Dynamics Days 2019: Talk Abstracts

Friday, Jan. 4

Morning talks, 8:45 a.m.–12:00 p.m.

Sculptures Formed By Fluidic Erosion and Dissolving
Invited talk. 8:45 a.m.–9:20 a.m.
Leif Ristroph, *NYU Courant Institute*.

In recent years in the NYU-Courant Applied Math Lab, we've been studying how solid but shapeable boundaries interact with flowing fluids. Although not at all the intended subject of our experiments, singular geometries have surprised us by popping up naturally in several problems. I will talk about a few case studies, starting with how a clay body is robustly reshaped by fluidic erosion into a peculiar shape with points and corners. I will also point out an intriguing connection to the shapes of meteoroids. Lastly, I'll cover some preliminary work on dissolving objects made of candy and how the flows naturally present during dissolution tend to carve singularly sharp "landscapes".

Emergent Dynamics in Active Fluids of Microrotors
Contributed talk. 9:20 a.m.–9:40 a.m.
Petia M. Vlahovska, *Northwestern University*.
Co-authors: Gerardo Pradillo, Hamid Karani, Cody Reeves, *Northwestern University*.

Populations of self-propelled living or synthetic microparticles, e.g., bacteria or chemically-activated colloids can collectively exhibit behavior that on the macroscale resembles fluid flow. While the individual particles are governed by relatively simple dynamics, the interaction of the particles can result in remarkably complex and intriguing phenomena. We study the collective behavior of self-rotating colloids suspended in viscous fluid. I will present our experiments with Quincke rotors (actuated by electric fields) which show the emergence of structure (e.g. vortices, crystals, chains) and discuss our discrete-particle and continuum models of these systems.

Dynamics of a Triangular Sessile Drop: a Minimal Model
Contributed talk. 9:40 a.m.–10:00 a.m.
Elizabeth Wesson, *Cornell University*.
Co-author: Paul Steen, *Cornell University*.

It is challenging to accurately model details of drop translations and deformations for real fluids in the presence of contact line motion. In addition, applications may make it necessary to simulate large populations of droplets that are translating and deforming dynamically. This motivates our minimal model of a moving droplet.

We consider a sessile drop modeled as a triangle which can deform and translate along a line in the lab frame. Its enclosed area is conserved, and its motions are governed by internal pressure and surface tension under Newton's law. The pressure function is chosen to impose a penalty for sharper corners. The motion of the drop's center of mass decouples from its deformation relative to the inertial frame. We therefore consider motions in the inertial frame, consistent with our focus on the drop's natural vibrations.

Applying Newton's law to the center of mass coordinates gives a four-dimensional nonlinear reversible dynamical system. We observe two-dimensional invariant manifolds corresponding to "bouncing" and "rocking" modes of the drop, as well as quasiperiodic torus trajectories surrounding these manifolds in phase space. We investigate bifurcations of the system as the equilibrium contact angle varies.

Temporal Asymmetry of Lagrangian Coherent Structures
Contributed talk. 10:45 a.m.–11:05 a.m.
Jeffrey Tithof, *University of Rochester*.
Co-authors: Balachandra Suri, *IST Austria*; Michael F. Schatz, Roman O. Grigoriev, *Georgia Institute of Technology*; Douglas H. Kelley, *University of Rochester*.

In fluid dynamics, viscosity breaks the time-reversal symmetry of the Navier-Stokes equation. However, in certain cases with a small Reynolds number (Re), time-asymmetry may be negligible, such as the famous demonstration by G. I. Taylor. Multiple recent studies of 2D and 3D turbulence have quantified the growth of time irreversibility with Re. We utilize a quasi-2D laboratory flow and a 2D direct numerical simulation (which accurately models the experiment) to quantify the growth of time-asymmetry in Lagrangian coherent structures (LCSs), which are the most important mixing barriers in the flow. We obtain attracting and repelling LCSs by computing ridges of the finite-time Lyapunov exponent (FTLE) fields using velocity fields evolving in backward or forward time, respectively. We find that the attracting and repelling LCSs exhibit an asymmetry that emerges with the onset of time dependence and grows with Re. The asymmetry is characterized by attracting LCSs that explore a larger fraction of the spatial domain than the repelling LCSs, which is consistent with a prior study. Our results suggest the asymmetry arises because hyperbolic stagnation points in the flow move preferentially along repelling LCSs. Our results help improve predictions of fluid mixing, as we find that repelling LCSs are more predictable than attracting LCSs.

Systems Analysis of Wall Turbulence: Characterizing Natural and Synthetic Self-sustaining and Self-similar Processes
Invited talk. 11:05 a.m.–11:40 a.m.
Beverley J. McKeon, *California Institute of Technology.*

The financial and environmental cost of turbulence is staggering: manage to quell turbulence in the thin boundary layers on the surface of a commercial airliner and you could almost halve the total aerodynamic drag, dramatically cutting fuel burn, emissions and cost of operation. Yet systems-level tools to model scale interactions or control turbulence remain relatively under-developed. The resolvent analysis for turbulent flow proposed by McKeon & Sharma (J. Fluid Mech, 2010) provides a simple, but rigorous, approach by which to deconstruct the full turbulence field into a linear combination of (interacting) modes and investigate flow dynamics. After a brief review of some key results that can be obtained by analysis of the linear resolvent operator concerning the statistical and structural make-up of wall turbulence, I will describe some of our recent progress towards determining how to reconstruct self-sustaining turbulent systems, both natural and synthetic. Implications for both the classical picture of wall turbulence and control of turbulent flows will be discussed.

Spatiotemporal Cat: The Simplest Turbulent Field Theory
Contributed talk. 11:40 a.m.–12:00 p.m.
Predrag Cvitanović, *Georgia Institute of Technology.*
Co-authors: H. Liang, B. Gutkin, *Georgia Institute of Technology.*

Recent advances in fluid dynamics reveal that the recurrent patterns observed in turbulent flows result from close passes to unstable invariant solutions of Navier-Stokes equations. While hundreds of such solutions been computed, they are always confined to small computational domains, while the flows of interest (pipe, channel, plane flows), are flows on infinite spatial domains. To describe them, we recast the Navier-Stokes equations as a spacetime theory, with all infinite translational directions treated on equal footing.

We illustrate this by solving what is arguably the simplest classical field theory, the discretized screened Poisson equation, or the "spatiotemporal cat," and describe its repertoire of admissible spatiotemporal patterns. We encode these by spatiotemporal symbol dynamics (rather than a single temporal string of symbols).

In the spatiotemporal formulation of turbulence there are no periodic orbits, as there is no time evolution. Instead, the theory is formulated in terms of unstable spacetime tori, which are minimal tilings of spacetime. The measure concept here is akin to the statistical mechanics understanding of the Ising model - what is the likelihood of occurrence of a given spacetime configuration?

Lunch, 12:00 p.m.–2:00 p.m.

Afternoon talks, 2:00 p.m.–5:20 p.m.

Flash Talk Session A
Flash talks. 2:00 p.m.–2:50 p.m.
See poster abstract booklet for full abstracts.

A4: Nonlinear Map Model of Functional Quantum Entanglement in Photosynthetic Bacteria
Siegfried Bleher, *Fairmont State University*
A5: Model-Free Control of Chaos with Deep Reservoir Computing
Daniel M. Canaday, *Ohio State University*
A7: Long-range Interactions of Kinks
Ivan C. Christov, *Purdue University*
A8: Mathematical Model of Gender Bias and Homophily in Professional Hierarchies
Sara M. Clifton, *University of Illinois at Urbana-Champaign*
A9: Nonlinear-Linear Alchemy: Koopman Operators, Linear Chaos, and Tape Recorders
Ned J. Corron, *US Army AMRDEC*
A14: Scalable Learning of Time-varying Vector Autoregression By Low Rank Tensors
Kameron Decker Harris, *University of Washington*
A18: Dynamical Stability of the Outer Solar System in the Presence of Hypothesized "Planet Nine"
Tali Khain, *University of Michigan*
A19: Levitating Granular Cluster: Typical Behavior and Noise-induced Rare Events
Evgeniy Khain, *Oakland University*
A24: Frequency Shredding and Its Presence in Nonlinear Fluid Flows
Michael Lee, *Duke University*
A26: Puzzles and Piecewise Isometries—1D, 2D, and 3D Possibilities
Richard M. Lueptow, *Northwestern University*
A33: Multifaceted Dynamics of Janus Oscillator Networks
Zachary G. Nicolaou, *Northwestern University*
A35: The High Forecasting Complexity of Noisy Periodic Orbits Limits the Ability to Distinguish Them From Chaos
Navendu S. Patil, *Pennsylvania State University*
A46: Random Beats Design in Network Synchronization
Yuanzhao Zhang, *Northwestern University*

The Plumber's Nightmare: Modeling Sugar Export From a Leaf
Invited talk. 2:50 p.m.–3:25 p.m.
Tomas Bohr, *Technical University of Denmark.*

Plant leaves perform an amazing task: to bring in water from the soil, to collect CO2 from the air, to perform photosynthesis and to export the sugar efficiently. The two parts of the vascular system, the xylem and the phloem, are extremely close to each other in the narrow space of the veins of the leaf, which means that the pressure can drop tens of atmospheres over, say, 5 micrometers. Most of the water coming up from the soil via the xylem evaporates, but a small part is used for photosynthesis and for the sugar transport from mesophyll cells, where it is produced, into the phloem tubes and further on to the rest of the plant via the phloem. In the talk, I shall concentrate on the simplest possible venation structure: the linear veins of pine needles. The phloem tubes in a pine needle form a bundle of parallel, porous tubes of almost constant radius and almost constant sugar concentration, and therefore constitute a simple testing ground for the osmotic mechanism by which the sugar is believed to be transported. We have recently shown that long needles face a serious problem since the phloem-sap near the tip will be stagnant and no sugar will be exported from there. Correspondingly, most needles are less than around 6 cm - the predicted characteristic length. However, needles that are 30 cm or more do exist, and to understand how they manage, we shall go deeper into the mechanism by which sugar is "loaded" into the phloem tubes.

Entropy Rate and Statistical Complexity Dimension of Hidden Processes
Contributed talk. 4:05 p.m.–4:25 p.m.
Alex M. Jurgens, *University of California, Davis.*
Co-author: James Crutchfield, *University of California, Davis.*

Hidden Markov chains are widely used statistical models of stochastic processes and symbolic dynamics, from fundamental physics and chemistry to finance, health, and artificial intelligence. The processes generated by general hidden Markov chains are notoriously complicated, however. Even if finite state: no finite expression for their Shannon entropy rate exists, the set of their predictive features is generically infinite, and their statistical complexity diverges. As such, it has not been possible to make general statements about how random they are nor how structured. Here, we show how to efficiently and accurately calculate their entropy rates and the rate of statistical complexity divergence—the dimension of the minimal set of predictive features. These rely on determining the full spectrum of Lyapunov characteristic exponents of the associated infinite random-product of the generating chain's transition matrices. Technically, we extend previous results that assume independent, identically-distributed matrix sampling to correlated and forbidden matrix products.

Using Machine Learning to Analyze Chaotic Systems
Invited talk. 4:25 p.m.–5:00 p.m.
Edward Ott, *University of Maryland.*

We consider how machine learning techniques can be used to discover properties and behaviors of dynamical systems, including consideration of large complex spatiotemporally chaotic systems. Topics that will be covered include prediction of state evolution and inference of ergodic properties from data. Collaborators on this work include J. Pathak, Z. Lu, S. Chandra, B. Hunt, and M. Girvan.

A General Framework For Non-feedback Control of Chaos
Contributed talk. 5:00 p.m.–5:20 p.m.
Dan Wilson, *University of Tennessee.*

Seminal work by Ott, Grebogi, and Yorke showed that chaotic dynamics could be controlled by stabilizing unstable periodic orbits contained within a chaotic attractor. This groundbreaking observation set off a flurry of interest in the development of chaos control strategies in the ensuing decades.

Thirty years later, almost all well-established chaos control strategies require real-time feedback about a system's state variables. In practice, however, it can be difficult to obtain sufficient real-time measurements in situations where the length scales are very small, time scales are very fast, or where recordings require intrusive equipment (many biological systems fall into one of these categories). Comparatively few methods exist for controlling chaos without real-time feedback with most of these limited to dynamical systems of low dimension. In this presentation, I will discuss a novel general strategy for exploiting system nonlinearities in order to achieve stabilization of chaos in systems of arbitrarily dimension. This strategy uses a recently developed high-accuracy phase-amplitude reduction approach. In particularly surprising numerical examples, the resulting non-feedback methods perform comparably to other well-established feedback control strategies in the presence of uncertainty.

Saturday, Jan. 5

Morning talks, 8:45 a.m.–12:10 p.m.

An Approach to Locating Interesting Structures in Flows
Invited talk. 8:45 a.m.–9:20 a.m.
Jonathan E. Rubin, *University of Pittsburgh.*

I will discuss a general new change of coordinates, local orthogonal rectification or LOR, that can be applied at any fixed base curve in the phase space of a dynamical systems (cf. Letson and Rubin, SIAM J. Appl. Dyn. Syst., 2018). LOR, based on the Frenet frame, yields a coordinate system, the LOR frame, which allows us to rigorously study structures in a flow – typically trajectories – that exhibit whichever properties we specify, such as periodicity or certain asymptotic behaviors. I will show how we use the LOR approach to derive a novel definition for rivers, long-recognized but poorly understood trajectories that locally attract other orbits yet need not be related to invariant manifolds or other familiar phase space structures, and I will present examples of rivers from neuronal models. I will also discuss preliminary work related to transient dynamics arising in the basin of an attracting periodic orbit; specifically, I will illustrate how we can use LOR to locate manifolds that are attracting or repelling for trajectories in the basin of the orbit and hence organize the transient dynamics arising in the process of convergence to the orbit.

The Replicator Dynamics For Multilevel Selection in Evolutionary Games
Contributed talk. 9:20 a.m.–9:40 a.m.
Daniel B. Cooney, *Princeton University.*

We consider a stochastic model for evolution of group-structured populations in which selection operates at two organization levels: individuals compete with other individuals in their group, while groups also compete with other groups. Individuals obtain payoff from playing a two-strategy game, either a generalized version of the Prisoner's Dilemma or of the Hawk-Dove game, against members of their group. Individual-level competition depends on individual payoff, while group-level depends on average payoff of group members. This creates a tension between the two levels of selection, as defectors are favored by at the individual level, whereas groups with cooperators outperform groups of defectors at the between-group level. In the limit of infinite group size and infinite number of groups, we derive a non-local PDE that describes the probability distribution of group compositions in the population. For special families of payoff matrices, we characterize the long-time behavior of solutions of our equation, with particular emphasis placed on understanding the average and most frequent group compositions at steady state.

When average payoff of groups is maximized by all-cooperator groups, the average and most abundant group composition at steady state range from featuring all-defector groups when individual-level selection dominates to featuring all-cooperator groups when group-level selection dominates. When groups are most fit with a mix of cooperators and defectors, then the average and most abundant group compositions always feature a smaller fraction of cooperators than required for the mix optimizing group payoff, even in the limit where group-level selection is infinitely stronger than individual-level selection.

In such cases, the conflict between the two levels of selection cannot be decoupled, and we even observe cases in which cooperation cannot be sustained even when between-group competition favors perfect coexistence of cooperators and defectors.

A Bursting Neuron CPG Model: Phase Reduction, Dynamical Mechanisms, and Gait Transitions
Contributed talk. 9:40 a.m.–10:00 a.m.
Zahra Aminzare, *University of Iowa.*
Co-authors: Vaibhav Srivastava, *Michigan State University*; Philip Holmes, *Princeton University.*

Insects are capable of complex walking gaits in which various combinations of legs can be simultaneously in stance and swing. It has been observed that fast running insects employ a tripod gait with three legs lifted off the ground simultaneously in swing, while slow walking insects use a tetrapod gait with two legs lifted off the ground simultaneously. Fruit flies use both gaits and exhibit a transition from tetrapod to tripod at intermediate speeds. Our goal is to understand the effect of stepping frequency on transitions between these gaits in an ion-channel bursting neuron model in which each cell represents a hemi-segmental thoracic circuit of the central pattern generator. Employing phase reduction and bifurcation theory, we study the existence and stability properties of tetrapod, tripod and transition gaits, analytically. We support our theory by showing two sets of data fitted to freely walking fruit flies.

Controlling Populations of Neural Oscillators
Invited talk. 10:40 a.m.–11:15 a.m.
Jeff Moehlis, *University of California, Santa Barbara.*

Some brain disorders are hypothesized to have a dynamical origin; in particular, it has been been hypothesized that some symptoms of Parkinson's disease are due to pathologically synchronized neural activity in the motor control region of the brain. This talk will describe several different approaches for desynchronizing the activity of a group of neurons, including maximizing the Lyapunov exponent associated with their phase dynamics, optimal phase resetting, controlling the phase density, controlling the population to have clustered dynamics, and leveraging machine learning algorithms. It is hoped that this work will ultimately lead to improved treatment of Parkinson's disease via targeted electrical stimulation.

Tuning Adaptive Evidence Accumulation in Stochastically Switching Environments
Contributed talk. 11:15 a.m.–11:35 a.m.
Zachary P. Kilpatrick, *University of Colorado Boulder.*

Co-authors: Nicholas W. Barendregt, *University of Colorado Boulder*; Krešimir Josić, *University of Houston*

In a constantly changing world, decision making requires adaptive evidence accumulation. Old information becomes less relevant as the environment changes more rapidly. We have used Bayesian methods to model how an ideal observer accumulates evidence in dynamic environments. We focus on binary choice tasks in which an observer must report the state of a continuous time Markov process that they observe noisily. The continuum limit of these models are nonlinear stochastic differential equations. Noise from observations is modeled by a Wiener process, and stochastic switches generate dichotomous noise. Ideal observers discount old evidence nonlinearly at a rate tuned to the environmental timescale. These models provide insight into how organisms can robustly implement adaptive evidence-accumulation to make accurate decisions in dynamic environments.

To jointly characterize observation noise and stochastic switching, we derive Chapman-Kolmogorov equations which associate the observer's belief (log-likelihood ratio) and the present state (correct choice) with two separate random variables. We then project the system to a jump-diffusion model in which the jumps correspond to state switches. The model can be integrated to determine how accurately an observer's belief represents the underlying state. We also compare the ideal observer model to approximate models that can be analyzed asymptotically, including a model with linear leak and a leak-less model with upper bounds on the observer's belief. Interestingly, both models can be tuned to have accuracy nearly identical to the optimal model, but they are sensitive to changes in their evidence discounting parameters. There are in fact several models whose performance is close to that of an ideal observer. Such heuristics may thus approximate the evidence accumulation strategies biological organisms employ in dynamic environments, as they manage a trade-off between accuracy and complexity.

Data Driven Machine Learning Approaches to Monitor and Predict Events in Healthcare. From Population-level Disease Outbreaks to Patient-level Monitoring

Invited talk. 11:35 a.m.–12:10 a.m.
Mauricio Santillana, *Harvard University.*

I will describe data-driven machine learning methodologies that leverage Internet-based information from search engines, twitter microblogs, crowd-sourced disease surveillance systems, electronic medical records, and weather information to successfully monitor and forecast disease outbreaks in multiple locations around the globe in near real-time. I will also present data-driven machine learning methodologies that leverage continuous-in-time information coming from bedside monitors in Intensive Care Units (ICU) to help improve patients' health outcomes and reduce hospital costs.

Lunch, 12:10 p.m.–2:00 p.m.

Afternoon talks, 2:00 p.m.–5:35 p.m.

Flash Talk Session B

Flash talks. 2:00 p.m.–2:50 p.m.
See poster abstract booklet for full abstracts.

B4: Snakes and Lattices: Understanding the Bifurcation Structure of Localized Solutions to Lattice Dynamical Systems
Jason Bramburger, *Brown University*

B6: When Is One Variable Enough to Reconstruct a Dynamical System?
Tom Carroll, *US Naval Research Lab*

B11: Encoding of Multimodal Sensory Information in a Sensorimotor System
Rosangela Follmann, *Illinois State University*

B16: A Minimal Mathematical Model For Free Market Competition Through Advertising
Joseph D. Johnson, *Northwestern University*

B19: Sliding on Moving Strings: From Regular Motions to Nonlinear Resonances and Chaos
Steven R. Knudsen, *West Virginia University*

B22: Variable Cutting-and-Shuffling to Enhance Mixing
Paul B. Umbanhowar, *Northwestern University*

B24: Machine-learning Inference of Variables of a Chaotic Fluid Flow From Data Using Reservoir Computing
Kengo Nakai, *University of Tokyo*

B25: Quasi-Periodicity to Period-Doubling of Parallel-Input/Parallel-Output Buck-Boost DC-DC Converter
Ammar Nimer Natsheh, *Higher Colleges of Technology; Dubai Women's College*

B29: Complex Contagion Leads to Complex Dynamics in Models Coupling Behavior and Disease
Matthew T. Osborne, *The Ohio State University*

B30: Stability of Multi-pulse Solutions to Nonlinear Wave Equations
Ross Hamilton Parker, *Brown University*

B32: Drainage Through Holes Drives Arctic Sea Ice Melt Ponds to the Critical Percolation Threshold
Predrag Popovic, *University of Chicago*

B37: Koopman Operator and Its Approximations For Dynamical Systems with Symmetries
Anastasiya Salova, *University of California, Davis*

B39: Bayesian Parameter Estimation in the Spatial Organization of Metabolism
Sasha Shirman, *Northwestern University*

~~**B42: New amplitude equations for ocean waves**~~
~~Jim Thomas, *Dalhousie University and Woods Hole Oceanographic Institution*~~

B46: Emotions Predict Presidential Voting Choices
Vicky Chuqiao Yang, *Santa Fe Institute*

Data-driven Dynamic Models in Neuroscience
Invited talk. 2:50 p.m.–3:25 p.m.
Bingni W. Brunton, *University of Washington.*

Discoveries in modern neuroscience are increasingly driven by quantitative understanding of complex, dynamic data. The work in my lab lies at an emerging, fertile intersection of brain, behavior, and data-driven models. Discovering principles of neural computation is of fundamental importance in biology: How does a collection of neurons and their interconnections give rise to such richness and flexibility of function? I will describe several projects in my lab that develop data-driven analytic methods that are applied to, and are inspired by, functions and dysfunctions of biological nervous systems.

Spatio-temporal Dynamics of Swarm Robotic Systems
Invited talk. 4:05 p.m.–4:40 p.m.
Andrea L. Bertozzi, *University of California, Los Angeles.*

The cohesive movement of a biological population is a commonly observed natural phenomenon. With the advent of platforms of unmanned vehicles, such phenomena have attracted a renewed interest from the engineering community. This talk will cover a survey of the speakers research and related work in this area ranging from aggregation models in nonlinear partial differential equations to control algorithms and robotic testbed experiments. One particular recent example is the control of a robotic swarm with limited sensor information to cover a crop field in the case of artificial pollination. Another such example are the drone shows that entertain audiences with synchronized lights in the sky.

Long Term Stability of the Low-dimensional Dynamics of Neural Population Activity Associated with the Consistent Execution of Learned Behavior
Contributed talk. 4:40 p.m.–5:00 p.m.
Sara A. Solla, *Northwestern University.*
Co-authors: Juan A. Gallego, *Spanish National Research Council*; Matthew G. Perich, *University of Geneva*; Raeed H. Chowdhury, Lee E. Miller, *Northwestern University.*

For learned actions to be executed reliably, the cortex must integrate sensory information, establish a motor plan, and generate appropriate motor outputs to muscles. Animals, including humans, perform such behaviors with remarkable consistency for years after acquiring a skill. How does the brain achieve this stability? Is the process of integration and planning as stable as the behavior itself? We explore these fundamental questions from the perspective of neural populations and investigate the hypothesis that neural dynamics associated with specific behaviors are preserved across time.

Recent work suggests that neural function may be built on the activation of population-wide activity patterns, the neural modes, rather than on the independent modulation of individual neurons. These neural modes, the dominant co-variation patterns within the neural population, define a low dimensional neural manifold that captures most of the variance in the recorded neural activity. We refer to the time-dependent activation of the neural modes as their latent dynamics. We hypothesize that the ability to perform a given behavior in a consistent manner requires that the latent dynamics underlying the behavior also be stable.

We present a method to examine the long term stability of the latent dynamics despite unavoidable changes in the set of neurons recorded via chronically implanted microelectrode arrays. We address the question of stability using the sensorimotor system as a model of cortical processing, to find remarkably stable latent dynamics for up to two years across three cortical regions, despite ongoing turnover of the recorded neurons. The stable latent dynamics, once identified, allows for the prediction of various behavioral features, using models whose parameters remain fixed throughout these long timespans. We posit that latent cortical dynamics within the manifold are the fundamental and stable building blocks underlying consistent behavioral execution.

The Dynamics of Malaria Infection
Invited talk. 5:00 p.m.–5:35 p.m.
Lauren Childs, *Virginia Tech.*

Each year, around 200 million people acquire infections with a malaria parasite and nearly 500,000 die as a result. Since the early 1900s, when Ronald Ross used mathematics to show that targeting adult mosquitoes would be the most effective means to combat vector-borne infectious disease, mathematical modeling has been a key tool in the study of and intervention against malaria. With recent enhanced control efforts, many countries are moving towards malaria elimination, perturbing the level of acquired immunity and natural protection across the population. In this talk, we examine the role of multiple scales – the within-host dynamics of the malaria parasite's interaction with the host immune response along with population-level transmission – on malaria burden and the ability to control the spread of disease. The changing landscape of malaria is further complicated by environmental variability, parasite heterogeneity, and human behavior. These complexities underline the need for additional computational and mathematical tools.

Sunday, Jan. 6

Morning talks, 8:45 a.m.–12:10 p.m.

Understanding the Deformation and Buckling of a Bicycle Wheel Through Modeling and Experiments
Invited talk. 8:45 a.m.–9:20 a.m.
Oluwaseyi Balogun, *Northwestern University.*

The tension-spoked bicycle wheel is an example of a tensegrity structure that achieves structural stability through the interplay between the slender spokes held in tension and the rim in compression. Under an applied external compressive load, the spoke tension decreases to accommodate the load without leading to the collapse of the rim. The tensegrity architecture is also responsible for the establishment of force balance and shape stability in other structural systems like the Ferris Wheel and filamentous actin biopolymers. In this lecture, I will review recent work aimed at understanding the principles behind the deformation and stability of tension-spoked wheels under external forces. By modeling the tensioned-spoked wheel as a symmetric elastic beam anchored by uniaxial elastic truss elements to a rigid foundation, a theoretical framework is established to predict the deformation, elastic stiffness, and the buckling spoke tension. Experimental measurements designed to obtain important model inputs and to valid the model will also be discussed.

Mechanisms Driving Period-Doubling Bifurcations in Spiral Waves
Contributed talk. 9:20 a.m.–9:40 a.m.
Stephanie Dodson, *Brown University.*
Co-author: Bjorn Sandstede, *Brown University.*

Spiral waves patterns seen in cardiac arrhythmias and chemical oscillations develop alternans and line defects. These instabilities that can be thought of as period-doubling bifurcations. We seek to understand how and why alternans and line defects develop. To investigate these questions, we analyze spectral properties of spirals formed in reaction-diffusion systems on bounded disks. We find that the mechanisms driving the instabilities are quite different—alternans are driven from the spiral core, whereas line defects appear from boundary effects. Moreover, the shape of the alternans eigenfunction is due to the interaction of a point eigenvalue with curves of continuous spectra.

Earth's Excitable Carbon Cycle
Invited talk. 9:40 a.m.–10:15 a.m.
Daniel H. Rothman, *Massachusetts Institute of Technology.*

The history of the carbon cycle is punctuated by transient changes in the ocean's store of carbon. Mass extinction is always accompanied by such a disruption, but most disruptions are relatively benign. The less calamitous group exhibits a characteristic carbon flux whereas greater surges accompany mass extinctions. Analysis of a two-component dynamical system suggests that disruptions are initiated by perturbation of a permanently stable steady state beyond a threshold. The ensuing excitation exhibits the characteristic surge of real disruptions. In this view, the excitation threshold and the characteristic flux are properties of the carbon cycle itself rather than its perturbation. Surges associated with mass extinction, however, require additional inputs from external sources such as massive volcanism. Modern inputs from anthropogenic emissions may exceed the excitation threshold during the present century.

Complexity Science to Study Macroscopic Dynamics in Traffic and Behavioral Patterns
Invited talk. 10:55 a.m.–11:30 a.m.
Marta Gonzalez, *University of California, Berkeley.*

I present a review on research related to the applications of big data and information technologies in urban systems. Data sources of interest include: Probe/GPS data, Credit Card Transactions, Traffic, and Mobile Phone Data. I present a multi-city study to unravel traffic under various conditions of demand and translate it to the travel time of the individual drivers. First, we start with the current conditions, showing that there is a characteristic time that takes to a representative group of commuters to arrive to their destinations once their maximum density has reached. While this time differs from city to city, it can be explained by the ratio of the vehicle miles traveled to their available street capacity. We identify three states of urban traffic, separated by two distinctive transitions. In the second part, I present Computational Social Science methods that use Credit Card Transactions to Uncover different habits on social groups, based on their mobility, their communication and daily purchases. Finally, I suggest how to use these methods to enhance the behavioral changes and recommendations in Social Networks to improve Cities.

Emergence of Laplace-Distributed Growth Rates in Network Dynamics
Contributed talk. 11:30 a.m.–11:50 a.m.
Sean P. Cornelius, *Northeastern University.*
Co-author: Chia-Hung Yang, *Northeastern University.*

The state of a complex system is rarely stationary in time, often exhibiting fluctuations that are sufficiently erratic so as to seem random. Curiously, empirical studies on annual fish catches, bird flock sizes, and company profits have revealed that the year-to-year growth rates of many systems follow a Laplace (or double-exponential) distribution, which is characterized by a higher probability of extreme fluctuations relative to the Gaussian statistics predicted by typical null models. Yet despite the prevalence of Laplacian growth rates in diverse systems, a mechanistic explanation of their origin has been elusive. Here we show that Laplacian growth statistics emerge generically from the interplay between two features ubiquitous in real dynamical systems: multistability and noise. We demonstrate that these factors conspire to allow frequent transitions between the basins of attraction of the underlying deterministic nonlinear system–leaps which broaden the tails of the system's growth rate distribution relative to that produced by a hypothetical random walk. Our findings suggests that "boom and bust" behavior may be the rule rather than the exception in real-world dynamical systems, with implications for problems from ecosystem management to financial system stability.

Synchronous Clustering in Multilayered Networks

Contributed talk. 11:50 a.m.–12:10 p.m.

Louis M. Pecora, *Naval Research Lab.*

Co-authors: Fabio Della Rossa, Abu Bakar Siddisque, Francesco Sorrentino, Karen A. Blaha, Ke Huang, Mani Hossein-Zadeh, *U. New Mexico.*

The topic of cluster synchronization of oscillators in networks has an active history and has recently experienced renewed interest in the nonlinear dynamics community because of the use of such graph theory tools as symmetries and equitable partitions to predict what cluster structures are possible, calculate their dynamic stability, and characterize their bifurcations as they desynchronize. Another recent network structure that has caught the interest of the dynamics community is multilayered networks. We show how to extend the graph theory tools to multilayered networks. Certain multilayered networks have a structure that allows their dynamics to be simplified and fit into the existing structure of analysis of synchronous clusters. We also present a recent experiment on a simple 4-oscillator multilayer system. We show what can be discerned from experimental data including bifurcation plots and desynchronization patterns. This is the first experiment on cluster synchronization that we know of that uses totally analog oscillators with no computer-aided control of the oscillators. We also will discuss how some of the concepts can be generalized.

Lunch, 12:10 p.m.–2:00 p.m.

Afternoon talks, 2:00 p.m.–4:55 p.m.

The Dynamics of Acoustically Levitated Granular Matter

Invited talk. 2:00 p.m.–2:35 p.m.

Heinrich M. Jaeger, *University of Chicago.*

Co-authors: Melody X. Lim, *University of Chicago*; Anton Souslov, *University of Bath, UK*; Vincenzo Vitelli, *University of Chicago.*

Granular matter is often used as a testbed to access the physics of athermal clustering and assembly. However, a full understanding of the role of attractive interactions in the formation of such clusters has remained elusive, in large part due to the lack of experimental methods that produce tunable attractive interactions between macroscopic particles. We address this by introducing a powerful new approach based on acoustic levitation, whereby particles are "floating" in a potential energy landscape generated by ultrasound. Importantly, the very same acoustic driving also generates particle-particle interactions through scattering, which we use to establish tunable attractive forces. This makes it possible to remove the effect of gravity, to manipulate particles and assembly them into clusters or even large sheets, and also to introduce active fluctuations. This talk will discuss some recent results that highlight the rich dynamics arising from the interplay of sound-mediated attractions and active fluctuations in acoustically levitated granular systems.

Heat Dissipation For Synchronization of Coupled Oscillators

Contributed talk. 2:35 p.m.–2:55 p.m.

Hyunsuk Hong (홍현숙), *Chonbuk National University, Korea.*

Co-authors: Junghyo Jo (조정효), *Keimyung University*; Changbong Hyeon (현창봉), Hyunggyu Park (박형규), *KIAS.*

We consider a system of coupled oscillators acting under thermal noise, and explore the synchronization behavior, in relation with thermodynamics. Specifically, we pay attention to the heat dissipation when the system reached the synchronized state. We derive the heat analytically, and examine its critical behavior near the synchronization transition. We found that the heat dissipation decreases as more and more oscillators join the synchronized group. Temporal fluctuation of the heat is also examined, by finding its probability distribution function.

Chiral Active Matter

Invited talk. 2:55 p.m.–3:30 p.m.

Vincenzo Vitelli, *University of Chicago.*

Active materials are composed of interacting particles individually powered by motors. In this talk, we focus on chiral active fluids and solids that violate parity and time reversal symmetries. First, we discuss a dissipationless viscosity that is odd under each of these symmetries and controls the non-linear hydrodynamics of compressible fluids of active rotors. Next, we show how this odd viscosity has a dramatic effect on topological sound waves in chiral fluids, including their number and spatial profile. Finally, we present a continuum mechanics that we dub Odd Elasticity, that breaks the major symmetry of the elastic tensor and thereby allows for the treatment of chiral active solids for which no elastic free energy can be defined. Physical realizations include metamaterials composed of active metabeams with internal torques that adapt to the compression or extension of the beam. Our work revisits the foundations of continuum mechanics, and provides a path towards the construction of materials that convert internal activity into useful mechanical work.

The Hidden Dynamics of Static Contact and Static Friction
Contributed talk. 4:00 p.m.–4:20 p.m.
Sam Dillavou, *Harvard University.*
Co-author: Shmuel M. Rubinstein, *Harvard University.*

The interface between two solid, static bodies is in fact extremely dynamic. This is true for a vast range of scales, from thousand-kilometer tectonic faults to sub-millimeter-scale contacts, and in nearly all materials, from rock to plastic to paper to metal. Due to small-scale roughness, even seemingly flat interfaces actually consist of sparse, scattered contact points, which comprise only a few percent or less of the interfacial area. These contact points vary in shape and size, exist under extreme pressures, and form an ensemble that evolves continuously in time.

We measure the evolution of this contact ensemble, and demonstrate that these multi-contact interfaces (MCIs) store a memory of the pressures they experienced. Unlike simple relaxation, e.g. a spring and dashpot system, which depends only on its current state, MCIs evolve according to their entire loading history. Their evolution closely resembles the slow relaxations of a class of disordered and glassy systems that includes crumpled paper, elastic foams, polymer glasses, granular piles, and more. In fact, using a model built for these seemingly unrelated systems, we are able to reproduce the observed interfacial dynamics; putting two solids in contact generates a new glassy system.

The frictional strength of an interface is dictated by its real area of contact. Thus, these new glassy behaviors have significant implications for systems like tectonic faults. Furthermore, by exploiting these memory effects we shed light on the heterogeneous nature of frictional interfaces, and identify regions of an interface that are most influential in nucleation of slip (earthquake!) without observing the rupture itself.

Stable Chimeras and Independently Synchronizable Clusters in Coupled Oscillator Networks
Invited talk. 4:20 p.m.–4:55 p.m.
Takashi Nishikawa, *Northwestern University.*

Cluster synchronization in a network of coupled oscillators is a phenomenon in which the network self-organizes into a pattern of synchronized sets. It has been shown that diverse patterns of stable cluster synchronization can be captured by symmetries of the network. Here, we establish a theoretical basis to divide an arbitrary pattern of symmetry clusters into independently synchronizable cluster sets, in which the synchronization stability of the individual clusters in each set is decoupled from that in all the other sets. Using this framework, we suggest a new approach to find permanently stable chimera states by capturing two or more symmetry clusters — at least one stable and one unstable — that compose the entire fully symmetric network.