Dynamics Days 2010

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Filtering Coherent Atomic Beams: The Peierls-Nabarro Energy Landscape of the Nonlinear Trimer

Atomic Bose-Einstein condensates (BECs) trapped in optical lattices (OLs) have been the subject of great recent experimental and theoretical interest, both in their own right and as analog models of certain solid state systems. Recent studies of the leakage of a BEC trapped in an OL have shown that localized nonlinear excitations known as “Discrete Breathers” (DBs) can prevent atoms from reaching the leaking boundaries, thereby slowing the decay of the condensate.

To understand the mechanism by which these DBs enhance the trapping, we study the case of atom transport—“tunneling”—through a DB on a nonlinear trimer. We show that this transport is related to the destabilization and subsequent motion of DB and that there exists a threshold in the total energy on the trimer that controls this destabilization. We find that this threshold and the resultant tunneling can be described analytically by defining a two-dimensional “Peierls-Nabarro” energy landscape which restricts the dynamics of the trimer to a limited region of phase space. We further establish that the value of the threshold is related to the Peierls-Nabarro barrier of a single DB. Our results suggest a possible means for controlling the transmission of coherent atomic beams in interferometry and other processes.

This work has been carried out in collaboration with Holger Hennig and Jerome Dorignac.

Geometry of Turbulence: A Stroll Through 61,506 Dimensions

In the world of moderate Reynolds number, everyday turbulence of fluids flowing across planes and down pipes a velvet revolution is taking place. Experiments are almost as detailed as the numerical simulations, DNS is yielding exact numerical solutions that one dared not dream about a decade ago, and dynamical systems visualization of turbulent fluid’s state space geometry is unexpectedly elegant.

We shall take you on a guided tour (ChaosBook.org/tutorials) of this newly breached, hitherto inaccessible territory. Mastery of fluid mechanics is no prerequisite, and perhaps a hindrance: the talk is aimed at anyone who had ever wondered why - if no cloud is ever seen twice - we know a cloud when we see one? And how do we turn that into mathematics?
Fragile Jamming and Hysteresis in 2D Granular Packing

The assembly and compaction of a network of rigid contacts among compressible discrete objects such as colloidal particles, the cells formed by foams, and granular materials is at the heart of important questions in disordered systems.

Theoretical ideas including a universal jamming transition, rigidity percolation, and random loose/close packing have helped guide a range of interesting experiments on physical systems. Here, an experiment on axially compressed photo-elastic disks is used to explore some of the theoretical concepts noted above and to come to grips with the real impact of stick-slip friction in real physical granular materials. As disks are initially compressed, they gradually form a packed or jammed state by progressing through a “fragile” state where the compaction pressure, the displacement field and the stress chain distribution all exhibit a smooth exponential increase with increasing packing fraction. Further, upon successive compression/decompression, the system packing fraction slowly increases, perhaps logarithmically, although the irreversible energy dissipated per compression/decompression cycle remains approximately constant.

Non-Equilibrium Particle Systems

I will try to review (mostly) rigorous results on extended 1-dimensional systems which are out of equilibrium and in which particles interact with scatterers. Thus, in line with the spirit of “Dynamics Days”, the rules of the game are completely deterministic, with the only randomness coming from the coupling of the system to (grand-canonical) heat baths. Astonishingly, most “evident” questions still await an answer: Is there a unique steady state? Can the system heat up? Can it “freeze”? I will try to summarize our present state of knowledge in this context.

Coagulation and Fragmentation of Inertial Particles in Chaotic Advection and Random Flows

Inertial particles in fluid flows are of increasing interest in different disciplines of science such as dynamical systems theory, atmospheric and marine science as well as engineering.
Coagulation and Fragmentation of Inertial Particles in Chaotic Advection and Random Flows

(continued)

In many cases particles are not only transported passively by advection but exhibit a dynamics of their own as they can form larger particles upon collision or can break up. Examples of particle dynamics are raindrop formation in clouds, sedimentation of particles in lakes and the ocean or flocculation of marine aggregates and cells.

We present a coupled model for advection, coagulation and fragmentation that is based on the dynamics of individual, spherical inertial particles in two-dimensional flows. The basic equations describing the dynamics of these particles are the Maxey-Riley equations. We consider idealized flows like periodic flows leading to chaotic advection of the particles as well as random flows. Due to the particle inertia advection leads to the accumulation of the particles on attractors in the flow. The collision of the particles leads to coagulation and larger coagulates are formed. These can in turn fragment due to shear forces in the flow. Two different mechanisms of fragmentation are taken into account: On the one hand coagulates can fragment if their size exceeds a predefined maximum size. On the other hand fragmentation can take place when the shear forces in the flow become larger than the binding forces of the coagulate. We find that the combination of coagulation and fragmentation leads to an asymptotic steady state for the size distribution of the coagulates which depends crucially on the considered mechanism of fragmentation. We discuss the dependence of the final size distributions on the properties of the coagulates as well as of the flow.

This work done in collaboration with Jens C. Zahnow, Tamás Tél, and Rafael D. Vilela.

Daniel Gauthier Duke University

Observation of Boolean Chaos

I will describe the recent observation of deterministic chaos in a simple network of electronic logic gates that are updated autonomously. The resulting power spectrum is ultrawide band, extending to beyond 2 GHz. The observed behavior is reproduced qualitatively using Boolean delay equations that take into account signal propagation times that depend on the recent history of the gates and filtering of pulses of short duration. I will discuss possible applications of Boolean chaos as an ultrawide-band source of radio waves and as a random number generator.


Figure: Hugo L. D. de S. Cavalcante, Daniel J. Gauthier, Joshua E. S. Socolar and Rui Zhang
Dynamics Days 2010 Invited Speakers

**Theo Geisel** Max Planck Institute for Dynamics and Self-Organization

*Phase Transitions Towards Self-Organized Criticality in Neuronal Systems*

In recent work we have demonstrated the existence of genuine self-organized criticality (SOC) in neuronal networks [1] caused by depressing dynamical synapses, i.e., where the synaptic coupling exhibits fatigue under repeated presynaptic firing. This adaptation mechanism drives the network into a self-organized critical regime by adjusting the average coupling strengths to a critical value. The size distribution of critical avalanches exhibits an inverse power law, which has been observed in the same form experimentally in neuronal cultures as well as in awake monkeys.

We have now generalized this study to include facilitating besides depressing synaptic dynamics as found in biological systems. We show analytically that the generalized model attains SOC in an extended region of parameter space that is reached through phase transitions. The critical region of the connectivity parameter is sandwiched between a sub- and a supercritical regime which also can be reached experimentally by a manipulation of the synaptic strengths. The system exhibits a rich dynamical behaviour including a hysteresis between critical and noncritical dynamics, switching of the dynamics in dependence of external inputs, and first- and second-order phase transitions that form a cusp bifurcation [2]. This is the first observation of a complex classical bifurcation scenario combined with a SOC phase.


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**Raymond Goldstein** University of Cambridge

*Synchronization of Eukaryotic Flagella*

It has long been conjectured that hydrodynamic interactions between beating eukaryotic flagella underlie their ubiquitous forms of synchronization, yet there has been no experimental test of this connection. The biflagellated alga *Chlamydomonas* is a simple model for such studies, as its two flagella are representative of those most commonly found in eukaryotes. Using micromanipulation and high-speed imaging we show that the flagella of a *C. reinhardtii* cell present periods of synchronization interrupted by phase slips. The dynamics of slips and the statistics of phase-locked intervals are consistent with a low-dimensional stochastic model of hydrodynamically coupled oscillators, with a noise amplitude set by the intrinsic fluctuations of single flagellar beats.

*(continued)*
Moreover, in the dark, a single cell stochastically switches between periods of synchrony with slips and periods of asynchrony (“drifts”) in which the two flagella beat at significantly different frequencies. We show by means of extensive three-dimensional tracking of swimming trajectories that drifts are associated with sharp turns, resulting in a eukaryotic version of the run-and-tumble locomotion found in bacteria. Finally, the dynamics of phototaxis in simple eukaryotes is considered from the perspective of evolutionary transitions to multicellularity. The unicellular alga *Chlamydomonas* swims in helical trajectories whose geometric properties are modulated by signals received from a photosensor that sweeps the surroundings as the cell rotates. Its large spherical multicellular descendent *Volvox* is composed of thousands of *Chlamydomonas*-like cells, and spins about a body-fixed axis as it swims. Using micromanipulation and particle-imaging velocimetry of flagella-driven flows, we show that the frequency response of *Volvox carteri* to periodic light signals is tuned to match the natural rotational frequency of the colony. A hydrodynamic model of phototactic steering shows that colony rotation is necessary to achieve accurate phototaxis.

Ensembles of networks are used as null models in many applications. However, simple null models often show much less clustering than their real-world counterparts. In this paper, we study a model where clustering is enhanced by means of a fugacity term as in the Strauss (or “triangle”) model, but where the degree sequence is strictly preserved — thus maintaining the quenched heterogeneity of nodes found in the original degree sequence. For regular graphs (identical degrees for all nodes) with degree $k>2$ we find a first order transition. For all non-regular networks that we studied (including Erdős-Rényi and scale-free networks) we find multiple jumps resembling Barkhausen jumps together with strong hysteresis. The latter transitions are driven by the sudden emergence of “cluster cores”: groups of highly interconnected nodes with higher than average degrees. To study these cluster cores visually, we introduce *q*-clique adjacency plots. We find that these cluster cores constitute distinct communities which emerge spontaneously from the triangle generating process. Finally, we point out that cluster cores produce pitfalls when using the present (and similar) models as null models for strongly clustered networks, due to the very strong hysteresis which effectively leads to broken ergodicity on realistic time scales.

*Work done in collaboration with David Foster, Jacob Foster, and Maya Paczuski.*
In order to understand social systems, it is essential to identify the circumstances under which individuals spontaneously start cooperating or developing shared behaviors, norms, and culture. In this connection, it is important to study the role of social mechanisms such as repeated interactions, group selection, network formation, costly punishment and group pressure, and how they allow to transform social dilemmas into interactive situations that promote the social system. Furthermore, it is interesting to study the role that social inequality, the protection of private property, or the on-going globalization play for the resulting “character” of a social system (cooperative or not). It is well-known that social cooperation can suddenly break down, giving rise to poverty or conflict. The decline of high cultures and the outbreak of civil wars or revolutions are well-known examples. The more surprising is it that one can develop an integrated game-theoretical description of phenomena as different as the outbreak and breakdown of cooperation, the formation of norms or subcultures, and the occurrence of conflicts.

2200 years ago Apollonius of Perga introduced the first space-filling tiling of discs or spheres. The underlying topology bears an astonishing richness of properties. I will show that the contact network is scale-free and small world. It allows to describe some basic properties of porous media and neural networks. It is robust against random attacks and can be optimized very well against malicious attacks. The Potts model shows unique anomalies when studied on Apollonian networks and car traffic models show an abrupt gridlock. A large family of related topologies allows for slipless rotations between touching disks. I will discuss their construction and their fractal dimensions. These configurations fulfill Kolmogoroff scaling and display Richardson’s diffusion law in the limit of small Stokes numbers and constitute therefore an interesting toy model for turbulence. The synchronization of rotations occurs in avalanches following a broad size distribution.
Dynamics Days 2010 Invited Speakers

Fred MacKintosh Vrije University

Non-Equilibrium Fluctuations and Mechanics of Active Gels and Living Cells

Much like the bones in our bodies, the cytoskeleton consisting of filamentous proteins largely determines the mechanical response and stability of cells. Such important cellular processes as locomotion, cell division, and mechanosensing are largely governed by complex networks of cytoskeletal biopolymers and the associated proteins that cross-link these and/or generate forces within the network. In addition to their important role in cell mechanics, cytoskeletal biopolymers have also provided new insights and challenges for polymer physics and rheology. Biopolymer networks, for instance, exhibit strongly nonlinear rheology—in many cases stiffening by orders of magnitude when subject to shear strains of less than unity. In the cell, these polymer networks or gels are far from equilibrium in a way unique to biology: they are subject to active, non-thermal internal forces generated by molecular motors. We describe recent theoretical and experimental results on active networks in vitro that demonstrate significant non-equilibrium fluctuations due to motor activity [1,2]. Furthermore, such gels hold out the promise of active materials, whose stiffness can be controlled by enzymatic activity. We also show how fluctuations and dynamics of individual cytoskeletal filaments can be used to probe both mechanical properties and non-equilibrium activity in living cells [3,4].


José Onuchic University of California at San Diego

The Energy Landscape for Folding and Molecular Motors – The Kinesin Story

Fueled by ATP, conventional kinesins take unidirectional steps along the single protofilament of microtubule by alternated binding of two motor domains to the binding sites. The structural changes of kinesin motors are closely coupled to the ATP binding and its subsequent hydrolysis. Although several experimental efforts have elucidated the physical principle of kinesin dynamics, schematically summarized in a mechanochemical cycle, limitations in the spatial and temporal resolution of current experiments have prevented a straightforward understanding of kinesin dynamics based on its microscopic structure. By exploiting a structure-based model of kinesin motor, we develop the energy landscape for this molecular motor and address a few selected issues on the kinesin dynamics. Firstly, the equilibrium ensemble of kinesin structures, whose both heads are bound to the microtubule binding sites, show that the internal tension (f ≈10-15 pN) built along the neck-linker exclusively disturbs the ATP binding pocket of the leading head from its native-like environment. This result clarifies the origin of kinesin's high processivity, supporting the rearward strain induced regulation mechanism between the two motor domains. Secondly, we address the controversial issue of substep formation during the stepping motion. By solving the potential of mean forces experienced...
The Evolution of Mixing: From Stretching and Folding to Cutting and Shuffling

The fingerprint of mixing is stretching and folding. Mathematically this entails forming homoclinic or heteroclinic points or the formation of a horseshoe map and has practical consequences such as exponential stretching of material lines. Heuristically this can be traced back to streamline crossing. Strictly speaking horseshoes are measure zero, and the effect of this measure zero set on a full neighborhood of trajectories has to be determined with the help of numerics. There are two branches in the previous there. The first has to do with analytical prediction. Linked Twist Maps embody the notion of “streamline crossing” in a rigorous mathematical sense and constitute one class of systems where mathematical prediction of chaos on a set of full measure (i.e. positive area) is possible without resorting to computations. The second with a new mechanism of mixing, one that does not involve stretching and folding but rather cutting and shuffling, a mechanism that can be put on a firm theoretical foundation using an emerging area of dynamical systems theory called piecewise isometries. An isometry is a map that preserves distances (for example, a rigid rotation). Piecewise means that two (different) isometries are joined along a curve separating the domains of the two isometries. A single isometry cannot be chaotic in the sense of having exponential separation of points as the map is iterated, since the distance between points remains constant during iteration. However, when two or more isometries are combined the resulting dynamics can exhibit great complexity.

Cooling Classical Particles with a Microcanonical Szilard Engine

We show that it is possible to extract energy from a single isolated system if its initial energy is known. We construct an explicit example based on the celebrated Szilard engine. Our microcanonical version of the engine allows extraction of energy without the need of any measurement. The extraction possible by a cyclic protocol which reduces the energy of a single particle by increasing the uncertainty of its energy, a mechanism that could be in principle extended to systems with several degrees of freedom.
Jeffrey Rogers  DARPA

Research Funding: A Perspective from the Other Side

Securing research funding is often time-consuming and, can be, a difficult task. This talk will provide a perspective on attracting and maintaining support from a scientist who joined the Defense Advanced Research Projects Agency (DARPA) to fund research involving nonlinear sciences. Funding opportunities through early career awards, advanced studies, and projects will be touched on in the context of the speaker’s current interests in exploiting dynamics of NEMS and nanophotonic architectures, managing laser instabilities, design and verification of multiscale electronic systems, and early detection of traumatic brain injury.

Mary Silber  Northwestern University

Quasipatterns by Design

I will describe the controlled generation of quasipatterns via a symmetry-breaking parametric instability in a model PDE. Two mechanisms for quasipattern and superlattice pattern formation will be reviewed, and the special challenges associated with using bifurcation theory to understand quasipatterns will be highlighted. My presentation describes some work done with Alastair Rucklidge.

Sara Solla  Northwestern University

Decoding Neural Signals for the Control of Movement

The activity of neurons in an area of the brain referred to as primary motor cortex provides the signals that control the ability to execute movements. One of the crucial questions, still unresolved, is that of identifying the code used by this neural ensemble. We address this question through the analysis of data obtained for an awake behaving monkey. An implanted multielectrode array records the activity of about one hundred neurons in primary motor cortex during the execution of a sequence of straight reaches to nearby targets. A natural representation for the ensemble activity is provided by a high-dimensional space in which each axis represents the activity of a single neuron as an independent degree of freedom. (Continued)
Decoding Neural Signals for the Control of Movement (Continued)

However, the observed correlations among neurons whose activity is detectably modulated by the task suggest that the population defines a low-dimensional space within the high-dimensional space of independent firing activities. We have used linear and nonlinear methods for dimensionality reduction to find the low-dimensional structure that captures the underlying relationship between population neural activity and behavioral task. The use of multidimensional scaling in conjunction with an empirical measure of geodesic distances yields a low-dimensional manifold whose intrinsic coordinates capture the geometry of the task in the external physical space. Although the dimensionality of this manifold follows from a linear model that considers neurons as independently modulated by reach direction, its curvature is a consequence of neural interactions.

Steven Strogatz Cornell University

Spiral Wave Chimeras

Chimera states are remarkable spatiotemporal patterns discovered recently in nonlocally coupled systems of limit-cycle oscillators. Their defining feature is that the system splits into synchronized and desynchronized subpopulations, even though all the oscillators are identical and symmetrically coupled. This talk will summarize what has been learned— and what remains unknown — about chimeras in 1-D arrays, 2-D arrays, and interacting populations. In particular, 2-D chimeras take the form of a new kind of spiral wave: In place of a phase singularity with zero-amplitude oscillators at the center of the spiral, here the core consists of desynchronized oscillators running at full amplitude. Simulations and analysis of this “spiral wave chimera” will be presented.

Harry Swinney The University of Texas at Austin

Lethal Protein Produced in Response to Competition Between Bacterial Colonies

We have conducted experiments on neighboring colonies of P. dendritiformis bacteria grown on an agar gel by inoculation from the same culture (i.e., the colonies are siblings). The colonies are found to mutually inhibit growth through secretions that become lethal if the level exceeds a well-defined threshold [1]. Analysis of the secretions reveals the presence of subtilisin (a protease) and a 12 kDalton protein, which we have named Slf (sibling lethal factor) [2]. Subtilisin promotes the growth of the colonies, while Slf is lethal. Slf is found to be encoded by a gene belonging to a large family of bacterial genes of previously unknown function. The experimental results are used to develop a model (six coupled PDEs), which predicts that once subtilisin exceeds a threshold, as occurs at the interface between competing colonies, then Slf is secreted into the medium and rapidly kills cells. Laboratory tests yield results for the dynamical behavior that is in accord with the predictions of the model. The existence in many (Continued)
bacteria of genes encoding homologs of the gene that encodes Slf suggests that the mechanism we observe for self-regulation of colony growth may well occur in other bacteria.


Eukaryotic genomes are packaged into nucleosome particles that occlude the DNA from interacting with most DNA binding proteins. We have discovered that genomes care where their nucleosomes are located on average, and that genomes manifest this care by encoding an additional layer of genetic information, superimposed on top of other kinds of regulatory and coding information that were previously recognized. We have developed a partial ability to read this nucleosome positioning code and predict the in vivo locations of nucleosomes. Most recently, we showed that the distribution of nucleosomes reconstituted on yeast genomic DNA in a purified in vitro system closely resembles that in vivo, implying that much of the in vivo nucleosome organization is explicitly encoded in the genomic DNA sequence itself, through the nucleosomes’ DNA sequence preferences. A statistical model based only on the in vitro nucleosome DNA sequence data is significantly predictive of the detailed distribution of nucleosome locations in yeast, C. elegans, and human, suggesting that there may exist a universal genomic code for nucleosome positioning. Our results suggest that genomes utilize the nucleosome positioning code to facilitate specific chromosome functions, including to delineate functional versus nonfunctional binding sites for key gene regulatory proteins, and to define the next higher level of chromosome structure. The physical basis of the nucleosome DNA sequences preferences lies in the sequence-dependent mechanics of DNA itself.
Erik Bollt Clarkson University

How Can I Say that a “Toy” Model Reminds Me of Observations? A Dynamical Systems Perspective of Comparing Non-Conjugate Systems

We address a fundamental modeling issue in science as related to the field of dynamical systems: when is a model of a physical system a “good” representation? Conjugacy provides a means to define if two systems are dynamically equivalent; it is the central equivalence relationship in the field of dynamical systems. However, it cannot cope with systems which are not dynamically identical. What then to do with the common scientific practice of modeling, whereby we build heuristic and phenomenological models which “remind” us of the true system? We develop mathematical technology to decide when dynamics of a toy model are like dynamics of the physical system. When applied to non-conjugate dynamical systems, we show that a fixed point iteration scheme yields a limit point, that is a function we call a “commuter” — a non-homeomorphic change of coordinates translating between dissimilar systems. This translation is true to the concepts of dynamical systems in that it matches systems within the language of their orbit structures. We introduce methods to compare nonequivalent systems by quantifying a defect of the commuter function’s failure to be a homeomorphism — an approach that better respects the dynamics than any traditional comparisons based on normed linear spaces. Our discussion addresses a fundamental issue — how does one make principled statements of the degree to which a “toy model” might be representative of a more complicated system. We highlight our methods with a lower-ordered models of more complicated systems.

Thomas L. Carroll Naval Research Laboratory

Detecting Recursive and Non Recursive Filters Using Chaos

Filtering a chaotic signal through a recursive (or IIR) filter has been shown to increase the dimension of the chaos under certain conditions. Filtering with a non recursive (or FIR) filter should not increase dimension, but it has been shown that if the FIR filter has a long tail, measurements of actual signals may appear to show a dimension increase. I simulate IIR and FIR filters that correspond to naturally occurring resonant objects, and I show that using dimension measurements, I can distinguish the filter type. These measurements could be used to detect resonances using radar, sonar or radar signals, or to determine if a resonance is due to an IIR or an FIR filter.

Pinaki Chakraborty University of Illinois at Urbana-Champaign

Rotating Volcanic Plumes: Lobate Umbrellas, Tornadoes, and Lightning Sheaths

A strong volcanic plume consists of a vertical column of hot gases and dust topped with a horizontal umbrella. The column rises buoyed by entrained and heated ambient air, reaches the neutral-buoyancy level, then spreads radially to form the (Continued)
Rotating Volcanic Plumes: Lobate Umbrellas, Tornadoes, and Lightning Sheaths (continued)

umbrella. In classical models of strong volcanic plumes, the plume is assumed to remain always axisymmetric and non-rotating. In this talk I show that the updraft of the rising column induces a hydrodynamic effect not addressed to date: a “volcanic mesocyclone”. This volcanic mesocyclone sets the entire plume rotating about its axis, as confirmed by an unprecedented analysis of satellite images from the 1991 eruption of Mount Pinatubo. The rotation triggers a turbulent Rayleigh-Taylor instability which makes the umbrella lose axial symmetry and become lobate in plan view, in accord with satellite records of recent eruptions on Mounts Pinatubo, Manam, Reventador, Okmok, Chaiten, and Ruang. The volcanic mesocyclone spawns waterspouts or dustdevils, as seen in numerous eruptions, and groups the electric charges about the plume to form the “lightning sheath” that was so prominent in the recent eruption of Mount Chaiten. The concept of volcanic mesocyclone provides a unified explanation for a disparate set of poorly understood phenomena in strong volcanic plumes. This talk is based on joint work with Gustavo Gioia and Susan Kieffer.

Ralph V. Chamberlin  Arizona State University

Nanothermodynamics and Nonlinear Corrections to Statistical Mechanics

The Boltzmann factor, which comes from the linear change in entropy of an infinite heat bath, does not fully account for nonlinear or inhomogeneous dynamics. Nonlinear terms have been used by Onsager to describe non-equilibrium response, and by Einstein to describe critical fluctuations in a small part of a large system. We apply similar nonlinear terms to the normal fluctuations of individual particles in thermal equilibrium. This “nanothermodynamics” provides a common explanation for the non-exponential relaxation, non-Arrhenius activation, and non-classical crossover scaling that is often found in complex systems. Theoretical arguments, computer simulations, and experimental data will be presented indicating that it is the local interaction between particles that often yields significant nonlinear corrections to the Boltzmann factor.

Sean Cornelius  Northwestern University

Paradox of Latency in Escherichia coli Metabolic Pathways

Gene-deletion experiments on single-cell organisms have established that expression of most genes is not needed for optimal growth. This problem acquired a new dimension with the recent discovery that environmental and genetic perturbations of the bacterium Escherichia coli are accompanied by the temporary activation of a large number of latent metabolic pathways, which suggests the hypothesis that temporarily activated reactions facilitate adaptation and hence impact growth in the presence of perturbations. We model the dynamics of perturbation and adaptation using a constraint-based approach and find, surprisingly, that the availability of latent pathways consistently offers no adaptive advantage in the short term, and tend in fact to inhibit adaptation after genetic perturbations. This adverse influence raises the possibility that latent pathway activation is a derivative effect of other, potentially suboptimal, adaptive response.
Matched Filter for Chaos

A chaotic differential equation is shown to admit a simple matched filter for detecting symbolic information in the waveform. The low-dimensional chaotic oscillator yields an exact analytic solution that can be written as a linear convolution of a basis pulse and information sequence. The information symbols form a symbolic dynamics for the chaotic oscillator, completely and uniquely specifying any chaotic trajectory. The matched filter output provides optimal symbol detection in the presence of noise, and an exact expression for the bit-error rate for detecting symbols is derived. The chaotic system and its matched filter are realized using low-frequency electronic circuits containing both analog and digital components. Experimental results confirm the effectiveness of the matched filter for receiving and detecting symbolic content. Scaled to higher-frequency, this realizable system has potential application in Hayes-type chaos communications, where a message signal is encoded in the symbolic dynamics via small perturbations. The discovery of a practical matched filter finally provides a receiver to complement the elegant encoding in such systems.

Filament Turbulence & Cardiac Fibrillation

How much information do you need to distinguish between different mechanisms for spatiotemporal chaos in three-dimensions? In this talk, I will show that the observation of the dynamics on the surface of a medium can be sufficient. Studying mechanisms for filament turbulence in the context of reaction-diffusion media, we found numerically that two major classes of instabilities leave a very different signature on what can be observed on the surface of a three-dimensional medium. These results are of direct relevance in the context of ventricular fibrillation — a turbulent electrical wave activity that destroys the coherent contraction of the ventricular muscle and its main pumping function leading to sudden cardiac death. While it has been proposed that the three-dimensional structure of the heart plays an important role in this type of filament turbulence, only the surface of the heart is currently accessible to experimental observation preventing the study of the full dynamics. Our results suggest that such observations might be sufficient.

Mitochondrial Modulation of Intracellular Ca$^{2+}$ Signaling

Mitochondria have long been known to sequester cytosolic Ca$^{2+}$ and even to shape intracellular patterns of endoplasmic reticulum-based Ca$^{2+}$ signaling. Evidence suggests that the mitochondrial network is an excitable medium which can demonstrate independent Ca$^{2+}$ induced Ca$^{2+}$ release via the mitochondrial permeability transition. The role of this excitability remains unclear, but mitochondrial Ca$^{2+}$ handling appears to be a crucial element in diverse diseases as diabetes, neurodegeneration and cardiac dysfunction that also have bioenergetic components. Here we extend a modular computational model for respiration-driven Ca$^{2+}$ handling to include a permeability transition based on a channel-like pore mechanism. We demonstrate both excitability and Ca$^{2+}$ wave propagation accompanied by depolarizations similar to those reported in cell and isolated mitochondria preparations. These waves depend on the energy state of the mitochondria, as well as other elements of mitochondrial physiology. Our results support the concept that mitochondria can transmit state dependent signals about their function in a spatially extended manner over an excitable medium.
Response of Oscillator Networks: A Centrality Measure Quantifying the Relative Importance of a Node

Some centrality measures are used to determine the relative importance of nodes specifically in directed networks. We analyze a centrality measure called the influence. When we consider an oscillator network, the influence of an oscillator quantifies the magnitude of the collective response to an small input to the oscillator. The influence can also be applied to a strong periodic inputs. For a type of random network, we show that the analytically derived entrainment threshold is approximately equal to the inverse of the influence. We numerically check that this relationship also holds true in a random scale-free network and a neural network.

Dynamics of Spatially Distributed Large Coupled Oscillator Systems

In the past few decades, studies of large systems of coupled oscillators have advanced greatly our understanding of global collective behaviors arose out of interactions among local constituents in complex systems. However, most classical models focus on the dynamics of oscillators assuming no spatial extent, while real physical systems have the oscillators spatially distributed. Our study further the study of large coupled oscillator systems with the oscillators distributed in space. We study the conditions for the occurrence of collective behaviors, and characterize the spatially manifested coarsening dynamics arose out of the systems.
Doing More with Less: Emergence of Large-Scale Connectivity in Networks with Design

Many biological, social, and technological systems take the form of complex networks. Over the past decade a science of networks has been emerging and providing insights into dynamic aspects of network structure as well as dynamic processes occurring on complex networks. The classic Erdős-Rényi (ER) model of network formation starts from a set of \( n \) unconnected nodes and sequentially adds edges between pairs of nodes uniformly at random. This dynamic process leads to a network with a Poisson degree distribution and a phase transition in network connectivity when the average degree is equal to unity. We present an adaptation of the model for systems possessing heterogeneous nodes. In this model we divide the set of \( n \) nodes into groups and set differing rates for the addition of edges within or between groups. For a range of comparative rates of edge addition within groups and between groups the model can show “cooperative enhancement” with the phase transition marking the onset of large-scale connectivity occurring with fewer edges than were required for the classic ER model. Previous work on altering the ER transition point relied primarily on processes requiring oversight in that a choice between two outcomes must be assessed at each step. Here enhanced connectivity is achieved in an unsupervised manner with a simple modular treatment. The model has implications for systems of interacting networks, single networks with modular or community structure, and networks with node populations. Applications of this work relate to our understanding of disease spreading across geographic regions and how to engineer minimalist communications networks.

Decision Making and Collective Behavior in Cell Migration

The focus of this work is collective migration, which is crucial e.g. in wound healing, immune response, or the formation of organs. Though the size, shape, and behavior of individual cells when placed by themselves under the microscope varies widely, groups of biological cells that communicate with each other (via biochemical signals and possibly physical interactions) are able to carry out complex tasks very reliably. We will review decision making and group behavior during cell migration in a simple model organism \textit{Dictyostelium discoideum}. We will assess how information is relayed in space and time on multiple scales from the mm scale where we follow the motion of thousands of individual cells to the micron scale where we have developed a method to follow cell shape dynamics and to monitor cell protrusions. Finally, we will also assess the ability of migrating cells to make more complex decisions such as migration in the presence of obstacles such as cliffs and ridges.
A Time-Delay Model of Protein Synthesis Obtained from Mechanistic Principles and its Application to Gene Networks

The engineering of gene regulatory circuits is one of the main objectives in synthetic and systems biology. Such circuits possess a great number of components with diverse and rich forms of interactions. Mechanistic models of gene networks are difficult to analyze due to the amount of details incorporated. The synthesis of mRNA and protein are carried out via template polymerization processes that possess intrinsic time delays. It has been shown that incorporating time delays in models of gene networks is often essential to capture the whole range of behavior. We present here the development of a time delay model for protein synthesis from a mechanistic model of the process. We use the reduced model to study the behavior of a simple gene network and obtain complex dynamic behavior not observed with commonly used heuristic models and which would be difficult to infer from the original mechanistic model, due to its complexity.

Discontinuous Phase Transitions in Random Network Percolation

The transition to extensive connectedness upon gradual addition of links, known as the percolation phase transition, provides a key prerequisite for understanding networked systems [1]. Until recently, random percolation processes were thought to exhibit continuous transitions in general, but now there is numerical evidence for discontinuities changes of the order parameter in certain percolation processes [2]. Here we present the concepts of weakly and strongly discontinuous percolation transitions and explain the microscopic mechanisms underlying them. We study both numerically and analytically under which conditions the order parameter may change discontinuously and classify the type of transition in dependence on the dynamics of cluster joining [3].

Work done in collaboration with Anna Levina and Marc Timme.

Network Destabilizations with Inverted Mechanical Responses

A solid material can be regarded as a large mechanical network, with nodes representing the particles composing the material and links between nodes representing interactions between these particles. The network must rearrange itself (continued)
in response to an applied force. The material’s response to applied pressures and tensions can then be modeled as a flow of forces through this network. Using this formulation, I will discuss the design of mechanical networks that exhibit properties not found in ordinary materials. I will show, in particular, that we can design a material that counter-intuitively expands when pressured or contracts when tensioned. These results are of potential interest for a wide range of applications.

Hiroya Nakao  Kyoto University

Self-Organization of Non-Uniform Dynamical Patterns in Complex Networks of Diffusively Coupled Oscillators

Complex networks are ubiquitous in a wide variety of real-world systems. To understand their functional roles, it is necessary to explore the dynamics that take place on them. As a simple prototype of network-organized dynamical systems, nonlinear oscillators interacting via complex networks have been extensively studied. In particular, macroscopic synchronization transition exhibited by coupled phase oscillators on complex networks has attracted much attention. However, even more interesting non-uniform dynamical patterns should also be possible on complex networks. Generally, coupled phase oscillators are derived from coupled limit-cycle oscillators by eliminating amplitude degrees of freedom for sufficiently weak coupling. For stronger coupling, such an approximation breaks down and much richer dynamics due to amplitude effects are expected. We demonstrate that diffusively coupled limit-cycle oscillators on complex networks actually exhibit various non-uniform dynamical patterns [1]. Near the supercritical Hopf bifurcation of the constituent limit-cycle oscillators, we can describe the system by a network version of the complex Ginzburg-Landau equation, which is a normal form of general self-oscillatory media. Uniformly oscillating solution of this equation can be linearly unstable with respect to spontaneous phase modulations due to the effect of diffusion, similarly to the Benjamin-Feir instability in spatially extended oscillatory media. Numerical investigations on scale-free networks under this instability condition reveal a wealth of complex non-uniform dynamical patterns, including partial amplitude death, clustering, and chaos. We explain these dynamical patterns by combining periodic mean-field approximation of the network and bifurcation analysis of the constituent oscillators.


Takashi Nishikawa  Clarkson University

Visual Analytics for Discovering Group Structures in Networks

We propose a visual and interactive method for discovering distinct groups of nodes in a network using a user-selected set of node properties computed from the network structure. The user’s input on the visual separation of nodes in random 2D projections of a high-dimensional node property space is systematically analyzed to divide the nodes into distinct groups, the number of which is selected by the user interactively. The discovered groups are then examined to reveal their distinguishing characteristics. Our method is capable of discovering communities structures, k-partite structures, or any other structures in which the groups can be distinguished by a combination of node properties. We demonstrate that our method can effectively find and characterize a variety of group structures in model and real-world networks.


**Regularization of Tunneling Rates with Quantum Chaos**

We study tunneling in various shaped, closed, two-dimensional double wells by calculating the energy splitting between symmetric and anti-symmetric state pairs. We use the boundary and finite element methods for the calculations. For shapes that have regular or nearly regular classical behavior (e.g. rectangular or circular wells) the tunneling rates for nearby energy states vary over wide ranges. Rates for energetically close quantum states can differ by several orders of magnitude. This contrasts sharply with the one-dimensional case in which the tunneling rates increase monotonically with energy. As we transition to well shapes that admit more classically chaotic behavior (e.g. the stadium, the Sinai billiard) the range of tunneling rates narrows, often by an order of magnitude or more. For well shapes in which the classical behavior appears to be fully chaotic (as determined from numerical bounce maps) the tunneling rates’ range narrows to about a factor of 2 or so between the smallest and largest rates in a wide range of energies. This dramatic narrowing appears to come from destabilization of periodic orbits in the regular wells that produce the largest and smallest tunneling rates. It is in this sense that we say the quantum chaos regularizes the tunneling rates to what appears to be a universal curve. Calculations of Husimi distributions suggest that the rates are strongly dependent on the magnitude of normal momentum and the magnitude of the wave function at the barrier.

**Communities in Networks**

Networks arise pervasively in biology, physics, technology, the social sciences, and a myriad of other areas. They typically exhibit a complicated mixture of random and structured features. Over the past several years, my collaborators and I have conducted several studies of cohesive mesoscopic structures known as “communities,” which consist of groups of nodes that are closely related. In this talk, I will discuss some of our results on network community structure in social, political, financial, and biological networks.

**Role of Bubbles on Heat Transfer and Turbulence in Rayleigh-Bénard Convection**

Using direct numerical simulations (DNS) of two-phase Rayleigh-Bénard convection in a cylindrical cell, we investigate how bubbles modify the heat transport and flow properties in the bulk and boundary layers. The dynamics of the system depends on the interaction between many length- and time-scales. The rapid growth of bubbles near the hot bottom plate intensifies the local fluctuations, their buoyancy destabilizes the flow, and the total heat transfer is amplified. These (continued)
Role of Bubbles on Heat Transfer and Turbulence in Rayleigh-Bénard Convection (continued)

effects depend strongly on the ratio of sensible heat to the latent heat and the number of bubbles present. However, if the bubbles are artificially forced to maintain a fixed size they stabilize the system by damping temperature gradients, and reduce the Reynolds number of the flow (based on the r.m.s. velocity). To disentangle the interaction of the bubbles with the boundary layers vs. the bulk flow, in separate simulations we introduce bubbles into homogeneous Rayleigh-Bénard convection, where the top and bottom plates have been eliminated.

Alexey Snezhko  Argonne National Laboratory

Dynamic Self-Propelled Structures in Nonequilibrium Magnetic Layers

Magnetic granular layers suspended at the liquid-air or liquid-liquid interface and energized by an alternating magnetic field develop nontrivial dynamic self-assembled structures (magnetic snakes) in a certain range of excitation parameters. These non-equilibrium structures emerge as a result of the competition between magnetic and hydrodynamic forces and have complex magnetic ordering. Strong induced vortex flows on the surface of the liquid finalize the rich hydrodynamic picture of the “magnetic snake”. Self-assembled snakes have a complex magnetic ordering. The segments of the snake exhibit long-range antiferromagnetic ordering mediated by the surface waves, while each segment is composed of ferromagnetically aligned chains of microparticles. Above some frequency threshold magnetic snakes spontaneously break the symmetry of self-induced surface flows (symmetry breaking instability) and turn into swimmers. Self-induced surface flows symmetry can be also broken in a controlled fashion by introduction of a large bead to a magnetic snake (bead-snake hybrid), that transforms it into a robust self-locomoting entity. Observed phenomena have been successfully described by developed phenomenological model.

James Yorke  University of Maryland, College Park

Infinitely Many Cascades Must Exist as Chaos Arises in Dimension 2

Evelyn Sander and I have established a general theory of why period-doubling cascades exist (in N dimensions), including why systems have infinitely many cascades. Feigenbaum’s results describe how a cascade’s bifurcations scale — if the cascade exists. We show that infinitely many cascades must exist as a system goes from having only finitely many periodic orbits to chaotic dynamics. Our theory is for generic smooth one-parameter maps $F(a,x)$ where $x$ is n-dimensional. Here is one corollary for maps with horseshoes in dimension 2 such as the time 1 map of the forced damped pendulum or double well duffing equation.

The Route to Chaos Theorem. Assume $F(a,x)$ is smooth and $x$ is two-dimensional. Under additional mild restrictions, if there are parameter values $a_0$ and $a_1$ for which: $F(a_0,)$ has at most a finite number of periodic orbits, and $F(a_1,)$ has chaotic dynamics. Then there are infinitely many period-doubling cascades between $a_0$ and $a_1$. The definition we use for “chaotic dynamics” is satisfied if there are infinitely many saddles whose unstable eigenvalue is $> 1$. The above result also holds when $x$ is one dimensional with minor wording changes. In addition we have discovered a new phenomenon in which there are “paired cascades,” that is, two cascades that are connected by a path of periodic orbits. The quadratic map $a - x^2$ has no paired cascades but almost all cascades are paired for the forced damped pendulum and for the forced single and double-well Duffing equations.
Marine aggregates are an important part of the global carbon cycle in the ocean and understanding their formation and dynamics has been a topic of increasing interest in recent years. Typically, such aggregates are created in aggregation and fragmentation processes as large fractal clusters of solid particles. However, the incorporation of this fractal structure of the aggregates as well as the incorporation of finite-size effects such as particle inertia into the usual mean field theory for aggregation and fragmentation is still an unsolved problem. We present results from the numerical simulation of a system formed of inertial particles suspended in a fluid flow, where the particles interact in the form of collisions, aggregation and fragmentation. Upon collision the particles can aggregate and form larger clusters which can break up again due to shear forces in the fluid, resulting in a distribution of aggregates of various sizes. We show how the fractal structure typical of many real aggregates can be included in such a model in form of an effective size and density of the aggregates and discuss consequences for aggregation and fragmentation. In particular, we demonstrate that the time to reach a steady state depends strongly on the fractal dimension of the aggregates. Additionally, we show that the fragmentation of the fractal aggregates is the relevant process that determines the total size distribution of the aggregates. This is of central importance in many natural phenomena such as the formation of clusters of suspended particulate matter in lakes and rivers and marine aggregates in the ocean. While most previous studies emphasize the role of aggregation, our results show that this is more relevant for transient effects. In situations where a steady state is of interest, fragmentation will be the most relevant process.
Dynamics Days 2010 Poster Session

1. Dynamical approximation of a reprogramming cell culture
   Bradley Alicea, Michigan State University

2. Sync-map description of coupled oscillators
   Gilad Barlev, University of Maryland, College Park

3. Asymptotics of grow-up solutions and global attractors of slowly non-dissipative PDEs
   Nitsan Ben-Gal, Brown University

4. Tour de Sys: the traveler's view of a network
   Christirkiel Brockmadyann, Northwestern University

5. Shear thickening in dense suspensions
   Eric Brown, University of Chicago

6. Universalty and the lack of it in multiscale human mobility networks
   Rafistianirk Bruthmarock, Northwestern University

7. Duality between time series and network analysis
   Andriana S. L. O. Campanharo, Northwestern University and National Institute For Space Research (Brazil)

8. Homoclinic Boolean chaos in a delayed feedback digital circuit
   Hugo L. D. de S. Cavalcante, Duke University

9. Evolutionary behavioral aspects of infectious disease: reactions to epidemiological events and hysteria in the media
   Alhaji Cherif, Arizona State University

10. Chaotic granular mixing in quasi-two-dimensional tumblers: streamline jumping and piecewise isometries
    Ivan Christov, Northwestern University

11. Mutation and copy number variation in a genome
    Brian K. Clark, Illinois State University

12. Dynamics of alternans in one dimensional cardiac models
    Shu Dai, Mathematical Biosciences Institute, The Ohio State University

13. Spatial scale in human mobility networks - What can we learn from renormalization?
    Vincent J. David and Dirk Brockmann, Northwestern University

14. The effect of directionality on the synchronizability of networks
    Eleanor Davis, Clarkson University

15. Investigating ion channel dynamics during high-frequency random noise stimulation using Hodgkin-Huxley model
    Anirban Dutta, Howard Hughes Medical Institute

16. Prediction retrodiction and the amount of information stored in the present
    Christopher J. Ellison, University of California at Davis

17. Using synchronization of chaos to identify multiple delay times in Boolean-delay systems
    Zheng Gao, Duke University

18. Generalized resonant forcing of nonlinear and chaotic dynamics
    Vadas Gintautas, Los Alamos National Laboratory
Dynamics Days 2010 Poster Session

19. The turbulent mean-velocity profile: it is all in the spectrum
   Gustavo Gioia, University of Illinois at Urbana-Champaign

20. Dynamic control for synchronization of separated cortical areas through thalamic relay
   Leonardo Lyra Gollo, IFISC

21. Dynamics and bifurcations in homogeneous rigid rod suspensions
   Arvind Gopinath, Massachusetts Institute of Technology

22. Flow irreversibility in particle suspensions with non-uniform strain
   Jeffrey S. Guasto, Haverford College

23. Foams in the phase field crystal equation
   Nicholas Guttenberg, University of Chicago

24. Synchronization of uncoupled oscillators by gamma impulses, from phase locking to noise-induced synchronization
   Shigefumi Hata, Kyoto University

25. Gravitationally-unstable premixed flames: the transition to chaos
   Elizabeth P. Hicks, University of Chicago

26. MEG study of cognitive functional activities in a human brain: nonlinear dynamical analysis
   Sanghyun Im, Korea Advanced Institute of Science and Technology

27. Effects of super-spreaders in epidemic models on dynamic small-world networks
   Matthew M. Jones, University of Maine

28. Clustering of brain tumor cells: theory and experiment
   Evgeniy Khain, Oakland University

29. Bistability and hysteresis in dense shear granular flow
   Evgeniy Khain, Oakland University

30. Macroscopic kinetic effect of cell-to-cell variation in biochemical reactions
   Pan-Jun Kim, University of Illinois

31. Firing patterns in a simple spiking model of neurons
   Nayoung Koh and Wook Hee Koh, Hanseo University

32. Modeling and parameter estimation for a spatiotemporal ecological system
   Sean Kramer, Clarkson University

33. The application of the transfer entropy to irregularly sampled time series
   Christopher Kulp, Lycoming College

34. Diffraction: wave dynamics near the break-up of an underwater bubble
   Lipeng Lai, University of Chicago

35. Social learning in social networks
   P’J Lamberson, MIT Sloan

36. Role of network topology in the dynamic range of coupled excitable systems
   Daniel B. Larremore, University of Colorado at Boulder
37. **Critical behavior of the Ising model in annealed scale-free networks**  
Sang Hoon Lee, Korea Advanced Institute of Science and Technology

38. **Finite-size effects of threshold behavior in the K-satisfiability problem**  
Sang Hoon Lee, Korea Advanced Institute of Science and Technology

39. **Universality in the one-dimensional chain of phase-coupled oscillators**  
Tony Lee, California Institute of Technology

40. **Why is Braess paradox rare and synthetic rescues common?**  
Joo Sang Lee, Northwestern University

41. **How well can one resolve the state space of a chaotic map with noise?**  
Domenico Lippolis, Georgia Institute of Technology

42. **Information accessibility and cryptic processes**  
John R. Mahoney, University of California at Davis

43. **Events before droplet splashing on a dry solid surface**  
Shreyas Mandre, Harvard University

44. **Spontaneous synchronization in fiber laser arrays**  
Yamato Matsuoka, Georgia Institute of Technology

45. **Chaos and the quantum: how nonlinear classical correlations can overlap with quantum correlations**  
Wm. C. McHarris, Michigan State University

46. **Optimizing mixing in channel flows: kinematic aspects associated with secondary flows in the cross-section**  
Kevin Mcilhany, US Naval Academy

47. **Obstacle and predator avoidance in a model for flocking**  
Nicholas Mecholsky, University of Maryland

48. **How to partition a mixed phase space – with applications to atomic ionization**  
Kevin Mitchell, University of California at Merced

49. **Calculating transition times in a model of language change**  
William G. Mitchener, College of Charleston

50. **Hybrid sensing using physical sensors**  
Todd Murphey, Northwestern University

51. **Resolving the network synchronization landscape: compensatory structures, quantization, and the positive effect of negative interactions**  
Takashi Nishikawa, Clarkson University

52. **Vehicular traffic dynamics: from human to robotic drivers**  
Gabor Orosz, University of California at Santa Barbara

53. **Evolutionary dynamics of metabolic networks**  
Adam R. Pah, Northwestern University

54. **Turbulent Taylor-Couette flow between independently rotating cylinders**  
Matthew Paoletti, University of Maryland
55. **Conjugacy distributions and modeling of stochastically perturbed dynamical systems**  
Rana Parshad, Clarkson University

56. **Paucity of attractors in nonlinear systems driven with complex signals**  
Shawn Pethel, U.S. Army Research - Development and Engineering Command

57. **River network scaling: anisotropy and scaling crossovers in space and time**  
Geoffrey M. Poore, University of Illinois at Urbana-Champaign

58. **Statistical data assimilation using Monte Carlo evaluation of path integrals**  
John C. Quinn, University of California at San Diego

59. **In toto characterizations of dynamical transitions in mouse cornea across the cell and tissue levels**  
Jerry Rhee, Northwestern University

60. **Multiplexed communications using chaotic systems with multiple delayed feedbacks**  
Damien Rontani, Georgia Institute of Technology

61. **Competing synchronous processes**  
Epaminondas Rosa, Jr., Illinois State University

62. **Leaky membrane dynamics**  
Robert Shaw, ProtoLife, Inc.

63. **An adaptive model for the dynamical regulation of conductances in cardiac myocytes**  
Sebastian Skardal, University of Colorado at Boulder

64. **Bifurcation and stability of a system of n coupled droplet oscillators with S_n symmetry**  
David Slater, Cornell University

65. **Normalized spacings between zeros of Riemann zeta function given by normalized Maxwell Boltzmann distribution**  
Siavash Sohrab, Northwestern University

66. **Effects of bubbling on the stability of adaptive synchronization of chaotic systems**  
Francesco Sorrentino, Università degli Studi di Napoli Parthenope

67. **Critical behavior of epidemic spreading in dynamic small world networks**  
Thomas E. Stone, University of Maine

68. **Dynamics of networks: a computational approach for analyzing time dependent networks**  
Jie Sun, Clarkson University

69. **Multi-scale modeling of coupled oscillator network**  
Jie Sun, Clarkson University

70. **The indegree-biased voter model**  
Samarth Swarup, Virginia Polytechnic Institute and State University

71. **Dynamics in actuator arrays**  
Randall Tagg, University of Colorado at Denver

72. **Effect of aging on dynamics in small-world networks of Rossler oscillators**  
Gouhei Tanaka, University of Tokyo
73. Spontaneous synchronization of oscillators with noisy frequency adaptation  
Dane Taylor, University of Colorado

74. Dynamics of vaccination with imperfect knowledge  
Olivia Woolley, Northwestern University

75. Propagation of information and estimation of states from data in wave-like spatiotemporal chaos  
Young-noh Yoon, University of Maryland

76. Relating turbulent friction and energy spectrum in rough-pipe flows  
Carlo C. Zuniga Zamalloa, University of Illinois at Urbana-Champaign

77. Mostly conjugacy: analysis on homeomorphic defect  
Jiongxuan Zhen, Clarkson University
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