Dynamics Days US 2024 Presentation Titles & Abstracts

UC Davis – January 8-10, 2024

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Poster Presentations

The abstracts are in alphabetical ordered.

Oscillatory and chaotic synchronization behavior in coupled oscillator systems with higher order interactions, community structure, and phase lags.
Sabina Adhikari, University of Colorado Boulder

Despite the prevalence of higher order interactions, phase lags, and community structure in many complex systems, their combined effects in synchronization processes remain unexplored. In this study, we consider coupled oscillator systems with higher order interactions mediated via hyperedges of size 2 (links) and size 3 (triangles), two communities, and identical phase lags between every interacting oscillator group. For some phase lags values, the system exhibits oscillatory and chaotic synchronization behavior, which is not present when only higher order interactions and community structure, or community structure and identical phase lags, are included. For other phase lag values, we observe synchronized states with in-phase, anti-phase and skew phase communities, and incoherent-synchronized states. These results are supported by analytical equations derived using the Ott-Antonsen ansatz and numerical simulations.

Structure and patterns of one-dimensional spin lattice models
Omar Aguilar, University of California Santa Cruz

Bridging ideas from information theory and automata theory, computational mechanics has been proven to be a powerful theory for quantifying and providing a mechanistic account of structure in physical systems. The former task is achieved by calculating information measures such as excess entropy and statistical complexity while the latter is achieved by deriving abstract machines known as ϵ-machines. Notably, this theory has been successfully applied to unravel structure in the one-dimensional (1D) nearest neighbor (nn) and next nearest neighbor (nnn) Ising models as a function of physical parameters such as temperature, external magnetic field and interaction couplings. However, the lack of a concise explanation and readily available code for implementing computational mechanics in the Ising model setting has limited its extension to other spin models and further exploration of the connection between computational and statistical mechanics. We take three key steps to overcome these challenges. First, we provide a clear and concise explanation of computational mechanics' application to the nn and nnn Ising models. Additionally, this work includes a package for computing structure information measures and epsilon-machines of these toy models. Second, the techniques are then extended to diverse spin models, including finite range Ising, solid-on-solid, and three-body models. Third, the study enhances the connection between computational and statistical mechanics by incorporating more specialized information measures and generating typical spin patterns as temperature, external magnetic field and interaction couplings evolve.

Hybridizing Traditional and Next-Generation Reservoir Computers to Accurately Forecast Complex Dynamics
Dael Amzalag, University of Chicago

Forecasting the dynamics of complex systems based on past history is a challenging task with many important applications. Two schemes that have been shown to produce impressive predictions with low computational cost are reservoir computers (RCs) and Next-Generation Reservoir Computers (NGRCs). Both approaches involve the creation of an input-output transformation that involves observing the dynamics of the complex system during a training period, transforming this input to some useful representation vector, and finding a linear combination of the vector's components that best replicates the desired output, i.e, the state of the complex system at the next time step. In RCs, the representation vector consists of the states of a recurrent neural network constructed with fixed, random connections between the input and the neurons and between the neurons themselves. In NGRCs, the representation vector is obtained by concatenating linear combinations of the present and previous input state variables with nonlinear combinations of the same. Testing on model systems, we find that a hybrid model combining an RC and an NGRC can provide significant improvements in near-term forecasts and better capture the long-term behavior of the system, compared with either an RC or an NGRC individually.

Generation of Novel Chord Progressions via a Musically-Inspired Chaotic Mapping
Zach Atkins, University of Colorado Boulder

We present a novel approach to generating chord progressions that does not rely on existing compositions, complex rules, or human input. Instead, we utilize a chaotic mapping onto a set of symbols to generate chord progressions. The symbols and their arrangement are determined by the Tonnetz, a representation of musical pitches as vertices on a doubly-periodic simplex mesh. The triangular faces of this mesh represent triads, which are collections of three pitches. We employ the nonlinear double pendulum as the chaotic attractor of interest due to its two loosely-coupled periodic degrees of freedom. By mapping a given trajectory onto the Tonnetz, we determine the sequence

in which each triangle on the mesh is visited, which in turn generates the chord progressions. Our experimental results demonstrate that the resulting chord progressions exhibit strong voice leading and low perceptual distance, as measured by metrics that correlate with positive listening experiences.

An Information-Theoretic Model for Firefly Flash Pattern Evolution
Nicholas Barendregt, University of Colorado Boulder

To achieve collective goals, groups of agents must develop effective methods of communication to share information and preferences with other agents. While these interactions are fundamental to any complex system's dynamics, how such communication strategies evolve over time remains an open scientific question. One particularly difficult aspect of quantitatively modeling these dynamics is the complex, multimodal communication signals utilized by most well-studied organisms. In this work, we will study the emergence of adaptive communication strategies using fireflies as a model system, a well-documented organism with visually identifiable communication signals that can be well-approximated as binary vectors. By assuming fireflies face evolutionary pressures based off of both the risk/metabolic cost of their flash and the identifiability of an individual's species flashes, we construct an information-theoretic model for flash pattern fitness, and propose an evolutionary algorithm that solves the stochastic optimization problem to maximize this fitness. Our work demonstrates how variability arises in firefly flash patterns and shows how a normative framework can give rise to flash pattern distributions we can observe in nature.

Rich dynamics in a modified vertex copy model motivated by protein-protein interaction networks
Leopold Bilder, Northwestern University

Models of network growth based on vertex copying provide insights into key mechanisms behind the evolution of a variety of natural and man-made systems, from protein-protein interaction networks to social systems and the world wide web [1,2]. In the simplest versions of the vertex copy model, the network evolution is determined by a single parameter p, which defines the probability of a new node forming an edge to each neighbor of its randomly selected parent. Despite its simplicity, the model exhibits some striking properties, such as the transition from a sparse to a dense regime and large fluctuations between different network realizations at p¿1/2. Existing vertex copy models are routinely used to capture protein-protein interaction networks, although there are two distinct types of proteins: those who can link to themselves (self-linking nodes, forming homomers), and those who cannot. Here, we show that this simple distinction has profound effects on the network topology as well as the statistical properties of self-linking and non self-linking nodes, such as their average degrees, degree distributions, and clustering. To capture this complex structure, we introduce a vertex copy model with self-linking nodes: if the parent of the node is self-linking, its child can inherit the self-linking property with probability p, and can connect to the parent node with the same probability. Using a combination of simulations and analytic techniques, we explore the properties of the model, such as the evolution of the average number of edges between nodes of different types, number of disconnected nodes of each type, and degree distributions of self-linking and non-self linking nodes. Our model opens up new opportunities towards gaining insights into the structure and evolutionary origin of biological networks. Simultaneously, its properties such as sensitivity to initial conditions at large values of p lead to interesting theoretical questions, such as quantifying chaotic dynamics of network evolution.

[1] Ispolatov, I., Krapivsky, P. L., & Yuryev, A. (2005). Duplication-divergence model of protein interaction network. Physical Review E, 71(6), 061911.

[2] Bhat, U., Krapivsky, P. L., Lambiotte, R., & Redner, S. (2016). Densification and structural transitions in networks that grow by node copying. Physical Review E, 94(6), 062302.

Chaos is not rare in plant seed production
Joe Brennan, University of California, Davis

Recent work has shown that chaos is not rare in animal populations. Theoretical models have shown that mast seeding plant populations, characterized by synchronous and highly variable seed production, can exhibit chaotic population dynamics. However, unlike animal populations, no previous studies have tested if strange attractors generally characterize time series of plant seed production. By employing a non-parametric chaos detection algorithm on over 400 time series of mast seeding populations, we find that about 28% of populations exhibit chaotic population dynamics. Subsequently, we explore if various attributes of chaotic systems (i.e., Lyapunov exponent, embedding dimension, time delay) are associated with geographic features such as latitude, longitude, and elevation, and biological traits of populations such as pollination and dispersal syndrome. For a subset of plant species, we analyzed individual-level time series of seed production. For these species, 42.5% of individuals' seed dynamics exhibit chaos while only 29% of their corresponding populations do. This result is consistent with theoretical models of mast seeding, which are based on feedbacks at the individual level that are only sometimes synchronized among individuals within populations. In summary, we show that chaos is not rare in mast seeding populations, having significant implications on the management of these populations. We hope that this study encourages researchers to incorporate plant population dynamics in future studies of chaotic ecological systems, moving beyond studies focused solely on animal populations.

Cardinality of collisions in the asymptotic phase-locking for the Kuramoto model with inertia
Hangjun Cho, University of Washington

In this talk, we study the cardinality of collisions between Kuramoto oscillators in the (asymptotic) phase-locking process in the presence of inertia. In the absence of inertia, it has been known that the finiteness of collisions between oscillators is equivalent to the emergence of phase-locking. Thus, a natural question is whether this finiteness result is still valid for the Kuramoto model with inertia or not. In a small inertia regime, we show that the finiteness of collisions is also equivalent to phase-locking like the Kuramoto model. In contrast, in a large inertia regime, we show that homogeneous Kuramoto ensemble with the same natural frequency can reach phase-locking, while there are a countable number of collisions between oscillators. This is the contrasted effect of a large inertia in phase-locking process. This work is based on the joint work with Jiu-Gang Dong and Seung-Yeal Ha.

How large flocks of birds turn: Insights from simulations
Maxfield Comstock, Georgia Institute of Technology

Flocks of tens of thousands of starlings, known as murmurations, perform fast coordinated aerial maneuvers that exhibit complex, dynamic patterns while maintaining group cohesion. While this behavior is believed to arise from the interactions between individuals, the underlying mechanism is not well-understood. Existing flocking models, although typically applied to small flock sizes on the order of a hundred, provide a natural starting point for modeling these dynamics. To evaluate the suitability of these models for reproducing murmurations, we have implemented several existing flocking models in a GPU-accelerated flocking simulation which is capable of running in near real-time for tens of thousands of birds. In particular, we test these models on the case of turning, where field studies have shown that a small number of individuals are able to rapidly change the direction of the entire flock. We find that classical flocking models are not able to capture this behavior, as large flocks either fail to turn or break into separate groups going different directions. However, an approach of modeling birds as control agents using a model predictive control scheme leads to successful turns for large and small flocks. In addition to the correct choice of model, other elements of the simulation are vital to achieve flocking behavior that scales up to realistic murmuration sizes. One example is that, in order for the acceleration required for a turn to propagate through the flock, birds must prioritize their alignment with other birds undergoing greater acceleration. We conclude that models which produce seemingly realistic behavior for small flocks may not be suitable for modeling large flocks under realistic conditions. On the other hand, the model predictive control formulation may represent a promising starting point for modeling the unique behaviors of large bird flocks such as murmurations.

Computing Ionization Rates from Periodic Orbits in Chaotic Rydberg Atoms
Ethan Custodio, UC Merced

When placed in parallel magnetic and electric fields, the electron trajectories of a classical hydrogenic atom are chaotic. The classical ionization rate of such a system can be computed with brute force Monte Carlo techniques, but these computations require enormous numbers of trajectories, provide little understanding of the dynamical mechanisms involved, and must be completely rerun for any change of system parameter, no matter how small. We demonstrate an alternative technique to classical trajectory Monte Carlo computations, based on classical periodic orbit theory. In this technique, ionization rates are computed from a relatively modest number, perhaps a few thousand, of periodic orbits of the system. One only needs the orbits' periods and stability eigenvalues. A major advantage is that as system parameters are varied, one does not need to repeat the entire analysis from scratch; one can numerically continue the periodic orbits as the parameters are varied. We demonstrate the periodic orbit technique for the ionization of a hydrogen Rydberg atom in applied parallel electric and magnetic fields.

Exploring (a, b)-Chaos: New Insights into Topological Dynamical Systems and Undecidability
Mauricio Díaz, Universidad del Bío Bío

This presentation introduces a new level of chaos, known as (a, b)-chaos, extending the established model for pairs of *Furstenberg Families* (specifically, $\overline{M}(a)$ and $\overline{M}(b)$, where $\overline{M}(x)$ represents the upper-density family for $0 \leq x \leq 1$). This explores two key levels: the inner chaos, where a and b are limited to the range of 0 to 1, and the bounded chaos, necessitating one value in the pair to be 0 or 1. These levels significantly expand the understanding of properties such as chaos in the sense of Li-Yorke and distributional chaos, utilizing upper and lower-density features. Moreover, an illustrative example of a cellular automaton is proposed to meet these criteria. This study aims to demonstrate how these levels effectively exhibit undecidability within these systems while retaining an uncountable scrambled property within each pair, offering new insights into the dynamics of chaotic systems.

Predicting and Explaining Thermohaline Flow Using Deep Learning
Simon Dräger, University of California, Davis

The Atlantic meridional overturning circulation (AMOC) is key to climate by transporting heat from tropical regions northward, regulating part of Europe's and the US East Coast's climate. Among its emergent behavior are tipping points with abrupt collapses that become more likely under climate change. Machine learning (ML) is increasingly being used to predict and understand changes under global heating, but research crucially does not include quantification of uncertainty or the assessment of whether the ML model learned the true dynamics of the underlying system or just spurious correlation structures. The ML black box problem is pressing across all fields adopting ML.

We use data from a model that approximates the AMOC using two boxes driven by an external forcing (e.g., fresh water or heating), as well as changes in temperature and salinity. This system of linear PDEs yields an emergent tipping point behavior and exhibits an attractor structure with 3 basins, consistent with the real-world AMOC. Through nonstationarity forcing a 'global heating' can be simulated. We consider both predicting AMOC on the basis of a past time series, as well as from time series of the forcing, salinity and temperature.

In order to estimate the uncertainty in predicting the AMOC with ML, we use several deep learning approaches that are capable of quantifying uncertainty. These include training many networks and averaging the results (ensembling) which we find to be able to capture the underlying system's dynamics, revealing what parts of the AMOC's behavior are most uncertain under different climate scenarios. Overall, we find a Bayesian approach to be more certain but having overall poorer predictive performance.

We generate explanations for the models' predictions using methods from explainable AI (XAI) to move beyond the black box. Predicting AMOC from the previous time series, the ML model learned the appropriate correlation structure consistent with theory. Predicting AMOC with the model components, the ML model also successfully made conjunctures consistent with the model configuration. Both cases captured the tipping point behavior, but especially under non-stationary forcing the magnitudes of the other states was poorly estimated. Our work suggests that ML models show promise for climate application, but that great care must be taken with increasing nonlinearity and complex future forcing projections.

From theory to experiment: construction and dynamics of a network nano-electro-mechanical oscillators
Scott Habermehl, Kavli Nanoscience Institute, California Institute of Technology

Networks of coupled nonlinear oscillators exhibit complex spatiotemporal dynamics which are fundamental to the operation of numerous natural and engineered systems, ranging from the human brain to the North American power grid. However, current laboratory experiments for studying these systems lack the necessary rigor for a deep exploration of the parameter space and, thus, have only examined a tiny slice. To address this, our group is currently building an experimental network of 8 nonlinear oscillators with highly controllable nodes (oscillators) and edges (couplings). In this talk, I will briefly review the underlying technology, nano-electro-mechanical systems (NEMS), and its relevant nonlinear dynamics. Then, I will discuss our efforts to combine oscillator networks, the tools of dynamical systems theory, and machine learning to understand how complex nonlinear systems are able to process information. In particular, we have numerically examined how the dynamics of a coupled oscillator network at a fixed point of synchronization can be used for reservoir computing. I will detail some these results and exhibit how they can be directly mapped to our experimental system.

The effects of electrical brain stimulation pulse sequence on dopamine release dynamics
Minh Duc Hoang, UC - DAVIS

The dopamine system plays an important role in arousal, movement, memory, and reward-related behavior. Deep brain stimulation (DBS) is an important tool for the causal investigation of neural circuits and is commonly used to treat conditions such as Parkinson's disease and depression. Traditionally, DBS has been applied using fixed inter-pulse interval stimulation at a given frequency, however, neural circuits are often more responsive to variable input. In collaboration with the experimental labs of Cowen and Heien labs at the University of Arizona, we examine how the timing structure of brain stimulation affects dopamine release in the nucleus accumbens. We find that the model of Montague et al., which includes two independent short-term adaptive processes that modulate dopamine release, captures the experimentally measured fluctuations in dopamine delivery over short periods with minimal tuning of parameters. We analyze the Montague et al. model to identify the dynamical and biophysical mechanisms underlying the dependence of dopamine release of stimulation properties. Specifically, we show how the stimulus properties interact with synaptic dynamics (i.e., facilitation and depression processes) and dopamine uptake dynamics to give rise to nonlinear low-pass filtering properties and threshold behavior for dopamine accumulation in the synaptic cleft. Our results provide insight into stimulus protocols that optimize the amount of Dopamine release, which in turn could lead to improved stimulus protocol for DBS and the treatment of Parkinson's and other diseases.

Comparing the Availability of ODE Solvers in R, Python, and MATLAB
Md Mazharul Islam, University of Nevada, Reno

I will present an overview of Ordinary Differential Equation (ODE) solvers available across three popular computing platforms: MATLAB, Python, and R. The ultimate goal is to create a comparative summary of the different ODE solvers available in each environment, and the types of ODE problem for which each was intended. This summary serves two purposes: first, to provide guidance for students and researchers who seek to select the most appropriate method for a given application; and second, to identify and highlight any gaps in the available methods to guide software developers in better meeting the needs of their users. This is a work in progress, and we welcome feedback from the Dynamics Days attendees regarding how well their current ODE solver needs are met by these and other computing platforms. We hope the products resulting from this work help to facilitate educators and researchers who use these computing platforms, and to foster a more versatile and powerful DE-solver ecosystem across R, Python, and MATLAB, thereby catering to a wider range of scientific and engineering challenges.

On the Dependency Structure of Multivariate Distributions
Ryan James, Reddit

One of the fundamental methods of understanding a complex system is to identify the patterns of interdependencies among its degrees of freedom. Information theory seems a natural frameowrk in which to approach this problem, and several approaches exist though none are widely accepted. One popular method is the partial information decomposition, though this method has several interpretational difficulties and the specifics of how it should be quantified are still be explored. Here, we develop an alternative approach based on decomposing a distribution into its statistical dependencies. Building upon the work of Ashby, Krippendorf, Zwick in cybernetics, and the authors own work in information theory, we develop the *reduced dependency diagram* as a method of understanding the structure of a distribution and the dependencies that go into building that structure. We further develop methods for quantifying the contribution of each dependency to the overall information content of a distribution.

Reproducing Experimentally Observed Alternans in Cardiac Tissue with Fractional Diffusion
Lynn Jin, Georgia Institute of Technology

Heart disease is the leading cause of mortality in the US while there exist many treatments to aid cardiovascular problems. Alternans of the heart's action potential has been shown to be a dangerous marker for mortality with over 80% of people identified with it dying within 2 years if not treated. Experimental studies have shown how alternans in space can lead to the initiation of complex arrhythmias because of the spatiotemporal dispersion in refractoriness they produce. Computational studies have shown mechanisms behind the dynamics of alternans, however to date they fail to reproduce the dynamics quantitatively, requiring much larger tissue domains compared to experiments. In this talk we argue that the voltage propagation in cardiac tissue in the mesoscopic scale can be described by fractional diffusion and this allows for models to be fitted in tissue sizes as in experiments.

Finite and Infinite Models: Optimal Prediction of Hidden Markov Proceses
Alexandra Jurgens, INRIA Bordeaux

Even simply defined, finite-state generators produce stochastic processes that require tracking an uncountable infinity of probabilistic features for optimal prediction. For processes generated by hidden Markov chains, the consequences are dramatic. Their optimal predictive models, known as epsilon machines, are generically infinite state. Until recently, one could determine neither their intrinsic randomness nor structural complexity. However, new methods have been developed to accurately calculate the Shannon entropy rate (randomness) and to constructively determine their minimal set of predictive features. We also address the complementary challenge of determining how structured hidden Markov processes are by calculating their statistical complexity dimension—the information dimension of the minimal set of predictive features. This introduces a scaling law for the minimal memory resources required to optimally predict a broad class of truly complex processes.

DNA Knotting Dynamics in Bacteriophages
Camille Korbut, Graduate Group in Applied Mathematics, UC Davis

Bacteriophages, viruses that propagate in bacteria, are equipped with a capsid that holds double-stranded DNA (dsDNA) that is ejected at the time of infection. While in the capsid, the dsDNA is under high confinement with an osmotic pressure that can reach up to 60 atmospheres. Under these conditions, DNA is known to be in a liquid crystalline form. Furthermore, due to this confinement and the long length of DNA, it is prone to knotting. DNA knots capture information about the packing reaction into the capsid and the 3-D conformation of the DNA after the packing reaction completes. Understanding the dynamics of knotting and reknotting of viral DNA is crucial for understanding how DNA knotting contributes to the packing reaction. To experimentally measure the dynamics of DNA knotting, we are using timed experiments with changing temperatures.

Efficient and Robust Numerical Methods to Study Traveling Waves in Detailed-Biophysical Models of Cardiac Tissue
Vincent Lovero, UC Davis

In the heart, repeated waves of electrochemical activity propagate through the tissue, triggering the coordinated contractions that allow the heart to pump blood. The propagated waves can be modeled as traveling wave solutions in reaction-diffusion systems in which local dynamics have been represented by highly idealized models (such as the two-variable FitzHugh-Nagumo equations) and high-dimensional biophysically-detailed models (such as the ten-variable ten Tusscher et al. model). In general, traveling waves in models of cardiac tissue cannot be computed analytically, and therefore suitable numerical methods are a necessity. It is common to solve for traveling wave profiles with root finding methods, and then continuation methods can capture the dependence of the existence of waves and their properties, such as wave speed, on cardiac model parameters and the frequency of the waves. Current numerical methods for computing traveling wave solutions are adequate for idealized models but are inadequate for the more computationally demanding detailed-biophysical models. Here, we attempt to develop robust and efficient numerical methods for computing traveling wave solutions, dispersion curves, and bifurcations for the detailed biophysical models. We use these numerical methods to uncover potential fundamental differences in wave propagation between the highly idealized and physiologically-detailed cardiac models.

An enhanced percolation model for establishing quantum communication
Xiangyi Meng, Northwestern University

The scalability of quantum communication networks is often overshadowed by the extreme vulnerability of quantum coherence over long distance. This issue renders the vast existing optical fiber infrastructures incapable of quantum communication, likened to a traditional continuum percolation model that fails to achieve widespread connectivity in the disconnected phase. Here, however, we demonstrate that the efficiency of continuum percolation can be enhanced by incorporating additional merging rules, inspired by current quantum distillation and repeater protocols. Our analysis indicates that the merging rules lead to the emergence of positive feedback in the percolation process. Similar positive feedback mechanisms have been previously explored in the context of quantum disordered lattice models (e.g. Ising and Heisenberg models, Josephson junctions, etc.), where they give rise to new universality classes. In a broader context, our results expand our understanding of positive feedback percolation processes, also present in explosive percolation, extended-range percolation, and interdependent percolation models, although operating on distinct underlying mechanisms. For practical applications, our findings suggest that quantum network connectivity can be significantly improved through modest upgrades to the existing infrastructure, enhancing the overall connectivity and potential of quantum information systems.

Network model simulation of the GB power system frequency during underfrequency events 2018–19
Ben Mestel, The Open University, UK

Conventional thermal generation has traditionally provided resistance to instability through inertia: synchronous turbines converting mechanical energy to and from electrical energy to dampen the effects of sudden drops and surges in supply. However, the stability of the power supply on the GB grid has been evolving in recent years due to the emergence of intermittent, distributed renewable generation as a significant contributor to the energy mix. These generation sources add to the power capacity of the network but not significantly to inertia, leading to a decrease in the aggregate system inertia over time. It is important to adequately evaluate the expected behaviour of frequency where planned changes in the energy mix are implemented to achieve the goal of a net-Zero power supply. Mitigation measures to ensure that stability is maintained should also be tested and the capacity of interventions required to achieve this objective are quantified. To facilitate the simulation of power imbalance events on the grid a multi-dimensional differential model of frequency change across a network is implemented that takes into account several characteristics of the grid that would impact on the frequency. A networked power system model is implemented, with generation and load buses connected by lines over which power flows are determined by their relative phase angles. A network of 328 buses is configured to represent the GB grid based on data from publicly available models of the synchronous grid distributed based on geolocation. This is enhanced by the inclusion of simulated frequency response, based on changes

in power and frequency. Dynamic data is derived from the characteristics of the GB grid at the time of 33 imbalances over the period 2018-2019. These events will form the basis of the evaluation of future scenarios determined by projected energy mix at milestones on the path to achieving a net-Zero grid.

A Dynamics-Inspired Model for Phonation-Induced Aerosolization
Corey Lynn Murphey, University of Colorado Boulder

Human speech causes the formation and ejection of aerosols from a speaker's mouth. In infectious speakers, phonation-induced aerosolization can facilitate the transmission of airborne viruses. However, the formation of such aerosols is challenging to visualize experimentally due to the complex structure of the larynx, the inability to directly measure aerosol generation at the laryngeal level, and the length scale at which fluid atomization occurs. To understand the complicated dynamics involved in laryngeal speech-induced aerosol formation, we have developed a computational framework that models the ejection and subsequent breakup of sessile liquid on the surface of the vocal folds. A vibration-induced Faraday instability drives the emission of droplets from the fluid-lined mucosal layer of the vocal folds. We apply Tate's law to simulate the resulting droplet ejection as unstable fluid jets break off into droplets. Much like Robert Shaw's classic dripping faucet system, droplets ejecting from a vibrating elastic surface can be modeled as a damped harmonic oscillator with nonlinear springs and dampers. With each oscillation, the vocal folds eject fluid mass when the oscillatory forces exceed the surface tension of the mucosal fluid. This vibration-induced atomization model accounts for nonlinear vibrational elastodynamics and fluid-structure interaction between exhaled air and the vocal fold tissues. The output of this model yields a spray distribution that we compare to experimental aerosol size distributions collected during phonation tasks. From this model, we gain insight into the role of laryngeal geometry and oscillatory dynamics in the production of aerosol.

Experimental and Theoretical Studies of Factors Linked to Complex Behaviors in Small Networks of Belousov-Zhabotinsky Oscillators
Simbarashe Nkomo, Oxford College of Emory University

The Belousov-Zhabotinsky (BZ) reaction is a well-known non-linear chemical oscillator that exhibits diverse complex behaviors. In the coupled system context, the reaction has been used to study diverse and complex dynamic behaviors including synchronization, chimera states, and spatiotemporal pattern formations. Using both experiments and theoretical models, we explore the dynamics of small networks of photochemical BZ oscillators. Our studies illuminate the critical role of initial concentrations of the BZ chemical species, temperature, coupling strength, coupling mode, and system heterogeneities in the emergence of these complex dynamics such as mixed periods, period cycling, and chimera-like states. Importantly, the results reveal the impact light perturbations have on the inhibitory and excitatory pathways of the BZ reaction. We demonstrate that even slight perturbations with correct timing of phases can cause the system to transit from periodic oscillations to more complex behaviors. The insights gained from the studies could have broad applications, such as gaining understanding of complex neuronal activities during epileptic seizures and designing chemical computing devices.

Coupled logistic maps for chaotic encryption of information
Jeffrey S. Olafsen, Department of Physics Baylor University

We report results of a numerical algorithm to examine coupling of two logistic maps where the mixing is chosen to maintain the stability of one map at the loss stability in the other. The long term behavior of the coupling is found to contain windows in which the mixing results in Gaussian fluctuations about a fixed point for the stabilized map. This deterministic behavior is the result of the destabilized map simultaneously being driven into a chaotic regime and not noise. The results are applicable to both chaotic encryption of data and recapturing equilibrium behavior in a non-equilibrium system.

Reconstructing recursive equations of complex systems using minimal reservoir computing
Davide Prosperino, Faculty of Physics, Ludwig-Maximilians-Universität München

Minimal reservoir computing is a novel machine learning technique for predicting complex systems. It simplifies the classical reservoir computing approach by eliminating the need for randomness. Instead of a random embedding, it embeds its input into a high-dimensional space structurally. Additionally, the reservoir is no longer a random graph, but a block-diagonal matrix. The reservoir states are simply evolved linearly, and the nonlinearity is pushed to the readout layer. The output is then a linear combination of the reservoir states, determined by a simple linear regression. In this work we simplify the initial approach even further by utilizing a diagonal matrix as a reservoir, effectively dropping the notion of it. In classical reservoir computing the reservoir states bear no obvious interpretation, as they are a representation of the reservoir at the time. However, in this setup the reservoir states are interpretable and represent nonlinear combinations of input space. Using a small number of data points, it is possible to fully capture the dynamics of the attractor in the short- and long-term using this simple setup. In this work we show that the weights of the linear regression can be utilized to derive recursive equations of complex systems. We analyze the stability of the discovered equations with regards to various hyperparameters. In the end we test its applicability on financial markets and try this approach on modelling interest rates.

Optimal Prediction of Partially-Observed Dynamical Systems
Adam Rupe, Pacific Northwest National Laboratory

Predicting a complex dynamical system without access to all its relevant degrees of freedom (DoF) is a common task (weather prediction, for example). The traditional approach is to use numerical integration of physics-based models that compute the interactions between the system's DoF. This requires explicit reconstruction of missing DoF from partial observations through data assimilation and model inversion. The recent alternative of data-driven prediction instead learns an optimal mapping to advance only the partial observations forward in time, without direct reference to the missing DoF. We provide a theoretical framework for optimal prediction of partially-observed systems using Koopman and Perron-Frobenius evolution operators. From this, we find that physics-based and data-driven models lie on opposite ends of an explicit-implicit modeling spectrum. We also find that optimal prediction of partially-observed systems is typically stochastic. The full predictive information available takes the form of predictive distributions—the probability over

the future conditioned on the past. Optimal stochastic models are then given through predictive equivalence, with pasts being predictively-equivalent if they have the same distribution over futures that follow. We demonstrate the benefits of optimal stochastic prediction with a straightforward approximation of predictive equivalence using K-Means clustering and kernel density estimation. The model reproduces statistical behavior of critical transitions in multi-scale dynamical systems, whereas deterministic prediction with reservoir computing fails to predict these transitions.

Quantifying Chaotic Self-mixing in Active Fluids
Md Mainul Hasan Sabbir, University of California, Merced

Active fluids are non-equilibrium systems that exhibit spontaneous flow dynamics to generate material stresses by consuming local energy. Active fluids describe self-organization in biological and bioinspired systems over a wide range of length scales ranging from flocks of birds to bacterial colonies. Microtubule-based active nematic is a well-known laboratory example of active fluid. It is composed of rod-like subunits with nematic ordering. This biological system exhibits spontaneous chaotic advection, thus making it an exciting paradigm to study chaotic dynamics. Inspired by experimental observations in 2D microtubule-based active nematic, we study the global mixing of the active fluid using tools from chaos theory. We simulate 2D nematohydrodynamics equation with spatially periodic boundary conditions. Using simulated data, we compute topological entropy to quantify the global mixing of the fluid. Then, we verify our results with experimental observations.

Nonlinear dynamics of temporal networks
Kazuya Sawada, Tokyo University of Science

As large-scale data become observable, network data, or information of connectivity of multiple elements, are attracting particular attention. Typical network data include networks of friendships, information diffusion, and infectious disease transmission. Since the late 1990s, research on networks has been active [1, 2], and today, the analysis frameworks for complex networks are well established. However, the networks analyzed in these studies are networks generated by the accumulation of connections between vertices, i.e., static networks that do not take temporal evolution into consideration. On the other hand, many real-world networks are dynamically evolving, namely, temporal networks and analysis of the temporal networks has been attracting attention in recent years [3]. In this study, we report on our analysis of the dynamics of temporal network generated from real contact data, by transforming them into time series. We use real contact data provided by Sociopatterns [4] for five classes of students and teachers in a French high school in 2012. In numerical experiments, the contact data is divided into time windows, and a network is generated in each time window. We then obtained a distance matrix by calculating the Hamming distance between the adjacency matrices of the networks in each time window. Furthermore, we obtained one-dimensional time series by applying the classical multidimensional scaling [5] to the distance matrix. Finally, we reconstructed attractors by transforming the obtained time series into a time-delay coordinate system [6]. We then found that temporal networks generated from real contact data have deterministic and recurrence structure.

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First and Second Laws of Information Processing
Mikhael T. Semaan, University of Utah

Autonomous Maxwellian ratchets are Maxwellian demons which can explicitly leverage correlations among information-bearing degrees of freedom to exchange thermodynamic resources—for example, to extract heat from a single bath and convert it to work, at the cost of modifying the values in a data tape. Previous studies have bounded this behavior in a variety of circumstances, deriving "information processing second laws" for the ratchet's functionality.
In this talk, we will switch perspective from energy to surprisal, review the stochastic dynamical foundations of previous results, and finally leverage them to derive a new "information processing first law" which generalizes and tightens—to strict equalities—various second laws for driven stochastic processes. We will then apply the new results to a model ratchet designed to explicitly violate detailed balance in its effective dynamics, thus explicating the quantitative and qualitative effects of housekeeping entropy production on ratchet functionality.

Unipedal Quiet Stance: Resolving Temporal Scaling using a Binary Record of the Jerk
Matthew Semak, University of Northern Colorado

We investigated balance control during human unipedal quiet stance. In this work, control is quantified by the time rate of change of the accelerations, or jerks, associated with the motion of each foot's center-of-pressure. Data were collected via a force plate for individuals attempting to maintain upright posture using one leg (with eyes open). The medial-lateral and anterior-posterior components of the jerk were considered. Our past studies have suggested the jerk's time series can be modeled as a (stationary) stochastic process and, with this, we took the jerk to be proportional to the increment of the force realizations. Also, these studies suggested the existence of temporal correlations with a range of scaling behavior. Elements of mutual information and multifractal analyses were the primary tools used to further explore the validity of these previous findings. To gain awareness as to what can be learned by studying the simpler aspects of the data, the time series was formed into a binary string tracking the jerk's sign. The processed data is seen to contain the information such that a quasiperiodic mutual information profile could be resolved - one not observed with the unprocessed data. Moreover, a simplified multifractal analysis of the binary sequence suggests the existence of a singularity spectrum.

Methods for Data-driven discovery with limited Data
Dr. Himanshu Singh, The University of Texas at Tyler

In order to comprehend dynamical systems, practitioners often encounters with various challenges and central to these challenges, *lack of data* is surely the primary one. The already established theory of Koopman and Liouville operators around kernel spaces do indeed help us in understanding them via reduced-ordered algorithms, in particular, DYNAMIC MODE DECOMPOSITION (DMD). However, we do not have sufficient mathematical framework to understand the system when *only* limited data is available.

In the present announcement, we are interested in certain mathematical framework that helps discovering the data-driven systems via DMD but in the light of limited data. To address this issue, the established theory around Koopman operators acting on certain kernel spaces will be leveraged. Along with this, in the interest of scientific computing, the present research work will be based on `julia` coding framework, which also be a major contribution in the direction of related research work as well. For this conference, it is also in plan to provide the representation of `julia` codes along with promising future research direction of present work.

Node stratification arises from simple walk-based preferential attachment rules
Kyle Soni, Northwestern University

One of the best-known network growth models, namely, the Barabasi-Albert (BA) model, generates scale-free networks via preferential attachment [1]. When a new node is added to the network, it attaches to m existing nodes with probability proportional to its degree. Equivalently, this attachment rule can be conceptualized as choosing a random edge (walk of length 1) in the network and attaching to one of its ends. We propose a simple modification of this attachment rule, where the new node connects to a randomly chosen end of a randomly chosen walk of length 2 or higher, therefore taking into account network structure beyond degree distribution. This model is different from other walk-based modifications of the BA model, where a new node is attached to the endpoint of a random walk from a randomly chosen node [2], and equivalent to the previously considered "k2 model" in a special case of walks of length 2 and $m = 1$ [3].
While our modification is simple, it leads to complex phenomena that have not yet been appreciated even for the k2 model [3]. The foremost is the emergence of three distinct groups: the highest degree node, its neighbors, and the remaining low degree nodes. The highest degree node forms an extremely rapidly growing "super hub", and the degrees of its neighbors grow much faster than the degrees of the rest of the network due having a large number of second neighbors. All the other nodes in the network who lack the advantage of being attached to the largest hub gain neighbors at a much slower rate. This behavior is in sharp contrast with the BA (k1) model where all the nodes evolve with the same exponents. Observing the degree evolution of individual nodes allows us to make self-consistent analytic predictions about the network growth and understand its degree distribution. With these results, we discuss how some emergent properties of this family of models can be reflected in real life networks.
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A reaction-diffusion model for the pattern formation of the tape-peeling trace
Keisuke Taga, Waseda University

The tape-peeling trace can exhibit various patterns that change with the peel speed. At slow peeling, the resulting pattern appears white, while at fast peeling, it turns black. At intermediate speeds, these two color switches and we obtain Sierpinski-gasket-like pattern that resembles the patterns obtained from certain reaction-diffusion equations. The mechanisms of the pattern formation have been considered and several mathematical models have been proposed. One of the features of those models is the asymmetric interaction that is to realize the asymmetric physical observation that the black region propagates into the white region but the white region will not propagate into the black region. However, the asymmetric interaction contradicts the Newton's law of action-reaction. Thus, we proposed a novel reaction-diffusion model for the tape-peeling trace based on the Newton's equation of motion. In this talk, we introduce our model and show that the model can reproduce the experimental results. Also, we discuss the mathematical mechanism of the tape-peeling pattern formation based on the model.

Efficient Learning of Models for Temporal Networks
Moyi Tian, Brown University

Graphs are widely used in social, physical, and biological sciences to represent populations of entities that are interconnected by relations. Exponential Random Graph Models (ERGMs) have been a popular statistical model for analyzing network attributes and facilitating inference from data. As an extension of ERGMs, Temporal Exponential Random Graph Models (TERGMs) further incorporate the Markov property to capture the dynamic evolution of network topologies over time. Although this family of random graph models provides an efficient description of network distributions and has nice properties that can be helpful with empirical analysis, learning such models from data has been challenging. Inspired by recent development in learning of discrete graphical models, we discuss efficient learning algorithms for TERGMs which come with favorable sample complexity. This framework can be specialized to random temporal hypergraph models and models with tractable sampling properties.

Cardiac Tissue in Chaos under Periodic Stimuli and Fibrillation: Experiments and Control
Mikael Toye, Georgia Institute of Technology

Many cardiac cell voltage models exhibit chaotic dynamics suggesting that the irregular heart rhythms of cardiac disease may, in part, be driven by chaos having a nonlinear control mechanism. However, little experimental evidence has documented the chaotic behavior of cardiac tissue excitations and their relevance to deadly fibrillation events. This study aims to both quantify and qualify the chaotic nature of cardiac tissue from the system's arrhythmic electrical response to fast periodic pacing and fibrillation events. First, leading Lyapunov Exponents were estimated from action potential duration (APD) time series from single cells of bullfrogs, yielding negative exponents for frequencies near period-doubling cascades and positive exponents for arrhythmic responses to periodic forcing. Additionally, several stable period-three orbits and unstable periodic orbits were identified. Further, applying a biphasic perturbation, to a forcing frequency that produces arrhythmic behavior, appears to be able to stabilize an unstable periodic orbit of the response. On a multicellular scale, unstable periodic behavior was also observed in the ventricle fibrillation of pigs and humans in isolated regions across the heart. These findings indicate complex cardiac tissue voltage dynamics are partly governed by chaotic factors and nonlinear control may be able to terminate arrhythmias.

Extended, Exactly Solvable Chaotic Oscillator
Micah Tseng, University of Alabama in Huntsville

Although the study of chaotic systems is theoretically mature for abounding examples, few are readily applicable to engineering problems. One notable barrier is the lack of analytic solutions to guide or validate an engineered intention. In this work, a small set of chaotic systems known for their analytic solutions is expanded. Specifically, a known solvable second order solvable chaotic oscillator with a simple matched filter is extended such that the data rate is decoupled from the natural oscillation frequency of the oscillator. This development allows for high frequency applications without the need for high frequency switching. An extended, exact analytic basis function solution and return map are presented. The oscillator is validated via electronic hardware at audio frequencies where these experimental results closely match theoretical expectations.

Bifurcation delay and front propagation in the real Ginzburg-Landau equation on a time-dependent domain
Troy Tsubota, University of California, Berkeley

This work analyzes bifurcation delay and front propagation in the one-dimensional real Ginzburg-Landau equation (RGLE) with periodic boundary conditions on monotonically growing or shrinking domains. First, we obtain closed-form expressions for the delay of primary bifurcations on a growing domain and find that the additional domain growth before pattern onset is independent of the growth time scale. We also quantify primary bifurcation delay on a shrinking domain; in contrast with a growing domain, the time scale of domain compression alters the amount of additional compression which occurs before pattern decay. For secondary bifurcations such as the Eckhaus instability, we obtain a lower bound on the delay of phase slips due to a time-dependent domain. We also construct a heuristic model to classify regimes with arrested phase slips, i.e. phase slips that fail to develop. Then, we study how propagating fronts are influenced by a time-dependent domain. We identify three types of pulled fronts: homogeneous, pattern-spreading, and Eckhaus fronts. By following the linear dynamics, we derive expressions for the velocity and profile of homogeneous fronts on a time-dependent domain. We also derive the natural ""asymptotic"" velocity and profile which deviate from the values obtained by the marginal stability criterion. Incorporating the cubic nonlinearity, this mismatch reveals a broken degeneracy of spatial eigenvalues and presents a fundamental distinction from the fixed-domain theory that we verify using direct numerical simulations. The effect of a growing domain on pattern-spreading and Eckhaus front velocities is inspected qualitatively and found to be similar to that of homogeneous fronts, and these more complex fronts can also experience delayed onset. Lastly, we show that dilution—a phenomenon realized by prescribing a conservation law—increases bifurcation delay time and amplifies changes in homogeneous front velocity under a time-dependent domain. These analyses provide general insight into the delay of pattern onset and pattern transitions as well as front propagation in systems across many scientific fields.

Machine Learning, Food Web Dynamics, and Species Extinction
Sepideh Vafaie, Montclair State University

Ecologists use a variety of synthetically generated food webs to predict key structural properties of complex food webs. The goal of this study is to incorporate Lotka-Volterra dynamics into a type of synthetic food web, the cascade food web, and to investigate the effect of the dynamics on the food web's structure. We show that cascade food webs are inherently unstable in the sense that incorporating dynamics, even deterministic dynamics, causes many species to go extinct. Using analytical and numerical methods, we investigate the influence of initial conditions, dynamical rates, and predation efficiency on species persistence. Additionally, we utilize a neural network model to predict extinctions under Lotka-Volterra dynamics, derive an analytical expression to elucidate the sequence of species extinctions, and employ clustering methods to unveil the role of rates in food web persistence. The results underscore the need for ecologists to exercise caution when infusing dynamics into structural food webs.

Ballistic Transport of Swimmers in a Periodic Vortex Lattice
Taylor Whitney, UC Merced

We show that there exists phase space structures that promote ballistic transport of smooth rigid ellipsoidal swimmers in a periodic vortex lattice. We explore ensemble simulations and show the counter-intuitive result that slower swimming speeds can undergo ballistic transport, while faster speeds are chaotic and diffusive. We construct a time reversible surface of section map using symmetry of the flow, and find stable periodic orbits surrounded by ballistic tori similar to KAM curves in Hamiltonian systems. These orbits undergo a cascade of period doubling that destroys the stable islands, and their bifurcations are correlated to the ballistic to diffusive transition. The robustness of these results to noise are tested with Monte Carlo simulations.

Persistence of Steady States for Dynamical Systems on Large Networks
Jackson Williams, George Mason University

We study systems of dynamical systems defined on networks. Such systems are often studied by passing to a continuum limit where the adjacency matrix is replaced by a non-local operator called a graphon. In many cases, this graphon equation is more amenable to analysis. We suppose that the graphon equation has a steady state solution whose linearization is invertible. We show that this steady state of the graphon system persists as steady state solutions on the discrete graph provided that the adjacency matrix and graphon are sufficiently close in degree and cut-norm. This provides conditions under which the discrete steady state is robust under large scale re-wirings of the network. The proof involves an analysis of a Newton type operator. Interestingly, this operator fails to be a contraction mapping in general and analysis of the second iterate of this operator is required to show a contraction. Stability of the network steady state is also determined by the graphon equation. We apply our theoretical results to study twisted states in a Kuramoto model of coupled oscillators, steady states in a model of neuronal network activity and a Lotka-Volterra model of ecological interaction.

Initiation of early afterdepolarizations by complex spatial dynamics in cardiac tissue
Noah Wiesner, UC Davis

Early afterdepolarizations (EADs) are complex depolarizing phenomena arising in the plateau phase of a cardiac action potential that can be lethal in certain conditions as they can cause arrhythmias. In this study, we will show that geometry at the tissue level is critical for the formation of EADs. We investigated how spatial action potential (AP) dynamics in

tissue can give rise to EADs. We used a physiologically detailed model of a rabbit action potential to simulate a variety of different tissue geometries. We created 2-dimensional tissue (600x100 cells) featuring a horizontal channel of diffusive cells and a vertical source-sink gap of diffusive. When an AP was generated at one end of the channel, it propagates normally until arriving at the source-sink gap where we found that the AP exhibited three phenomena. The AP propagates normally when the channel size exceeds the gap. Conduction block occurs when the gap exceeds the size of the channel. And EADs form when the channel is roughly the size of the gap. Our findings underscore that tissue geometry is critical not only for the action potential wave propagation but also for the formation of EADs.

A dendrite-based model of the storage of novel, graded-amplitude inputs in working memory
Jiacheng Xu, Ucdavis Physics

Working memory is a fundamental component of many cognitive functions, including reasoning, recall, and decision-making. A key characteristic of working memory is its flexibility, as it allows for the active retention of a novel input without relying on pre-existing learned attractors. Previous models of the storage of novel inputs in working memory have primarily focused on binary memories in which inputs or features are characterized as either present or not present. Here we construct a network model capable of storing a novel, graded-amplitude input in working memory. The model consists of a randomly connected network of neurons, each with an integrate-and-fire soma connected to multiple dendrites. Building upon previous work showing how networks of neurons with NMDA-mediated plateau potentials can store novel binary inputs, each dendrite is endowed with robust voltage bistability mediated by NMDA and GABA-B conductances.

We show that the network can maintain a graded novel input over a large range of input patterns. To understand this result analytically, we map the spiking model onto a rate-based model with all-to-all connectivity. When the pattern of external inputs to the network obeys a linearly decreasing distribution, we show analytically that the network not only maintains firing in the set of neurons that were stimulated, but also their precise intensities. In other words, the network perfectly stores the novel input pattern (up to discretization by the number of independent dendritic compartments). For an input pattern not obeying this ideal distribution, we show that the relative input intensities can still be maintained with a pattern of errors related to the uniform structure of the connectivity matrix and the deviations of the input pattern from the linearly decreasing pattern of intensities. Altogether, this work provides a biophysical network mechanism for encoding a graded, novel input in working memory.

Noise-Induced Transitions in Anisotropic Two-Dimensional Turbulence
Lichuan Xu, Department of Physics, University of California, Berkeley

Two-dimensional (2D) turbulence features an inverse energy cascade that produces large-scale flow structures such as hurricane-like large-scale vortices (LSVs) and unidirectional jets. We investigate the dynamics of such large-scale structures using extensive direct numerical simulations (DNS) of stochastically forced, viscously damped 2D turbulence within a periodic rectangular (Cartesian) domain $[0, L_x] \times [0, L_y]$. LSVs form and dominate the system when the domain aspect ratio $\delta = L_x/L_y \approx 1$, while unidirectional jets predominate at $\delta \gtrsim 1.1$. At intermediate values of δ, both structures are metastable, and noise-induced transitions between LSVs and jets are observed. Based on large-scale energy balance in the condensate, we derive and verify predictions for the dependence of the total kinetic energy and the flow polarity on the nondimensional control parameters. We further collect detailed statistics on the lifetimes of LSVs and jets from simulations of up to 9257 viscous time units in length, showing that the statistics agree with those of a memoryless process. Based on our DNS results, both an exponential and an algebraic dependence of the mean lifetime on the aspect ratio δ are compatible with the data. We also show that the mean lifetimes depend sensitively on the Reynolds number R. As R increases, the energy gap between LSV (lower energy) and jet states (higher energy) increases, leading to an increase in the lifetimes which follows power laws in R with distinct exponents for LSVs and jets. Similarly, as the scale separation between the forcing scale and domain size increases, the transition frequency decreases sharply, confirming earlier findings. We investigate the transition dynamics in terms of kinetic energy, flow polarity, and 2D phase-space diagrams, revealing that the transitions occur in two stages: during an initial stage, an efficient redistribution of kinetic energy by nonlinear triadic interactions facilitates a rapid transition from LSVs to jets and vice versa. In the second stage, the kinetic energy of the newly formed structure slowly adjusts to its associated (higher or lower) equilibrium value on a longer, viscous timescale, which leads to a time delay producing hysteretic transition behavior. Noise-induced transitions may occur between different numbers of jets. Our findings shed new light on the dynamics of coherent large-scale structures in anisotropic turbulence.

Dynamic Treatment by Credit Constraints on Households
Xueqing Yang, Ph.D candidate

The decision to switch from wage employment to entrepreneurship holds significant economic implications, especially regarding job creation. This study investigates how the speed of asset accumulation influences households' decisions to start businesses across different macroeconomic conditions, notably the credit environment. Using data from the Panel Study of Income Dynamics (PSID), two key questions are addressed: (1) Does the impact of asset accumulation on entrepreneurship vary with changing economic conditions, especially credit availability? (2) Does the wealth-building approach of households affect their entrepreneurial choices? This research sheds light on these dynamics in entrepreneurial decision-making amid evolving economic contexts.

This paper adopts G-estimation, a technique common in medical research, to explore the causal factors influencing entrepreneurship initiation. This method accounts for the credit constraint as a simultaneous influence on various factors, including household wealth, business revenue, and decisions. Macro-level factors are incorporated using canonical component analysis, while a dynamic model is presented to illustrate how credit conditions impact occupational choices through wealth accumulation channels.

This research demonstrates that entrepreneurial decisions are more sensitive to the credit environment for households accumulated wealth by inheritance, with 6.3% amplification on the growth rate of wealth, than asset appreciation, which is only 0.2%.

Structural Interventions on Persistent Social Inequalities
Aurora Zhang, Massachusetts Institute of Technology

As algorithmic decision-making systems become increasingly utilized in socially impactful settings, researchers have developed guidelines and metrics that attempt to make decisions non-discriminatory and fair. However, recent work on the dynamics of fairness has shown that decisions that have been made to conform to commonsense fairness standards may often adversely impact the groups they intend to help in the long run. Furthermore, algorithmic decision-making systems may often perpetuate longstanding historical inequities between different populations. In this study, we ask two questions: under what circumstances do structural inequalities persist despite attempts to close the outcome gap? And what kind of interventions are most beneficial for long-term utility? We first create a dynamic model of a loan decision mechanism, and propose sufficient conditions under which this mechanism will inevitably perpetuate starting-state inequalities in the long run, showing that systemic inequalities cannot be mitigated by a certain class of technical interventions. Then, we simulate the effects of a structural intervention on the parameters of the model. Based on a policymaker's preferences for equity or efficiency, we propose conditions under which certain types of interventions are preferable to others. Additionally, we show that in many cases, an increased preference for efficiency over outcome parity suggests that the optimal intervention is one that exclusively benefits the disadvantaged group. Finally, I demonstrate these results on a dataset of mortgage loans, showing how persistent racial disparities in homeownership may be best eased not by simple "affirmative action"-type policies that superficially benefit a disadvantaged group in the short run, but rather by policies that materially decrease the financial risk associated with late payment or default either for the disadvantaged group or for the entire population.

Detecting and Resetting Tipping Points to Create More HIV Post-treatment Controllers with Bifurcation and Sensitivity Analysis (canceled)
Wenjing Zhang, Texas Tech University

The existence of HIV post-treatment controllers (PTCs) gives a hope for HIV functional cure and understanding the critical mechanisms determining PTCs represents a key step toward this goal. Here, we have studied these mechanisms by analyzing an established mathematical model for HIV viral dynamics. In mathematical models, critical mechanisms are represented by parameters that affect the tipping points to induce qualitatively different dynamics and, in cases with multiple stability, the initial conditions of the system also play a role in determining the fate of the solution. As such, for the tipping points in parameter space, we developed and implemented a sensitivity analysis of the threshold conditions of the associated bifurcations to identify the critical mechanisms for this model. Our results suggest that the infected cell death rate and the saturation parameter for cytotoxic T lymphocyte proliferation most significantly affect post-treatment control. For the case with multiple stability, in state space of initial conditions, we first investigated the saddle-type equilibrium point to identified its stable manifold, which delimits trapping regions associated to the high and low viral set points. The identified stable manifold serves as a guide for the loads of immune cells and HIV virus at the time of therapy termination to achieve post-treatment control.

Quantifying patterns and their transitions in spatially extended systems
Wenjun Zhao, Brown University

To identify curves in 2D parameter space that distinguish dynamically different pattern behaviors, we propose a general framework and a corresponding continuation algorithm using initial-value problem solvers. Solutions are mapped to a set of features such as the number and roundness scores of their sublevel sets that are calculated based on alpha-shape geometries. We quantify the differences between patterns via Wasserstein distance in the feature space, and a maximization procedure is employed to find the parameter values that result in significant pattern changes in the local region.
Importantly, our methodology is purely data-driven, allowing for automatic and efficient bifurcation tracing with limited prior knowledge of the underlying system. The applicability is demonstrated through a range of examples involving homogeneous states, spots, stripes, and spiral waves.

Synthesis of Catalyst-Loaded Alginate (F-LA) Beads for the Belousov-Zhabotinsky (BZ) Reaction
Ivan Zhu, Oxford College of Emory University

Alginate, a naturally occurring polysaccharide derived from marine brown algae, has seen applications across a wide range of industries. For instance, recent pharmaceutical research has focused on alginate as a form of oral drug delivery due to its potential to encapsulate therapeutic proteins such as insulin. Our interest in alginate lies in its potential to encapsulate a metal ion complex catalyst, such as ferroin, for the Belousov-Zhabotinsky (BZ) reaction. In addition to the different dynamics the alginate beads may bring, they are a simple, biodegradable, and cheap alternative to the commonly used cation-exchange resin beads. Sodium alginate beads loaded with ferroin are fabricated using the extrusion method. We demonstrate the effect of varying parameters such as the ratio of ferroin to SA, gelation length, gelation solution concentration, and drying procedures on bead characteristics. The beads fabricated varied in both shape and size (1-2 mm) and drying beads at room temperature resulted in size reduction of the beads. The amount of catalyst retained in the beads is tested by placing the beads in deionized water and monitoring for change in color and concentration of ferroin in water using UV-Vis Spectroscopy. Beads dried at room temperature retain the least amount of ferroin. Preliminary results show the expected color changes when the catalyst-loaded alginate beads are placed in a BZ solution.