complex gene networks. I will then discuss several synthetic multicellular systems that were programmed to exhibit unique coordinated cell behavior. These are the pulse generator, band detector, and Conway’s Game of Life. These systems allow us to explore programmed pattern formation and observe how complex global behavior emerges from localized interactions between cells. I will also discuss the implementation of artificial cell-cell communication and quorum sensing behavior in higher level organisms such as yeast. Finally, I will discuss preliminary results in mouse embryonic stem cells of implementing synthetic gene networks that regulate gene expression, direct differentiation, and orchestrate artificial cell-cell communication with the ultimate goal of programmed tissue engineering.

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Date: February 19
Speaker: Zvi Artstein, Mathematics and Computer Science, The Weizmann Institute of Science
Title: Averaging of ordinary differential equations revisited
Abstract: The Averaging Method replaces a time-varying perturbation of a differential equation by a time-invariant one, while introducing only a relatively small error. The origin of the method goes back to calculations of stellar orbits; it has many modern applications in both modeling and numerical issues. A variety of mathematical tools have been developed in order to derive accurate estimates of the resulting errors. A new estimation criterion will be offered, which is based on rather "soft" estimates, namely, carrying out a comparison of integrals on a fast time scale. If, in addition, Young measures are employed, the method allows a natural extension to control systems, and carrying out the averaging in an environment with slowly moving averages.

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Date: February 26
Speaker: Ron DeVore, Courant Institute, New York University
Title: A Taste of Compressed Sensing

Abstract: The usual paradigm for encoding signals is based on the Shannon sampling theorem. If the signal is broad-banded then this requires a high sampling rate even though the information content in the signal may be small. Compressed Sensing is an attempt to get out of this dilemma and sample at close to the information rate. The fact that this may be possible is embedded in some old mathematical results in functional analysis, geometry and approximation. This talk will be an excursion into these topics which will focus on the relation between the number of samples we take of a signal and how well we can approximate the signal. It will take place in the discrete setting for vectors in Euclidean space. The talk should be understandable to graduate students and non specialists.

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Date: March 5
Speaker: Robert Vanderbei, ORFE & PACM, Princeton University
Title: Linear Stability of Ring Systems
Abstract: (Co-author: Egemen Kolemen) We give a self-contained modern linear stability analysis of a system of n equal mass bodies in circular orbit about a single more massive body. Starting with the mathematical description of the dynamics of the system, we form the linear approximation, compute all of the eigenvalues of the linear stability matrix, and finally derive inequalities that guarantee that none of these eigenvalues have positive real part. In the end, we rederive the result that J.C. Maxwell found for large n in his seminal paper on the nature and stability of Saturn's rings, which was published 150 years ago. In addition, we identify the exact matrix that defines the linearized system even when n is not large. This matrix is then investigated numerically (by computer) to find stability inequalities. Furthermore, using properties of circulant matrices, the eigenvalues of the large $4n \times 4n$ matrix can be computed by solving n quartic equations, which further facilitates the investigation of stability. Finally, we have implemented an n-body simulator and we verify that the threshold mass ratios that we derived mathematically or numerically do indeed identify the threshold between stability and instability. Throughout the paper we consider only the planar n-body problem so that the analysis can be carried out purely in complex notation, which makes the equations and derivations more compact, more elegant and therefore, we hope, more transparent. The result is a fresh analysis that shows that these systems are always unstable for $2 <= n <= 6$ and for $n > 6$ they are stable provided that the central mass is massive enough. We give an explicit formula for this mass-ratio threshold.

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Date: March 12
Speaker: Dwight Barkley, Mathematics, University of Warwick
Title: Patterns of Turbulence
Abstract: Plane Couette flow -- the flow between two infinite parallel plates moving in opposite directions -- undergoes a discontinuous transition from laminar flow to turbulence as the Reynolds number is increased. Due to its simplicity, this flow has long served as one of the canonical examples for understanding shear turbulence and the subcritical transition process typical of channel and pipe flows. Only recently was it discovered in very large aspect ratio experiments that this flow also exhibits remarkable pattern formation near transition. Steady, spatially periodic patterns of distinct regions of turbulent and laminar flow emerges spontaneously from uniform turbulence as the Reynolds number is decreased. The length scale of these patterns is more than an order of magnitude larger than the plate separation. It now appears that turbulent-laminar patterns are inevitable intermediate states on the route from turbulent to laminar flow in many shear flows. I will explain how we have overcome the difficulty of simulating these large scale patterns and show results from studies of three types of patterns: periodic, localized, and intermittent.

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Date: March 26
Speaker: David Blei, Computer Science, Princeton University
Title: Modeling Science: Topic models of Scientific Journals and Other Large Text Databases
Abstract: A surge of recent research in machine learning and statistics has developed new techniques for finding patterns of words in document collections using hierarchical probabilistic models. These models are called "topic models" because the word patterns often reflect the underlying topics that are combined to form the documents; however topic models also

naturally apply also such data as images and biological sequences.
After reviewing the basics of topic modeling, I will describe two related lines of research in this field, which extend the current state of the art.
First, I will describe probabilistic models designed to capture the dynamics of topics as they evolve over time. Many document collections change over time: scientific articles, emails, and search queries reflect evolving content, and it is important to model the corresponding evolution of the underlying topics.
Second, I will describe a probabilistic topic model which can capture correlations between the hidden topics. Previous models assume that the occurrence of the different topics are independent. In many document collections, however, the presence of a topic may be correlated with the presence of another. For example, a document about sports is more likely to also be about health than international finance. In addition to giving quantitative, predictive models of a corpus, topic models provide a qualitative window into the structure of a large document collection. This allows a user to explore a corpus in a topic-guided fashion. I will demonstrate the capabilities of these new models on the archives of the journal Science, founded in 1880 by Thomas Edison. The models are built on the noisy text from JSTOR, an online scholarly journal archive, resulting from an optical character recognition engine run over the original bound journals.
(joint work with M. Jordan, A. Ng, and J. Lafferty)

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Date: April 2
Speaker: Frans Pretorius, Physics, Princeton University
Title: Simulation of Black Hole Collisions
Abstract: The collision of two black holes is thought to be one of the most energetic events in the universe, emitting in gravitational waves as much as 5-10% of the rest mass energy of the black holes. An international effort is presently underway to detect gravitational waves from black hole collisions and other cataclysmic events in the universe. The early success of the detectors will rely on the matched filtering technique to extract what are, by the time the waves reach earth, very weak distortions in the local geometry of space and time. In the case of binary black hole mergers, obtaining the predicted waveforms for use in the matched filters requires numerical solution of the merger process during the final stages of the collision. In this talk I will describe the computational challenges and techniques required to simulate black holes within the framework of Einstein's theory of general relativity, and present results form recent successful simulations of black hole coalescence.

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Date: April 9
Speaker: Jason W. Fleischer, Electrical Engineering, Princeton University
Title: Dispersive shock waves in homogeneous and periodic systems
Abstract: Dispersive shock waves (DSW) are a fundamental type of nonlinear wave and appear in many hydrodynamic settings, including fluids, superfluids, plasma, and optics. Their basic existence conditions are a dispersive medium with positive pressure (e.g. repulsive interactions or defocusing nonlinearity) and a high density/intensity region atop a low-level background. In the ensuing dynamics, different components of the initial hump couple to the background and walk off from each other. Unlike ordinary shock waves, which have a well-defined front due to viscosity, DSWs are characterized by an oscillating front. Here, an overview of DSWs is given in both homogeneous and periodic media. In homogeneous media, particular attention is paid to shock wave interactions and the dynamics of mode coupling, in both one and two dimensions. In periodic media, the focus is on modified dynamics due to the underlying Floquet-Bloch mode structure and the momentum-dependent dispersion profile. The results show enhanced energy transport among modes and bands and represent the opposite nonlinear regime from lattice (gap) solitons. In all cases, theory is compared to recent experiments in nonlinear optical systems, Bose-Einstein condensates, and plasma.

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Date: April 16
Speaker: Daniel Rockmore, Mathematics, Dartmouth College

Title: Fast Fourier Transforms for Semigroups
Abstract: A general version of the Fast Fourier Transform is as an algorithm for the efficient calculation of a change of basis, where the target basis is one that reflects some sort of group invariance. The implicit group action reflects a globabl symmetry of the underlying domain for the data. In this talk we revisit this idea with the goal of extending these notions to the case of semigroups, where the invariance can be local in nature. We discuss in some detail the case of the "rook monoid" and its potential application to the analysis of partial ranking data. This is joint work with Martin Malandro.

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Date: April 23
Speaker: Mikko Haataja, MAE, Princeton University
Title: Heterogeneous Lipid Bilayers: Evolving Microstructures in Biology
Abstract: The design and processing of materials with novel physical and mechanical properties requires a fundamental understanding of the connections between processing, microstructure, and properties. For example, mechanical properties in pure metals and alloys can be varied by manipulating the polycrystalline grain size or the size of the compositional domains through heat treatment, while elastic strain provides a way to tune the optical properties of self-assembled quantum dots during growth. In an analogous manner, the biological function of cell membranes is strongly affected by the details of the local "microstructure".
Typically, microstructural evolution takes place across multiple length and time scales, ranging from atomistic to mesoscopic ones. In this talk I will describe our recent efforts in developing physically-based, coarse-grained continuum models, which bridge the atomistic and mesoscopic scales, to elucidate lateral organization and non-equilibrium dynamics of heterogeneous lipid bilayers. In particular, I will focus on spatially organized, dynamic heterogeneities in the local lipid composition ("lipid rafts") which have been implicated in many important cellular processes including signal transduction, membrane trafficking, cytoskeleton organization, and pathogen entry.

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Date: September 19
Speaker: Naomi Leonard, Mechanical & Aerospace Engineering, Princeton University
Title: Collective Motion in Engineered and Natural Multi-Agent Systems
Abstract: The collective control of mobile, multi-agent systems is motivated by a range of engineering applications that require the coordination of a group of individually controlled systems. A closely related problem focuses on the role of feedback and interconnection in the collective motion of animal groups. Tools from control and dynamical systems can be used to study both engineered and natural mobile networks in a systematic and scalable way. One goal is to prove stability and robustness of designed patterns or emergent behaviors. In this talk I will describe recent collaborative work on models for collective motion based on a planar group of self-propelled particles with steering control. We extend phase models of coupled oscillators to include spatial dynamics and use these models to stabilize and control collective motion patterns. The patterns can be parametrized, in part, by the extent of oscillator synchrony. I will conclude the talk with some discussion of open problems in the area of cooperative control.

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Date: October 10
Speaker: Clancy Rowley, Mechanical & Aerospace Engineering, Princeton University
Title: Low-order models for control of fluids
Abstract: The ability to effectively control a fluid would enable many exciting technological advances, including the design of quieter, more efficient aircraft. Most of the flow control strategies tried so far have been largely ad hoc, and have not used many of the available tools from control theory and dynamical systems, which can guide controller design as well as placement of sensors and actuators. These tools require knowledge of a model of the system in terms of a system of

differential equations, and the equations governing a fluid, though known, are too complex for these tools to apply. This talk addresses model reduction techniques, which are used to simplify existing models, to obtain low-order models tractable enough to be used for analysis and control, while retaining the essential physics. These techniques provide a bridge between complex problems and the mathematical tools useful for their analysis.
Specifically, the talk will focus on recent developments of two techniques, Proper Orthogonal Decomposition (POD) and balanced truncation. Each of these techniques has strengths and weaknesses, and we show how ideas from both techniques may be combined, to exploit their strengths. We illustrate the methods by obtaining reduced-order models for a compressible flow past a cavity, and an incompressible channel flow.

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Date: October 17
Speaker: Gunnar Carlsson, Mathematics, Stanford University
Title: Algebraic topology and the statistics of natural images
Abstract: Natural images taken with a digital camera can be viewed as vectors in a high-dimensional vector space whose dimension is the number of pixels. To understand the set of natural images within this vector space is a very interesting problem, but as stated it is very difficult and likely intractable. A. Lee, D. Mumford, and K. Pedersen have created a data set consisting of small (3 by 3) patches, and one can then ask questions about this set. We (V. de Silva, T. Ishkanov, and myself) have used algebraic topological techniques to obtain information about this set, and I will discuss this application of topological methods in this talk. I will also discuss potential applications in compression and in the neuroscience of vision.

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Date: October 24
Speaker: Terence Tao, Mathematics, University of California, Los Angeles
Title: Sparse recovery
Abstract: Suppose one is given a small number of (possibly noisy) linear measurements of a signal. If the number of measurements is less than the number of degrees of freedom of the signal, then one of course cannot reconstruct the signal from the measurements in general. But if one makes the additional hypothesis that the signal is sparse, or at least compressible, then it does become possible to recover the signal accurately, stably, and quickly. The key is decoherence: the measurement basis has to be very "skew" with respect to the sparsity basis. We will survey a number of recent theoretical developments of this idea by several groups and in several contexts (Fourier reconstruction, linear codes, statistical selection.)

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Date: November 7
Speaker: Sal Torquato, Chemistry, Materials Institute & PACM, Princeton University
Title: Bounds on the Optimal Density of Sphere Packings in High Dimensions
Abstract: Sphere packings in high dimensions are of great interest to mathematicians and physicists, and have direct applications in communications theory. Remarkably, no one has been able to provide exponential improvement on a 100-year-old lower bound on the maximal packing density due to Minkowski in d-dimensional Euclidean space \Re^d. The asymptotic behavior of this bound is controlled by 2^{-d} in high dimensions. Using an optimization procedure that we introduced earlier [1] and a conjecture concerning the existence of disordered sphere packings in \Re^d, we obtain a provisional lower bound on the density whose asymptotic behavior is controlled by 2^{-0.7786…d}, thus providing the putative exponential improvement of Minkowski's bound [2]. The conjecture states that a hard-core nonnegative tempered distribution is a pair correlation function of a translationally invariant disordered sphere packing in \Re^d for asymptotically large d if and only if the Fourier transform of the autocovariance function is nonnegative. The conjecture is supported by two explicit analytically characterized disordered packings, numerical simulations in low dimensions, and known necessary conditions that only have relevance in very low dimensions. A byproduct of our approach is an asymptotic lower bound on the average kissing number whose behavior is controlled by 2^{0.2213…d}, which is to be compared to the best known asymptotic lower bound on the individual kissing number of 2^{0.2075…d}. Interestingly, our optimization procedure is

precisely the dual of a primal linear program devised by Cohn and Elkies [3] to obtain upper bounds on the density, and hence has implications for linear programming bounds. [1] S. Torquato and F. H. Stillinger, "Controlling the Short-Range Order and Packing Densities of Many-Particle Systems," Journal of Physical Chemistry B, 106, 8354 (2002); ibid, 106, 11406 (2002). [2] S. Torquato and F. H. Stillinger, "New Provisional Lower Bounds on the Optimal Density of Sphere Packings," http://arxiv.org/abs/math.MG/0508381. [3] H. Cohn and N. Elkies, "New upper bounds on sphere packings I," Annals of Mathematics, 157, 689 (2003); H. Cohn, "New upper bounds on sphere packings II," Geometry and Topology, 6, 329 (2002).

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Date: November 14
Speaker: Robert Ghrist, Mathematics, University of Illinois
Title: Homological Methods for Sensor Networks
Abstract: As sensor engineering and manufacturing evolve to produce smaller devices, we will have the problem of dealing with large numbers of very localized objects. What types of global problems can be solved by a swarm of local sensors? Topologists solved a similar problem nearly a century ago. This talk will demonstrate the surprising effectiveness of homology theory in sensor networks.

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Date: November 21
Speaker: Guust Nolet, Geosciences, Princeton University
Title: Seismic tomography: some mathematical aspects
Abstract: "Seismic tomography" is the term geophysicists use for a collection of methods to use seismic waves to image the interior of the Earth, much like in a CAT scan. Tomographic imaging has led to important discoveries, such as the observation that ocean floor subducts to the bottom of the Earth's mantle and - more recently - that plumes of hot material rise up from the lower mantle.
In its simplest form, the approximations of geometrical optics are applied to high frequency seismic waves. These waves then follow raypaths and the most useful observable is a travel time along the ray: T = \int ds / v(r). In a typical interpretation, \mathcal O (10^6) data with a signal-to-noise ratio of order 1 are inverted for \mathcal O (10^4-10^5) parameters. The mathematical challenge is mostly that of an adequate regularization of the problem that minimizes artifacts. More accurate travel time measurements can be obtained using cross-correlation on digital seismograms with sensitivity to lower frequency. For such waves a first order perturbation theory is needed to include the effects of wave diffraction around small anomalies. The travel time becomes then frequency dependent, and T is given by a volume integral, with an increase by several orders of magnitude in the numerical effort. Finally, for the lowest frequency waves we use the whole waveform as data. These waveforms can be modeled by summation of normal modes, but the problem is inherently nonlinear and again a ray approximation is needed to render the inverse problem feasible. The challenge is to relax this constraint and take effects of diffraction into account. We shall speculate about the possible role of wavelets in meeting these challenges.

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Date: November 28
Speaker: Maria Reznikoff, Mathematics, Princeton University
Title: Thermally-driven rare events and large deviation theory
Abstract: Thermal or stochastic effects are prevalent in physical, chemical, and biological systems. Particularly in small systems, noise can overpower the deterministic dynamics and lead to "rare events," events which would never be seen in the absence of noise. One example is the thermally-driven switching of the magnetization in small memory elements. Wentzell-Freidlin large deviation theory is a mathematical tool for studying rare events. It estimates their probability and also the "most likely switching pathway," which is the pathway in phase space by which rare events are most likely to occur. We explain how large deviation theory and concepts from stochastic resonance may be applied to analyze thermally-activated magnetization reversal in the context of the spatially uniform Landau-Lifschitz-Gilbert equations. The time-scales of the experiment are critical. One surprising and physically relevant result is that in multiple-pulse experiments, nonconvential

"short-time switching pathways" can dominate. The effect is dramatic: the usual pathway (connected with the Arrhenius-law) underestimates the probability of switching by an exponential factor.
An advantage of the method via large deviation theory is that it generalizes to systems with spatial variation. To discuss the complications and richness that emerge when spatial variation is taken into account, we consider the (simpler) Allen-Cahn equation. In this context, the rare event of interest is phase transformation from u =–1 to u=+1, and the most likely switching pathway is a pathway through function space. A natural reduced problem emerges in the "sharp-interface limit." We give a brief overview of some results (rigorous in d = 1, heuristic in d > 1.)
The first part of the talk is joint work with Bob Kohn and Eric Vanden-Eijnden. The second part includes work that is also joint with Felix Otto and Yoshihiro Tonegawa.

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Date: December 5
Speaker: Robert Schapire, Computer Science, Princeton University
Title: The Boosting Approach to Machine Learning
Abstract: Machine learning studies the design of computer algorithms that automatically make predictions about the unknown based on past observations. Often, the goal is to learn to categorize objects into one of a relatively small set of classes. Boosting, one method for solving such learning problems, is a general technique for producing a very accurate classification rule by combining rough and moderately inaccurate "rules of thumb." While rooted in a theoretical framework of machine learning, boosting has been found to perform quite well empirically. After introducing the boosting algorithm AdaBoost, I will explain the underlying theory of boosting, including our explanation of why boosting often does not suffer from overfitting. I also will touch on some of the other theoretical perspectives on boosting, and describe some recent applications and extensions.

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Date: February 13
Speaker: Barbara Terhal, IBM
Title: Fault-Tolerant Quantum Computation
Abstract: I will review the theory of fault-tolerant quantum computation and the use of quantum error-correcting codes in future quantum computers. I will discuss the most recent developments in this area.

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Date: February 20
Speaker: Christopher A. Fuchs, Bell Labs, Lucent Technologies
Title: Math Problems from the Far Side of Quantum Information
Abstract: The field of Quantum Information has recently rightly attracted great interest for the technological fruits it may bear. But there is a sect of its practitioners who think it stands a chance to bring us much more than that---namely, that its theoretical tools will give us a means for exploring what quantum mechanics is really all about and for settling some of the deepest problems in physics. The roots of this optimism come from a very old thought: that a quantum state has more to do with representing its user's information, than any inherent physical property of the system to which it is ascribed. What is new and nice is that quantum information teaches us how to formulate this idea precisely and even check its consistency. Nicer still for the mathematics community is the number of juicy mathematical problems the consistency-checking process poses. In this talk, I will review some of the history of this and then quickly settle on a sample problem that has been annoying me a lot lately: the question of the existence of symmetric informationally complete positive-operator-valued measures for finite dimensional Hilbert spaces. I'm not alone---it turns out to be equivalent to a 30-year-old problem in coding theory---but I will say some things about it that you may not have heard before.

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Date: February 27

Speaker: Mung Chiang, Electrical Engineering, Princeton University
Title: Layering As Optimization Decomposition
Abstract: Layered network architecture has traditionally been designed based on engineering heuristics. Recently a mathematically rigorous, practically relevant, and unifying framework has emerged to view the network as a solver of a generalized utility maximization problem, with alternative decompositions of the problem corresponding to different layering schemes, each decomposed subproblem corresponding to a different layer, and functions of variables coordinating the subproblems as the interfaces among the layers. Such decompositions can be carried out both horizontally across geographically disparate network elements and vertically into various functional modules. This talk surveys the recent advances in establishing this framework as a systematic approach to analyze and design protocol stacks in a holistic way that reveals the underlying structures and explores network design alternatives. Connections with distributed subgradient algorithm, convex and nonconvex optimization, stochastic optimization, differential topology, and algebraic geometry will be highlighted.

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Date: March 6
Speaker: Robert Nowak, Electrical and Computer Engineering, University of Wisconsin-Madison
Title: Wireless Sensing, Active Learning and Compressive Sampling
Abstract: Wireless sensor networks promise a fundamentally new approach for gathering information about the physical environment via a distributed network of sensors that can communicate with each other and/or with a (usually distant) fusion center through radio-frequency wireless links. Limited power resources make energy conservation essential in these envisioned sensing systems. Thus, it becomes crucial to strategically decide when, where and how to collect samples and communicate information. Active learning methods adaptively select samples based on previous observations in order to "learn" a target function using as few samples as possible, which could clearly be advantageous in sensor network operations. Compressive sampling refers to taking non-traditional samples in the form of randomized projections of data. Recent results show that compressive sampling can allow one to reconstruct signals from far fewer samples than required by traditional Shannon-Nyquist sampling schemes, again suggesting promising opportunities for wireless sensing. In this talk I will discuss the theory of active learning and compressive sampling, connections to information and coding theory, and some intriguing potential applications to wireless sensing systems.

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Date: March 27
Speaker: Scott Rickard, Electronic and Electrical Engineering, University College Dublin
Title: Sparsity and Source Separation: just DUET
Abstract: Detroit MI, April 2001.
A woman is found stabbed to death in the kitchen of her apartment. The police find that a video recorder in the family room was recording during the murder, but the camera lens cap was on and, as a result, the video portion of the recording reveals nothing. The audio channel of the recording, however, has captured the entire crime. Unfortunately, a stereo was playing loud schmaltzy music during the conversation leading up to the assault, and the speech on the recording cannot be understood. Fortunately, the police have the tape that was playing at the time, but traditional approaches for removing the interfering music from the mixture fail.
Princeton NJ, June 2002.
Murder victim gets the last word - case closed.
In this talk I will discuss the sparse revolution which is occurring in signal processing which is allowing researchers to solve systems of equations with more unknowns than constraints. We've all been taught that if we have 2 unknowns, we require 2 equations to solve for the unknowns. For 3 unknowns, we need 3 equations (and 4 require 4, and so on...). This is not true - as long as you're willing to cheat. For example, we 'cheat' in cocktail parties when we listen to one person while a dozen speak in the background. Mathematically, we would need 13 ears to eliminate the dozen unwanted speakers to allow us to focus on the one speaker of interest. The DUET Blind Source Separation Algorithm mimics this human auditory ability in that it can separate an arbitrary number of sources from just two mixtures (such as those heard by two ears in a cocktail party). I will reveal how we use sparsity to cheat and thus solve the problem of more unknowns than equations. Also, I will

discuss various related modifications of DUET, one of which was used to solve the above murder case. This talk will feature a live demonstration of DUET.

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Date: April 10
Speaker: Lisa Fauci, Mathematics, Tulane University
Title: Spirochetes and spermatozoa: Fluid dynamic models of microorganism motility
Abstract: The observed swimming behavior of a motile microorganism is the result of a complex interplay between mechanisms of internal force generation, the passive elastic properties of its structure, and a surrounding viscous fluid. In this talk, we will focus on two very different types of microorganisms: the spirochetes, which are a type of bacteria characterized by an efficient mode of motility that allows them to screw through viscous fluids and mucosal surfaces, and spermatozoa, that undulate as a result of the action of thousands of molecular motors positioned along the flagellum. We will present mathematical and computational models that couple the internal force generating mechanisms of these microorganisms with external fluid mechanics. We will describe our methodology, which includes both the method of regularized Stokeslets and the immersed boundary method. We will discuss recent successes as well as challenges associated with these models.

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Date: April 11, rm 314
Speaker: Christian Van den Broeck, Theoretical Physics, Hasselt University, Belgium
Title: From Maxwell demon to Brownian refrigerator
Abstract: Maxwell was under the impression that it should be possible to violate the second law of thermodynamics provided one could operate on a molecular scale. This comment was the beginning of a discussion stretching over the whole of the 20th century involving outstanding physicists including Smoluchowski, Onsager, Szilard, Feynman and Landauer. The issue has now become of more than academic interest because of recent developments in nanotechnology and molecular biology. We present a simplification of the Feynman ratchet that can be studied in detail by hard disk molecular dynamics and for which an exact microscopic calculation is possible. We will show how this construction can be used as a Brownian motor but also as a Brownian heat pump and refrigerator.

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Date: April 17
Speaker: Geoff Vallis, Geosciences / Atmospheric & Oceanic Sciences, Princeton University
Title: Turbulence and Large-scale Circulation in the Ocean and Atmosphere
Abstract: The large-scale circulation is not only affected but is essentially effected by turbulent flows. This turbulence is not the small-scale turbulence that is (unfortunately) sometimes connoted by the word turbulence, but is turbulence up to the scale of the large-scale flow itself. This is largely two-dimensional, so-called geostrophic turbulence. We will discuss what is known and what is unknown about such flow, the problems of both simulating it and of understanding it, and whether these two are the same.

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Date: April 24
Speaker: Lee Deville, Courant Institute of Mathematical Sciences, New York University
Title: Coherence in stochastic dynamical systems
Abstract: It is known that random perturbations to dynamical systems can be small and irrelevant, or, alternately, so large as to overwhelm the dynamics. More interesting are cases where small random perturbations introduce qualitative changes in a system without introducing significant randomness. In effect, these are generating noise-induced, yet coherent, dynamics. We will show that this phenomenon is present in a large class of dynamical systems and describe several examples in detail. The examples will include stochastically-forced ODEs and PDEs, and Markov chains.

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Date: April 27, 8pm, A02 McDonnell Hall
Speaker: *Distinguished Lecture Series* Peter Shor, Mathematics, Massachusetts Institute of Technology
Title: Quantum Computers: How physics experiments might solve mathematical problems
Abstract: Quantum computers are hypothetical devices which use the principles of quantum mechanics to perform computations. For some difficult computational problems, including the cryptographically important problems of prime factorization and finding discrete logarithms, the best algorithms known for classical computers are exponentially slower than the algorithms known for quantum computers. Although they have not yet been built, quantum computers do not appear to violate any fundamental principles of physics. I will explain how quantum mechanics provides this extra computational power. One of the main difficulties in building quantum computers is in manipulating coherent quantum states without introducing errors or losing coherence. This problem can be alleviated by the use of quantum error correcting codes; if a quantum computer can be built with only moderately reliable hardware, then software can be used to make it extremely reliable. I will discuss these results as well.

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Date: May 1
Speaker: Eric Vanden-Eijnden, Courant Institute of Mathematical Sciences, New York University
Title: Rare events in complex systems: How to determine their transition pathways and rate?
Abstract: The dynamical behavior of many systems arising in physics, chemistry, biology, etc. is dominated by rare but important transition events between long lived states. Important examples include nucleation events during phase transition, conformational changes of macromolecules, or chemical reactions. Understanding the mechanism and computing the rate of these transitions is a topic that has attracted a lot of attention for many years. In this talk, I will discuss the theoretical background and algorithmic details of the finite-temperature string method, which gives a firm theoretical background to the concept of reaction coordinate to describe these transitions, and allows to determine their pathways and rate. The string method will be illustrated via several examples.

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2004-2005Collapse/Expand

Date: September 13, 2pm, Joseph Henry Room, Jadwin Hall
Speaker: Alexander Vardy, University of California, San Diego
Title: Old Problems and New Results in Coding Theory
Abstract: Coding theory was born in 1948 with the work of Claude Shannon, who proved that for every information rate R up to channel capacity, there exists a code of rate R that guarantees a vanishing probability of decoding error. Shannon, however, did not tell us how to find such codes nor how to decode them. It was recognized early on that codes with good Hamming distance can correct many errors, while codes endowed with algebraic structure admit efficient algebraic decoding algorithms. This has led to over 50 years of research in algebraic and combinatorial coding theory. We will survey several key problems and new results in this area. In particular, we'll elaborate upon a new asymptotic improvement of the Gilbert-Varshamov bound and upon recent methods for decoding Reed-Solomon codes using bivariate polynomial interpolation. About 10 years ago, the field of coding theory was transformed by the discovery of codes defined on certain graphs, with no algebraic structure, that perform extremely close to the Shannon capacity under probabilistic message-passing decoding. We will briefly review this exciting development, and point out the challenges that lie ahead in the area of "probabilistic" coding theory.

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Date: September 27

Speaker: Walter Willenger, AT&T Labs Research
Title: Internet Topology Modeling and the Role of Design
Abstract: The assumption that the Internet has become sufficiently large-scale and homogeneous to be amenable to statistical physics-inspired analysis techniques has recently led to the popular "scale-free" models of Internet topology, which are claimed to explain, for example, the structure of the Internet's router-level connectivity graph by simple random processes that are void of any engineering tradeoffs. An alternative perspective, motivated by engineering, suggests that nonrandom design rather than randomness plays a primary role in the construction and evolution of complex systems, and the complex structure of highly engineered technology and of biological systems is viewed as the natural by-product of Highly Optimized Tradeoffs (HOT) between system-specific objectives and constraints.
This talk shows how and why the latter view, when applied to the study of router-level Internet connectivity, results in conclusions that are fully consistent with the real Internet, but are the exact opposite of what the scale-free models claim. The reasons for reaching such divergent conclusions about one and the same system go well beyond the Internet and scale-free models and are endemic in the application of ideas from statistical physics to problems in technology and biology, where it is assumed that the details related to a complex system's design, functionality, constraints, and evolution (i.e., all ingredients that make engineering and biology different from physics) can be safely ignored in favor of random ensembles and their emergent properties.

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Date: October 4
Speaker: Greg Forest, Institute for Advanced Materials, NanoScience and Technology, University of North Carolina, Chapel Hill
Title: What's Applied and Computational Math Got to Do with High-Performance Nano-Composites?
Abstract: Nano-composite materials of interest for this lecture consist of high aspect ratio, spheroidal macromolecules, known as "nematic polymers", in a traditional polymer matrix. Rod-like, tube-like, and platelet molecules are added to traditional polymeric materials to enhance a variety of properties, from thermal or electrical conductivities to barrier and mechanical properties. There is no direct theoretical prediction that begins with the composition of nano-inclusions and matrix, tracks the flow into films, fibers, or molded parts, and then infers the effective properties of the composite. Each stage is a mathematical theory, modeling, and simulation challenge; modeling the entire nano-composite pipeline is a conceivable target. Progress and open problems that remain will be discussed, aimed at the graduate students in the Program.

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Date: October 11
Speaker: Philip Holmes, PACM, MAE and CSBMB, Princeton University
Title: Optimal decisions: From neural spikes, through stochastic differential equations, to behavior
Abstract: There is increasing evidence from in vivo recordings in monkeys trained to respond to stimuli by making left- or rightward eye movements, that firing rates in certain groups of 'visual' neurons mimic drift-diffusion processes, rising to a (fixed) threshold prior to movement initiation. This supplements earlier observations of psychologists, that human reaction time and error rate data can be fitted by random walk and diffusion models, and has renewed interest in optimal decision-making ideas from information theory and statistical decision theory as a clue to neural mechanisms.
I will review some results from decision theory and stochastic ordinary differential equations, and show how they may be extended and applied to derive explicit parameter dependencies in optimal performance that may be tested on human and animal subjects. I will then describe a biophysically-based model of a pool of neurons in a brainstem organ - locus coeruleus - that is implicated in widespread norepinephrine release. This neurotransmitter can effect transient gain and response threshold changes in cortical circuits of the type that the abstract drift-diffusion analysis requires. I will argue that, in spite of many gaps and leaps of faith, a rational account of how neural spikes give rise to simple behaviors is beginning to emerge.
This work is in collaboration with Eric Brown, Rafal Bogacz, Jeff Moehlis and Jonathan Cohen (Princeton University), and Ed Clayton, Janusz Rajkowski and Gary Aston-Jones (University of Pennsylvania). It is supported by the National Institutes of Mental Health.

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Date: October 18
Speaker: Larry Peterson, Computer Science, Princeton University
Title: PlanetLab: A Platform for Introducing Disruptive Technology into the Internet
Abstract: PlanetLab is a geographically distributed overlay network designed to support the deployment and evaluation of planetary-scale network services. Two high-level goals shape its design. First, to enable a large research community to share the infrastructure, PlanetLab provides distributed virtualization, whereby each service runs in an isolated slice of PlanetLab's global resources. Second, to support competition among multiple network services, PlanetLab decouples the operating system running on each node from the network-wide services that define PlanetLab, a principle referred to as unbundled management. This talk describes how PlanetLab realizes these two goals, and highlights several novel network services running on PlanetLab.

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Date: November 1
Speaker: Ioannis Kevrekidis, PACM and Chemical Engineering, Princeton University
Title: Equation-free modeling for complex, multiscale systems
Abstract: In current modeling, the best available descriptions of a system often come at a fine level (atomistic, stochastic, microscopic, individual-based) while the questions asked and the tasks required by the modeler (prediction, parametric analysis, optimization and control) are at a much coarser, averaged, macroscopic level. Traditional modeling approaches start by first deriving macroscopic evolution equations from the microscopic models, and then bringing our arsenal of mathematical and algorithmic tools to bear on these macroscopic descriptions.
Over the last few years, and with several collaborators, we have developed and validated a mathematically inspired, computational enabling technology that allows the modeler to perform macroscopic tasks acting on the microscopic models directly. We call this the "equation-free" approach, since it circumvents the step of obtaining accurate macroscopic descriptions.
I will argue that the backbone of this approach is the design of (computational) experiments. In traditional numerical analysis, the main code "pings" a subroutine containing the model, and uses the returned information (time derivatives, function evaluations, functional derivatives) to perform computer-assisted analysis. In our approach the same main code "pings" a subroutine that sets up a short ensemble of appropriately initialized computational experiments from which the same quantities are estimated (rather than evaluated). Traditional continuum numerical algorithms can thus be viewed as protocols for experimental design (where "experiment" means a computational experiment set up and performed with a model at a different level of description).
Ultimately, what makes it all possible is the ability to initialize computational experiments at will. Short bursts of appropriately initialized computational experimentation -through matrix-free numerical analysis and systems theory tools like variance reduction and estimation- bridges microscopic simulation with macroscopic modeling. Remarkably, if enough control authority exists to initialize laboratory experiments "at will", this computational enabling technology can become a set of experimental protocols for the equation-free exploration of complex system dynamics.

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Date: November 8
Speaker: Ronald Coifman, Mathematics, Yale University
Title: Multiscale Analysis and Diffusion Geometries on Digital Data Sets
Abstract: We will discuss simple methodologies for analyzing and discovering geometric structures in massive data sets. We introduce multiscale Harmonic analysis on graphs and on subsets of Euclidean spaces. The methods augment spectral graph theory, kernel principal component analysis, manifold learning and other methods from machine learning.

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Date: November 15
Speaker: Jim Stone, PACM and Astrophysical Sciences, Princeton University
Title: Astrophysical Gas Dynamics
Abstract: Most of the visible matter in the Universe is a plasma, that is a dilute gas of electrons, ions, and neutral particles. In many cases the dynamics of this plasma is described to a good approximation by the equations of compressible hydrodynamics, magneto-hydrodynamics (in the case that magnetic fields are present), or radiation MHD (in the case that photons provide significant energy or momentum transport). Studying multidimensional, time-dependent and/or highly nonlinear processes in astrophysical plasmas usually requires numerical methods, however developing accurate and robust methods for compressible MHD and/or radiation MHD is still an active area of research in applied mathematics. I will describe some problems in astrophysics which motivate the development of such methods, describe recent advance in numerical algorithms for MHD and their implementation on parallel processors, and describe some of what we have learned from application of the methods.

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Date: November 22
Speaker: Eduardo Sontag, Math and BioMaPS Institute for Quantitative Biology, Rutgers University
Title: Qualitative/Quantitative Analysis of a Class of Biological Networks
Abstract: The analysis of signaling networks constitutes one of the central questions in systems biology: there is an pressing need for powerful mathematical tools to help understand, quantify, and conceptualize their information processing and dynamic properties. Approaches based upon detailed modeling and simulation are hampered by the fact that is virtually impossible to experimentally validate the form of the nonlinearities used in reaction terms, or, even when such forms are known, to accurately estimate coefficients (parameters). In this presentation, we show how some signaling systems may be profitably studied by first decomposing them into several subsystems, each of which is endowed with certain "qualitative" mathematical properties. These properties, in conjunction with a relatively small amount of "quantitative" data, allow the behavior of the entire, reconstituted system, to be deduced from the behavior of its parts. This novel approach emerged originally from our study of possible multi-stability or oscillations in feedback loops in cell signal transduction modeling, but turns out to be of more general applicability. (Most of the work reported in this talk was carried out in collaboration with D. Angeli, and parts of it with J. Ferrell, G. Enciso, and P. de Leenheer.)

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Date: November 29
Speaker: Jelena Kovacevic, Center for BioImage Informatics, Carnegie Mellon University
Title: Frames and the Fundamental Inequality
Abstract: In recent years, we have seen an explosion of work on frames, in particular finite frames. We find finite tight frames when the lengths of the frame elements are predetermined. In particular, we derive a "fundamental inequality" which completely characterizes those sequences which arise as the lengths of a tight frame's elements. Furthermore, using concepts from classical physics, we show that this characterization has an intuitive physical interpretation. At the end of the talk, we also examine some recent applications of frames.

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Date: December 6
Speaker: Emily Carter, PACM and Mechanical & Aerospace Engineering, Princeton University
Title: Reduced Scaling Methods for Quantum Electronic Structure
Abstract: The problem of solving the Schroedinger equation in quantum mechanics, in order to describe the behavior of N electrons, is in principle an N! hard problem in an infinite basis. This is due to the need to describe the correlated motion of electrons. Some typical approaches to solving this 3N-dimensional PDE will be introduced, including mean-field and many-body methods. An analysis of their scaling properties will be given. My research group's particular strategies for reducing the prohibitive scaling of these methods while retaining accuracy of the solution will be presented. These schemes are based on simple physical and mathematical principles, for both molecular quantum chemistry and for condensed matter

electronic structure. We will end with an outlook of the applied mathematical research challenges that remain for describing large numbers (e.g., thousands) of atoms with quantum mechanics. When these challenges are overcome, we will be able to predict the behavior of complicated molecules and materials with unprecedented fidelity.

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Date: January 31
Speaker: Daryl Pregibon, Google Labs
Title: Graph Mining
Abstract: Transactional data that occurs in telecommunications, financial, and retail applications can be represented as a graph. The size of such graphs can be very large so that mining such data poses significant technical challenges. We discuss our experience in mining large graphs paying special attention to the dynamic nature of the underlying applications, namely that the data presents itself not as a static data set but rather as a continuous data stream. We introduce a definition of a dynamic graph that has served us well in representing telecommunications data. We illustrate the ideas with examples from toll fraud detection.
Joint work with Corinna Cortes and Chris Volinsky

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Date: February 8, Carl Icahn Lab 101
Speaker: Joshua Plotkin, Harvard University
Title: Selection pressures on proteins at the genomic scale: Applications to microbial evolution
Abstract: Joint with the Lewis-Sigler Institute & EEB

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Date: February 14
Speaker: Robert Vanderbei, Operations Research and Financial Engineering, Princeton University
Title: On Fair and Balanced Presentations of Election Data
Abstract: The media has made much of the red-blue divide in America. As is well known, the sparsely populated states are mostly republican whereas the densely populated urban areas are mostly democratic. This creates interesting challenges in data representation which will be discussed.

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Date: February 21
Speaker: Vincent Poor, Electrical Engineering and Applied Mathematics, Princeton University
Title: Signal Processing and Wireless Networks
Abstract: A major issue in today's wireless world is the dramatic increase in demand for new capacity and higher performance of wireless networks. The development of these capabilities is limited severely by the scarcity of two of the principal resources in wireless networks, namely energy and bandwidth. Consequently, the community has turned to a third principal resource, the addition of intelligence throughout the network, in order to exploit increases in processing power afforded by Moore's Law type improvements in microelectronics. This talk will focus on two aspects of this phenomenon: the effects of advanced node-level signal processing on the higher-layer performance of wireless communication networks, including energy efficiency, spectral efficiency, throughput and delay; and the use of advanced signal processing principles, including collaborative beam-forming, sensor scheduling, and distributed learning, in the design, deployment and operation of wireless sensor networks.

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Date: February 28
Speaker: Nigel Boston, University of Wisconsin

Title: Invariant-Based Face Recognition
Abstract: After a brief review of recent striking applications of algebra to engineering and computer science, the currently significant problem of face recognition is addressed. We introduce a new approach to obtaining invariants of Lie groups adapted to this problem and describe its success in implementations.

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Date: March 7
Speaker: Weinan E, Applied Mathematics and Mathematics, Princeton University
Title: Progresses and Challenges in Multiscale Modeling
Abstract: In the last several years, there has been tremendous growth of interest on multiscale modeling from many scientific and engineering disciplines. What are the issues involved? How much progress has been made? What are the challenges that we face in order to realize the full potential of multiscale modeling? This talk presents a personal view on these and related questions. We will begin with a quick discussion of the general issues in multiscale modeling. We then review some of the most successful multiscale methods, including the Car-Parrinello method and the quasicontinuum method for crystalline solids. In the second half of talk, we will focus on the problems from complex fluids and micro-fluidics. We end the talk with a canonical example in multiscale modeling, the contact line problem.

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Date: March 21
Speaker: John Benedetto, University of Maryland
Title: Finite frames and quantum detection
Abstract: We discuss quantum measurement in terms of positive operator-valued measures (POMs). For any tight frame with frame constant 1 for a separable Hilbert space there is an associated POM. Our setup is d-dimensional Hilbert space H and frames for H consisting of N elements. H represents a physical system, and it is known that the state x of the system is in E, a set of N given possible states. The problem is to perform a measurement in order to determine x. This is equivalent to constructing a POM on the subsets of E with a natural probabilistic property. Because of the relationship with frames, the problem reduces to constructing a tight frame with frame constant 1 which minimizes a probability of detection functional defined in terms of E. A compactness argument shows the existence of a solution. We solve the problem using techniques from Lagrangian mechanics and properties of SO(N) with the goal of constructing solutions numerically from the resulting equations. Geometrically uniform and Grassmannian frames are natural background material. This is a collaboration with Andrew Kebo.

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Date: March 28
Speaker: Nick Duffield, AT&T
Title: Challenges for Using Sampled Traffic Measurements
Abstract: Traffic measurements are increasingly sampled due to ever growing line rates and concomitant traffic volumes. On the other hand, measurement-based applications increasingly depend on fine grained traffic characterization. Can these applications work effectively with existing sampled measurements? And if not, can we better match sampling techniques to applications? This talk describes the challenges and limitations for using sampled traffic measurements, and some recent approaches that move beyond traffic sampling methods in predominant use today.

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Date: April 4
Speaker: David Johnson, AT&T
Title: 33 Years of Bin Packing

Abstract: In the bin packing problem, one is given a list of 1-dimensional items and asked to pack them into a minimum number of unit-capacity bins. This was one of the first NP-hard problems to be studied from the "approximation algorithm" point of view, and over the years it has served as a laboratory for the study of new questions about approximation algorithms and the development of new techniques for their analysis. In this talk I present a brief survey of this history, covering worst-case, average-case, and experimental results. The latter have led to many interesting conjectures and theorems, as well as the new "sum-of-squares" algorithm for the problem.

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Date: April 11
Speaker: Pino Martin, Mechanical & Aerospace Engineering, Princeton University
Title: A Parallel Implicit Method for the Direct Numerical Simulation of Compressible Turbulent Flows
Abstract: The detailed simulation of compressible turbulent flows requires solving the conservation of mass, momentum and energy equations. For direct numerical simulations (DNS) all possible length scales and time scales must be resolved by the numerical method. Thus, DNS requires accurate representation of time-dependent wave propagation with high wave number (or high frequency) and small amplitude waves. Thus, numerical methods with minimal dissipation and dispersion properties are necessary to obtain accurate results.
In addition, gathering turbulence statistics requires large amounts of computing time because the simulations must be run on very large grids for many thousands of time steps. Generally, explicit Runge-Kutta methods are used to approximate the time derivative because they have large stability limits and are easy to program. In this seminar, I will present a new implicit method for the time integration that yields significantly reduced computational time of typical DNS of compressible flows while providing an accurate representation of the solution.

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Date: April 13, 8pm, A02 McDonnell Hall
Speaker: *Distinguished Lecture Series* David Donoho, Department of Statistics, Stanford University
Title: More Unknowns than Equations? Bring it on!
Abstract: Everything you were taught about underdetermined systems of linear equations is wrong... Okay, that's too strong. But you have been taught things in undergraduate linear algebra which, if you are an engineer or scientist, may be holding you back. The main one is that if you have more unknowns than equations, you're lost. Don't believe it. At the moment there are many interesting problems in the information sciences where researchers are currently confounding expectations by turning linear algebra upside down: An imaging system can produce an accurate N-pixel image using only N 1/4 log3 (N) (specially chosen) samples to reconstruct it, far fewer than the N pixel samples you might have naively thought. A Fourier imaging system can observe just the lowest frequencies of a sparse nonnegative signal and perfectly reconstruct all the unmeasured high frequencies of the signal. a communications system can transmit a very weak signal perfectly in the presence of intermittent but arbitrarily powerful jamming. Moreover, in each case the methods are convenient and computationally tractable. Mathematically, what's going on is a recent explosion of interest in finding the sparsest solution to certain systems of underdetermined linear equations. This problem is known to be NP-Hard in general, and hence the problem sounds intractable. Surprisingly, in some particular cases, it has been found that one can find the sparsest solution by l 1 minimization, which is a convex optimization problem and so tractable. Many researchers are now actively working to explain and exploit this phenomenon. It's responsible for the examples given above. In my talk, I'll discuss that this curious behavior of l 1 minimization and connect with some deep mathematics and a broad range of fun applications.

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Date: April 18
Speaker: David Cai, New York University
Title: Modeling of large-scale neuronal network dynamics
Abstract: It has been shown experimentally that spontaneous cortical activity in the absence of sensory inputs modulates stimulus-evoked activity and is correlated with behavior. In the visual cortex, there is a close relationship between ongoing spontaneous activity and the spontaneous firing of a single neuron. There are dynamic switchings amongst these

spontaneous cortical states, which may span several hypercolumns spatially and are closely associated to orientation maps. To study theoretically these spatially coherent patterns of spontaneous activity, which emerge in a fluctuation-dominated neuronal network with anisotropic long-range cortical couplings in addition to isotropic short-range interactions, we have developed a coarse-grained representation of neuronal network dynamics in terms of (1+1)-D kinetic equations, which are derived via a novel moment closure, directly from the original large-scale integrate-and-fire (I&F) network. This powerful kinetic theory captures the full dynamic range of neuronal networks — from the mean-driven limit (a limit such as the number of neurons N\rightarrow\infty, in which the fluctuations vanish) to the fluctuation-dominated limit (such as in small N networks or sparsely connected networks). Both analytical insights and scale-up of numerical representation can be achieved via this kinetic approach. We illustrate the power of the theory by studies of the dynamical properties of networks of various architectures, including excitatory and inhibitory neurons of both simple and complex type, which exhibit rich dynamic phenomena, such as, transitions to bistability and hysteresis, even in the presence of large fluctuations. To overcome the loss of detailed spike information in many coarse-grained procedures, we have further developed a hybrid theoretical framework to retain spike information by embedding a sub-network of point neurons within, and fully interacting with, a coarse-grained network of dynamical background. Comparison with full numerical simulations of the original I&F network establishes that our kinetic theory and embedded network approach are dynamically very accurate and numerically extremely efficient.

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Date: April 25
Speaker: Sergio Verdu, Applied Mathematics and Electrical Engineering, Princeton University
Title: Discrete Denoising
Abstract: Finite-alphabet signals corrupted by discrete noisy channels arise naturally in a wide range of applications spanning fields such as statistics, engineering, and computer science. Examples include DNA sequence analysis and processing, text correction, Hidden Markov model state estimation, and image denoising. While the field of filtering or denoising of continuous-alphabet signals has a long history, the field of discrete denoising has seen far less progress.
In many discrete denoising applications, a good model for the randomness of the noisy channel is known, whereas the statistical description of the noiseless signal is either unknown or too complex. It is therefore of considerable interest to pose the problem of discrete universal denoising where no knowledge exists about the statistics of the noiseless signal while the channel statistics are assumed known.
I will present the DUDE algorithm for discrete universal denoising which has linear complexity and attains universal optimality in a stochastic sense as well as a stronger semi-stochastic sense. I will also show several DUDE-based algorithms for channel decoding of systematically encoded redundant data.
Joint work with E. Ordentlich, G. Seroussi, M. Weinberger and T. Weissman.

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2003-2004Collapse/Expand

Date: September 29
Speaker: Weiqing Ren, Mathematics, Princeton University
Title: Heterogeneous Multiscale Methods for the Modeling of Fluids
Abstract: We apply the framework of the heterogeneous multiscale methods to develop numerical methods for the study of macroscale dynamics of fluids in situations where either the constitutive relation is not explicitly available or the macroscopic model is invalid in part of the computational domain. The methods rely on an efficient coupling between the macroscopic and microscopic models. The continuum hydrodynamics is employed as the macroscopic model while molecular dynamics serves as the microscopic model and is used to supply the necessary data for the macroscopic model. Scale separation is exploited so that macroscopic variables can be evolved in macroscopic spatial/temporal scales using data that are predicted based on molecular dynamics on microscale spatial/temporal domains. Applications to complex fluids and contact line dynamics are presented.

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Date: October 6
Speaker: Cyrill Muratov, NJIT
Title: Signal transmission by autocrine cells in model epithelial layers
Abstract: Autocrine signaling induced by growth factors is crucial in various stages of development and in adult multicellular organisms across species. At the present level of complexity, systematic evaluation of cell communication mechanisms is next to impossible without mathematical modeling of cell signaling networks. In this talk, I will discuss recent results of our mechanistic modeling and analysis of Epidermal Growth Factor Receptor (EGFR)-mediated cell communication. I will first introduce a modeling framework which is relevant to the development and physiology of epithelial layers and to a number of in-vitro experimental formats. Mathematically, this leads to a series of interesting nonlocal/discrete nonlinear problems. I will then concentrate on the mechanism in which autocrine positive feedback loops are established by ligand-activated ligand release regulated by EGFR via a signaling network consisting of an autocrine switch (an intracellular protease) and a messenger (a secreted EGFR ligand). Such autocrine relays are found to be capable of supporting traveling waves with a number of unusual properties, such as a non-monotone dependence of the wave speed on the ligand-receptor binding rate. I will then consider the effect of cell discreteness in a physiologically relevant context and obtain the characteristics of discrete traveling waves and propagation failure. The analysis allows to characterize signal transmission in epithelial layers in terms of the biophysical and geometric parameters of the problem.

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Date: October 13
Speaker: Markos Katsoulakis, University of Massachusetts
Title: Coarse-grained stochastic processes and Monte Carlo simulations in lattice systems
Abstract: In this talk we present a new class of coarse-grained stochastic processes and corresponding Monte Carlo simulation methods capable of describing efficiently much larger scales than conventional Monte Carlo simulations, as well as providing a tool for direct hierarchical modeling across space/time scales. Our work mainly addresses microscopic models for the adsorption, desorption and diffusion of interacting molecules between a surface and an overlying gas phase, while this methodology is also applied on prototype stochastic models for unresolved features of moist atmospheric convection.
We demonstrate analytically and numerically that the new coarse-grained stochastic models can capture large scale structures while retaining significant microscopic information, such as particle/particle interactions and random fluctuations. Furthermore, computational comparisons of coarse-grained and microscopic MC simulations along with accompanying rigorous estimates on the loss of information (i.e. relative entrop) between the coarse-grained and the microscopic probability distribution functions (PDF), highlight the regimes where microscopic and coarse-grained processes and MC simulations are asymptotically identical.
Finally we discuss adaptive Monte Carlo algorithms constructed using the coarse-grained stochastic processes tools we have already developed. The adaptivity criterion is based, in analogy to PDE finite element methods, on a posteriori estimates which in our stochastic context take the form of a posteriori estimations on the loss of information between the coarse-grained and the microscopic PDFs.

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Date: October 20
Speaker: Chao Tang, NEC Laboratories, Inc.
Title: Dynamic Properties of Biological Regulatory Networks
Abstract: The interactions between proteins, DNA, and RNA in living cells constitute molecular networks that govern various cellular functions. To investigate the global dynamical properties and stabilities of such networks, we studied the cell-cycle regulatory network of the budding yeast. With the use of a simple dynamical model, it was demonstrated that the cell-cycle network is extremely stable and robust for its function. The biological stationary state-the G1 state-is a global attractor of the dynamics. The biological pathway-the cell-cycle sequence of protein states-is a globally attracting trajectory

of the dynamics. These properties are largely preserved with respect to small perturbations to the network. These results suggest that cellular regulatory networks are robustly designed for their functions.

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Date: November 3
Speaker: Martin Bazant, Massachusetts Institute of Technology
Title: Transport-limited aggregation in two dimensions
Abstract: Over the past two decades, Diffusion-Limited Aggregation (DLA) has become the canonical model of fractal growth controlled by bulk transport (as opposed to interfacial kinetics). A key feature of DLA, also arising in related phenomena of Laplacian growth such as viscous fingering, is the assumption of steady diffusion, governed by a harmonic concentration field. As first described by Hastings and Levitov (1998), this allows DLA in the plane to be recast in terms of a stochastic conformal map with ``bumps" chosen according to the harmonic measure. Here, we apply conformal mapping to certain systems of transport equations [1] to generalize the Hastings-Levitov formalism to a new class of (discrete and continuous) non-Laplacian growth phenomena limited by nonlinear diffusion, advection-diffusion in a potential flow, and/or electrochemical transport [2]. Motivated by the viscous-fingering analysis of Entov and Etingov (1991), we also consider curved two-dimensional manifolds, including DLA on a sphere or pseudo-sphere [3]. Another interesting example is Advection-Diffusion-Limited Aggregation in a potential flow, which exhibits a universal crossover from DLA to a new advection-dominated regime, controlled by a time-dependent Peclet number. Remarkably, the fractal dimension is not affected by spatial curvature or advection, in spite of dramatic changes in anisotropy and growth rate. [1] M. Z. Bazant, to appear in Proc. Roy. Soc. A (2003). http://arXiv.org/abs/physics/0302086 [2] M. Z. Bazant, J. Choi, and B. Davidovitch, Phys. Rev. Lett. 91, 045503 (2003). http://arXiv.org/abs/cond-mat/0303234 [3] J. Choi, D. Crowdy, and M. Z. Bazant, in preparation.

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Date: November 10
Speaker: Mario Ohlberger, University of Maryland
Title: A posteriori error estimates and adaptivity for convection dominated flow problems
Abstract: We consider a class of implicit finite volume schemes on unstructured grids to approximate solutions of convection dominated weakly coupled non-linear convection--diffusion--reaction systems. An a posteriori error estimate is proven. The L^1-error estimate obtained is robust in the diffusion coefficient, i.e. it applies in particular in the convection--dominated case and is even valid in the hyperbolic limit. Numerical experiments with an associated grid-adaptive algorithm are presented. Examples include environmental problems and combustion. From the numerical results it can be seen that the first order adaptive method is an adequate tool for non-linear convection with some self-sharpening effect. However, it is not convincing for linear advection problems because of its low order of convergence. To improve the method we introduce a higher order discretization of the convective part by MUSCL-type reconstruction. The improvement is demonstrated in several numerical examples.

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Date: November 17
Speaker: Barry Merriman, University of California, Los Angeles
Title: Biological Molecular Algorithms -- A Mathematician's Perspective on Molecular Biology
Abstract: Coming from applied mathematics, I have spent three years working in molecular biology, with the goal of merging mathematical and molecular techniques to create new tools for studying biology at the "genomic" scale. In this talk, I will briefly summarize the state of genomics, and then attempt to answer the frequently asked question "Where's the Math?". Towards this end, I will present a hidden but central role that mathematical concepts play in this field.
The incredible pace of development in molecular biology is driven by breakthroughs in manipulating DNA. From a mathematician's perspective, these experimental techniques—such as DNA sequencing—can be viewed as clever "algorithms", based on operators unique to the biological "programming language". These are executed in a loosely organized "bio-computer" composed of DNA, enzymes, and diverse components for "I/O and memory". The current

situation is similar to the early development of computers, when both algorithms and the hardware used to execute them were rapidly and cooperatively evolving.
I will present Molecular Biology from this algorithmic perspective, by interpreting the major techniques of DNA manipulation as biomolecular algorithms. I will also present new algorithms from my own genomics research, motivated by this way of thinking. The talk will be understandable to mathematicians and computer scientists with no biological background, and will emphasize the fundamental role that biomolecular algorithms will play in solving the outstanding problems of genomics. I also hope to promote the idea that researchers from "abstract" mathematical disciplines can make key contributions to this important area of Molecular Biology.

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Date: November 24
Speaker: Steve Cox, Rice University
Title: Eavesdropping on Synaptic Traffic
Abstract: Nerve cells communicate to one another across synapses. The receiver encodes this message as a change in local, in space and time, conductance. This change engenders a postsynaptic change in potential that actively diffuses through the dendritic tree and eventually may lead to the firing of a nervous impulse which may in turn lead to a long term change in the aforementioned synaptic conductance. To quantify this synaptic plasticity we propose a non invasive cocktail of optical imaging via voltage sensitive dyes and numerical determination of synapse location and conductance time course. In this talk we will focus on the mathematical and numerical study of the sideways Hodgkin-Huxley system that permits one to eavesdrop on synapses.

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Date: February 9
Speaker: Shi Jin, University of Wisconsin
Title: Numerical methods for multiscale kinetic problems
Abstract: I will review several recent methods for kinetic problems where the mean free path has different orders of magnitude. In particular, I will present 1. asymptotic-preserving methods: which solve the kinetic problems with numerical resolution at hydrodynamic scales without using the hydrodynamic equations, and 2. domain decomposition methods: we provide interface conditions that allow us to couple a kinetic equation with a (hydrodynamic) diffusion equation for numerical computation without using iterations at each time step.

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Date: February 16
Speaker: Martin Burger, University of California, Los Angeles and Johannes Kepler University
Title: Design of Semiconductor and Nano Devices
Abstract: The subject of this talk is the solution of mathematical problems related to the design of classical semiconductor and novel nano-scale devices. For the first class, we present optimization problems related to the drift-diffusion model, whose solution allows to improve the characteristics of currently produced devices. In particular, we discuss a novel design approach recently introduced in collaboration with Rene Pinnau (TU Darmstadt), which allows to optimize a device with a computational effort comparable to three direct simulations. For nano-scale devices, which are still in a pre-technological phase, we discuss some mathematical models of self-organized growth by elastic relaxation and surface diffusion, and their numerical solution, which might be used for design tasks in the future.

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Date: February 23
Speaker: Erik VanMarcke, Civil and Environmental Engineering, Princeton University
Title: Testable New Theory about Early-Universe Density Fluctuations and Origins of Cosmic Structure, with Focus on Mathematical-Probability and Computational Aspects

Abstract: The talk will summarize the main findings, predictions and interdisciplinary research opportunities stemming from a new probabilistic model of how complex patterns of extreme density fluctuations may have emerged from the inflation phase of the Big Bang. Based on quantum-physical principles and requiring a minimum number of (observationally-accessible) parameters, the "embryonic inflation model" yields a coherent set of testable hypotheses about the formation, evolution and composition of galaxies, stars and planets. Implying a robust (and testable, hence falsifiable) alternative to the dual paradigm of spatially-uniform light-element primordial nucleosynthesis and stellar "recycling" of matter as the sole mechanism of heavy-element production, it integrates astrophysical and planetary sciences with cosmology and galaxy formation in a coherent evolutionary framework. Overall cosmic flatness, an accelerating component, dark matter and dark energy all fit, in quantifiable and testable ways, into the framework of the theory. (Prof. VanMarcke's book on the subject, Quantum Origins of Cosmic Structure, was published in Nov. 1997, before the observation-based discovery of the "accelerating universe", which fits the theory.)

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Date: March 1
Speaker: Jianqing Fan, Operations Research and Financial Engineering, Princeton University
Title: New developments of nonparametric methods in financial econometrics
Abstract: This talk gives an overview on the nonparametric techniques that are useful for financial econometric problems. The problems include estimation and inferences of instantaneous returns and volatility functions, time-dependent stochastic models, estimation of transition densities and state price densities. We first briefly describe the problems and then outline main techniques and main results. Some useful probabilistic aspects of diffusion processes are also briefly summarized to facilitate our presentation and applications.

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Date: March 8, 8pm, A02 McDonnell Hall
Speaker: *Distinguished Lecture Series* George Papanicolaou, Department of Mathematics, Stanford University
Title: Time reversal, imaging and communications in richly scattering environments
Abstract: Signals received by an array, time reversed and re-emitted into the environment will pack-propagate to the vicinity of the sources that produced them. It is remarkable that the focusing resolution in time reversal is much better in a strongly scattering medium than in a homogeneous one, assuming dissipation is negligible. This interesting pheno-menon has many surprising applications in imaging and communications through clutter.
I will describe time reversal and its properties, explain mathematically how super-resolution occurs in random media and introduce some imaging methods that deal effectively with clutter. I will also describe how time reversal can be used in communications.

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Date: March 22, 4pm, Carl Icahn Lab 101
Speaker: James Collins, Boston University
Title: Engineered Gene Networks: A Reductionist Approach to Systems Biology
Abstract: a Lewis-Sigler Topical Seminar Series 2004, Functional Genomics speaker

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Date: March 29
Speaker: Robert Kohn, Courant Institute of Mathematical Sciences, New York University
Title: Upper bounds on coarsening rates
Abstract: I will discuss surface-energy-driven coarsening of two-phase microstructures. Such coarsening is observed in many physical systems; two basic examples are motion by surface diffusion and Mullins-Sekerka (evaporation-condensation) dynamics. Experiments and simulations suggest that solutions are in some sense statistically self-similar. There is, however, virtually nothing known with mathematical rigor. I will briefly introduce this topic, then present recent

joint work with Felix Otto (Comm. Math. Phys. 2002). Our main accomplishment is an upper bound on the coarsening rate, consistent with the conjectured self-similar behavior. Our work is also interesting for its viewpoint, which is new and potentially applicable to many other problems. I will close with one such application, to epitaxial growth -- joint work with Xiaodong Yan (Comm. Pure Appl. Math. 2003).

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Date: April 5
Speaker: Fernando Reitich, University of Minnesota
Title: Efficient high-order methods for acoustic and electromagnetic scattering simulations
Abstract: In this talk we will present a variety of techniques for the solution of electromagnetic and acoustic scattering problems that are aimed at overcoming the limitations of state-of-the-art scattering solvers. We will begin with a brief review of the techniques most commonly used for the numerical simulation of scattering experiments, highlighting their advantages and shortcomings. In addition to providing a context for the presentation, the review will motivate the continued need for algorithms that can tackle these problems efficiently without sacrificing accuracy and error-controllability. In this connection, we shall first discuss some theoretical considerations that lead to a class of efficient, high-order perturbative methods that are particularly well-suited for rough-surface scattering (e.g. ocean surfaces, diffraction gratings, etc). We shall further explain how these algorithms can be used to resolve the scattering off multi-scale surfaces, leading to consideration of high-frequency problems. With regard to the latter, we shall next present the main ideas behind our recent design of a technique for the solution of the integral-equation formulation of the scattering problem in the high-frequency regime. As we will show, our scheme can deliver error-controllable answers without the need to discretize on the scale of the wavelength of radiation, and it therefore holds significant promise for applicability in a variety configurations (e.g. military vehicles illuminated with centimeter, or even millimeter, waves). Finally, as we shall explain, our high-frequency strategy possesses the additional property that it continuously reduces to a full discretization of the integral equations as the frequency is decreased to a moderate regime. In this regard, and if time permits, we will also present an innovative technique for the efficient solution of the (singular) integral-equations pertaining to volumetric scattering up to these moderate frequencies, that can exhibit arbitrarily large, tunable orders of convergence.

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Date: April 12
Speaker: Nicholas J. Pippenger, Computer Science, Princeton University
Title: Inequalities of Quantum Information Theory
Abstract: The recent upsurge of interest in quantum communication and quantum computation has led to a renewed interest in quantum information theory. Specifically, many results concerning quantum communication and quantum computation involve the quantum entropy, a measure of quantum information, introduced by von Neumann in 1927, that generalizes the classical entropy introduced by Shannon in 1948. (The classical entropy is the special case of quantum entropy in which all density matrices are diagonal.) Even for classical information, a complete characterization of the inequalities satisfied by the entropy is available only when the number of variables is at most three, or when the allocation of entropy is symmetric (though some tantalizing results due to Z. Zhang and R. W. Yeung hint at the complexity of the general case. In this talk we shall discuss the extent to which this theory can be extended to the quantum case.

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Date: April 13, 10am
Speaker: Leonid Berlyand, Penn State University
Title: Ginzburg-Landau minimizers with prescribed degrees in perforated domains. Capacity of the domain and emergence of vortices
Abstract: Let Omega be a 2D domain with holes omega_0, omega_1, ... , omega_j , j = 1... k. In domain A = Omega \ (U^k_{j=0} omega^j) consider class J of complex valued maps having degrees 1 and -1 on partial Omega, partial omega_0 respectively and degree 0 on partial omega_j , j = 1 ... k.

We show that if cap(A) >= π, minimizers of the Ginzburg-Landau energy E_k exist for each k. They are vortexless and converge in H1(A) to a minimizing S1-valued harmonic map as the coherency length k-1 tends to 0. When cap A< π, we establish existence of quasi-minimizers, which exhibit a different qualitative behavior: they have exactly two zeroes (vortices) rapidly converging to partial A.
This is a joint work with P. Mironescu (Orsey, Paris).

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2002-2003Collapse/Expand

Date: September 23
Speaker: John Reinitz, The University at Stony Brook
Title: A Computational Approach to Drosophila Development and Transcriptional Control
Abstract: The central problem in animal development is the generation of body form. This problem was first considered by Aristotle, and in the nineteenth century it was shown that basic body form is determined by interactions among cells in a morphogenetic field. The determination of a morphogenetic field in development involves the expression of genes in spatial patterns. Spatially controlled gene expression cannot as yet be assayed in microarrays, but certain special properties of the fruit fly Drosophila which make it a premier system for developmental genetics also enable it to be used as a naturally grown differential display system for reverse engineering networks of genes. In this system we can approach fundamental scientific questions about development as well as certain computational questions that arise in the analysis of genomic level gene expression data.
We approach this problem by constructing dynamical models of the pattern formation process, which can be formulated as systems of ordinary or partial differential equations. These equations are then fit to gene expression data by a large-scale optimization process. Finally, the results are used to gain new insight into the biological system. Each of these components of the work involves computational mathematics, which I will discuss.

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Date: September 30
Speaker: Li-Tien Cheng, University of California, San Diego
Title: The Level Set Method and Schroedinger's Equation
Abstract: The level set method has recently been succesfully applied to the construction wavefronts in geometrical optics. We extend the approach here to wavefronts found in Schroedinger's equation as well as other quantities of interest. Advantages such as an Eulerian foundation and the ability to handle multivaluedness are preserved in the extension.

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Date: October 7
Speaker: Fadil Santosa, University of Minnesota
Title: Wave localization and guidance in photonic bandgap structures
Abstract: Photonic bandgap structures are anticipated to play an important role in the development of devices for optical communication. These nano-structures are made of material with periodic index of refraction. Defects are introduced to guide and manipulate light. In this talk, the speaker will provide an introduction to photonic bandgap structures, and the mathematical tools needed to analyze them. Major ideas are illustrated with numerical examples. Some of the open problems will be described.

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Date: October 14
Speaker: Zhilin Li, North Carolina State University
Title: Theoretical and Numerical Analysis for Some Non-linear Interface Problems

Abstract: Non-linear partial differential equations with discontinuity in the coefficient have many applications. In this talk, I will focus on two different non-linear interface problems. One is the potential equation for magneto-rhological (MR) fluid that contains metal particles. The permeability is discontinuous across the interface between the fluid and the particles. The second problem is the weighted minimal surface problem. We have generalized the Sneil's law for optical path to the three dimensional weighted minimal surface problem. Numerically, we use the substitution method to solve the non-linear PDE. Since the coefficient of the potential equation depends on the gradient of the solution, we use the maximum preserving immersed interface method coupled with multigrid solvers to solve the linearized problems. Numerical examples will also be presented.

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Date: October 21
Speaker: Michael Weinstein, Bell Laboratories
Title: Theory and Computation of Resonances of Photonic Microstuctures
Abstract: Photonic crystal waveguides are a class of optical waveguides with novel transverse microstructure. A great deal of tunability of optical properties is achieved through variations in the geometry of microfeatures, their distribution and refractive index contrasts. We discuss a multiple scale approach to the study of photonic crystal waveguides. Energy escapes from the core due to a combination of propagation and tunneling. Of central importance are leaky modes (resonance states) and their associated complex effective indices (scattering resonance poles). The leading order theory agrees with classical homogenization theory, describing an effective homogeneous medium with dielectric properties given by an appropriate averaging of the refractive index profile. We compute the first non-trivial correction, which takes into account the microstructure, and find that the higher order homogenization expansion gives very good agreement with full simulations by Fourier and multipole methods. The higher order expansion is crucial for estimation of leakage rates; in various examples of physical interest, the leading order (homogenization) gives a substantial underestimation. Finally, a rigorous justification of the homogenization expansion of scattering resonances is obtained as part of a resonance perturbation theory for an appropriate "preconditioned" Lippmann-Schwinger equation.

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Date: November 4
Speaker: John Guckenheimer, Cornell University
Title: The Forced van der Pol Equation: New Insights on an Old Problem
Abstract: The forced van der Pol equation is the original example of chaos in dynamical systems. It is also an example of relaxation oscillations, periodic motions with short and fast time scales. This lecture describes joint work, primarily with Kathleen Hoffman and Warren Weckesser, to understand bifurcations of dynamical systems with multiple time scales. Using the forced van der Pol equation as a case study, we illustrate how canards - solutions that track unstable slow manifolds - play an important role in both bifurcations and chaos. In many situations canards cannot be computed by solving initial value problems, so many of the phenomena that we exhibit are missed by typical simulation studies of multiscale systems.

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Date: November 11
Speaker: Stanley Osher, University of California, Los Angeles
Title: The Level Set Method-what's in it for you?
Abstract: The level set method for capturing moving fronts was introduced in 1987 by Osher and Sethian. It has proven to be phenomenally successful as a numerical device. For example, typing in "Level Set Methods" on Google's search engine gives roughly 3200 responses. Applications range from capturing multiphase fluid dynamical flows, to special effects in Hollywood to visualization,image processing, control, epitaxial growth, computer vision and many more. In this talk we shall give an overview of the numerical technology and a few applications.

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Date: November 18
Speaker: Xiantao Li, PACM, Princeton University
Title: An Eulerian Method for Multiphase Computations of the Schrodinger Equation
Abstract: We present a new numerical method for the computation of the semiclassical limits of the Schrodinger equation. We first use Wigner transform technique to derive a Vlasov equation in the phase space, and then find its solution in the multiphase regime. By taking moment closure, we obtain the multiphase equations in the physical space. The numerical procedure follows the solution of the Vlasov equation, but only operates in the physical space, which offers great efficiency and simplicity. In addition, we will show some other application of this technique, such as the multivalued solutions of the Euler Poisson system in Klystron.

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Date: November 25
Speaker: Michael Celia, Civil and Environmental Engineering, Princeton University
Title: Pore-scale Network Models for Two-phase Flow in Porous Media
Abstract: Pore-scale network models for two-phase flow in porous media describe fluid movement and interface displacements at the scale of individual pores. Aggregation of many pores, into an interconnected network structure, allows for simulations from which volume-averaged properties may be computed. Typical averaged variables include fluid saturations, average capillary pressures, specific interfacial areas, and measures of contact-line length. We have been using both quasi-static and dynamic network models to explore new constitutive relationships at the continuum porous-medium scale, with a focus on relationships involving specific interfacial area and dynamic capillary pressure, and on the nature of hysteresis. We have also coupled interface displacement models with models of miscible displacement to investigate upscaling relationships for problems of inter-phase mass transfer, with application to groundwater contamination problems. This talk will present the underlying mathematical models, and describe computational upscaling studies from which continuum-scale properties are derived.

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Date: December 2
Speaker: Natalia Berloff, University of Cambridge
Title: Nonlinear Scroedinger equations as models of superfluidity
Abstract: Quantum effects dominate the behaviour of liquid helium and other Bose-Einstein condensed fluids. These effects, which include the existence of discrete quantized vortices and the quantization of hydrodynamic circulation, place severe restrictions on the types of flow that can take place in the superfluid phase. Turbulent flows in such systems are also of great interest, not only in their own right, but also because they often appear to share important characteristics with those found in classical fluids.
The Gross-Pitaevskii (GP) equation, also known in nonlinear optics as the defocusing nonlinear Schroedinger equation, is used to elucidate different aspects of superfluid behaviour: the motion, interactions, annihilations, nucleation and reconnections of vortex lines, vortex rings, and vortex loops; the motion of impurities and their capture by vortex lines. New variations of the GP equation that are more faithful to real helium II are also considered.

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Date: February 10, 12 noon
Speaker: Akbar Sayeed, University of Wisconsin-Madison
Title: A Virtual Representation for Multi-Antenna Wireless Channels
Abstract: The use of multiple-antenna arrays has emerged as a promising technology for dramatically increasing the information capacity and reliability of wireless communication systems. Accurate yet tractable channel modeling is critical to realizing the potential of antenna arrays. The underlying physical channel exhibits complex characteristics due to signal scattering over multiple paths, each path associated with a propagation delay, a Doppler shift (due to motion), directional angles, and a complex path gain. Current modeling philosophies are exemplified by two extremes: idealized but unrealistic statistical models and detailed physical (ray tracing) models that directly capture the multipath propagation but are difficult

to incorporate in system design. The key premise of our work is that it is not the physical channel by itself but a fundamental understanding of its interaction with the signal space that is critical from a communication theoretic viewpoint. I will present a four-dimensional Karhunen-Loeve-like virtual representation for space-time channels that captures the essence of such interaction in time, frequency and space and exposes the intrinsic degrees of freedom in the channel. The virtual representation is essentially a Fourier series dictated by the finite array apertures, signaling duration and bandwidth and corresponds to a uniform, fixed sampling of the angle-delay-Doppler scattering space. It yields a simple geometric interpretation of the effects of scattering on channel statistics and capacity. The talk will discuss various insights into the structure of space-time channels afforded by the virtual representation as well its applications in capacity assessment, space-time code design, and wireless networks.

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Date: February 13, 8pm, A02 McDonnell Hall
Speaker: *Distinguished Lecture Series* Noga Alon, School of Mathematics and Computer Science, Tel Aviv University
Title: Modern Discrete Mathematics: Methods, Applications and Challenges
Abstract: Combinatorics is a fundamental mathematical discipline as well as an essential component of many applied mathematical areas, and its study has experienced an impressive growth in recent years. I will discuss two of the main general techniques that played a crucial role in the development of modern Discrete Mathematics; algebraic tools and probabilistic methods. Both techniques will be illustrated by examples, where the emphasis is on the basic ideas and on applications to other areas including Information Theory and Computer Science.

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Date: February 17
Speaker: Weiqing Ren, Institute for Advanced Study
Title: String method for the study of Rare events
Abstract: Many problems in physics, material sciences, chemistry and biology can be abstractly formulated as a system that navigates over a complex energy landscape of high or infinite dimensions. Well-known examples include pahse transitions of condensed matter, conformational changes of biopolymers, and chemical reactions. The state of these systems is confined for long periods of time in metastable regions in configuration space and only rarely switches from one region to another. The separation of time scale is a consequence of the disparity between the effective thermal energy and typical energy barrier in these systems, and their dynamics effectively reduce to a Markov chain on the metastable regions. The analysis and computation of the transition pathways and rates between the metastable states represent the major challenges, especially when the energy landscape exhibits multiscale features. I will present the string method that has proven to be effective for some truly complex systems in material science and chemistry.
This is a joint work with Weinan E and Eric Vanden-Eijnden.

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Date: February 24
Speaker: Heinz Kreiss, University of California, Los Angeles
Title: Numerical experiments on the interaction between the large- and small-scale motion of the Navier-Stokes Equations
Abstract: The problem we want to discuss is motivated by weather prediction. To start a numerical forcast one needs initial data which must be provided by observations. Unfortunately, the observational net is too sparse to determine the small-scale of the initial data. We ask the following question: Using the time history of the large-scale data, can one reconstruct the small-scale of the data?
As a model problem, we consider solutions to the unforced incompressible Navier-Stokes equations in a 2\pi-periodic box. We split the solution into two parts representing the large-scale and small-scale motions. We define the large-scale as the sum of the first k_c Fourier modes in each direction, and the small-scale as the sum of the remaining modes. We attempt to reconstruct the small-scale by incorporating the large-scale solution as known forcing into the equations governing the evolution of the small-scale. We want to find the smallest value of k_c for which the time evolution of the large-scale sets up the dissipative structures so that the small-scale is determined to a significant degree. Existing theory based on energy

estimates gives a pessimistic estimate for k_c that is inversely proportional to the smallest length-scale of the flow. At this value of k_c the energy in the small-scale is exponentially small. In contrast, numerical calculations indicate that k_c can often be chosen remarkably small. We attempt to explain why the time evolution of a relatively few number of large-scale modes can be used to reconstruct the small-scale modes in many situations. We also show that similar behavior is found in solutions to Burgers' equation.

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Date: March 3
Speaker: Luminita Vese, University of California, Los Angeles
Title: Modeling textures with total variation minimization and oscillating patterns in image processing
Abstract: This talk is devoted to the decomposition of a given (possibly textured) image f into a sum of two components u+v, where u is a function of bounded variation (a cartoon approximation of f), while v is an oscillating function, representing texture or noise. To model the oscillatory component v, we investigate the use of some spaces defined by duality, instead of the standard L^2 norm. These new techniques for image decomposition and texture modeling follow some recent ideas of Y. Meyer. The obtained algorithms are very simple, making use of differential equations and are easily solved in practice. Finally, I will present various numerical results on real textured images, showing the obtained decomposition u+v. I will also illustrate how the proposed methods can be used for image restoration, texture discrimination and texture segmentation. This is joint work with S. Osher and A. Sole.

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Date: March 10
Speaker: Andrea Bertozzi, Duke University
Title: New challenges for hydrodynamics: microfluidics, imaging science, and mobile sensors
Abstract: This talk will showcase three new research areas involving mathematical fluid dynamics. Microfluidics is a rapidly growing field being driven by new technological applications in the medical, materials, and chemical sciences. Surface tension effects (Marangoni stresses) are important on these scales. We consider the basic physics of surface tension gradients (used to move liquids) in conjunction with body forces on fluids and show that the ensuing dynamics can yield multiple shock structures involving undercompressive waves.
In the field of imaging science, Image inpainting involves filling in part of an image or video using information from the surrounding area. We introduce a class of automated methods for digital inpainting using ideas from classical fluid dynamics. The main idea is to think of the image intensity as a `stream function' for a two-dimensional incompressible flow. The method is directly based on the Navier-Stokes equations for fluid dynamics, which has the immediate advantage of well-developed theoretical and numerical results.
An emerging area of mobile sensor control is the design of algorithms for multiple unmanned vehicles. Taking ideas from mathematical biology, we consider swarming algorithms for fluid-like motion based on simple rules for self-propulsion and local interaction. Applications range from mine detection algorithms to perimeter patrol and gradient searching.

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Date: March 24, 12:30pm
Speaker: Steven Strogatz, Cornell University
Title: Weird Phase Transition in a Randomly Grown Graph
Abstract: We analyze a minimal model of a growing network. At each time step, a new vertex is added; then, with probability \delta, two vertices are chosen uniformly at random and joined by an undirected edge. This process is repeated for t time steps. In the limit of large t, the resulting graph displays surprisingly rich characteristics. In particular, it appears that a giant component emerges in an infinite-order phase transition at delta = 1/8, but it's still an open problem to prove this rigorously.
This is joint work with Duncan Callaway, John Hopcroft, Jon Kleinberg, and Mark Newman

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Date: March 24
Speaker: Oscar Bruno, California Institute of Technology
Title: New high-order, high-frequency methods in computational electromagnetism
Abstract: We present a new set of algorithms and methodologies for the numerical solution of problems of scattering by complex bodies in three-dimensional space. These methods, which are based on integral equations, high-order integration, fast Fourier transforms and highly accurate high-frequency methods, can be used in the solution of problems of electromagnetic and acoustic scattering by surfaces and penetrable scatterers --- even in cases in which the scatterers contain geometric singularities such as corners and edges. In all cases the solvers exhibit high-order convergence, they run on low memories and reduced operation counts, and they result in solutions with a high degree of accuracy. In particular, our algorithms can evaluate accurately in a personal computer scattering from hundred-wavelength-long objects by direct solution of integral equations --- a goal, otherwise achievable today only by supercomputing. A new class of high-order surface representation methods will be discussed, which allows for accurate high-order description of surfaces from a given CAD representation. A class of high-order high-frequency methods which we developed recently, finally, are efficient where our direct methods become costly, thus leading to a general and accurate computational methodology which is applicable and accurate for the whole range of frequencies in the electromagnetic spectrum.

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Date: March 31
Speaker: Anna-Karin Tornberg, Courant Institute of Mathematical Sciences
Title: Direct Simulations of Suspensions of Long Slender Elastic Filaments
Abstract: The dynamics of long slender filaments or fibers suspended in fluids are fundamental to understanding many flows arising in physics, biology and engineering. Such filaments often have aspect ratios of length to radius ranging from a few hundred to several thousand. Full discretizations of such thin objects in a 3D domain is very costly. Slender body theory yields an integral equation along the filament centerline, relating the force exerted on the body to the filament velocity. The equation is asymptotically accurate to O(\varepsilon^2 \log \varepsilon), where the slenderness parameter \varepsilon is the aspect ratio of the filament. The equation is extended to the case of multiple interacting filaments.
We consider filaments that are inextensible and elastic. Replacing the force in the integral equation by an explicit expression using Euler-Bernoulli elasticity, yields a time-dependent integral equation for the motion of the filament centerline, coupled with an auxiliary integro-differential equation for the filament tension. Our numerical method is based on a regularized version of these slender body equations that is asymptotically equivalent to the original formulation. The filament centerline is parameterized by arclength, and discretized uniformly. The numerical algorithm is based on a combination of finite differences and special quadrature methods.
We present three dimensional simulations of single as well as interacting filaments in a shear flow, in parameter ranges where the filaments develop rather large curvatures, and discuss some interesting features of these simulations.

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Date: April 7
Speaker: Isabelle Braems, MAE, Princeton University
Title: Interval analysis and set-membership techniques in estimation
Abstract: Interval analysis has been developed more than four decades ago to control numerical round-off errors in computers, in a rigorous way. It has then reached many other fields (assisted proof demonstrations, numerical simulation, estimation…) and applications (biology, chemical engineering, economics, computer vision, robotics…) where guaranteed computations are essential. In this talk we shall focus on parameter and state estimation problem. We will emphasize how interval analysis permits to estimate in a guaranteed way a reliable enclosure of all the global minima in optimization problems, or of all the acceptable solutions in the bounded-error context. This talk will first briefly present (or recall) the bases of interval analysis. Several applications -including non-identifiable kinetic parameter identification, reliable characterization of a thermal set-up, and robot localization- will illustrate the performance of this approach.

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Date: April 14
Speaker: Russel Caflisch, University of California, Los Angeles
Title: Elastic strain in epitaxial thin films
Abstract: In an epitaxial thin films the lattice properties of the film are determined by those of the underlying substrate. A mismatch between the lattice spacing of the substrate and film will introduce a strain into the film, which can significantly influence the material structure and properties. This talk will describe analysis and computation for strain in an epitaxial film with harmonic interatomic potentials and intrinsic surface stress. The resulting force field at a step and the interactions between steps will be described. Generalizations to epitaxial wires and particles will be presented.

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Date: April 21
Speaker: Carlos Castillo-Chavez, Cornell University
Title: Questions and models associated with the deliberate release of biological agents and their consequences
Abstract: The talk will include two intertwined parts. One will deal with the 'transmission dynamics of behaviors" and the second with the spread of epidemics on various topologies. The concept of (a fixed) core group was introduced in epidemiology by Hethcote and Yorke (1984) in the context of gonorrhea dynamics. Hadeler and Castillo-Chavez (1995) and Huang and Castillo-Chavez (2002) have shown that core group dynamics (in non-structured and structured populations) have important implications on disease transmission and control. We use these results as the starting point for the development of simple models for the dynamics of drug use (ecstasy), collaborative learning and ideologically driven behaviors (fanaticism).
The results point out to the tremendous impact that "invading" small subpopulations of individuals with strong behaviors can have on the establishment of drug cultures, fanatic ideologies or good learning environments.
The models developed naturally support sub-critical bifurcations with troublesome implications for disease dynamics and control (Castillo-Chavez and Baojun Song, 2003).
Intertwined with the first topic, I will discuss the spread of diseases on different topologies. I will address some issues that are relevant including recent efforts to define worst-case scenarios or to model epidemics on mass-transportation systems (Gerardo Chowell et al. 2003 and Castillo-Chavez and Baojun, 2003).

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Date: April 28
Speaker: Irene Gamba, University of Texas
Title: Quantum charged transport models in bounded domains
Abstract: We shall discuss quantum hydrodynamic models (QHM)-Poisson systems in bounded domains with inflow boundary conditions in the context of charged transport to induced by an electric field for a rather general termalization closure. These problems appear in the modeling of nano-scale electronic devices as well as Bose Einstein condensates and other approximations to charged non-linear Shroedinger transport by WKB expansions. We show non-existence of weak solutions to stationary states for a large set of boundary conditions, and, in particular, a blow up in finite time for transient solutions. However the stationary problem is solvable when a nonlinear friction term is added. Finally, we discuss comparisons corresponding Wigner-Poisson systems, both for either collision or collisionless regimes and we present numerical approximations to solutions of the Wigner equation and discuss the relation to QHD models. These results are part of recent collaborations with Ansgar Jungel, Ping Zhang and Jing Shi.

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2001-2002Collapse/Expand

Date: September 17
Speaker: Tim Healey, Cornell University
Title: Elastic Rods with Chirality
Abstract: We consider long, thin elastic structures possessing a uniform helical micro-structure in a natural state. Examples motivating our work include man-made ropes and cables, and biological filaments occurring in nature, e.g. mammalian tendon and DNA strands. We adopt a Cosserat-rod model for initially straight filaments of such material. The helical symmetry leads to natural restrictions on the free energy. Assuming that the period of the helical structure is much smaller than the length of any rod under consideration, we obtain, by averaging, a homogeneous, hemitropic rod model. We show that this model has built-in chirality or "handedness", viz., unlike the usual isotropic rod model, the hemitropic model can distinguish between rods with right-handed and left-handed micro-structures. In particular, the model is characterized by a coupling between extension and twist.
We consider two classes of problems for straight, hemitropic rods under end thrust, demonstrating that the post-buckling behavior depends crucially upon the end conditions. In particular, we show that a "fixed-free" rod responds essentially like an isotropic rod, while a "fixed-fixed" rod behaves drastically different from the isotropic case.

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Date: September 24
Speaker: Natalia Komarova, Institute for Advanced Study
Title: Languagre learning and evolution
Abstract: Motivated by the paradox of natural language acquisition, we will explore the concept of individual learning. One immediate result is the necessity of a finite search space, or Universal Grammar of Chomsky. We will further talk about learning algorithms and calculate the rate of convergence of the so-called memoryless learner algorithm. The resulting mathematical problem involves finding eigenvalues of a class of stochastic matrices and calculating the statistics of a harmonic mean.
Next, we will introduce the concept of population learning. Using ideas of theoretical biology, a system of nonlinear ODE's can be derived which describes the learning and evolution of language. A certain universality property of this system will be demonstrated which will enable us to link the results for individual learning with population dynamics and maintaining grammatical coherence by a population.

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Date: October 1
Speaker: Martin Z. Bazant, Massachusetts Institute of Technology
Title: The Fractal Central Limit Theorem in Percolation
Abstract: "Percolation" is the standard model for random connectivity in many applications such as secondary oil recovery, polymer gelation, and epidemic spreading. The key feature of the model is its "phase transition" in the infinite-system limit: Above a critical bond concentration, there is an infinite cluster of connected bonds, and below it there is not. Of course, real systems are finite, so an important quantity for applications is the size of the largest cluster, a random variable whose poorly understood distribution is the subject of this talk.
Away from the phase transition, this distribution obeys classical limit theorems for independent random variables, namely the Fisher-Tippett theorem for extremes (subcritical) and the Central Limit Theorem for sums (supercritical). In the critical regime, however, long-range correlations exist, and various unusual distributions are observed. It is argued that these distributions can be explained by a simple probabalistic model based on self-similar random sums of random variables. The limiting behavior of these sums is governed by a "Fractal Central Limit Theorem" which predicts a non-universal central region (at the scale of the mean) and universal stretched exponential tails. These predictions are in excellent agreement with numerical simulations of critical percolation on the square site lattice, as well as known properties of the Ising model and random graphs.

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Date: October 8

Speaker: Eliot Fried, University of Illinois at Urbana-Champaign
Title: Disclinated states in nematic elastomers
Abstract: We present a theory for uniaxial nematic-elastomers with variable asphericity. As an application of the theory, we consider the time-independent, isochoric extension of a right circular cylinder. Numerical solutions to the resulting differential equation are obtained for a range of extensions. For sufficiently large extensions, there exists an isotropic core of material surrounding the cylinder axis where the asphericity vanishes and in which the polymeric molecules are shaped as spherical coils. This region, corresponding to a disclination of strength +1 manifesting itself along the axis, is bounded by a narrow transition layer across which the asphericity drops rapidly and attains a non-trivial negative value. The material thereby becomes anisotropic away from the disclination so that the polymeric molecules are shaped as ellipsoidal coils of revolution oblate about the cylinder radius. In accordance with the area of steeply changing asphericity between isotropic and anisotropic regimes, a marked drop in the energy density is observed. The boundary of the disclination core is associated with the location of this energy drop. For realistic choices of material parameters, this criterion yields a core on the order of 10^{-2} microns, which is consistent with observations in conventional liquid-crystal melts. Also occurring at the core boundary, and further confirming its location, are sharp transitions in the behavior of the constitutively determined contribution to the deformational stress and a minimum in the pressure. Furthermore, the constitutively determined contribution to the orientational stress is completely concentrated at the core boundary.

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Date: October 15
Speaker: Mitchell Luskin, University of Minnesota
Title: Mathematical and computational modeling of the martensitic phase transformation
Abstract: We present a mathematical model and computational results for the martensitic phase transformation of a thin film as the film is cyclically heated and cooled. Our model utilizes a surface energy that allows sharp interfaces with finite energy and a Monte Carlo method to nucleate the phase transformation since the film would otherwise remain in metastable local minima of the energy.

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Date: October 22
Speaker: Bradley J. Lucier, Purdue University
Title: Wavelet Methods for Medical Tomography
Abstract: The mathematics of Computed Tomography (CT) and Positron Emission Tomography (PET) medical imaging is based on inverting the Radon transform. The Radon transform is a linear, smoothing operator, so its inverse, while linear, is unbounded, and the presence of noise (especially for PET imaging) makes applying this inverse problematic. David Donoho introduced Wavelet Shrinkage applied to Wavelet-Vaguelette decompositions to solve this problem. This talk describes how Donoho's method can be cast in a variational framework, how to choose the scaling of shrinkage parameters, and gives experimental results that compare our method with the so-far standard method, Filtered Back Projection.

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Date: October 29
Speaker: Stanislav Shvartsman, Chemical Engineering, Princeton University
Title: Modeling Cell Communication in Drosophila Oogenesis
Abstract: Until recently, cell communication in tissues was studied using exclusively biochemical and genetic approaches. As a rule, mechanisms deduced from these studies are difficult to evaluate without the aid of mathematical models. I will present our recent work on modeling of cell communication in Drosophila oogenesis (egg development). The model focuses on autocrine loops - a mode of cell signaling that is established when soluble ligands released by cells stimulate receptors on their surfaces.
Autocrine signaling through the Epidermal Growth Factor Receptor (EGFR) is highly conserved across species and operates at various stages of development, patterning the developing tissues and organs[1]. A recent hypothesis suggested that a distributed network of positive and negative EGFR autocrine feedback loops in Drosophila oogenesis is capable of spatially

modulating a simple single-peaked input into a more complex two-peaked signaling pattern, specifying the formation of a pair organ (a pair of respiratory appendages)[2]. To test this hypothesis, we have integrated genetic and biochemical information about the EGFR network into a mechanistic model of transport and signaling[3]. Computational analysis of the model enables the evaluation of the proposed mechanism and the interpretation of the phenotypic transitions observed in this system[4]. [1] Casci, T. & Freeman, M. Control of EGF receptor signalling: Lessons from fruitflies. Cancer And Metastasis Reviews 18, 181-201 (1999). [2] Wasserman, J.D. & Freeman, M. An autoregulatory cascade of EGF receptor signaling patterns the Drosophila egg. Cell 95, 355-364 (1998). [3] Shvartsman, S.Y., Muratov, C.B. & Lauffenburger, D.A. Modeling and Computational Analysis of EGFR Autocrine Loops in Drosophila Oogenesis. in preparation (2001). [4] Nilson, L. & Schupbach, T. EGF receptor signaling in Drosophila oogenesis. Current topics in developmental biology 44, 203-243 (1999).

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Date: November 5
Speaker: Chun Liu, Penn State University
Title: Complex fluids: liquid crystals, mixtures and polymeric materials
Abstract: In this talk, several dynamical systems modeling specific types of complex fluids are introduced. The relation between these and other existing models will be discussed. We will also study the relations between the variational procedure; the basic energy law; stability; and the higher order energy estimates. The different non-Newtonian properties such systems exhibit is of particular interest. Finally we will study a differential-integral equation system that allows us to consider couplings and interactions of different spatial length scales.

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Date: November 12
Speaker: John Tyson, Virginia Polytechnic Institute and State University
Title: Eukaryotic Cell Cycle Controls: An Example of the 'Last Step' in Computational Molecular Biology
Abstract: The cell cycle is the sequence of events by which a growing cell duplicates all its components and partitions them more-or-less evenly between two daughter cells. In the last 15 years, molecular biologists have made great progress in identifying the genes, proteins and molecular interactions that control the basic events of the cell cycle (DNA synthesis and mitosis). The control system is so complex that its behavior cannot be understood by casual, hand-waving arguments. We use biochemical kinetics and dynamical systems theory to convert hypothetical molecular mechanisms of cell cycle control into quantitative computational models. By testing our models against experimental observations, we gain new insights into how the control system works. The approach is generally applicable to any complex gene-protein network that regulates some physiological characteristics of a living cell. References: Tyson et al. (1996) Trends in Biochemical Sciences 21:89-96. Chen et al. (2000) Molecular Biology of the Cell 11:369-391.

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Date: November 19
Speaker: Yong Duan, University of Delaware
Title: Protein folding by all-atom simulations
Abstract: Elucidation of the mechanisms of protein folding has challenged the scientific community for decades. It has also been termed as the second half of genomics. The challenge lies at the detailed description of the processes. Our approach is to apply all-atom molecular dynamics simulations to accurately replicate the folding processes of small proteins on computer. I will discuss the status of the field and use a few examples to demonstrate how one can effectively use such an approach in the studies of protein folding.

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Date: November 26
Speaker: William Cook, PACM, Princeton University

Title: The Traveling Salesman Problem
Abstract: The traveling salesman problem, or TSP for short, is easy to state: given a number of "cities" along with the cost of travel between each pair of them, find the cheapest way of visiting all the cities and returning to your starting point. We will present a survey of recent progress in algorithms for large-scale TSP instances, including the solution of a million city instance to within 0.09% of optimality, the exact solution a 15,112-city instance, and developments in heuristic search algorithms.

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Date: December 3
Speaker: Shiyi Chen, Johns Hopkins University
Title: Lattice Boltzmann Method for fluid flows
Abstract: The lattice Boltzmann method has become an alternative computational scheme for solving partial differential equations and modeling physical and engineering systems. In this talk, we will briefly introduce the basic principles of the lattice Boltzmann method, its mathematical background and numerical implementations. Comparisons of the lattice Boltzmann method with traditional numerical schemes, including finite difference schemes and pseudo-spectral methods, for solving the Navier-Stokes equations will be presented. The applications of the lattice Boltzmann method for simulating multiphase flows, flow through porous media, MEMS and suspended particle motions will be discussed.

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Date: February 11
Speaker: Richard Tsai, University of California, Los Angeles
Title: An Eulerian Framework for Geometrical Optics using Level Sets
Abstract: We propose a framework to study high frequency wave propagation that arises several different fields. By solving the Liouville equation in phase space, we are able to maintain a uniform representation of the wavefronts and obtain multiple phases when waves cross each other. Our framework is an Eularian one that uses the level set methods for wavefront representation and evolution. I will discuss the numerical issues of our implementation in the second half of the talk.

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Date: February 18
Speaker: Eitan Tadmor, University of California, Los Angeles
Title: Critical Thresholds in Restricted Euler Dynamics
Abstract: We study the questions of global regularity vs. finite time breakdown in Eulerian dynamics, ut+u\nabla u=\nabla F, which shows up in different contexts dictated by different modeling of F's. To address these questions, we propose the notion Critical Threshold (CT), where a conditional finite time breakdown depends on whether the initial configuration crosses an intrinsic, O(1) critical threshold. We shall outline three prototype cases. We begin with the Euler-Poisson equations, in one-dimension and in the case of multidimensional geometric symmetry, with or without forcing mechanisms of relaxation, viscosity,... . Next, we extend our discussion to a range of genuinely multidimensional problems by tracing their eigenvalues, \lambda=\lambda(\nabla x u), which are shown to be governed by the forced Riccati equation \lambda t+u\nabla\lambda+\lambda^2=. Equipped with this spectral dynamics description we turn to the n-dimensional Restricted Euler equations. Here we obtain [n/2]+1 global invariants which enable us to precisely characterize the local topology at breakdown time, (extending previous studies in the n=3-dimensional case initiated by Vieillefosse). And finally, we introduce the corresponding n-dimensional Restricted Euler-Poisson (REP) system, identifying a set of [n/2] global invariants, which yield (i) sufficient conditions for finite time breakdown, and (ii) a remarkable characterization of two-dimensional initial REP configurations with global smooth solutions. Consequently, the CT in this case is shown to depend on the initial density, \rho 0, the initial divergence, div u0, and the initial spectral gap, \lambda 1(0)-\lambda 2(0).

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Date: February 25
Speaker: Felix Otto, University of Bonn
Title: Multiscale analysis in micromagnetism: the cross--tie wall
Abstract: The magnetization of ferromagnetic materials forms complex structures of different dimensionality and on a broad range of length scales: domains, walls of different internal structure, Bloch lines and vortices.
The cross--tie wall is a wall--type (transition layer) which occurs in moderately thin films of ferromagnetic material. The magnetization lies entirely in the film plane and is constant in the direction of the film normal. But curiously, the wall has an internal structure in tangential direction: If one looks closely, the transition layer consists of a periodic arrangement of narrow N\'eel walls separated by Bloch lines.
Does the well--accepted micromagnetic model predicts this interesting pattern? Does it at least predict how the distance w between two Bloch lines (hence the period) scales in the material parameters? The material parameters are the exchange length d, the film thickness t and the non--dimensional anisotropy parameter Q. Surprisingly, this question has not been answered in the applied literature. We give the answer $$\frac{w}{d}\;\sim\;\frac{1}{Q}\frac{d}{t},$$ in an appropriate parameter regime. This answer is in qualitative agreement with the experiments. The derivation of this scaling law is based on the rigorous analysis of an interesting cross--over of the energy scaling law for a N\'eel wall. This is joint work with A. DeSimone, R.V. Kohn and S. Müller.

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Date: March 4
Speaker: William Gear, NEC Research
Title: Solving Differential Equations Without the Equations
Abstract: Sometimes we have a method for performing an integration of a system over a small interval but do not know the governing differential equation. This can happen when we have a legacy code, or a simulator that runs on a "microscopic" scale. We present methods for performing integrations of the unknown equations over large time steps, or for extracting information that can be used to solve related problems such as steady states and bifurcations.

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Date: March 5, 8pm, A01 McDonnell Hall
Speaker: *Distinguished Lecture Series* Andrew J. Majda, Courant Institute of Mathematical Sciences, and Center for Atmosphere Ocean Sciences, New York University
Title: New Perspectives on Atmosphere/Ocean Science Through Modern Applied Mathematics
Abstract: This is an exciting time for the multidisciplinary interaction of modern applied mathematics and atmosphere ocean science. This interaction is driven by the facts that distant places on earth such as the tropical Western Pacific and Labrador and Greenland seas can have profound effect on short-term climate in places such as Princeton and NYC and that many spatio-temporal scales of motion are involved in this interaction. Thus, several novel and challenging scientific issues emerge. This talk presents some of the phenomena involved in these physical processes as well as several examples of new perspectives on these issues currently being developed through modern applied mathematics.

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Date: March 11
Speaker: Pingwen Zhang, Peking University & Princeton University
Title: Moving Mesh Methods Based on Harmonic Maps
Abstract: In this talk, we will propose a moving mesh method which also contains two parts, a solution algorithm and a mesh-redistribution algorithm. A framework for adaptive meshes based on the Hamilton-Schoen-Yau theory was proposed by Dvinsky. We will extend Dvinsky's method to provide an efficient solver for the mesh-redistribution algorithm. The key idea is to construct the harmonic map between the physical space and a parameter space by an iteration procedure, and to update the interior and boundary grids simultaneously, rather than considering them separately. Application of the proposed moving mesh scheme is illustrated with some two- and three-dimensional problems with large gradients. The numerical experiments show that our methods can accurately resolve detail features of singular problems in 3D.

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Date: March 18
Speaker: Chi-Wang Shu, Brown University
Title: Local Discontinuous Galerkin Methods for Partial Differential Equations with Higher Order Derivatives
Abstract: In this talk I will present recent results on developing local discontinuous Galerkin methods for solving time dependent partial differential equations containing third spatial derivatives (KdV type equations), containing fourth spatial derivatives (time dependent bi-harmonic type equations) and containing fifth spatial derivatives. For these new methods we present correct interface numerical fluxes and prove L^2 stability for a quite general class of nonlinear problems. These methods are especially suitable for the "convection dominated" cases, namely when the coefficients in front of the higher order derivatives are small or vanishing in certain parts of the domain and the nonlinear first derivative terms dominate. Preliminary numerical examples are shown to illustrate these methods. Finally, we present new results on a post-processing technique, originally designed for equations with first derivatives and tested for equations with second derivatives, on equations with higher derivatives. Numerical experiments show that this technique works as well for the new higher derivative cases, in effectively doubling the rate of convergence with negligible additional computational cost, for linear as well as some nonlinear problems, with a local uniform mesh. This is joint work with Jue Yan.

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Date: March 25
Speaker: Bard Ermentrout, University of Pittsburgh
Title: Flash & Turn: Self-organization and dynamics of fireflies and ants
Abstract: Many species of insects are able to organize global patterns and solve a variety of computationally intersting problems by using local sensory cues. In this talk, I will focus on two examples: (i) synchronous flashing in Southeast Asian fireflies and (ii) trail formation in army ants. I will suggest that many of the individual-level strategies used to accomplish these tasks are analagous to those used at the single neuron level. I will show that the synchronous flashing of fireflies uses a mechanism like spike-time dependent plasticity. I also show that models for the formation of ant trails are similar to those used in Hebbian learning. Thus, trails that are used are strengthened and those which are not are weakened.

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Date: April 1
Speaker: Eduardo Sontag, Rutgers University & Princeton University
Title: Some themes of feedback control theory, and their relevance to systems molecular biology
Abstract: In this talk, I will provide an expository introduction to some of the central themes of feedback control theory. I will illustrate the general principles with simple examples, and, time permitting, will discuss a couple of research vignettes. In parallel to this, I will speculate on how some of the central topics in "systems molecular biology" might benefit from an analysis based on control-theoretic ideas (such as: internal model principle and integral control, small gain theorems for stability, mathematical necessity of switching actions, and systems identification and filtering).

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Date: April 15
Speaker: Christodoulos Floudas, Chemical Engineering, Princeton University
Title: Structure Prediction in Protein Folding
Abstract: Proteins serve as vital components in our cellular makeup and perform many biological functions that are essential for sustaining life. An important feature which determines the functionality of a protein is the form of its three-dimensional structure. The structure is in turn related to the protein sequences encoded by our genes, and these sequences were identified as part of the data from the human genome project. Therefore, a logical undertaking upon completion of the human genome project, and an important step in understanding and treating disease, would be to develop a method to predict the structure of a protein given its sequence information.

Accurate prediction of the three-dimensional structure of a protein relies on both the mathematical model used to mimic the protein system and the technique used to identify the correct structure. In this presentation, a novel ab initio approach for the protein folding problem is introduced. The models are based solely on first principles, as opposed to the myriad of techniques relying on information from statistical databases. In addition, the search techniques rely on the foundations of deterministic global optimization, methods which can guarantee the correct identification of a protein's structure. The multistage approach begins with the identification of helical secondary structure elements, which is followed by the prediction of beta sheet and disulfide bridge configurations from a set of postulated beta strands. In the final stage the aforementioned predictions are used to derive structural restraints for the determination of the overall three-dimensional structure.

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Date: April 18
Speaker: Steve Morse, Yale University
Title: Coordination of Groups of Mobile Autonomous Agents Using Nearest Neighbor Rules TIME: 4:30pm PLACE: 110 Fine Hall
Abstract: In a recent Physical Review Letters paper, Vicsek et. al. propose a simple but compelling discrete-time model of n autonomous agents {i.e., points or particles} all moving in the plane with the same speed but with different headings. Each agent's heading is updated using a local rule based on the average of its own heading plus the headings of its "neighbors." Agent i's neighbors at time t, are those agents which are either in or on a circle of pre-specified radius r centered at agent i's current position. In their paper, Viscek et. al. provide a variety of interesting simulation results which demonstrate that the nearest neighbor rule they are studying can cause all agents to eventually move in the same direction despite the absence of centralized coordination and despite the fact that each agent's set of nearest neighbors change with time as the system evolves. In this presentation we provide a theoretical explanation for this observed behavior. In addition, convergence results are given for several other similarly inspired models. The results to be presented provide a graphic example of a switched linear system which is stable, but for which there does not exist a common quadratic Lyapunov function.
This research was done in collaboration with A. Jadbabaie and J. Lin

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Date: April 22
Speaker: Ken Church, AT&T Labs Research
Title: The chance of Two Noriegas is Closer to p/2 than p^2: Implications for Language Modeling, Information Retrieval and Gzip
Abstract: Bag-of-word independence models are commonly found in many language modeling applications including information retrieval, speech recognition and data compression. But, because repetition is so common, the speech literature has recently become interested in adaptive language models. Adaptive models allow probabilities to change or adapt after seeing just a few words of a text. Using a novel method for estimating adaptation, we find that adaptation effects are surprisingly large. The first Noreiga in a document has probability 0.006, two orders of magnitude more surprising than the second (0.75). Using query expansion methods borrowed from Information Retrieval, the method is generalized to account for priming. In this way, the first mention not only increases the chance of a second, but it also primes related words like "Bush" and "Panama." A wide range of applications will be discussed, mostly related to language. Interestingly, there are also non-language applications: gzipping binary tables (of telephone call detail) often works better if the table is enumerated in a convenient order that makes it easier for Lempel-Ziv compression methods to take advantage of the adaptation possibilities.

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Date: April 29
Speaker: Herb Keller, California Institute of Technology
Title: The Three Body Problem and Space Mission Design

Abstract: The circular restricted three body problem (CR3BP) of gravitational dynamics governs the motion of satellites near the earth and moon and in many other configurations. The determination of periodic, homoclinic and heteroclinic orbits and indeed unstable orbits of satellites in this configuration is important in mission planning. We show how the code AUTO 2000 has been used to calculate such orbits. A bifurcation diagram showing how most of the known and some new families of periodic orbits are related and connect all the five libration points of the CR3BP. We also treat the new exact three body figure eight solution of Montgomery and Chenciner and show how by reducing the mass of one of the bodies a homotopy to a periodic CR3BP solution results.
AUTO is software for continuation and bifurcation of solutions of parameter dependent nonlinear systems of equations. In particular it solves two point boundary value problems with great speed and accuracy. We show how it is adapted to the periodic N-body problem of gravitational dynamics.

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Date: May 9, 4:30pm
Speaker: David McLaughlin, Courant Institute of Mathematical Sciences, NYU
Title: Modeling of Primary Visual Cortex: An example of Mathematical Neural Science
Abstract: The Primary Visual Cortex (V1) is the first region in the cortical pathway in which visual information is processed by the brain. As the processing in V1 is very elementary, this cortical region is a natural candidate for computational and mathematical modelling.
We have developed a large-scale computational model of a local patch of an input layer of V1, and used this model to investigate cortical mechanisms for orientation selectivity. In this talk, I will (i) define "orientation selectivity", (ii) describe the construction and performance of our large-scale model, and (iii) use asymptotic analysis to derive a coarse-grained reduction of the large-scale model. This derivation of the reduced model follows from a temporal scale separation which emerges from cortical activity. Finally, the reduced model will be used to identify cortical mechanisms underlying orientation selectivity.

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2000-2001Collapse/Expand

Date: September 25
Speaker: Ingrid Daubechies, PACM, Princeton University
Title: Mathematical problems suggested by Analog-to-Digital conversion
Abstract: In Analog-to-Digital conversion, continuously varying functions (e.g. the output of a microphone) are transformed into digital sequences from which one then hopes to be able to reconstruct a close approximation to the original function. The functions under consideration are typically band-limited (i.e. their Fourier transform is zero for frequencies higher than some given value, called the bandwidth); such functions are completely determined by samples taken at a rate determined by their bandwidth. These samples then have to be approximated by a finite binary representation. Surprisingly, in many practical applications one does not just replace each sample by a truncated binary expansion; for various technical reasons, it is more attractive to sample much more often and to replace each sample by just 1 or -1, chosen judicously. In this talk, we shall see what the attractions are of this quantization scheme, and discuss several interesting mathematical questions suggested by this approach. This will be a review of work by many others as well as myself, including Ron DeVore, Sinan Gunturk, Thao Nguyen and Ozgur Yilmaz. It is also a case study of how continuous interaction with engineers helped to shape and change the problems as we tried to make them more precise.

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Date: October 2
Speaker: Mary Pugh, University of Pennsylvania
Title: Long-wave unstable thin film equations - singularities, steady states, and heteroclinic orbits

Abstract: I consider long-wave unstable interface models of the type $h_t = - (h^n h_{xxx})_x - B (h^m h_x)_x$ where B 0, and n and m are constants. Equations of this type appear in fluid dynamics and in population biology. I will discuss the models as well as some of the mathematical difficulties one confronts in working on fourth-order PDEs. One interesting aspect of these equations is that there is a range of long-time behavior. There is a competition between a stabilizing fourth-order term and a destabilizing second-order term. Is it possible for the second-order term to win and cause finite-time singularities? I will discuss when this may be possible (joint work with Andrea Bertozzi of Duke University). Also, I will discuss the steady states, their linear stability properties, and will present numerical simulations of evolving solutions (joint work with Richard Laugesen of the University of Illinois of Champaign-Urbana). At least a third of the talk will be within the reach of first and second-year graduate students and I hope some will attend.

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Date: October 9
Speaker: Yannis Kevrekidis, Chemical Engineering, Princeton University
Title: "Coarse" stability and bifurcation analysis ursing time steppers
Abstract: Evolutionary, pattern forming partial differential equations are often derived as limiting descriptions of microscopic, kinetic theory based models of molecular processes (e.g. diffusion and reaction). The PDE dynamic behavior can be probed through direct simulation (time integration) or, more systematically, through stability/bifurcation calculations; time-stepper based approaches, like the recursive projection method (Shroff and Keller, 1993) provide an attractive framework for the latter. We demonstrate an adaptation of this approach that permits a direct, effective ("coarse") bifurcation analysis of certain microscopic, kinetic based models. This is illustrated through a comparative study of the Fitzhugh-Nagumo PDE and of a corresponding Lattice-Boltzmann model.

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Date: October 16
Speaker: Alex Mahalov, Arizona State University
Title: Global Regularity of 3D NS with Uniformly Large Vorticity
Abstract: We prove existence on infinite time intervals of regular solutions to the 3D Navier-Stokes Equations for three-dimensional flows having uniformly large vorticity at an initial time t=0. This global regularity is proven for periodic or stress-free boundary conditions for all domain aspect ratios; smoothness assumptions are the same as for local existence theorems. The global regularity is proven using techniques of the Littlewood-Paley dyadic decomposition. Infinite time regularity is obtained by bootstrapping from global regularity of the limit equations and convergence theorems. In generic cases, sharper regularity results are derived from the algebraic geometry of resonant Poincare curves.

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Date: October 23
Speaker: Victor Yakhot, Institute for Advanced Study and Boston University
Title: Mean field theory and a small parameter for turbulence
Abstract: Numerical and physical experiments on two-dimensional (2d) turbulence show that the differences of transverse components of velocity field are well described by Gaussian statistics and Kolmogorov scaling exponents. In this case the dissipation fluctuations are irrelevant in the limit of small viscosity. In general, one can assume the existence of a critical space-dimensionality $d=d_c$, at which the energy flux and all odd-order moments of velocity difference change sign and the dissipation fluctuations become dynamically unimportant. At $d< d_c$ the flow can be described by the mean-field theory, leading to the observed gaussian statistics and Kolmogorov scaling of transverse velocity differences. It is shown that in the vicinity of $d=d_c$ the ratio of the relaxation and translation characteristic times decreases to zero, thus giving rise to a small parameter of the theory. The expressions for pressure and dissipation contributions to the exact equation for the generating function of transverse velocity differences are derived in the vicinity of $d=d_c$. The resulting equation describes experimental data on two-dimensional turbulence and demonstrate onset of intermittency as $d-d=d_c > 0$ and $r/L \to 0$ in three-dimensional flows in close agreement with experimental data. In addition, some new exact relations between correlation functions of velocity differences are derived. It is also predicted that the single-point pdf of transverse velocity

components in developing as well as in the large-scale stabilized two-dimensional turbulence is a gaussian.

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Date: October 30
Speaker: Jeremiah P. Ostriker, AST, Princeton University
Title: Testing Cosmological Models
Abstract: The study of cosmology, the origin, nature and future evolution of structure in the universe, has been totally transformed in the last decade, and computers have played a major role in the change. New theories have arisen which make the subject, formerly almost a branch of philosophy, into a quantitative science. Initial, semi-quantitative tests of these theories, either using data on galaxy distributions in the local universe or the cosmic background radiation fluctuations reaching us from the distant universe, indicate rough agreement with the simplest predictions of the theories. But now that fully three dimensional, time dependent numerical simulations can be made on modern, parallel architecture computers, we can examine (using good physical modelling) the detailed quantitative predictions of the various theories that have been proposed to see which, if any, can produce an output consistent with the real world being revealed to us by the latest ground and space based instruments.
Simulations could address 32^3 = 10^4.5 independent volume elements a decade ago. Now 512^3 = 10^8.1 is the standard for hydro computations, with 1024^3 = 10^9.0 the current state-of-the art. Increasingly, unstructured, adaptive or moving mesh techniques are being used to improve the resolution in the highest density regions. In purely darkmatter (gravitation only) calculations, the ratio of volume to resolution element has reached 16,000^3 = 10^12.6. This has enabled detailed computation for phenomena, from gravitational lensing to X-ray clusters, to be made and compared with observations. Using these tools, we have been able to reduce to a small number the currently viable options for the correct cosmological theory.

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Date: November 6
Speaker: Tom Powers, Brown University
Title: Twist, kinks, and drag: whirling elastica
Abstract: Cellular biophysics provides many examples of flexible elastic filaments rotating in a viscous fluid, from DNA transcription to supercoiling bacterial colonies. Motivated by these problems, we study the whirling instability of a twirling rod, which illustrates the implications for open rods of White's theorem relating link, twist, and writhe for closed ribbons. We then turn to the torsional stress and steady-shape shape for a rotating rod with a kink, and show theoretically and experimentally how the rod exhibits bistability between extended and folded states.

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Date: November 13
Speaker: Arthur T. Winfree, University of Arizona
Title: Knotted Phase Singularities in Motionless Media
Abstract: Idealized models of such excitability as found in a wide variety of biological media and some chemical media in gas and liquid states facilitate thinking about their possible modes of activity. These include periodic waves radiating from space curves defined by a phase singularity. In the laboratory these form closed rings that shrink and vanish. In numerical experiments with the corresponding parabolic PDE of reaction and diffusion the rings can also link and knot, making the rings topologically stable. Activity then persists indefinitely.

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Date: November 27
Speaker: Sankaran Sundaresan, Chemical Engineering, Princeton University
Title: Non-uniform structures in granular and gas-solid flows

Abstract: Meso-scale structures that take the form of clusters and streamers are commonly observed in dilute gas-particle flows, such as those encountered in riser reactors. Continuum equations for gas-particle flows, coupled with constitutive equations for particle phase stress deduced from kinetic theory of granular materials are able to capture the formation of such meso-scale structures. These structures arise as a result of an inertial instability associated with the relative motion between the gas and particle phases, and a material instability due to inelastic collisions between particles. It is demonstrated that the meso-scale structures are too small, and hence too expensive, to be resolved completely in simulation of gas-particle flows in large process vessels. At the same time, failure to resolve completely the meso-scale structures in a simulation leads to grossly inaccurate estimates of inter-phase drag, production/dissipation of pseudo-thermal energy associated with particle fluctuations, the effective particle phase pressure and the effective viscosities. A simple ad hoc sub-grid model for the effects of the unresolved meso-scale structures is constructed and incorporated into coarse-grid simulation of riser flows. Dramatic impact of sub-grid corrections on the predicted flow structures is demonstrated.

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Date: December 4
Speaker: Salvatore Torquato, Chemistry and PMI, Princeton University
Title: Revisting an Old Problem: Random Close Packirng of Spheres
Abstract: Bernal (1965) has remarked that "heaps (random close-packed arrangements of particles) were the first things that were ever measured in the form of basketfuls of grain for the purpose of trading or of collection of taxes." Random packings of identical spheres have been studied by biologists, materials scientists, engineers, chemists and physicists to understand the structure of living cells, liquids, granular media, glasses and amorphous solids, to mention but a few examples. Despite its long history, there are many fundamental issues concerning random packings of spheres that remain elusive, including a precise definition of random close packing (RCP). If such a definition of the RCP state could be presented, then one might go about quantifying the problem with the rigor that has been used very recently to prove that the densest possible packing fraction of spheres in three-dimensional space is 0.7405..., corresponding to the close-packed face-centered cubic (FCC) lattice or its stacking variants. It is shown that the current picture of the RCP state cannot be made mathematically precise and support this conclusion via a molecular dynamics study of hard spheres. We suggest that this impasse can be broken by introducing the new concept of a "maximally random jammed" state, which can be made precise.

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Date: December 11
Speaker: Antony N. Beris, University of Delaware
Title: Brownian Dynamics Methods for the Solution of Complex Polymeric Flows Based on Kinetic Theory Models: Early (CONNFFESSIT) and More Recent (Configuration Field) Approaches
Abstract: In the past, closed-form continuous models have been used for the solution of complex (i.e. multidimensional and/or time-dependent) flow problems involving polymer solutions or melts. However, those models involve closure approximations that result in unpredictable errors in the complex flows that they are employed. Nevertheless, the presence of one or more internal variables makes the dimensionality of the microscopic problem prohibitively large to allow for a direct solution of the microscopic equations (such as those arising from kinetic theory) in even the simplest multidimensional flow problems. Fortunately, in the last decade new methodologies has emerged that allow for such solutions to be obtained at significantly less computational cost through the coupling of a stochastic solution for the polymer chain configuration to a more traditional macroscopic finite-element or spectral flow approximation of the momentum and continuity equations. In this presentation, after reviewing the first of these approaches (called CONNFFESSIT) which has first been developed by Laso and Oettinger, we will discuss the more recently developed (by Hulsen and co-workers) configuration fields approach that result in even more reduced computational requirements.

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Date: February 5
Speaker: Hongkai Zhao, University of California, Irvine
Title: Super-Resolution in Time-Reversal Acoustics

Abstract: In time-reversal acoustics a signal is recorded by an array of transducers, time-reversed and then re-transmitted into the medium. The re-transmitted signal propagates back through the same medium and refocuses on the source. The possibility of refocusing by time reversal has many important applications in medicine, geophysics, non-destructive testing, underwater acoustics, wireless communications, etc. In a homogeneous medium, the refocusing resolution of the time-reversed signal is limited by diffraction. When the medium has random inhomogeneities the resolution of the refocused signal can in some circumstances beat the diffraction limit. This is super-resolution. We give a theoretical treatment of this phenomenon and use numerical simulations to confirm the theory.
This is a joint work with P. Blomgren and G. Papanicolaou.

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Date: February 12
Speaker: Terry Lyons, University of Oxford
Title: Taking the rough with the smooth - controlling short time behaviour
Abstract: Consider a continuously evolving system with state y subject to some external stimulus (or control) and modelled by the equation modelled by dy^i(t)=f^{i,j}(y(t))dx^j(t). Consider the functional relating control x and response y.
In many application settings the control is far from smooth (wind on a bridge) and it becomes interesting theoretically, as well as for numerical analysis to ask how one should approximate to x if one wishes to efficiently capture enough information to compute y accurately.
It turns out that there are interesting answers that suggest that the correct approach is via iterated integrals (or in fancy language: generalised loops and bi-algebras) and one produces an algebraic transform of the path x somewhat analogous to a fully non-commutative version of Fourier series. At least in theoretical examples, this approach can be very computationally effective. We discuss the faithfulness of this algebraic representation of paths.

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Date: February 19
Speaker: Paul Barford, University of Wisconsin-Madison
Title: Performance Measurements in the Internet
Abstract: Accurate and representative measurement is an essential component in the development of models which are meant to describe a system. Within the context of the Internet, in addition to modeling, measurements can also used for real-time decision making such as determining where to route client requests or when performance of a server falls below a specified threshold. Measurements are commonly used for these and other applications however the task of making measurements in the Internet which are accurate and representative is fraught with difficulty. In this talk, we will present an overview of Internet measurement techniques and Internet measurement projects in both research and commercial settings. We will present data from our current study which highlights differences between the two principal techniques for measuring Internet performance: passive capture of packet traffic and active probing of the network. We will also describe the challenges associated with interpreting measurement data and present a means for applying critical path analysis (CPA) to analyze TCP transactions. CPA enables the precise set of events which determine delay to be extracted. We present initial results of applying CPA to Internet data transfers which show how latency in the principal components of an end-to-end transaction contribute to the overall file transfer delay.

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Date: February 22, 8pm, Taplin Auditorium, Fine Hall
Speaker: *Distinguished Lecture Series* Charles S. Peskin, Courant Institute of Mathematical Sciences, New York University
Title: Stories About the Heart: Mathematical Tales of Nature's Design
Abstract: Changes in the Heart and Circulation Occurring at Birth: Before birth, the lungs are collapsed and present a high resistance to blood flow. Oxygen is obtained from the placenta, which offers a low resistance to blood flow. At birth, the first breath expands the lungs, and the doctor's clamp on the umbilicus (or a natural physiological constriction in the absence of such a clamp) cuts off the placental circulation. We use a simple mathematical model to study the circulatory consequences of these dramatic events, consequences that include closure of the special pathways that shunted blood away from the lungs

during fetal life.
Fiber Architecture of the Heart and its Valves: Muscle fibers of the left ventricular wall are arranged in nested toroidal layers, within which the fibers follow nearly geodesic paths. Heart valve leaflets are reinforced by collagen fibers, which, in the case of the tri-leaflet outflow valves, have a branching braided character suggestive of a fractal geometry. In each case, we show how the observed anatomy is a consequence the mechanical task that the fibers must perform.
Blood Flow in the Cardiac Chambers: The fluid mechanics of the heart is intimately coupled to the tissue mechanics of the muscular heart walls and of the flexible heart valve leaflets. This is a classic case of fluid-structure interaction. We describe a numerical method, known as the Immersed Boundary Method, that takes a unified approach to such problems by treating the structure as a part of the fluid where additional forces happen to be applied. We show results of such computations in the form of a computer-generated animation of the beating heart.

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Date: February 26
Speaker: Ronnie Sircar, ORFE, Princeton University
Title: Stochastic Optimization Problems in Finance
Abstract: We discuss some stochastic control problems that arise in financial applications involving derivative securities like options. These are related to state-dependent utility maximization problems in classical economics.
We analyze the dual problem obtained from the Legendre transform of the associated Bellman equation and interpret the optimal strategy as the perfect hedging strategy for a modified claim. Under the assumption that volatility is random and "fast mean-reverting", we derive, using a singular perturbation analysis, approximate value functions and strategies that are easy to implement and study. The analysis identifies the usual mean historical volatility and the harmonically-averaged long-run volatility as important statistics for such optimization problems without further specification of a stochastic volatility model.
We discuss some example problems such as partial hedging of derivative risk, optimal asset allocation and utility-indifference pricing, and study the effectiveness of these strategies using simulated stock paths.

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Date: March 5
Speaker: Jan Hesthaven, Brown University
Title: Absorbing Boundary Conditions for Acoustics
Abstract: The numerical solution of wave-dominated problems in domains of infinite extend often require careful attention to the design and application of artificial absorbing boundary conditions to enable an accurate, efficient and robust solution of the infinite problem using a smaller finite computational domain. Although this problem is almost as old as computational modeling itself and approximate solutions numerous, it remains one of the central, yet essentially open, issues in the accurate solution of a multitude of problems in, e.g., electromagnetics, gas-dynamics, aero-acoustics, and non-linear optics. Solutions to such problems become ever more important as the development of computational methods and resources enables the high-order accurate solution of very large problems over very long periods of time where even very low levels of reflections from the artificial boundary can prohibit the expected fidelity of the solution.
The 1994 introduction of the Perfectly Matched Layer (PML) methods, consisting of a sponge layer capable of absorbing all incoming waves, regardless of their frequency and angel of incidence, seemed at first to essentially eliminate this critical issue for problems of electromagnetics and, shortly thereafter, for related problems in acoustics and linear elasticity. However, subsequent analysis of these scheme has exposed many problems and many open questions to address.
In this talk we shall focus the attention on the construction and analysis of PML methods for problems in acoustics. We shall begin by showing that the original approach by which the PML equations are obtained, utilizing a non-physical splitting of the equations, leads to loss of strong wellposedness of the partial differential equations and, subsequently, the possibility of exponential instability of the semi-discrete form under low-order perturbations. As we shall discuss briefly, this is a general result for splitfield formulations of PML methods as illustrated by examples from electromagnetics, acoustics, and elasticity. We continue by discussing PML schemes for the special case of ambient acoustics before addressing the more general, and much more complex, question of PML schemes for general convective aero-acoustics. Rather than using physical arguments, we present a general mathematical procedure that enables the derivation of a strongly wellposed PML scheme

for the case of a constant mean flow. Computational experiments show its superior performance but also exposes a very curious problem with this, and all other PML methods, when subjected to a special excitations. We shall conclude by explaining this issue and propose a solution.
This work has been done in collaboration with Saul Abarbanel (Tel Aviv University) and David Gottlieb (Brown University).

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Date: March 12
Speaker: Richard Mclaughlin, University of North Carolina
Title: Passive Scalar Mixing: Averaging in Time Varying Flow
Abstract: We discuss enhanced mixing induced by complex fluid motion, first overviewing the importance of these problems from a general perspective in modelling turbulence with closure coefficients, and then focusing upon rigorous averaging theories in idealized contexts to try to explicitly quantify effective mixing coefficients.
We overview the idealized problem of calculating enhanced diffusivities for passive transport in steady periodic geometries, reviewing the poor dependence of these coefficients upon large scale flow parameters. Through the introduction of temporal variation into these models through rapid wind fluctuations, we present a theory which identifies regions in the Peclet-Strouhal plane for which fluctuation massages the poor coefficient dependence existing in the steady geometry, and regions with the mixing coefficients plagued by non-mononotic Peclet dependence. Two-parameter asymptotics in time varying shear geometries show that the limiting behavior of vanishing Strouhal number and infinite Peclet number varies with path, indicating different scaling regimes. Numerical simulations of the time varying cell problem for more general non-sheared geometries will be discussed.

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Date: March 26
Speaker: Thomas Liggett, University of California, Los Angeles
Title: Stochastic Growth Models on Lattices and Trees
Abstract: For the past thirty years, probabilists have studied a number of stochastic growth models that were motivated by problems in physics and biology. One of the most important of these is known as the contact process -- growth occurs as the result of "contact" with existing individuals. Such models often exhibit phase transitions, and this is the feature that leads to most of our interest in them.
Until a decade ago, the contact process was studied almost exclusively on Euclidean lattices, leading to a rather complete theory in that context. Since then, it has been discovered that the behavior of the process can be quite different on exponentially growing structures such as homogeneous trees. In particular, the phase structure is richer than it is in the lattice case.
In this lecture, I will briefly describe the most important results about the contact process on Z^d, and then the contrasting results for the process on a tree. I will then discuss a variant of the contact process on a tree that has the appealing property that the critical value for the phase transition can be computed explicitly. One of the ingredients in the computation is a collection of combinatorial identities satisfied by the d-ary Catalan numbers.

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Date: April 2
Speaker: John Hopfield, Molecular Biology, Princeton University
Title: Collective Dynamics for Brain Decisions
Abstract: The network of nerve cells in a brain carries out computations through exploiting the dynamics of its electrical activity. A transient dynamical 'phase transition' coordinating the activity of many neurons can represent and signal a 'decision' in the brain. The phase transition can implement powerful algorithms that are part of the brain's computational resources. The use of such an algorithm is illustrated in a designed 'neural' system that recognizes a spoken word independent of the speed at which the word is spoken. Such integration over a brief 'moment' is common to many perceptual systems.

No previous biology will be assumed of the audience.

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Date: April 9
Speaker: Andrew Bernoff, Harvey Mudd College
Title: Stability and Dynamics of Self-similarity in Evolution Equations
Abstract: Similarity methods have been used to derive special solutions for a broad variety of physical problems in the past few decades. In this talk I will discuss a methodology for studying linear stability for self-similar blow-up and pinch-off. I will present three problems: a simple ODE model, the Sivashinsky equation which arises in solidification, and the pinch-off of a solid filament due to the action of surface diffusion. The goal is to show that self-similar phenomena can be studied using many of the now familiar ideas that have arisen in the study of dynamical systems. In particular, I will discuss rescaling methods, linearization and the role of symmetries in the context of self-similarity. I will demonstrate that the symmetries in the problem give rise to "anomalous" positive eigenvalues associated with the rescaling symmetries as opposed to instability, and show how this stability analysis can identify a unique stable (and observable) solution from a countable infinity of similarity solutions.

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Date: April 16
Speaker: Christopher Jones, Brown University
Title: Creating Stability from Instability
Abstract: The current state-of-the-art technology in optical communications is based on the use of Dispersion Managed Solitons (DMS). These propagate on fibers with dispersion compensating itself periodically. Using variational methods and averaging, a full mathematical theory for DMS will be given. Surprisingly, it is shown that the strategy can be pushed to the point where the "pulse" is oscillating between unstable states and yet remains stable itself. Another case in which two unstable objects are put together to make a stable pulse is exhibited in the FitzHugh-Nagumo system, originally derived as a model of nerve impulse propagation. While these two phenomena are unrelated, mathematically and scientifically, they both suggest that two "wrongs" can make a "right."

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Date: April 30
Speaker: Eric Vanden-Eijnden, Courant Institute, New York University
Title: Optimal switching path for bi-stable systems under random perturbations
Abstract: We will present theoretical and numerical results on thermally activated switching process. We will also present a new numerical method for computing the most probable switching pathways in such systems. We will end by discussing the issue of nucleation vs. propagation in general Ginzburg-Landau systems.

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Date: May 7
Speaker: Rainer Hollerbach, Geosciences, Princeton University
Title: Time-dependent Taylor Vortices in Wide-Gap Spherical Couette Flow
Abstract: Motivated by experimental work, the possibility of obtaining Taylor vortices in a spherical shell of aspect ratio 1/3 is investigated numerically. It is found that Taylor vortices can exist for Reynolds numbers in the range 415< Re< 2040. With increasing Re, the initially equatorially symmetric vortices become asymmetric at Re = 1390. Increasing Re still further, these asymmetric vortices become time dependent at Re = 1940, followed by a period-doubling cascade to chaos around Re = 2035. For Re > 2040 the chaotic solution collapses back to the basic state having no Taylor vortices. Finally, some preliminary results at different aspect ratios will be presented, the ultimate goal being to map out the complete two-parameter (aspect ratio and Reynolds number) bifurcation diagram.

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Date: September 27
Speaker: Peter Deuflhard, Konrad-Zuse-Zentrum fur Informationstechnik Berlin
Title: From molecular dynamics to conformational dynamics in drug design. First steps toward virtual RNA lab
Abstract: Rational drug design involves the numerical integration of the Hamiltonian Differential equations associated with the dynamics of the molecular systems. The trajectories are known to be chaotic, which in the terms of Numerical Analysis means that the initial value problems (IVPs) are ill-conditioned after rather short time spans (typically some psec). As a consequence, only information from short term trajectories should be exploited.
On the basis of this insight, a novel concept for the computation of the essential features of such dynamical systems has recently been suggested by the author and his molecular dynamics (MD) group. The key idea is to interpret chemical conformations as almost invariant sets of the Hamiltonian dynamical system. These metastable mathematical objects are then directly computed including their life spans and the dominating patterns of changes.
This leads to an eigenproblem for eigenvalue clusters around the Perron root of a stochastic operator, which appears to be selfadjoint over some weighted L^2 space. Discretization of that operator by means of certain {\it Hybrid Monte Carlo} methods generates nearly uncoupled Markov chains, whose almost invariant aggregates (the discrete analog of the sets) need to be computed. As it turns out, the eigenvectors associated with the Perron cluster of eigenvalues contain the desired information about the conformations. The described approach is presently worked out within some RNA drug design project in collaboration with biochemists. The common aim is to substitute time consuming and costly experiments in the chemical RNA lab by simulations in a Virtual RNA Lab.

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Date: October 4
Speaker: Zhigang Suo, MAE, Princeton University
Title: Dynamics of Pattern Formation in a Binary Epilayer
Abstract: A thin binary epilayer on a substrate often exhibits intriguing phase separation behaviors. The phases may self-organize into a regular pattern, such as an array of periodic stripes or a lattice of islands. The size of the phases may be stable on annealing-that is, the phases may resist coarsening. This talk describes a thermodynamic framework to study These remarkable phenomena, based on the ongoing work in collaboration with my graduate student Wei Lu. We model the substrate-epilayer composite as a bulk solid coupled with a superficial object. The bulk solid is linear elastic. The superficial object is prescribed with an excess energy, which is a function of the concentration, the surface strain, and the concentration-gradient. Atomic diffusion is confined within the epilayer, and the surface remains nominally flat. The concentration dependence dictates the relative stability of the phases. The model leads to a nonlinear dynamical system. The strain dependence couples the morphology in the epilayer to the deformation in the substrate, mediating a long range action that refines the phases. The concentration-gradient dependence gives a continuum description of the phase boundary energy, mediating a short range action that coarsens the phases. The competition of the refining and the coarsening actions sets a length scale and leads to phase patterns. I will describe analytical and numerical results of this model.

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Date: October 11
Speaker: Ed Spiegel, Columbia University
Title: The Bifurcation of Species
Abstract: We discuss a model of evolution based on a one-dimensional desciption of phenotype together with a simplified equation for the environmental abundance that influences the survival of the organisms. A species is described by a solitary wave whose members cannot readily mate with those in another species, according to the rules of the model. Splitting of the solitary waves is interpreted as speciation and the aim of the project is to identify the mathematical mechanism that

engenders this behavior.

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Date: October 18
Speaker: Andy Majda, Courant Institute
Title: Statistucal mechanics of vortices in 2- and 3-D and crude closure for geophysical flows

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Date: October 25
Speaker: Roberto Car, Department of Chemistry and Princeton Materials Institute, Princeton University
Title: Molecular Dynamics from First-Principles
Abstract: Molecular dynamics provides a very valuable tool to simulate on a computer the dynamics of matter at the atomic scale. It consists in finding numerically the classical trajectories of the atoms in a microscopic piece of matter or a molecule. The predictive power of the approach depends crucially on the accuracy of the interatomic potential energy function. While this is often modeled empirically, within first-principles molecular dynamics this is calculated "on the fly" from the instantaneous ground-state of the electrons. This greatly improves the predictive power of molecular dynamics simulations, particularly when chemical bonds break or form as a consequence of the nuclear dynamics. However, this is also a very demanding computational task requiring the simultaneous update of nuclear coordinates and of fields representing the electronic wavefunctions. In this talk I will give a brief overview of the first-principles molecular dynamics approach, emphasizing algorithmic aspects and current challenges.

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Date: November 8
Speaker: Jinchao Xu, Penn State University
Title: Multigrid methods and applications
Abstract: The speaker will first give a brief description on the state of the art on multigrid methods for solving partial differential equations and then present some recent results and applications.

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Date: November 15
Speaker: David Srolovitz, PMI/ MAE, Princeton University
Title: Morphological Instabilities of Surfaces and Growing Films
Abstract: While surface tension is capable of stabilizing flat surfaces against shape perturbations in unstressed solids, the presence of a stress can destabilize the surface. I will begin by discussing thermodynamic and kinetic issues associated with the stability of surfaces of stressed solids. I will show that non-hydrostatic stresses will destabilize flat surfaces of isotropic solids at wavenumbers that depend on the stress, surface tension and elastic modulus. I will then show numerical evidence that these instabilities produce cusp like features that can be thought of in terms of cracks. Next, I will consider the stability of the surface of a growing film and demonstrate that multilayer films can be stabilized against this form of morphological instability.

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Date: November 22
Speaker: Randall Kamien, University of Pennsylvania
Title: Scherk's First Surface, Twist-Grain-Boundaries and All That
Abstract: Large twist-angle grain boundaries in layered structures are often described by Scherk's first surface whereas small twist-angle grain boundaries are usually described in terms of an array of screw dislocations. I will discuss this and other minimal surfaces and will show that there is no essential distinction between minimal surface and topological defect

descriptions and that, in particular, their comparative energetics depends crucially on the core structure of their screw-dislocation topological defects.

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Date: November 29
Speaker: Bjorn Engquist, UCLA
Title: Closing the gap in electromagnetic simulations

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Date: December 6
Speaker: Sandra Troian, Chemical Engineering, Princeton, University
Title: Novel Instabilities in Thin spreading Films: Solved and Unsolved Mysteries
Abstract: Technological advances in process and instrument miniaturization for industrial and medical purposes has spawned interest in the transport behavior of small liquid volumes. The large surface to volume ratio in these systems produces extreme sensitivity to nearby solid or liquid interfaces. For practical purposes, exposure to or interaction with nearby surfaces can substantially affect operational efficiency since larger contact areas produce more drag and a greater susceptibility to surface disturbances.
During the past several years we have studied the dynamic behavior of thin micronic films advancing over a solid or liquid substrate. In this talk, we will describe modeling efforts probing the stability characteristics of two types of Marangoni driven flows, one sheared by thermal gradients and the other by concentration gradients. Our interest lies in understanding the origin of several instabilities which generate either rivulet, dendritic or cellular type moving fronts. The theoretical approaches rely on conventional modal analysis and transient growth analysis of non-normal operators. Using a combination of experimental and theoretical work, we have identified some of the important physical mechanisms leading to transient or absolute instability. The examples we will discuss represent a wide spectrum of flows in the lubrication regime which exhibit some of the most intriguing phenomena in interfacial science.

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Date: December 13
Speaker: Jane Wang, Cornell University
Title: Unsteady Aerodynamics of Insect Flight
Abstract: The myth `bumble-bees can not fly according to conventional aerodynamics' simply reflects our poor understanding of unsteady viscous fluid dynamics. In particular, we lack a theory of vorticity shedding due to dynamic boundaries at the intermediate Reynolds numbers relevant to insect flight, typically between 10^2 and 10^4, where both viscous and inertial effects are important. In our study, we compute unsteady viscous flows, governed by the Navier-Stokes equation, about a two dimensional flapping wing which mimics the motion of an insect wing. I will present two main results: the existence of a prefered frequency in forward flight and its physical origin, and 2) the vortex dynamics and forces in hovering dragonfly flight.

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Date: February 7
Speaker: Jimmy Zhu, Department of Electrical and Computer Engineering, Carnegie Mellon University
Title: Micromagnetic Modeling of Magnetic Thin Films and Its Applications
Abstract: Micromagnetic modeling has become a powerful tool for understanding complicated microscopic dynamic magnetization processes in thin magnetic films. It also has become a very useful tool for aiding device designs over the recent years. In this talk, micromagnetic modeling work on thin magnetic films will be reviewed. Computer simulations on magnetization reversal processes on films patterned into different geometry and comparison with the corresponding experimental observations will be discussed. The talk will also cover applications utilizing micromagnetic modeling to aid the designs of magnetic random access memory (MRAM) and the engineering of material microstructures for thin film

recording media in disk drive applications.

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Date: February 14
Speaker: Martin Nowak, Program in Theoretical Biology, Institute for Advanced Studies
Title: The Evolution of Language
Abstract: Language is a specific human trait. It is an evolutionary innovation that changed radically the performance of one species and as a consequence the appearance of the planet. The last century has seen important advances in our understanding of complex features of human language and the cognitive aspects of the language instinct. There was, however, very little progress toward understanding how Darwinian evolution led to human language. This is the aim of my current research. I will show how natural selection can guide the emergence of simple communication systems. I will characterize an error limit for early language evolution and show how word-formation can overcome this limit. I will calculate the basic reproductive potential of words and the maximum size of a lexicon. I will define the conditions under which natural selection favors syntactic communication.

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Date: February 21
Speaker: Simon Levin, PACM & EEB, Princeton University
Title: The Ecology and Evolution of Communities
Abstract: Ecological communities, just as economic markets, exhibit patterns that emerge from the collective dynamics of individual agents. Implications will be given for the theory of ecological competition, and for the self-organization of ecological systems.

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Date: February 28
Speaker: Philip Holmes, PACM & MAE, Princeton University
Title: Non-Holonomic and Piecewise-Holonomic Mechanical Systems
Abstract: Nonholonomic (velocity dependent) constraints can lead to asymptotically stable motions in certain conservative mechanical systems; the Chaplygin sleigh is a canonical example. In studying models for legged locomotion, piecewise-holonomic constraints (due to intermittent foot placements) are typical. The resulting hybrid dynamical systems include flows along a smooth vectorfield punctuated by impulsive jumps governed by discrete `collision maps.' They may be viewed as generalisations of billiards-type problems. Such systems can also exhibit partial asymptotic stability, even while conserving total energy. I will describe joint work with Michael Coleman (Cornell University) and John Schmitt (Princeton University) on a discrete sister to the Chaplygin sleigh, and on a simple model for rapidly running insects, which illustrate this phenomenon.

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Date: March 6, 8pm, Taplin Auditorium, Fine Hall
Speaker: *Distinguished Lecture Series* Alexandre Chorin, Department of Mathematics, University of California-Berkeley
Title: How to Put guesswork Back into Computing
Abstract: Many problems in science are described by equations whose solutions are too complicated to be solved reliably on any computer; the question is what is the best one can do in such circumstances. One often has some idea about a family of possible outcomes of a computation, and I will explain how such knowledge can be used to find a most likely solution given the limitations on computing power. It turns out that often the most mathematically likely solution looks very unlikely to the naked eye. The reason is related to uncertainty principles that are well understood in physics; I will give examples and show how the paradoxes can be resolved.

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Date: March 20
Speaker: Walter Willinger, AT&T Labs-Research
Title: On Internet-Related Scaling Phenomena, and What They Tell Us About the Internet
Abstract: Compared to the Public Switched Telephone Network, the Internet is a prime example of a truly large-scale complex system. To illustrate how various aspects of the Internet's complexity are directly reflected in the nature of the traffic that it carries, we discuss some of the recently observed scaling phenomena in measured Internet traffic (e.g., self-similarity, multifractal scaling), and comment on the few things that they can tell us and on the many things that they may tell us (in due time) about the Internet.

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Date: March 27
Speaker: Mike Shelley, Courant Institute, New York University
Title: Mechanisms Underlying Realistic Response in a Model of the Visual Cortex
Abstract: What might be the cortical mechanisms underlying neuronal responses in the primary visual cortex V1, such as orientation selectivity, diversity in its degree, and Simple/Complex cell behaviors. I will discuss a minimal, but realistic, neuronal network model of a V1 input layer. In an inhibitorily dominated regime, the network dynamics yields orientation selectivity, dynamics, response diversity, and Simple behaviors, in qualitative agreement with experiment. A mathematical analysis of data, and of reduced "coarse-grained" network models, reveal some of the underlying network mechanisms.

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Date: April 3
Speaker: Athanasios Tzavaras, Department of Mathematics, University of Wisconsin-Madison
Title: A Variational Approximation Scheme for Three Dimensional Elastodynamics with Polyconvex Energy
Abstract: The topic of this talk is the construction of a variational approximation scheme for the equations of three dimensional elastodynamics with polyconvex stored energy. The assumption of polyconvexity is instrumental in the existence theory for the equations of elastostatics, and the purpose is to investigate its role for the equations of elastodynamics. The scheme is motivated by embedding the equations of elastodynamics into a larger system consisting of the equation of motion and some geometric evolutions of the null Lagrangians (the determinant and cofactor matrix). The scheme decreases the mechanical energy, and its solvability is reduced to the solution of a constrained convex minimisation problem. We will survey certain results on stability and convergence of such approximations of the equations of elastodynamics in the 3-d and in the 1-d setting. (joint work with S. Demoulini (Oxford) and D. Stuart (Cambridge)).

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Date: April 10
Speaker: Chao Tang, Physical Sciences Research, NEC Research Institute, Inc.
Title: How Are Protein Structures Selected in Nature?
Abstract: Natural protein sequences and structures are very special classes among all possible sequences and structures. A protein sequence has, as its folded native state, a distinct global minimum of free energy well separated from other misfolded states--a property not shared by random sequences. Protein structures often exhibit a high degree of regularity, with a wealth of secondary structures, preferred motifs, and tertiary symmetries. With the use of simple models of protein folding, we demonstrate that these special properties of proteins are related to high "designability" and evolutionary and thermodynamic stability. The designability of each structure is measured by the number of sequences that can design the structure--that is, sequences that possess the structure as their unique ground state. Structures differ drastically in terms of their designability; highly designable structures emerge with a number of associated sequences much larger than the average. These highly designable structures possess "proteinlike" secondary structures, motifs, and even tertiary symmetries. In addition, they are thermodynamically more stable than other structures. These results suggest that protein structures are

selected in nature because they are readily designed and stable against mutations, and that such a selection simultaneously leads to thermodynamic stability.

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Date: April 17
Speaker: Nicholas Alikakos, Department of Mathematics, University of Tennessee
Title: OSTWALD RIPENING: The effect of the Geometry of the Distribution
Abstract: We consider a two-phase system in 3d . We are interested in the coarsening of the spatial distribution, driven by the reduction of interfacial energy, and limited by diffusion as described by the quasi static Stefan free boundary problem. We address the regime where the one phase covers only a small fraction of the total volume, and consists initially of many disconnected Components (particles). In this situation mass diffuses from the vicinity of the smaller particles towards the larger, a phenomenon known as Ostwald Ripening. In the early 60's Lifshitz, Slyosov, and Wagner separately, formally derived an evolution for the distribution of the particle radii. We present a refinement of their theory, which takes into account the geometry of the spatial distribution and appears to agree qualitatively better with experiments.

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Date: April 24
Speaker: Bud Mishra, Courant Institute, New York University
Title: 0-1 Laws for Single Molecules
Abstract: Single molecule methods (e.g., optical mapping, molecular combing, fluorescent flow cytometry, ion channels, etc.) for genomics and proteomics rely on the statistical properties of a large number of identical molecules. We will use ideas from probabilistic methods to show existence of 0-1 laws governing the behavior of the group of molecules and how we exploit it in devising powerful algorithmic and automation tools to create restriction maps and sequence information from parsimonious and noisy data from single DNA molecules.
The set of tools underlying our "Computational Optical Mapping Project" have been used in making clone maps (BACS and cosmids, Y-DAZ locus), microbial genomic maps (P. falciparum, D. radiodurans, E. coli, etc.), and a partial human genome map.

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Date: September 28
Speaker: Monique Chyba, Harvard University
Title: Motion Planning for Nonholonomic Systems
Abstract: How can a robot decide what motions to perform in order to achieve tasks in the physical world? One of the components for the necessary autonomy of robots in real contexts (space exploration, undersea work, ...) is motion planning. Most types of mobile robot deal with nonholonomic constraints (any path in the configuration space does not necessarily correspond to a feasible path for the system). Optimal length paths have been at the origin of the very first nonholonomic motion planners for car-like mobile robots. This leads us to the second part of the talk in a natural way where we consider the framework yielded by the sub-Riemannian geometry (also called sometimes nonholonomic geometry). It has been a fully fledged research domain for fifteen years, with motivations and ramifications in several parts of pure and applied mathematics. We will see that the sub-Riemannian sphere (the set of reached points by optimal trajectories when the cost if fixed) has bad properties of regularity.

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Date: October 5
Speaker: Naomi Leonard, Mechanical & Aerospace Engineering, Princeton University

Title: Controlled Lagrangians and the Stabilization of Mechanical Systems
Abstract: Control theory for mechanical systems has much to g ain from recent advances in geometric mechanics and dynamical systems theory which have introduced tools for understanding and exploiting the structure in mechanical systems. In this talk I will describe joint work with J.E. Marsden and A.M. Bloch on a constructive approach to the derivation of stabilizing control laws for Lagrangian mechanical systems with symmetry. This "method of controlled Lagrangians" involves making structured modifications to the Lagrangian for the uncontrolled system thereby constructing a new Lagrangian which describes the closed-loop system. That is, we construct control laws that yield closed-loop dynamics which remain in Lagrangian form. Accordingly, energy methods can be used to find control gains that provide closed-loop stability, and stabilization can be understood in terms of energy shaping. Our approach, which can be viewed as a kinetic shaping, will be demonstrated for stabilizing balance systems (e.g., an inverted planar or spherical pendulum on a cart) as well as systems with gyroscopic forces such as spacecraft and underwater vehicles with internal rotors.

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Date: October 12
Speaker: Edward Belbruno, PACM and Innovative Orbital Design, Inc.
Title: Unstable Lunar and Planetary Captures with Applications to Positioning Earth Orbiting Satellites and Motion of Edgeworth-Kuiper Belt Objects
Abstract: A new type of transfer from the earth to the moon was discovered in 1987 which had the important property that capture at the moon, although chaotic in nature, occurred 'ballistically' - that is, required no additional energy such as rocket engines. A useful variation of this was discovered in 1990 which was used to salvage a failed Japanese lunar mission. It was successfully used the following year to enable the Japanese spacecraft to reach the moon. In 1993 it was placed on the lunar surface. This provided a proof that this type of transfer worked, being doubted from 87 to 91. It is being used again in 1999 also by Japan. The principles behind ballistic capture and this transfer have many other applications to astronomy, aerospace and provide many open problems to study in theoretical mathematics. One application can be made to the commercially important notion of repositioning earth orbiting satellites using these lunar transfers. The speaker has, in fact, formed a company behind this and several other things. There was a recent demonstration of this idea by Hughes in May of this year on one of their satellites using our suggestion. Another application discussed is on understanding resonant motion with Neptune in the Edgeworth-Kuiper belt, based, in part, on some recent joint work with Brian Marsden.

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Date: October 19
Speaker: Robert Jerrard, University of Illinois at Urbana-Champaign
Title: Vortex Dynamics for Conservative Ginzburg-Landau Systems
Abstract: We present a rigorous analysis of the behavior of quantized vortices in solutions of the Gross-Pitaevsky equation, which is used as a model for certain kinds of superfluid Helium. We prove that, when the equation is considered in two space dimensions with appropriate initial data, the vortices behave in the incompressible limit exactly like classical fluid dynamical point vortices. We will also discuss similar results for a related nonlinear wave equation.

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Date: October 26
Speaker: Wojbor A. Woyczynski, Case Western Reserve University
Title: Interacting Particle Approximation for Nonlocal Nonlinear Evolution Problems
Abstract: I will discuss an interacting particle system approximation (known as the "propagation of chaos problem") for a class of integrodifferential equations of evolution type with the fractal anomalous diffusion and nonlocal nonlinear term. The work is motivation by the problems of modeling growing semiconductor interfaces.

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Date: November 9

Speaker: Stanislav Boldyrev, Plasma Physics Laboratory, Princeton University
Title: Burgers Turbulence in d Dimensions
Abstract: The randomly driven Navier-Stokes equation without pres sure in d-dimensional space is considered as a model of strong turbulence in a compressible fluid. Under the very general physical assumption of Galilean and scaling invariance, and a particular form of the operator product expansion for the dissipative term, a closed equation is derived for the velocity-gradient probability density function (PDF). The asymptotics of this function are found for the case of the gradient velocity field (Burgers turbulence), and numerical solutions are provided for one-, two-, and three-dimensional cases. Comparison with direct numerical simulations for the one-dimensional case is presented. In the one-dimensional case, the velocity-difference PDFs are also discussed. It is shown that the phenomenon of intermittency is related to the algebraic decay of the obtained PDFs.

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Date: November 16
Speaker: Isaac Held, Atmospheric & Oceanic Sciences, Princeton University
Title: Some Problems in Geostrophic Turbulence
Abstract: A common difficulty in the study of turbulent transport is the absence of any separation between the scale of the energy containing eddies and the scale of the inhomogeneity of the turbulence. (Think of heat transport in Benard convection or momentum mixing across the turbulent flow through a pipe.) As a result intuitive concepts such as mixing lengths and turbulent diffusion have limited utility, and it is difficult to relate studies of homogeneous turbulence to questions about turbulent fluxes.
A distinctive kind of turbulence occurs in the atmosphere and the oceans, on scales large enough that the vorticity is a small departure from the vorticity of solid body rotation (flows with small Rossby number). In the atmosphere, the energy-containing eddies of this "geostrophic turbulence" are the cyclones and anticyclones familiar from weather maps, with a typical horizontal scale of 1000 km. The heat transported by these eddies determines the north-south temperature gradient on our Earth. In the oceans, the geostrophic eddy scale is smaller (10 - 100 km), so these eddies are much more difficult to account for by direct numerical simulation, and their role in global ocean circulation is a key unsolved problem. In this seminar I describe an idealized model of geostrophic turbulence designed to shed light on the parameters that control poleward heat transport in the atmosphere. In this model, there IS a natural scale separation between the eddies and the external forcing. Therefore, one can design a homogeneous framework in which to measure the "turbulent diffusivity" of the medium. Numerical results show how well this diffusivity accounts for the fluxes in a simple inhomogeneous problem of interest. Most of the seminar will then be devoted to a scaling argument for the diffusivity. This theory depends on an elaboration of the picture of energy and enstrophy cascades in two-dimensional turbulence. It suggests that the poleward heat flux in the atmosphere is proportional to the fourth power of the north-south temperature gradient.

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Date: November 23
Speaker: Eric M. Rains, AT&T Labs--Research
Title: An introduction to quantum coding theory
Abstract: One of the major difficulties in building useful quantum computers (computers which use the laws of quantum mechanics to perform computations faster than we know how to do classically) is that such computers are inherently analog, and thus much more susceptible to noise than classical computers. Indeed, until Peter Shor's discovery in early 1994 of the first quantum code, it was commonly believed that this problem of noise was intractable. I'll explain why quantum codes can't exist (:-)), give some examples, and then explain the framework (additive codes over GF(4)) in which nearly all known quantum codes can be constructed. Time permitting, I will touch briefly on some other topics (nonadditive codes, upper bounds, open problems).

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Date: November 30
Speaker: Gigi Martinelli, Mechanical & Aerospace Engineering, Princeton University

Title: Coupling Computational Fluid Dynamics and Numerical Optimization Methods for Aircraft Design
Abstract: The definition of the aerodynamic shapes of modern aircraft relies heavily on computational simulation to enable the rapid evaluation of many alternative designs. Wind tunnel testing is then used to confirm the performance of designs that have been identified by simulation as promising to meet the performance goals. The use of computational simulation to scan many alternative designs has proved extremely valuable in practice, but it still suffers the limitation that it does not guarantee the identification of the best possible design. To ensure the realization of the true best design, the ultimate goal of computational simulation methods should not just be the analysis of prescribed shapes, but the automatic determination of the true optimum shape for the given measure of performance. This is the underlying motivation for the combination of computational fluid dynamics with numerical optimization methods.
Following the lead of Jameson, we selected to approach the problem using the framework of the mathematical theory for the control of systems governed by partial differential equations. In this view the wing is regarded as a device to produce lift by controlling the flow, and its design is regarded as a problem in the optimal control of the flow equations by changing the shape of the boundary. In the past three years I contributed to the development and implementation of this approach for designs in three-dimensional viscous flow. I will present an overview of this approach using the compressible Reynolds Averaged Equations as the mathematical model of the flow, give a detailed account of the numerical building blocks which make our approach computationally feasible, and discuss some illustrative designs.

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Date: December 7
Speaker: Michael Tabor, University of Arizona
Title: The Dynamics of Twist and Writhe in Bacterial Filaments and Tendril Perversion in Climbing Plants
Abstract: A number of filamentary structures in biology can be modeled as thin elastic rods with the Kirchhoff equations providing an effective but challenging mathematical model. A combination of linear and nonlinear stability analyses is used to explain how the twist in a rod is converted to writhe (spatial deformation). These results are helpful in explaining the self-assembly dynamics of the bacterial filaments of Bacillus subtilis, and the helix hand reversal (perversion) exhibited by the tendrils of climbing plants.

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Date: December 14
Speaker: Paul Kolodner, Bell Laboratories, Lucent Technologies, Inc.
Title: Controlling Dispersive Chaos
Abstract: Amid the recent enthusiasm for applying new techniques of nonlinear dynamics to the control of chaos, it has been recognized that control of spatially-extended systems which exhibit erratic behavior is an important and unsolved problem. In this talk, I will describe a convection experiment in which this goal has been achieved. "Dispersive chaos" is a state observed in experiments on oscillatory convection in binary fluids in a narrow, quasi-one-dimensional, annular geometry. This state which is characterized by the erratic appearance and abrupt decay of spatially-localized bursts of traveling waves. In numerical simulations of this system based on the complex Ginzburg-Landau equation, my collaborators and I have been able to suppress dispersive chaos by applying a spatially-inhomogeneous stress parameter which is computed from the phase of the complex state variable. We have also implemented such spatial feedback in an actual convection experiment by adjusting the voltages applied to 24 small heaters arranged along the circumference of the lower plate of the convection cell. The applied stress-parameter profile is computed from the complex amplitude of the convection pattern as derived from shadowgraph images. With the right feedback algorithm, we can suppress chaos near onset and make measurements of the unstable branch of the bifurcation diagram.

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Date: February 1
Speaker: Michael Vogelius, Rutgers University
Title: A Study of the Behavior of the Stresses in Reinforced Composites with Closely Spaced Fibers

Abstract: In spite of the deliberately very "engineering" title of this talk, the main contents are some new $W^{1,\infty}$ and $C^{1,\alpha}$ estimates that we have obtained for the solutions to divergence form second order elliptic equations (cf. [1] and [2]).
The novelty is that our class of coefficients contains very unsmooth elements, modelling for instance composite materials with arbitrarily close material interfaces, but that the particular gradient estimates are valid independently of the distance between these interfaces. The estimates do depend on the ellipticity bounds and a certain measure of the curvature of the interfaces. For this (quite natural) class of coefficients one may, in a certain sense, consider our estimates extensions of the classical $C^{0,\alpha}$ estimates of DeGiorgi and Nash. 1. Eric Bonnetier and Michael Vogelius, An elliptic regularity result for a composite medium with "touching" fibers of circular cross- section. To appear SIAM J. Math. Anal., 2. YanYan Li and Michael Vogelius, Gradient estimates for solutions to divergence form elliptic equations with discontinuous coefficients. Preprint, Rutgers University, October 1998, pp. 1--57.

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Date: February 8
Speaker: Stéphane Mallat, Ecole Polytechnique and Courant Institute
Title: Signal Representations Through Deformations
Abstract: Harmonic analysis and wavelet techniques interpret signals as elements of functional spaces, leaving aside geometrical properties. The refinement of current approaches has lead to unstable decomposition algorithms in large dictionaries. We claim that improving significantly these techniques requires taking into account the geometry, which can be done with deformation models using PDE. This talk covers applications to data compression, optical flow measurement and surface recovery from texture gradient.

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Date: February 15
Speaker: Michael P. Brenner, Massachusetts Institute of Technology
Title: How Drops Break and Other Singularities
Abstract: This talk will give an overview of some physical phenomena whose essence involves singularity formation in a nonlinear partial differential equation. We will describe in detail two different problems where understanding the structure of a singularity provides insight into the underlying physical process. The first problem is droplet breakup: Based on a combination of numerics, asymptotics and experiments we will argue that viscous drops develop long necks when they break, which then spawn a series of smaller necks with ever thinner diameters. The second problem involves singularities occurring during the clumping of material interacting by long ranged, Laplacian interactions, motivated by experiments involving e. Coli (E. O. Budrene and H. C. Berg, Nature, 376:49 (1995)). The dynamics raises general questions about what happens when a system has several singular solutions in different spatial dimensions competing with each other.

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Date: February 22
Speaker: Fabrice Planchon, CNRS and Universiti Paris VI
Title: Self-Similar Solutions and the Cauchy Problem for a Non-Linear Schrödinger Equation
Abstract: Self-similar solutions (solutions which are invariant under a proper rescaling) are of interest for many evolution equations, as examples of singular solutions or as possible candidates for describing the asymptotics (for large time or for blow-up). Recently such solutions were constructed for the Schrödinger equation $\partial_t u+\Delta u = \pm |u|^{u-1} u$ by T. Cazenave and F. Weissler, using very simple techniques, but for which the set of admissible initial data is not well understood. We intend to provide a different approach by solving the usual Cauchy problem in a Besov space bigger than the Sobolev space where the problem is well-posed, which contains homogeneous data, thus allowing self-similar solutions in that Besov space. This provides a better understanding of such solutions, as well as extending the known results for Sobolev spaces.

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Date: March 8
Speaker: Georgiy Medvedev, Boston University
Title: A Reaction-Diffusion System with Periodic Front Dynamics
Abstract: A model motivated by Proteus mirabilis bacterial colony development is presented and analyzed in this work. Mathematically, we study a system of a degenerate parabolic partial differential equation and an ordinary differential equation. The most interesting feature of the model is that it generates interface dynamics that are periodic in time, just as seen in the biological experiments. We analyze the dynamics of different phases of colony evolution, as well as switches and transition between them, using the method of matched asymptotic expansions and parabolic equation techniques. Finally, we present rigorous estimates for the inner and outer solutions developed in the matched asymptotic analysis, and for their domains of validity.

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Date: March 29
Speaker: Nathan Kutz, University of Washington
Title: The Optical Parametric oscillator: Dynamics, Bifurications, and Stablization
Abstract: We consider the dynamics associated with topological solitons (localized structures) of the optical parametric oscillator which models the parametric exchange of energy between optical fields at a fundamental and second harmonic frequency. Simulations show that this nonlinear interaction can support stable front structures as well as localized, bistable solitary wave solutions. We perform a systematic study of the birufcation structure and stability analysis of both solitary wave and front solutions which arise. The stability analysis is carried out for the onset of instability which arises from a Ginzburg-Landau description as well as a modified Swift-Hohenberg description at resonance. The analysis, which is carried out in 1-D, can be utilized in predicting the dynamical behavior in 2-D systems. Further, the theoretical conclusions provide important practical predictions which are verified via extensive numerical simulations.

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Date: April 5
Speaker: Susan Friedlander, University of Illinois, Chicago and Institute for Advanced Study
Title: A World of Fluid Instabilities
Abstract: The issue of stability/instability of fluid flows presents an important example of a physical problem which may be addressed through sophisticated mathematical techniques. The answers have direct physical interpretations: stable flows are robust under inevitable disturbances in the environment while unstable flows may break up rapidly. The question of stability/instability of a fluid flow is a classical one, however there remain many open problems that are mathematically challenging. In this talk we will introduce the concept of a "fluid Lyapunov exponent" and describe an effective sufficient condition for detecting instabilities in an inviscid fluid. We use this tool to show that in some sense "most" steady flows of ideal fluid are unstable. We illustrate the instability with particular examples including smoke rings and so called "chaotic flows".

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Date: April 12
Speaker: Denis Zorin, Courant Institute, New York University
Title: Universal Mappings for Subdivision Surfaces
Abstract: Subdivision is an algorithmic technique to generate smooth surfaces as a sequence of successively refined arbitrary polyhedral meshes. Special choices of subdivision rules allow to introduce features into a surface in a simple way. I will present a general framework for analysis of smoothness of subdivision surfaces based on the concept of the universal surface. Any surface generated by subdivision locally can be viewed as a projection of a higher-dimensional surface, uniquely defined by the scheme. In this way, the analysis of smoothness properties of all surfaces produced by a subdivision

algorithm, can be reduced to the analysis of a discrete collection of higher dimensional surfaces. In this framework, all previously known results can be generalized and given a natural geometric interpretation. This approach also highlights the connection between higher-order subdivision surfaces and quasihomogeneous polynomials often used in singularity theory. I will consider applications to the construction and analysis of subdivision rules for surfaces with piecewise-smooth boundaries. A remarkable fact is that the "obvious rules" for the boundary do not always work correctly, and less intuitive modified rules should be used.
Finally, I will discuss the Sobolev class estimates for the functions generated by subdivision that were derived using our framework.

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Date: April 19
Speaker: Sal Torquato, Civil Engineering & Operations Research and Princeton Materials Institute
Title: Exact Expression for the Effective Elastic Tensor of Disordered Composites
Abstract: The problem of determining exact expressions for the effective elastic tensor of macroscopically anisotropic, two-phase composite media of arbitrary microstructure in arbitrary space dimension d is considered. We depart from previous treatments by introducing an integral equation for the "cavity" strain field. This leads to new, exact series expansions for the effective elastic tensor. The nthorder tensor coefficients of these expansions are explicitly expressed as absolutely convergent integrals over products of certain tensor fields and a determinant involving n-point correlation functions that characterize the random microstructure. These series expressions perturb about the optimal structures that realize certain rigorous bounds (e.g., coated-inclusion assemblages or finite-rank laminates). Accurate approximate relations for the effective elastic moduli of isotropic dispersions are obtained by truncating, after third-order terms, the exact series expansions. Our third-order approximations are in very good agreement with benchmark simulation data, always lie within rigorous bounds, and are superior to popular self-consistent approximations.

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Date: April 26
Speaker: Bin Yu, Bell Laboratories, Murray Hill and University of California at Berkeley
Title: Codes and Models
Abstract: In this talk, we explore the intricate connections between codes (representations of messages in a communication system) and models (mathematical postulations about data). We draw parallels between theories of information and algorithmic complexity on the one side and concepts and approaches to building statistical models on the other. In particular statistical models give rise to effective codes -- as in current wavelet image coding schemes; while codes provide insight into models -- through the Principle of Minimum Description Length (MDL) for model selection.

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Date: May 3
Speaker: Rubin Rosales, Massachusetts Institute of Technology
Title: Large Amplitude Nonlinear Acoustic Waves without Shocks
Abstract: A new class of solutions for the inviscid Euler equations of Gas Dynamics in a bounded domain is studied. These solutions do not present the usual wave breaking leading to shock formation, even though they have highly nontrivial acoustic components and operate in the nonlinear regime. Furthermore, these "Non Breaking for All Times" (NBAT) solutions are globally attracting for the long time evolution of the equations and are quasiperiodic in time, with two periods. NBAT solutions are possible due to the cumulative effect of nonlinear resonances between the genuinely nonlinear sound waves and a third "passive" wave such as, for example, entropy variations. This is possible only in a bounded domain where the waves interact with each other repeatedly and creates an effective dispersion on the acoustic field --- which is responsible for stopping the shocks from forming. Extremely large amplitudes are possible even with rather small amplitudes in the passive wave.

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