Schedule

THURSDAY, JANUARY 3

1200-1300	Registration
1300-1310	Welcome
1310-1350	Arkady Pikovsky
1350-1410	Jeff Rogers
1410-1430	Qingfei Chen
1430-1510	Andrzej Banaszuk
1510-1540	Break
1540-1620	Katharina Vollmayr-Lee
1620-1640	Shawn Pethel
1640-1720	Kay Robbins
1720-1800	Adilson Motter

FRIDAY, JANUARY 4

0730-0830	Breakfast & registration
0830-0910	Suzanne Lenhart
0910-0930	James Springham
0930-0950	Bradley Marts
0950-1030	Bard Ermentrout
1030-1100	Break
1100-1140	Tamás Tél
1140-1200	Claudio Tebaldi
1200-1215	Way Kuo & Johney Green
1220-1350	Lunch
1350-1430	Jay Fineberg
1430-1450	Simon Gravel
1450-1530	Bob Behringer
1530-1600	Break
1600-1620	Dean Edwards
1620-1640	Marko Budisic
1640-1720	John Pojman
1730-1930	Posters and reception

SATURDAY, JANUARY 5

0730-0830	Breakfast & registration
0830-0910	Peter Jung
0910-0930	Mark Nelson
0930-0950	Masahiro Toiya
0950-1030	Michael Todd
1030-1100	Break
1100-1120	Oleg Kogan
1120-1200	Gene Tracy
1200-1220	Viktor Nagy
1220-1350	Lunch
1350-1430	James Crutchfield
1430-1450	Dawn Wendell
1450-1530	Kerwyn Huang
1530-1600	Break
1600-1640	Sadruddin Benkadda
1640-1700	Tiffany Vora
1700-1740	Leonid Bunimovich
2000-2200	Posters and refreshments

SUNDAY, JANUARY 6

0730-0830	Breakfast & registration
0830-0910	Bill Ditto
0910-0930	Gregg Lois
0930-1010	Yi Guo
1010-1030	Break
1030-1110	Maria D’Orsogna
1110-1130	Vadas Gintautas
1130-1150	Xiaopeng Zhao
1150-1230	Roman Grigoriev
1230-1235	Closing

THURSDAY, JANUARY 3

1310-1350 Arkady PIKOVSKY

Synchronization of coupled oscillators: from Huygens clocks to chaotic systems and large ensembles

Arkady Pikovsky
University of Potsdam, Germany

I introduce basic features of the synchronization phenomenon, starting with classical examples and an elementary theory for coupled periodic oscillators. Then an extension to chaotic systems is discussed. In large ensembles the synchronization appears as a nonequilibrium phase transition. Together with classical results of Kuramoto I discuss specific features appearing due to nonlinear coupling.

1350-1410 Jeff ROGERS

A dynamical view of coherent laser arrays

Jeffrey Rogers[1,2], William Ray[3,1] and Kurt Wiesenfeld[3]
[1]HRL Laboratories LLC, Malibu, California USA
[2]California Institute of Technology, Pasadena, California USA
[3]Georgia Institute of Technology, Atlanta, Georgia USA

A flurry of recent experiments examining passively coupled fiber laser arrays have reported stable synchronized behavior without any requirements for active control. If these findings can be extended to larger arrays and higher powers there are opportunities for new technologies. Initial laboratory attempts at scaling up based on traditional eigenmode analysis have failed. Nonlinear sciences offer alternative approaches. As a first step in this direction we report quantitative comparisons between several of these recent experiments and a relatively simple model of coupled nonlinear iterative maps. We find the dynamical model is an attractive alternative to the traditional static eigenmode analysis of coupled laser cavities. In addition to performing equally as well as predicting the experimentally observed behavior near lasing threshold the dynamical model extends correct predictions well into the lasing domain where the light output may assume a variety of dynamical states including sustained pulsing.

1410-1430 Qingfei CHEN

Intrinsic localized modes in microelectromechanical oscillator arrays: a dynamical approach

Qingfei Chen[1], Liang Huang[1] and Ying-Cheng Lai[1,2]
[1]Department of Electrical Engineering, Arizona State University, Tempe, Arizona USA
[2]Department of Physics and Astronomy, Arizona State University, Tempe, Arizona USA

A nonlinear-dynamics based approach is developed to understand the origin of intrinsic localized modes (ILMs) in microelectromechanical oscillator arrays. Equilibrium solutions in the zero-coupling limit, their stabilities, and analytic continuation into the finite-coupling regime provide the necessary conditions for ILMs. A striking finding is that spatiotemporal chaos is ubiquitous and more importantly, it provides a natural platform for actual realization of various ILMs through frequency control. The finding is expected to be experimentally verifiable and it also suggests that ILMs can occur in a more general setting than previously thought.

1430-1510 Andrzej BANASZUK

The role of control in design: from fixing problems to the design of dynamics

Andrzej Banaszuk
United Technologies Research Center, East Hartford, Connecticut USA

We will summarize lessons learned in industrial research on mitigation of flow and structure oscillations in jet engines. We will show how the decisions on the control system architecture impact the achievable level of suppression of oscillations. Attempts to introduce control late in the design process and without proper attention to control architecture often fail because of high cost to modify the design to add on active control. We will also show how certain aspects of design (symmetry) contribute to the origin of detrimental oscillations and point out how the dynamical systems and control theory methods can guide the design to prevent the oscillations. The control and dynamics methods used early in design allow one to manipulate the physical feedback loops in the system to create beneficial dynamics and exploit design flexibility at low cost.

1510-1540 Break

1540-1620 Katharina VOLLMAYR-LEE

Self-organized criticality in a glass

Katharina Vollmayr-Lee
Department of Physics and Astronomy, Bucknell University, Lewisburg, Pennsylvania USA

We study a glass out of equilibrium via molecular dynamics simulations of a model glass-former. To investigate the dynamics of the system we define single particle jumps via their single particle trajectories. We present as a function of temperature the number of jumps, jumps size and waiting time between jumps. To study how the single particle jumps are correlated in time and space we identify clusters of cooperatively jumping particles [1]. We find string-like clusters whose size is power-law distributed not only close to T_c but for *all* temperatures below T_c, indicating self-organized criticality which is suggestive of a freezing in of critical behavior.

[1] K. Vollmayr-Lee and E. A. Baker, Europhys. Lett. **76**, 1130 (2006).

1620-1640 Shawn PETHEL

Deconstructing spatiotemporal chaos using local symbolic dynamics

Shawn D. Pethel[1], Ned J. Corron[1] and Erik Bollt[2]
[1]U.S. Army, Redstone Arsenal, Alabama USA
[2]Clarkson University, Potsdam, New York USA

We approximate the global symbolic dynamics of a diffusively coupled map lattice (CML) with a local model consisting of a relatively small number of symbols. Coupled map lattices are popular models of spatiotemporal chaos and their description via symbolic dynamics provides a complete basis for understanding them. Indeed, the topology of unimodal maps has been completely elucidated in terms of 2-symbol alphabets, and recently it has been conjectured that these results extend simply to the CML case. Nevertheless, one still has to contend with the high dimensionality of lattices. While a single logistic map is fully described by 2 symbols, an N-element lattice requires an alphabet of 2^N symbols. In the case of diffusive coupling, however, we find that the symbolic dynamics at a particular site is largely determined by a local neighborhood, at least for some range of coupling strengths. Here we propose using symbolic information from a small neighborhood to reconstruct the dynamics of the entire lattice. We use interval analysis to quantify this idea and show that the global symbolic dynamics can be well approximated by a compact local model for weak to moderate coupling strengths. Examples are presented of extracting a local symbolic model from data and of controlling spatiotemporal chaos. In the final example we extend these results to a high-dimensional system of ODEs.

1640-1720 Kay ROBBINS

Visual approaches to understanding dynamics and structure in high-dimensional data sets

Kay A. Robbins
Department of Computer Science, University of Texas at San Antonio, San Antonio, Texas USA

Visual approaches such as Poincare maps and bifurcation diagrams have been used since the very early days by the dynamical systems community to summarize and delineate the behavior of complex systems. Such techniques help researchers understand and compare experimental data sets even when underlying equations or system models are not known.

Technological advances such as high-throughput measurement devices have revolutionized many areas of science, particularly the biological sciences, by allowing scientists to assess system properties at finer resolutions over more global scales. The resulting avalanche of complex data is both a blessing and a curse. Fundamental questions of what the dynamics of a data set are, how the dynamics of two data sets compare and how these dynamics depend on underlying parameters must now be addressed on a larger scale. Fortunately, simple visual approaches are still possible and can assist users in understanding and organizing high-dimensional dynamic data in a meaningful way.

This talk presents an overview of visual techniques that are applicable for understanding dynamics and structure of high-dimensional data. We particularly focus on techniques that reduce dimensionality by projections or other transformations and then use sorting, cross plotting or geometric mapping to reveal structure such as bifurcations, symmetry breaking, and variable interactions. We illustrate these techniques with a variety of applications including the evolution of cortex waves, the extinction of premixed flames and the normalization structure of microarray data for gene expression.

1720-1800 Adilson MOTTER

Controlling complex systems

Adilson E. Motter
Department of Physics and Astronomy, Northwestern University, Evanston, Illinois USA

In this talk, I will discuss how the interplay between network structure and dynamics can be used to manipulate the behavior of complex systems. In particular, using cellular metabolism as a model system, I will present a framework for predicting environmental changes and gene mutations capable of enhancing or suppressing the production of specific metabolic compounds. This framework has potential applications for recovering lost cellular function and for transforming materials of industrial interest. From the perspective of this framework, I will also discuss a relation between metabolism and the seemly unrelated problems of cascade control and synchronization phenomena.

FRIDAY, JANUARY 4

0830-0910 Suzanne LENHART

Optimal control of discrete time models

Suzanne Lenhart
University of Tennessee, Knoxville, Tennessee USA
Oak Ridge National Laboratory, Oak Ridge, Tennessee USA

This talk will present optimal control of two examples which are discrete in time. The first example involves difference equations that model cardiopulmonary resuscitation. The goal is to design an external chest amd abdomen pressure pattern to improve the blood flow in the heart in standard CPR procedure. The second example is an epidemic model for rabies in raccoons on a spatial grid. The goal is to find the optimal distribution pattern for vaccine baits to slow the spread of the disease.

0910-0930 James SPRINGHAM

The linked-twist map approach to modeling fluid flows having strong mixing properties on domains of full measure

James Springham and Stephen Wiggins
University of Bristol, Bristol, UK

We present some new results concerning the ergodic properties of a class of maps known as *linked-twist maps* and discuss how these results might inform the design of certain fluid mixing devices. There are two broad reasons why linked-twist maps are important. From the mathematical point-of-view, linked-twist maps provide one of the few known examples of explicitly defined dynamical systems for which it is possible to rigorously prove strong mixing (the Bernoulli property, in fact) on a set of full Lebesgue measure. From an applied perspective, it has been noted in recent years by a number of authors that they are physically realistic as models of certain fluid flows, and in particular of certain mixing devices where the crossing of streamlines is a central ambition.

In this talk we will describe a number of linked-twist maps along with a framework which, in spirit, is due to Ya. B. Pesin, for studying their ergodic properties. We will describe successes which predate our work and some applications of these results which are to be found in emerging technologies, such as DNA microarrays. However, we will go on to see that there are many areas of applications (in particular, we single out microfluidic mixing devices) which are naturally modeled by certain other linked-twist maps for which strong mixing results have *not* been rigorously established. In particular, numerical simulations suggest that seemingly quite similar systems have quite radically different mixing properties. We would like to understand this behaviour and discuss our progress to this end. The difference between those systems for which strong ergodic properties have already been established, and the other systems we would like to study, is the existence of a suitable global coordinate system.

We conclude by introducing an original and novel approach to these problems. It will transpire that the systems we wish to study are semi-conjugate to certain other systems, also linked-twist maps. At first sight it may appear that we are complicating the problem further but, crucially, for the new systems we introduce there *is* a suitable global coordinate system; as a consequence they are amenable to the approach that we have previously described. Furthermore a result of D. S. Ornstein says that the strong mixing properties in which we are interested are preserved under this semi-conjugacy. We describe some results that this method has already yielded and those on which we are presently focusing.

0930-0950 Bradley MARTS

Twisted scroll rings in three-dimensional excitable media

Bradley Marts, Tamas Bansagi Jr., and Oliver Steinbock
Department of Chemistry, Florida State University, Tallahassee, Florida USA

In three-dimensional excitable systems, scroll waves rotate around one dimensional curves, called filaments. The dynamics of a scroll wave can be described by the filament dynamics, which have been studied numerically in biological contexts such as cardiac systems. We study filament and wave dynamics experimentally in the 1,4-cyclohexanedione Belousov-Zhabotinsky chemical reaction. A circular scroll ring with a twisted phase is generated and the evolution of the twist is measured. The development of asymmetries in the twist are qualitatively described by a modified Burgers' equation.

0950-1030 Bard ERMENTROUT

A coupla ducks: synchrony and clustering in oscillators near canards

Bard Ermentrout
University of Pittsburgh, Pittsburgh, Pennsylvania USA

1030-1100 Break

1100-1140 Tamás TÉL

Leaking dynamical systems; a fresh view on Poincaré recurrences

Tamás Tél
Eötvös Lórand University, Budapest, Hungary

One can gain useful information on the dynamics of closed chaotic systems by considering their leaked versions. To this end, one defines a subset of the phase space, the leak, through which escape of particles is possible. The dynamics is thus converted into a transiently chaotic one, and never escaping points form a fractal chaotic saddle which governs the escape dynamics. The escape properties are shown to depend sensitively on the location and form of leaks of finite size. This way one can obtain information about the closed system, and the method will be applied to simple models and to hydrodynamical flows. This leaking method can also be applied to better understand Poincaré recurrences, a standard tool to investigate closed systems. We show that the exponential decay rate is exactly the same as the escape rate of the leaked system when choosing the recurrence region to be the leak. Moreover, with a special initial ensemble for the leaked system, the escape and recurrence problems are shown to be fully equivalent. Poincaré recurrences can thus be described in terms of the ergodic theory of transient chaos, in particular, in terms of the conditionally invariant measure. The results remain valid for Hamiltonian systems with mixed phase space, and validate a split of the chaotic saddle in hyperbolic and non-hyperbolic components.

[1] J. Schneider, T. Tel, Z. Neufeld, Phys. Rev. E 6, 066218 (2002)

[2] J. Schneider, J. Schmalzl, T. Tel, Chaos 17, 033115 (2007)
[3] E.G. Altmann, T. Tel, Poincare recurrences from the perspective of transient chaos, preprint (2007), arXiv:0712.0532v1 [nlin.CD]

1140-1200 Claudio TEBALDI

Reduction properties and synchronization in logistic networks with adaptive competition

C. Tebaldi
Department of Mathematics, Politecnico di Torino, Torino, Italy

A general N-node network is considered for which, in absence of interactions, each node is governed by a logistic equation. Interactions among the nodes take place in the form of competition, which also includes adaptive abilities through a (short term) memory effect. As a consequence the dynamics of the network is governed by a system of N^2 nonlinear ordinary differential equations. The existence of classes of invariant subspaces, related to symmetries, allows the introduction of reduced models, where N appears as a parameter, which give full account of existence and stability for the equilibria in the network. Reduced models are found effective also in describing time-dependent regimes, both in the form of periodic oscillations and chaotic behavior and with remarkable properties of synchronization.

1200-1215 Institutional Greetings

Way Kuo
College of Engineering, University of Tennessee, Knoxville
Johney Green, Jr.
Fuels, Engines and Emissions Research Center, Oak Ridge National Laboratory

1215-1350 Lunch

1350-1430 Jay FINEBERG

A review of fast fracture: Where are we now and where are we going?

Jay Fineberg
The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

The physics of crack propagation are critically linked to our fundamental understanding of material strength and stability. Fracture is a process in which a putatively singular stress field, formed at the tip of a crack, preferentially breaks the bonds ahead of the crack's tip. Once the fracture process begins, cracks in brittle materials will rapidly accelerate to velocities on the order of material sound speeds. Thus the fracture process is characterized by a singular stress field that is propagating at nearly the speed of information within a given material. We present a brief review of the field, highlighting both the central open questions and a number of new experimental and theoretical approaches to their solution.

1440-1450 Simon GRAVEL

Think locally, act globally: how to search with iterated maps

Simon Gravel and Veit Elser
Department of Physics, Cornell University, Ithaca, New York USA

We present a family of iterated maps that can be used to find solutions to a wide variety of hard computational problems including protein folding, boolean satisfaction, and packing problems. The solutions are encoded as fixed points of the maps, and the dynamics of the system can be interpreted as a chaotic search for these fixed points. We explain how to derive these dynamical systems for a selection of problems and compare the results obtained with the state-of-the-art.

1450-1530 Bob BEHRINGER

Dynamics of dense granular media

Bob Behringer
Department of Physics, Duke University, Durham, North Carolina USA

Granular materials present a host of interesting scientific challenges. They can exist in gas-like states, flow like a liquid, or support stresses in a solid-like state. Granular systems consist of large collections of particles, and therefore fall within the rubric of many-body statistical systems. But, the usual tools of statistical physics must be modified or even replaced in order to account for the fact that granular interactions are dissipative. This talk will focus on dynamcal processes in dense granular states with an eye towards understanding what new statistical principles apply to granular solids and fluids. I will discuss a series of experiments that have probed the jamming transition, where granular fluids become solid or vice versa. This transition may take place under isotropic compression/dilation, or under shear, and the associated states are qualitatively different in terms of their statistical properties. An important aspect of our approach has been the novel use of photoelastic particles, which has, for the first time, allowed experimenters to determine contact forces and all other relevant microscopic properties in physical experiments. A related series of experiments focuses on the nature of granular friction and stick-slip behavior. In particular, we show that this process is inherently stochastic, and that it can be modelled as a failure process, associated with structures known as force chains, within an elastic medium.

1530-1600 Break

1600-1620 Dean EDWARDS

Modeling dynamical instability of homogeneous charge compression ignition in combustion engines

K.D. Edwards, R.M. Wagner, J.B. Green Jr., V.K. Chakravarthy, C.S. Daw and C.E.A. Finney
Fuels, Engines and Emissions Research Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee USA

We propose a simple model for the cyclic combustion variations in internal combustion engines operating with homogenous charge compression ignition (HCCI). HCCI is of interest because of its potential to lower emissions and increase efficiency. Our model focuses on conditions where HCCI is sustained with high levels of exhaust gas recirculation and where fuel burning rate varies non-monotonically with

temperature. Using burning rate approximations derived from detailed kinetics simulations of n-heptane combustion, we demonstrate that the model produces cycle-by-cycle combustion variations rich in bifurcations and deterministic chaos and with interesting similarities to experimental observations.

1620-1640 Marko BUDISIC

From trajectories to the ergodic partition of a dynamical system — an algorithm

Marko Budisic and Igor Mezic
University of California Santa Barbara, USA

The trajectory plot is a well-established empirical method of visualization of behavior of a dynamical system in its phase space. However, when systems that exhibit complicated behavior are considered, trajectory plots tend to become cluttered and less useful, especially in analysis of iterative maps. Furthermore, trajectories of systems with sensitivity to initial conditions might not be the best objects to visualize since, in general, not much can be said about neighboring solutions of such systems. An algorithm for computation the ergodic partition of the phase space of measure-preserving dynamical systems will be presented as an effort to efficiently visualize invariant sets in their phase spaces. The ultimate goal is to quickly and efficiently segment the phase space of a dynamical system into regions of qualitatively different, observable dynamics.

Most other approaches to the same problem are based on computing eigenfunctions of Perron-Frobenius operator yielding invariant measures. Our algorithm analyzes trajectories instead, which can be interpreted as a Koopman-operator perspective of analysis. The algorithm infers the structure of the phase space by assembling individual trajectories into approximations of ergodic sets.

The algorithm consists of two steps: simulation and aggregation. The simulation step computes sample trajectories and time averages of a set of observables along those trajectories. Observables are chosen as a subset of a basis of square-integrable functions on the phase space. Since restriction of a dynamical system onto an ergodic set in its phase space yields an ergodic system, Birkhoff's ergodic theorem tells us that any two trajectories starting in the same ergodic set should have equal time averages of any observable along them. This establishes a criterion for aggregation.

The aggregation step uses data clustering techniques to associate trajectories having similar time averages with larger objects — approximations of ergodic sets. The method used is a variant of spectral clustering that has been extensively researched in machine learning.

Performance of the algorithm will be demonstrated on sample two dimensional system which has a known phase space structure. Effects of different parametrizations of the algorithm on the partition of phase space and algorithm running time will be shown.

1640-1720 John POJMAN

Dynamics of thermal frontal polymerization

John A. Pojman
Department of Chemistry and Biochemistry, University of Southern Mississippi, Hattiesburg, Mississippi USA

Frontal polymerization is the propagation of a localized polymerization reaction zone through an unstirred medium. Thermal frontal polymerization is the propagation of a localized reaction zone through the coupling of Arrhenius dependence of the rate of an exothermic polymerization and thermal diffusion. We will consider the types of nonplanar modes that can be observed with multifunctional acrylates in a cylinder. The functionality of the acrylate has a profound effect on the dynamics. We will show how Snell's law applies to fronts in quasi-two-dimensional media. And we examine novel modes on the surface of expanding spherical fronts.

1730-1930 Posters and reception

SATURDAY, JANUARY 5

0830-0910 Peter JUNG

The role of spatial organization for biologic excitable systems

Peter Jung
Ohio University, Athens, Ohio USA

Ion channels in membranes of biological cells are often organized in clusters. The role of clustering for function, however, is poorly understood. I will focus on a specific cell-signaling mechanism, i.e. intracellular calcium signaling, to elucidate the possible roles of ion channel clustering for signaling-function based on mathematical and computational modeling. While calcium dynamics belongs into the realm of excitable systems, the clustering of the key-signaling effectors generates novel dynamic behavior associated with the spatial inhomogeneities, fluctuations due to the small size of the clusters and discreteness effects. For example, clustered signaling arrangement allows for global cellular oscillations for the same (physiologically relevant) parameters homogeneous systems do not. Such effects may be important for the biologic cell where calcium signals with different spatiotemporal shape in general signal a different function.

0910-0930 Mark NELSON

The continuous production of bioethanol: analysis of one, two and three tank reactor designs

M.I. Nelson[1], S.D. Watt[2], H.S. Sidhu[2], and A.K. Ray[3]
[1]School of Mathematics and Applied Statistics, The University of Wollongong, Wollongong, NSW, Australia
[2]School of Physical, Environmental and Mathematical Sciences, The University of New South Wales at, The Australian Defence Force Academy, Canberra, Australia
[3]Department of Chemical and Biochemical Engineering, The University of Western Ontario, Canada

The use of biofuels as an environmentally friendly sustainable supplement to petrol and diesel is of growing interest, particularly in Europe and the US. One such fuel is bioethanol, which can be produced from a variety of agricultural products and which has the advantage of being compatible with existing fuel distribution systems and vehicle fleets. It is likely that in the long term biofuels will form part of the vehicle fuel solution. However, in order to become competitive with fossil fuels advances in bioethanol production are required to increase production volumes and reduce costs.

We analyse a model for the production of bioethanol through continuous fermentation. The biochemical model contains five variables representing substrate, product (ethanol) and biomass(viable cells, non-viable cells and dead cells). The biochemical scheme is an existing literature model that has previously been validated against experimental results.

We first investigate the production of bioethanol in a single reactor. This leads to a system of four coupled ODEs, as the equation for the dead cells uncouples from the system. This system is investigated using path-following methods. We investigate the productivity of bioethanol production as a function of the the substrate concentration and the residence time within the reactor — the latter being the main control parameter. Although the system has a period-doubling route to chaos, the maximum productivity is obtained when the reactor is operated at a steady-state solution well away from the region of interesting dynamics.

We then investigate how the reactor performance can be improved by using a reactor cascade of either two or three reactors. Knowledge of the optimal performance that can be obtained in a single reactor provides a benchmark to evaluate performance efficiencies that can be obtained in a reactor cascade. (This point has not been appreciated in the chemical engineering literature). We consider the cases when the reactors have both equal and non-equal residence time distributions. This leads to systems with eight (two reactors) and twelve (three reactors) ODEs. For the case of two reactors the performance can be investigated using continuation methods. Significant increases in reactor performance are obtained using a cascade of two reactors, but a cascade of three reactors leads to only a marginal increase in performance.

0930-0950 Masahiro TOIYA

Synchronization of chemical oscillators in a microfluidic assembly

Masahiro Toiya, Vladimir K. Vanag and Irving R. Epstein
Brandeis University, Waltham, Massachusetts USA

We report results of our experimental investigation on the interactions among droplets (10-100 nanoliters) of diffusively coupled Belouzov-Zhabotinsky (BZ) solution. A linear array of BZ droplets are separated by octane, through which the signaling molecules diffuse to neighboring droplets. Out-of-phase synchronization of oscillations has been observed for a wide range of droplet/separation ratios. A model is proposed to account for the observed behavior, in which bromine produced in the BZ reaction is responsible for the signaling.

0950-1030 Michael TODD

Using evolutionary algorithms to tailor or optimize dynamic systems for applications in structural health monitoring

Colin Olson and Michael Todd
Department of Structural Engineering, University of California San Diego, La Jolla, California USA

Evolutionary algorithms are optimization schemes that mimic mechanisms of biological evolution by using the principles of natural selection and survival of the fittest to “evolve” candidate solutions to a given problem and seek out an optimum. In this work, we explore how such algorithms may be used to tackle a number of inverse dynamics problems—ranging from finding parameters of a dynamic system to breeding entire systems from scratch—that meet some desired dynamic criterion (e.g., a prescribed Lyapunov spectrum, matched dynamic evolution as measured by a comparison metric, etc.). We show that in a master-slave dynamical system the master may be modified or even created from scratch such that changes in the slave dynamics are amplified. Such a scenario is useful, for example, when the slave system is a structural filter whose response is mined for indicators of change that arise from the onset of damage.

1030-1100 Break

1100-1120 Oleg KOGAN

Renormalization Group approach to describing frequency clusters in a 1 dimensional chain of nearest-neighbor coupled phase oscillators

Oleg Kogan, Michael C. Cross, Gil Refael and Jeffrey L. Rogers
California Institute of Technology (Caltech), Pasadena, California USA

We develop a Renormalization Group method to predict frequency clusters and their statistical properties in a 1-dimensional chain of nearest-neighbor coupled phase oscillators with random intrinsic frequencies and couplings. The method is designed to work in the regime of strong randomness, which holds when the distributions of these intrinsic freqencies and couplings have long tails. We use two types of decimation steps: elimination of oscillators with exceptionally large frequency and renormalization of two oscillators bonded by a very large coupling into a single one. A numerical RG calculation based on these steps is performed. We compare properties of frequency clusters obtained this way with those that result directly from the evolution of the equations of motion.

1120-1200 Gene TRACY

Phase space methods in plasma wave theory

Eugene R. Tracy
Department of Physics, College of William and Mary, Williamsburg, Virginia USA

A brief survey of the study of waves in plasmas and fluids will be given, with an emphasis upon the use of ray-based (WKB) methods. The talk will be largely historical and conceptual. Themes include the use of geometrical pictures as a guide for asymptotic approximations, the use of symmetries and action principles as a means to derive conservation laws, and the unifying power of phase space concepts. Examples will be given that illustrate the fruitful use of modern mathematical ideas to solve problems in physics. Applications that will be briefly touched upon include RF heating in fusion plasmas, equatorial waves in the Atlantic, neutrino oscillations, and magnetohelioseismology.

1200-1220 Viktor NAGY

Control of rare intense events in spatiotemporally chaotic systems

Viktor Nagy and Edward Ott
University of Maryland, College Park, USA

We address the problem of using feedback control for the purpose of suppressing rare intense events in spatially extended systems. As an example, we investigate the use of control to suppress turbulent spikes in the complex Ginzburg-Landau equation in the limit of small dissipation. We explore how information obtained by forecasting can be used to implement spatially and temporally localized control parameter changes and how control strength and cost are related to effectiveness in this framework. The effects of model error and imperfect state measurement are also considered.

1220-1350 Lunch

1350-1430 James CRUTCHFIELD

Structure or noise?

James P Crutchfield[1] and Susanne Still[2]
[1]Complex Systems Center, University of California at Davis, Davis, California USA
[2]Information and Computer Sciences, University of Hawai‘i at Manoa, Honolulu, Hawaii USA

I will show how theory building can naturally distinguish between regularity and randomness. Starting from basic modeling principles, using rate distortion theory and computational mechanics we argue for a general information-theoretic objective function that embodies a trade-off between a model’s complexity and its predictive power. The family of solutions derived from this principle corresponds to a hierarchy of models. At each level of complexity, they achieve maximal predictive power, identifying a process's exact causal organization in the limit of optimal prediction. Examples show how theory building can profit from analyzing a process's causal compressibility, which is reflected in the optimal models’ rate-distortion curve.

1430-1450 Dawn WENDELL

An experimental model of slurry peristaltic pumping in the human intestine

D. M. Wendell[1], A. E. Hosoi[1] and Sarit K. Das[2]
[1]Massachusetts Institute of Technology, Cambridge, Massachusetts USA
[2]Indian Institute of Technology, Madras, Chennai, India

Peristaltic pumping is common in biological systems, including the circulatory system, transport of urine from the kidneys to the bladder, swallowing, and movement of chyme in the intestinal system. However, pumping in the gastrointestinal tract is complicated by the slurry of solid and fluid particles being transported. Prior work has created models of peristaltic pumping of dilute suspensions but has failed to adequately analyze high-volume-fraction systems. In order to develop a new fluid dynamic model of the intestine, we performed an experimental investigation of peristaltically-pumped glass beads in Newtonian fluids of various viscosities. Results show that the transport direction of the glass beads is reversed with an increase in viscosity. We discuss the results of the experiments, compare the results to existing models of peristaltic motion, and theorize implications for biological systems.

1450-1530 Kerwyn HUANG

Finding your center: the role of Min-protein oscillations in bacterial cell division

Kerwyn Casey Huang
Department of Molecular Biology, Princeton University, Princeton, New Jersey USA

In the past decade, fluorescence microscopy has fashioned a new appreciation for the diversity of ways in which proteins organize and segregate on bacterial membranes. Though some targeting anchors are known, cellular symmetry breaking ultimately requires molecular components that self-organize. The remarkable accuracy of cell division in *E. coli* and related bacteria is partially regulated by the Min-protein system, which prevents division near the cell ends by oscillating spatially from pole to pole. We have developed a model of the Min system, using only known properties of the proteins, which accurately reproduces the observed oscillations in rod-shaped, round, and branched cells. In particular, we have

shown that Min-protein oscillations can select the long axis in nearly round cells, a potentially important factor in division-plane selection in round bacteria such as *Neisseria gonnorhoeae*. In branched cells, the branch lengths dictate a specific pattern of Min oscillations that restores a rod shape after a few cell divisions. These results suggest that oscillations may provide a general mechanism by which proteins can detect and exploit the geometry of the cell.

1530-1600 Break

1600-1640 Sadruddin BENKADDA

Patterns, intermittent transport and universality in convective turbulence in magnetic fusion plasmas

Sadruddin Benkadda
Laboratoire PIIM CNRS-Université de Provence, Marseille, France

Buoyancy-driven flows such as thermal convection are of great importance for a wide range of phenomena in geophysical, astrophysical and fusion plasmas [1,2,3]. We consider here intermittent aspects of convective turbulence and transport in magnetized plasma of magnetic fusion machines such as tokamaks or stelerators. These investigations use Direct Numerical Simulation (DNS) of Ion Temperature Gradient instability (ITG) which is identical to the Rayleigh-Bénard thermal convection problem in neutral fluids [4,5,6]. Rayleigh-Bénard convection in particular is a fundamental paradigm for nonlinear dynamics including instabilities and bifurcations, pattern formation, chaotic dynamics and developed turbulence.

Using a weakly non-linear analysis, we show that the back-reaction on the OAmean profile is the natural mechanism for saturation and suggest that it will stay the main non-linear coupling mechanism in the turbulent state. We also will review some basic aspects of the interaction between convective cells and a mean flow [7,8]. In particular and still along the line of the “defreezing”assumption we study the behavior of a model for shear flow instability : transient bursts of vorticity flux are generated in this model. We briefly discuss the advantage of this kind of formulation compared to the “non-normal” operator approach where the mean velocity is also assumed frozen .

An extension of Herring model is derived. It takes into account the self-consistent generation of a mean flow. It is shown that our model has substantially richer dynamics than the one of Herring. In particular the interaction between the convective modes and the mean flow leads in the turbulent state to a transition in the statistical properties of the transport. This bifurcation is analogous the so-called soft to hard turbulence transition in convection. In the strongly turbulent state, intermittent bursts of thermal transport are observed in both cases. For the latter regime, the reduced model as well as DNS show that the Nusselt number Nu (normalized heat flux) scales with the normalized ion pressure gradient Ki as $Nu \sim Ki^{1/3}$[6]. Since the Rayleigh number for ITG turbulence is proportional to Ki, the Nusselt number scaling for ITG turbulence is thus similar to the classical Globe & Dropkin scaling for Rayleigh-Bénard convection in neutral fluids.

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1640-1700 Tiffany VORA

Experimental and computational studies of the *in vivo* genomic repertoire of DNA-protein interactions in *Escherichia coli*

Tiffany Vora[1] and Saeed Tavazoie[2]
[1]American University in Cairo, Cairo, Egypt
[2]Princeton University, Princeton, New Jersey USA

The ability to monitor the occupancy of transcription-factor binding sites *in vivo* is an important pre-requisite to modeling and understanding regulatory network dynamics. To this end, we have developed a technology for whole genome identification and monitoring of protein-DNA "footprints" in bacterial genomes. Unlike chromatin immunoprecipitation, which allows genome-wide mapping of a single transcription factor's binding sites, our approach aims to identify all protein occupancies without *a priori* knowledge of the factors involved. We employed the power of genome-wide analyses to detect underlying complex patterns connecting the set of DNA-protein interactions and the transcription regulatory network. In addition to monitoring the occupancy dynamics of sequence-specific transcription factors, we are using this technology to gain a better understanding of the structural organization of the bacterial genome in terms of nucleoid proteins and the domains they help to organize. We present detailed analyses of many computational and experimental data sets to explore the contribution of "bacterial heterochromatin" to overall genomic architecture.

1700-1740 Leonid BUNIMOVICH

DYNAMICAL NETWORKS: interplay of topology, interactions and local dynamics

Leonid Bunimovich
Georgia Institute of Technology, Atlanta, Georgia USA

We develop a symbolic dynamics approach to the studies of dynamical networks with arbitrary topology (structure of the graph of interactions). This approach is a far development of the previous one developed by Sinai and the speaker to the studies of Coupled Map Lattices, where the graph of interactions is just a lattice. The new approach allows to analyse a combined effect of all three features which characterize a dynamical network (complexity of its topology and the strengthes if local dynamics and interactions). The networks are of the most general type, e.g. the local systems and interactions need not to be homogeneous, nor restrictions are imposed on a structure of the graph of interactions. We obtain general conditions on stability of dynamical networks and demonstrate that some subnetworks can evolve regularly while the others evolve chaotically.

2000-2200 Posters and refreshments

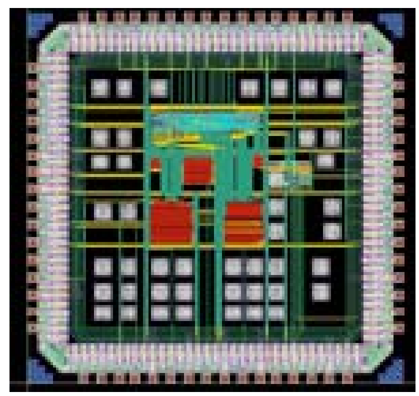
SUNDAY, JANUARY 6

0830-0910 Bill DITTO

Theory, design and construction of Reconfigurable Chaotic Logic Gates

W. Ditto[1], K. Murali[1,2] and S. Sinha[3]
[1]J. Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, Gainesville, Florida USA
[2]Department of Physics, Anna University, Chennai, India
[3]Institute of Mathematical Sciences, C.I.T. Campus, Taramani, Chennai, India

Recently there has been much progress in exploiting the sensitivity and pattern formation features of chaotic systems to create reconfigurable computing systems[1]. One promising direction is to exploit a single chaotic element to reconfigure into different logic gates through a threshold based chaotic morphing mechanism. In contrast to a conventional field programmable gate array element, where reconfiguration is achieved through switching between multiple single purpose gates, reconfigurable chaotic logic gates (RCLGs) are comprised of chaotic elements that morph (or reconfigure) logic gates through the control of the pattern inherent in their nonlinear element. Two and three input RCLGs have recently been realized and shown to be capable of reconfiguring between all logic gates in discrete circuits. Thus we have created an alternative to conventional logic gates being used for integrated circuits today: the Chaogate. This new type of logic gate exploits chaotic dynamics to switch behaviors extremely quickly, allowing Chaogates to rapidly morph, or change functionality, on the fly to perform any needed logic function. The ability to morph allows a single Chaogate to take the place of multiple conventional logic gates[2]. Now, rather than masses of dedicated gates, chip functions may be created from far fewer Chaogates using much less silicon area – reducing the complexity, size, cost, and power consumed by the chip. We have designed and developed a prototype VLSI chip (TSMC CMOS, 0.18μ, 30Mhz clock) incorporating proof of concept Chaogates which establishes the technical feasibility of the Chaogate by demonstrating the morphing capability of Chaogates and higher level functions constructed of Chaogates in an industry standard CMOS chip. The demonstration chip implemented the following:



- A small ALU with three switchable functions, two arithmetic functions (adder, multiplier, divider, barrel shifter, or others) and one function of scratchpad memory.
- A cyclic redundancy check (CRC) calculation switchable between two different CRCs.
- An example of switching between two communication protocols: SPI and I2C

I will conclude the presentation with brief summary of commercialization efforts and the extension of as well as some open questions in the field of chaotic computing that may have more profound implications for computation.

1. "Chaos Computing: ideas and implementations," W. L. Ditto, K. Murali and S. Sinha, Philosophical Transactions of the Royal Society London A, (2007) (10.1098/rsta.2007.2116).
2. "Method and apparatus for a chaotic computing module," W. Ditto, S. Sinha and K. Murali, US Patent Number 07096347 (August 22, 2006).

0910-0930 Gregg LOIS

Reliable protein folding on non-funneled energy landscapes: the free energy reaction path

Gregg Lois, Jerzy Blawzdziewicz and Corey S. O'Hern
Deptartment of Physics, Department of Mechanical Engineering, Yale University, New Haven, Connecticut USA

Under appropriate conditions, proteins spontaneously fold from an extended one-dimensional chain of amino acids to a unique three-dimensional native configuration. How this occurs on timescales accessible to experiment — and relevant to biological function-- is a question that has intrigued theorists for decades. We develop a theoretical framework to understand general properties of the folding process. The key insight is that the rate r at which external parameters are adjusted to induce folding dynamically alters the available states. A theory based on this insight predicts that (1) in contrast to the prevalent view, proteins with non-funneled energy landscapes can fold reliably, (2) reliable folding can occur in equilibrium or out of equilibrium, and (3) reliable folding occurs only when r is below a limiting value, which can be quantitatively determined from measurements of the free energy. These predictions are tested in simulations and we find excellent agreement.

0930-1010 Yi GUO

Smooth sliding of a one-dimensional particle array for friction control

Yi Guo
Department of Electrical and Computer Engineering, Stevens Institute of Technology, Hoboken, New Jersey USA

We discuss the friction control problem for a one-dimensional particle array sliding on a surface. The frictional dynamics can be described by the Frenkel-Kontorova model which represents a nonlinear interconnected system. Open-loop stability of the system without external forces is first studied in the presence of linear and nonlinear particle interactions, respectively. Two tracking control problems are defined and nonlinear feedback control laws are developed to solve the problems and to achieve that 1) the velocity of the center mass tracks any given constant targeted velocity; 2) the velocity of each single particle tracks a given constant targeted velocity. Due to physical accessibility, the control variables are average quantities, the position and velocity of the center of mass. Computer simulations show satisfactory performances that verify the theoretical claim.

1010-1030 Break

1030-1110 Maria D'ORSOGNA

Patterns, stability and collapse for two-dimensional biological swarms

Maria D'Orsogna
Department of Mathematics, California State University, Northridge, California USA

One of the most fascinating biological phenomena is the self-organization of individual members of a species moving in unison with one another, forming elegant and coherent aggregation patterns. Schools of fish, flocks of birds and swarms of insects arise in response to external stimuli or by direct interaction, and are able to fulfill tasks much more efficiently than single agents. How do these patterns arise? What are their properties? How are individual characteristics linked to collective behaviors?

In this talk we discuss various aspects of biological swarming by investigating a non-linear system of self propelled agents that interact via pairwise attractive and repulsive potentials. We are able to predict distinct aggregation morphologies, such as flocks and vortices, and by utilizing statistical mechanics tools, to relate the interaction potential to the collapsing or dispersing behavior of aggregates as the number of constituents increases. We also discuss passage to the continuum and possible applications of this work to the development of artificial swarming teams.

1110-1130 Vadas GINTAUTAS

Resonant forcing of chaotic dynamics

Vadas Gintautas, Glenn Foster and Alfred W. Hübler
University of Illinois at Urbana-Champaign, USA

We study resonances of multidimensional chaotic map dynamics. We use the calculus of variations to determine the additive forcing function that induces the largest response, that is, the greatest deviation from the unperturbed dynamics. We include the additional constraint that only select degrees of freedom be forced, corresponding to a very general class of problems in which not all of the degrees of freedom in an experimental system are accessible to forcing. We find that certain Lagrange multipliers take on a fundamental physical role as the efficiency of the forcing function and the effective forcing experienced by the degrees of freedom which are not forced directly. Furthermore, we find that the product of the displacement of nearby trajectories and the effective total forcing function is a conserved quantity. We demonstrate the efficacy of this methodology with several examples.

1130-1150 Xiaopeng ZHAO

Indefinite patterns of cardiac alternans due to spatiotemporal border-collision bifurcation

Xiaopeng Zhao
University of Tennessee, Knoxville, Tennessee USA

Cardiac alternans, a beat-to-beat alternation in action potential duration (at the cellular level) or in ECG morphology (at the whole heart level), is a marker of ventricular fibrillation, a fatal heart rhythm that kills hundreds of thousands of people in the US each year. Investigating cardiac alternans may lead to a better understanding of the mechanisms of cardiac arrhythmias and eventually better algorithms for the prediction and prevention of such dreadful diseases.

In this work, we study spatiotemporal patterns of cardiac alternans using numerical simulations and theoretical analyses. In simulating a detailed ionic model, which integrates the Ca cycling model developed by Shiferaw *et al.* (Biophysics 2003) with the canine membrane dynamics model developed by Fox *et al.* (Am. J. Physiol. 2002), we observe that, for a periodically paced fiber, there coexist multiple spatiotemporal patterns of alternans regardless of the length of the fiber, the type of coupling between the transmembrane voltage (V_m) and the intracellular Ca content, and the junctional diffusion of Ca. Instead, these different alternans patterns result from different pacing protocols and initial conditions. A particularly striking observation is that spatially discordant alternans can arise in short fibers consisting of only a few tens of cells.

To explore the mechanism that underlies the coexistence of multiple alternans solutions, we first approximate the ionic membrane model with a 2-D mapping model, whose state variables are APD and intracellular Ca content. The mapping model accounts for the bidirectional V_m/Ca coupling. Inspired by previous experimental observation in Diaz *et al.* (Circulation Research 2004) and numerical simulations in Shiferaw *et al.* (Biophysics 2003), we represent the Ca relation in the mapping model using a piecewise linear function. As a result, the mapping model shows alternans through a border-collision bifurcation; that is, under variation of a bifurcation parameter (the pacing rate in cardiac context), a solution branch collides with a border, where discontinuities in the system's properties result in a qualitative change in the solution. While the mapping model is developed for dynamics of a single cell, we can form a coupled-maps model to study alternans on fibers. Simulations of the coupled-maps model reproduce the phenomenon of coexistence of multiple alternans solutions that has been observed in simulations of the Shiferaw-Fox model. Bifurcation analysis of the coupled-maps model reveals that the multiple alternans solutions are born through a spatiotemporal border-collision bifurcation.

The fact that multiple alternans solutions coexist makes it extremely difficult to predict and to control alternans. Investigation of spatiotemporal border-collision bifurcations may shed light on these challenges.

1150-1230 Roman GRIGORIEV

The role of resonance phenomena in chaotic mixing

Roman Grigoriev
Georgia Institute of Technology, Atlanta, Georgia USA

Although the field of fluid mixing via chaotic advection is relatively new, it has matured enough for us to see some common features that reappear for different geometries and different physical mechanisms used for driving the flow. In this talk I will discuss two examples of mixing in near-integrable 3D volume-preserving flows: thermocapillary-driven droplets and a Lorenz-force driven cellular flow in a channel. In both cases a small perturbation of the integrable flow leads to the destruction of the exact invariants and the emergence of an adiabatic invariant. I will show how the adiabatic invariant can be destroyed to enable essentially complete mixing by introducing either a separatrix (for a steady flow) or a resonant surface (for a time-periodic flow). I will also explain how the volume of the mixed domain and the mixing rate can be computed analytically for the class of flows considered.