BRIN MATHEMATICS RESEARCH CENTER

Bifurcation and Chaos in Population Biology

May 28-30, 2025

About the workshop

This workshop brings together a multidisciplinary team of researchers (including mathematicians, modelers, ecologists, epidemiologists, and immunologists). Participants will discuss the current challenges and state-of-the-art advances in the application of bifurcation theory and chaos to analyze the long-term behavior of autonomous and non-autonomous (climate-driven) dynamical systems arising in population biology.

Organizers

Roberto De Leo, Howard University
Abba Gumel, University of Maryland
Sana Jahedi, University of Maryland
Alex Safsten, University of Maryland
Jim Yorke, University of Maryland

Speakers

Lauren Childs, Virginia Tech
Stanca Ciupe, Virginia Tech
Nick Cogan, Florida State University
Daniel Cooney, UIUC
Ulrike Feudel, University of Oldenburg
Nir Gavish, Technion Institute of Technology
John Glasser, Emory University
Martin Golubitsky, Ohio State University
Maria Gutierrez, University of Cambridge
Wenrui Hao, Pennsylvania State University
Kathleen Hoffman, UMBC
Thomas Jun Jewell, University of Oxford
Sayomi Kamimoto, Howard University
Vadim Karatayev, University of Maryland
Jean Lubuma, Wits University
Steve Munch, UC Santa Cruz
Yurij Salmaniw, Oxford University
John Vandermeer, University of Michigan

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DEPARTMENT OF MATHEMATICS

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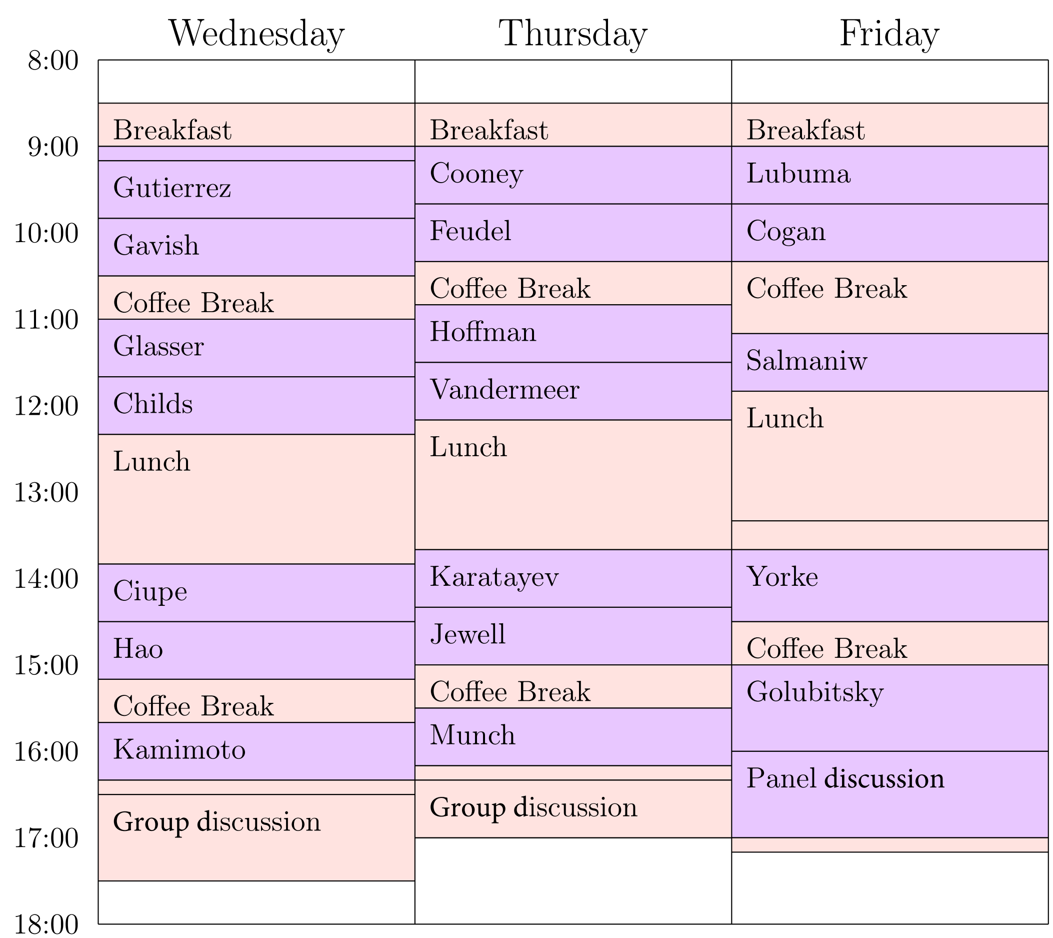
Schedule at a Glance



Workshop Overview

This workshop brings together a multidisciplinary team of researchers (including mathematicians, modelers, ecologists, epidemiologists, and immunologists) to discuss the current challenges and state-of-the-art advances in the application of bifurcation theory and chaos to analyze the long-term behavior of autonomous and non-autonomous (climate-driven) dynamical systems arising in population biology. Phenomena in ecology, oncology, immunology, epidemiology, social science (human behavior), conservation and sustainability of species and ecosystems, etc., will be targeted. The main themes of the proposed workshop are: bifurcations and chaos in multi-strain disease dynamics, bifurcations in immunology (e.g., between acute and chronic infections), bifurcations in models of tumor growth and treatment, and the onset of and recovery from chaotic behavior in ecological models.

Organizing committee

Abba Gumel, University of Maryland

Sana Jahedi, University of Maryland

Alex Safsten, University of Maryland

Roberto De Leo, Howard University

Jim Yorke, University of Maryland

Workshop Schedule

Wednesday, May 28, 2025

8:30 - 9:00 Breakfast

9:00 - 9:10 Doron Levy (University of Maryland)
Opening

9:10 - 9:50 Maria Gutierrez (University of Cambridge)
Bifurcations in a Time-Inhomogeneous Branching Process for the Invasion of Emerging Pathogen Strains

9:50 - 10:30 Nir Gavish (Technion Institute of Technology)
A new Oscillatory Regime in Two-strain Epidemic Models with Partial Cross-immunity

10:30 - 11:00 Coffee Break

11:00 - 11:40 John Glasser (Emory University)
Modeling the Invasion of Novel SARS-CoV-2 Variants and their Co-Existence With or Replacement of Ancestral Variants in the United States

11:40 - 12:20 Lauren Childs (Virginia Tech)
Appearance of Multistability and Hydra Effect in a Discrete-time Epidemic Model

12:20 - 1:50 Lunch

1:50 - 2:30 Stanca Ciupe (Virginia Tech)
Bistability between acute and chronic states in a Model of Hepatitis B Virus Dynamics

2:30 - 3:10 Wenrui Hao (Pennsylvania State University)
Bifurcation Analysis for Cardiovascular Disease Modeling and Beyond with Data-Driven Bifurcation Computation

3:10 - 3:40 COFFEE BREAK

3:40 - 4:20 SAYOMI KAMIMOTO (Howard University)
Intentional Dynamics and Codimension-Two Bifurcation in Contact-Based Coordination Inspired by Blind Termites

4:20 - 4:30 COFFEE BREAK

4:30 - 5:30 Group DISCUSSION

Thursday, May 29, 2025

8:30 - 9:00	Breakfast
9:00 - 9:40	Daniel Cooney (University of Illinois, Urbana-Champaign) *Spatial Pattern Formation in Eco-Evolutionary Games with Environment-Driven Motion*
9:40 - 10:20	Ulrike Feudel (University of Oldenburg) *Rate-Dependent Critical Phenomena in Ecosystems*
10:20 - 10:50	Coffee Break
10:50 - 11:30	Kathleen Hoffman (University of Maryland Baltimore County) *Predator-Prey Dynamics: Scavengers, Cascades, Productivity and Sustainability*
11:30 - 12:10	John Vandermeer (University of Michigan) *Intransitive Loops and Chaos in a Community of Ants in Puerto Rico*
12:10 - 1:40	Lunch
1:40 - 2:20	Vadim Karatayev (University of Maryland) *Bifurcation Transients Illuminate Ecosystem Dynamics and Sustainability Solutions*
2:20 - 3:00	Thomas Jun Jewell (University of Oxford) *Long-Ranged Interactions Shape Populations and Patterns in Biology*
3:00 - 3:30	Coffee Break
3:30 - 4:10	Steve Munch (University of California, Santa Cruz) *Revealing Unseen Dynamical Regimes Using Empirical Dynamic Modeling*
4:10 - 4:20	Coffee Break
4:20 - 5:00	Group Discussion
6:30 - 8:30	Conference Dinner

Friday, May 30, 2025

8:30 - 9:00	Breakfast
9:00 - 9:40	Jean Lubuma (University of Witwatersrand) *Nonstandard Finite Difference for Optimal Control Metapopulation Models: Case of the 2014-2016 Ebola Virus Disease*
9:40 - 10:20	Nick Cogan (Florida State University) *Insights into Dynamics and Parameters Using Sensitivity Analysis*
10:20 - 11:10	Coffee Break
11:10 - 11:50	Yurij Salmaniw (Oxford University) *Bifurcation Analysis of Nonlocal Aggregation-Diffusion Equations and Systems*
11:50 - 1:20	Lunch
1:20 - 1:40	Group Photo
1:40 - 2:30	Jim Yorke (University of Maryland) *The equations of nature reveal the nature of equations*
2:30 - 3:00	Coffee Break
3:00 - 4:00	Martin Golubitsky (Ohio State University) *Infinitesimal Homeostasis*
4:00 - 5:00	Panel Discussion
5:00 - 5:10	Workshop Closing

Abstracts of talks

Bifurcations in a Time-Inhomogeneous Branching Process for the Invasion of Emerging Pathogen Strains

MARIA GUTIERREZ

University of Cambridge

Wednesday, May 28, 2025 @ 9:10 AM

Deterministic models predict that a pathogen strain can invade a host population if its effective reproduction number, R, exceeds 1. However, stochasticity may prevent successful establishment of the emerging strain. Classical branching process theory quantifies this effect using a birth-death model, where the establishment probability depends on R (the initial effective reproduction number of the emerging strain). In reality, emerging strains often appear in the presence of an already-circulating wildtype strain, whose prevalence fluctuates over time. The ongoing spread of the wildtype depletes the pool of hosts susceptible to the emerging strain, so that the emerging strain's reproduction number is time-dependent, i.e., R=R(t). Thus, this time-inhomogeneity invalidates the standard birth-death calculation, which assumes a constant R (for example, if the wildtype strain is endemic). I will present a model for strain establishment based on a time-inhomogeneous birth-death process, where the birth rate is time-dependent, proportional to R(t). The establishment probability satisfies a non-autonomous first-order differential equation, which we solve analytically. I will show that the reproduction number of the emerging strain at the end of the wildtype epidemic, R(end), significantly impacts the establishment probability of the emerging strainoeven if the strain appears well before the wildtype epidemic is over. In particular, a bifurcation occurs at R(end)=1. If R(end)<1, the establishment probability is zero for all emergence times t, even if R(t)>1 at the time t when the new strain emerges. I will also illustrate the general behavior of the establishment probability, including the effects of ecological strain interference. Finally, I will discuss the implications of these results for the invasion of immune escape strains in antigenically evolving pathogens, such as the Omicron variant of SARS-CoV-2.

A new Oscillatory Regime in Two-strain Epidemic Models with Partial Cross-immunity

Nir Gavish

Technion Institute of Technology

Wednesday, May 28, 2025 @ 9:50 AM

In this talk, I will explore conditions under which a two-strain epidemic model with partial cross-immunity can lead to self-sustained oscillations. Contrary to previous findings, our results indicate that oscillations can occur even with weak cross-immunity and weak asymmetry. Using asymptotic methods, we reveal that the steady state of coexistence becomes unstable near specific curves in the parameter space, leading to oscillatory solutions for any basic reproduction number greater than one. Numerical simulations support our theoretical findings, highlighting an unexpected oscillatory region.

Modeling the Invasion of Novel SARS-CoV-2 Variants and their Co-Existence With or Replacement of Ancestral Variants in the United States

John Glasser

Emory University

Wednesday, May 28, 2025 @ 11:00 AM

Background: During the COVID-19 pandemic, we endeavored to keep pace with understanding of biological phenomena that might affect S ARS-CoV-2 t ransmission b y d eveloping, e valuating, and improving models structured via age and location or variant.
Objective: To increase understanding of the replacement of successive SARS-CoV-2 variants during the COVD-19 pandemic. Methods: With probabilities of infection on contact and initial conditions from a serial, cross-sectional sur-vey of antibodies to nucleocapsid protein among commercial laboratory clients before vaccination began, our age- and location-structured models reproduce subsequent seroprevalence from a na-tionwide survey of antibodies to spike as well as nucleocapsid protein among blood-donors. As all other parameters except the efficacy of physical distancing when possible and masking otherwise were sourced from the literature, these may be unique among SARS-CoV-2 transmission models in having their predictions corroborated by accurate independent observations. Here we derive conditions for invasion and coexistence or replacement and explore immune escape and other bi-ological phenomena that might explain the observed succession of variants.
Results: To invade, novel variants require invasion reproduction numbers greater than one when ancestral ones are at their endemic equilibria. Replacement occurs when one variant can invade at the other's endemic equilibrium, but not vice versa, and coexistence occurs when both variants can invade at the other's endemic equilibrium. Aided by partial derivatives of an expression for the invasion reproduction number derived from our model with respect to relevant variables, we explore various hypotheses for the observed succession of variants.
Conclusions: The process of developing, evaluating, and improving transmission models increases understanding of biological phenomena affecting observed dynamics.
Authors: Zhilan Feng, Troy Day, and John W Glasser

Appearance of Multistability and Hydra Effect in a Discrete-time Epidemic Model

Lauren Childs

Virginia Tech

Wednesday, May 28, 2025 @ 11:40 AM

One-dimensional discrete-time population models, such as Logistic or Ricker growth, can exhibit periodic and chaotic dynamics. Incorporating epidemiological interactions through the addition of an infectious class causes an interesting complexity of new behaviors. Here, we examine a two-dimensional susceptible-infectious (SI) model with underlying Ricker population growth. In particular, the system with infection has a distinct bifurcation structure from the disease-free system. We use numerical bifurcation analysis to determine the influence of infection on the types and appearance of qualitatively distinct long-time dynamics. We find that disease-induced mortality leads to the appearance of multistability, such as stable four-cycles and chaos dependent upon the initial condition. Furthermore, previous work showed that infection that alters the ability to reproduce can lead to unexpected increases in total population size. A similar phenomenon is seen in some models where an increase in population size with a decreased growth rate occurs, known as the 'hydra effect'. Thus, we examine the appearance and extent of the hydra effect, particularly when infection is introduced during cyclic or chaotic population dynamics.

Bistability between acute and chronic states in a Model of Hepatitis B Virus Dynamics

Stanca Ciupe

Virginia Tech

Wednesday, May 28, 2025 @ 1:50 PM

Understanding the mechanisms responsible for different clinical outcomes following hepatitis B infection requires a systems investigation of dynamical interactions between the virus and the immune system. To help elucidate mechanisms of protection and those responsible from transition from acute to chronic disease, we developed a deterministic mathematical model of hepatitis B infection that accounts for cytotoxic immune responses resulting in infected cell death, non-cytotoxic immune responses resulting in infected cell cure and protective immunity from reinfection, and cell proliferation. We analyzed the model and presented outcomes based on three important disease markers: the basic reproduction number, the infected cells death rate (describing the effect of cytotoxic immune responses), and the liver carrying capacity (describing the liver susceptibility to infection). Using asymptotic and bifurcation analysis techniques, we determined regions where virus is cleared, virus persists, and where clearance-persistence is determined by the size of viral inoculum. These results can guide the development of personalized intervention.

Bifurcation Analysis for Cardiovascular Disease Modeling and Beyond with Data-Driven Bifurcation Computation

Wenrui Hao

Pennsylvania State University

Wednesday, May 28, 2025 @ 2:30 PM

The low-density lipoprotein (LDL)/high-density lipoprotein (HDL) cholesterol ratio is a critical biomarker for assessing cardiovascular risk, yet its mechanistic role in the early progression of atherosclerosis remains mathematically underexplored. In this talk, I will present a bifurcation analysis of a mathematical model describing plaque formation with a free boundary, where the LDL/HDL ratio serves as a key bifurcation parameter. By deriving explicit radially symmetric steady-state solutions and applying perturbation analysis, we establish the existence of bifurcation branches and identify theoretical conditions for mode-dependent transitions. Beyond this specific application, I will introduce a general data-driven framework - equation-driven neural networks (EDNNs) - for computing bifurcations in general nonlinear parametric systems. This approach inte-grates empirical solution data with neural network approximations, enabling efficient detection and tracking of bifurcations across high-dimensional parameter spaces. Together, these methodologies offer a dual perspective: one grounded in classical mathematical analysis and the other powered by modern machine learning, providing new insights into both cardiovascular disease modeling and computational bifurcation theory in broader scientific applications.

Intentional Dynamics and Codimension-Two Bifurcation in Contact-Based Coordination Inspired by Blind Termites

Sayomi Kamimoto

Howard University

Wednesday, May 28, 2025 @ 3:40 PM

This talk presents a dynamical framework inspired by coordination behavior in blind termites, where movement is governed by tactile contact and asymmetrically structured interaction. We model this through intentional dynamics, where one component anticipates another's motion via an exponentially weighted memory, implemented as a Volterra-type convolution operator.
The resulting discrete-time system is analyzed in the Hilbert space ℓ^2, where we uncover a rich bifurcation structure including fold, period-doubling, and Neimark–Sacker transitions. At a critical regime, a codimension-two bifurcation emerges where the fixed point ceases to be unique and the memory operator becomes marginally regularizing. This point marks a structural collapse of well-posedness, linking operator-theoretic degeneration to emergent nonlinear behavior.
The framework offers a symbolic and analytical bridge between biologically motivated coordination and fundamen-tal questions of uniqueness, stability, and spectral geometry in systems with asymmetric memory and directional influence.

Spatial Pattern Formation in Eco-Evolutionary Games with Environment-Driven Motion

Daniel Cooney

University of Illinois, Urbana-Champaign

Thursday, May 29, 2025 @ 9:00 AM

The sustainable management of common resources often leads to a social dilemma known as the tragedy of the commons: individuals benefit from rapid extraction of resources, while communities as a whole benefit from more sustainable extraction strategies. In this paper, we explore a PDE model of evolutionary game theory with environmental feedback, describing how the spatial distribution of resource extraction strategies and environmental resources evolve due to reaction terms describing eco-evolutionary game-theoretic dynamics and spatial terms describing diffusion of environmental resources and directed motion of resource harvesters towards regions of greater environmental quality. Through linear stability analysis, we show that this biased motion towards higher-quality environments can lead to spatial patterns in the distribution of extraction strategies, creating local regions with improved environmental quality and increase payoff for resource extractors. However, by measuring the average payoff and environmental quality across the spatial domain, we see that this pattern-forming mechanism can actually decrease the overall success of the population relative to the equilibrium outcome in the absence of spatial motion. This suggests that environmental-driven motion can produce a spatial social dilemma, in which biased motion towards more beneficial regions can produce emergent patterns featuring a worse overall environment for the population. This talk is based on joint work with Tianyong Yao.

Rate-Dependent Critical Phenomena in Ecosystems

Ulrike Feudel

University of Oldenburg

Thursday, May 29, 2025 @ 9:40 AM

Nowadays, populations are faced with unprecedented rates of global climate change, habitat fragmentation and destruction causing an accelerating conversion of their living conditions. Critical transitions in ecosystems, often called regime shifts, lead to sudden shifts in the dominance of species or even to species' extinction and decline of biodiversity. Many regime shifts are explained as transitions between alternative stable states caused (1) by certain bifurcations when certain parameters or external forcing cross critical thresholds, (2) by fluctuations, (3) by extreme events or (4) by rate-dependent transitions. We address here several of the aforementioned mechanism and show their relevance for ecosystems. First, we discuss rate-dependent critical transitions (4) which do not require alternative states but instead, the system performs a large excursion away from its usual behaviour when external environmental conditions change too fast. During this excursion, it can embrace dangerous, unexpected states. We demonstrate that predator-prey systems can either exhibit a population collapse or a population outbreak if the rate of environmental change crosses a certain critical rate. Whether a system will track its usual state or will tip with the consequence of either a possible extinction of a species or a large population outbreak like, e.g., a harmful algal bloom depends crucially on the time scale relations between the ecological timescale and the time scale of environmental change.

In addition, we demonstrate another rate-dependent phenomenon, in which a system can cross the basin boundary of a stable ecosystem state changing from a desirable to an undesirable coexistent stable state. In particular, we show how the interplay between bifurcation-induced critical transitions (1) and rate-dependent basin boundary crossings due to large perturbations (extreme events) can lead to population outbreak or collapse. Again, the relationship between the different timescales in the system like the intrinsic timescale of the ecosystem dynamics and the timescale of environmental change plays a decisive role in the possi-bly contrasting outcomes after the impact of an extreme event.

Joint work with Lukas Halekotte, Anna Vanselow, Sebastian Wieczorek, Ayanava Basak, Syamal K. Dana and Nandadulal Bairagi.

Predator-Prey Dynamics: Scavengers, Cascades, Productivity and Sustainability

Kathleen Hoffman

University of Maryland Baltimore County

Thursday, May 29, 2025 @ 10:50 AM

A classical two-species Lotka-Volterra predator-prey model exhibits a bounded paired period doubling cascade when a scavenger is introduced. However, the sustainability of a classical n-species food chain depends on the parity of n. Conditions on parameters determine which species are not sustainable or which species exhibit unbounded behavior, which indicates that an additional species could be supported. Persistence favors even.
Joint work with Joe Previte and Nicole Massarelli.

Intransitive Loops and Chaos in a Community of Ants in Puerto Rico

John Vandermeer

University of Michigan

Thursday, May 29, 2025 @ 11:30 AM

The dichotomy of stable equilibrium versus indeterminate competition is a core principle of ecological theory, as is the effect of a predator in the competitive dynamics. Using a model of invasive ant species that act as pest control agents in Puerto Rican coffee farms I explore the intricate interplay between competition, predation, and species coexistence within ecological systems. First I examine the dynamics between two invasive ground-foraging ant species, Solenopsis invicta, and Wasmannia auropunctata, and the interaction of S. invicta with phorid fly parasitoids. Empirical data from field and laboratory experiments demonstrate that S. invicta typically dominates W. auropunctata unless phorid flies are present, the latter of which alter the S. invicta behavior and reduce its competitive advantage. Extending the Lotka-Volterra framework, I demonstrate a parameter-dependent chaotic interregnum where neither species maintains consistent dominance, contrary to traditional models of coexistence. Yet the interregnum contains elements well-known in complex systems: period doubling, chaos, basin/boundary collision and chaotic transients. Both of the ant species also forage arboreally where they encounter a third species, the arboreally nesting and foraging Monomorium floricola. These three species form an intransitive triplet, the dynamics of which play out in a well-known way on the carrying simplex and provide a theoretical base for an expanded community, what I call the "tail" of the community. The triplet acts as a keystone intransitivity, theoretically permitting a theoretically very large community of strong competitors (no pair of which could coexist alone) to coexist. The coexistence reflects the idea of an interreg-num in that there are complicated trajectories, some chaotic some periodic (but seemingly more complicated than chaos), yet frequently retain the qualitative kernel observed in basic natural history observations.

Bifurcation Transients Illuminate Ecosystem Dynamics and Sustainability Solutions

Vadim Karatayev

University of Maryland

Thursday, May 29, 2025 @ 1:40 PM

Transient dynamics when systems undergo bifurcations can provide deep insights into the clockwork of nature and illuminate novel control pathways. I will show how transients involving saddle-node bifurcations reveal the mechanisms of climate change impacts on giant kelp forests, windows of opportunity in restoring ecosystems, and effective solutions to global warming. I will also point out open mathematical problems associated with each question.

Long-Ranged Interactions Shape Populations and Patterns in Biology

Thomas Jun Jewell

University of Oxford

Thursday, May 29, 2025 @ 2:20 PM

Movement shapes how populations distribute across space and evolve over time. Across biological scales, individuals move in response to interactions that are often long-ranged (nonlocal). Animals use scent cues to establish territorial boundaries, predators pursue prey based on sight or sound, and cells can aggregate by extending pseudopodia toward distant neighbours. We explore these processes using nonlocal advection-diffusion models, analysing their bifurcations to gain insight into emergent spatial and temporal dynamics.

A key result is that, unlike in local models (e.g. Fickian diffusion), Turing bifurcations in these nonlocal systems fundamentally depend on spatial dimension. For example, purely repulsive interactions cannot generate spatial patterns in one spatial dimension, but can in two. Additionally, even simple interactions, such as attraction and logistic growth within a single species, can produce spatio-temporal oscillations that exhibit signs of chaos. This provides an example of spatio-temporal complexity of relevance to ongoing debates on how common chaos is in ecosystems. We also explore more complex mechanisms like chiral movement, which is often exhibited by cells and also used by prey to evade predators. We show how it can suppress oscillations, and instead promote stationary patterns. Finally, we highlight cautionary cases where linear stability analysis fails to predict long-term behaviour, including populations with a Turing instability that forms patterns only transiently before collapsing to extinction. These results emphasise the need for analytical tools which go beyond local linear stability analyses in order to understand ecosystems in the long-term.

Revealing Unseen Dynamical Regimes Using Empirical Dynamic Modeling

Steve Munch

University of California, Santa Cruz

Thursday, May 29, 2025 @ 3:30 PM

Many dynamical systems can exist in alternative regimes for which small changes in an environmental driver can cause sudden jumps between regimes. Predicting the regime of population fluctuations in novel environments is thus an important challenge with implications for conservation and management. Integrating population time-series data and information on a putative driver using a Gaussian Process Empirical Dynamic Model can help us identify new dynamical regimes without specifying the equations of motion of the system. As a proof of concept, we demonstrate that we can accurately predict fixed-point, cyclic, or chaotic dynamics under unseen levels of a control parameter for a range of simulated models. For a model with an abrupt population collapse, the approach goes beyond an early warning signal by characterizing the regime that follows the tipping point. These results lay the groundwork for making rational decisions about preventing, or preparing for, regime shifts in natural ecosystems.

Nonstandard Finite Difference for Optimal Control Metapopulation Models: Case of the 2014-2016 Ebola Virus Disease

Jean Lubuma

University of Witwatersrand

Friday, May 30, 2025 @ 9:00 AM

The 2014-2016 West African Ebola Virus Disease (EVD), the largest outbreak of its kind, arose with the unprecedented challenge of spreading simultaneously across multiple countries with significant travel activity. In this presentation, we consider two optimal control metapopulation models with exit screening of travellers as the basic intervention. In the first model, the exit screening is supplemented by the entry screening, whereas the combination of the exit screening with the vaccination is implemented in the second model. We prove the well-posedness of both optimal control problems by Pontriagin's maximum principle. For each problem, we construct a Nonstandard Finite Difference Forward-Backward-Sweep-Method, which preserves the dynamics of the continuous state variable model. Numerical simulations, which are based on real data from the three most affected countries and support the theory, are provided. They also suggest that the vaccination alone is sufficient to control the disease.

Insights into Dynamics and Parameters Using Sensitivity Analysis

Nick Cogan

Florida State University

Friday, May 30, 2025 @ 9:40 AM

Sensitivity analysis refers to a broad group of methods used to asses the impact of parameters on the dynamics. These methods can rank or quantify the impact of parameter variations on a wide variety of quantities of interest (QoI). We show how these methods provide insight into the dynamics of a model for an auto-immune disease, alopecia areata (AA), that affects hair follicles. Hair follicles are immune privilege sites where the immune system is restricted. The collapse of this privilege appears to be the cause of the disease. AA can present as distinct patches of hair-loss that can be dynamic in time. We will show several results including insights from parameter estimation and sensitivity analysis.

Bifurcation Analysis of Nonlocal Aggregation-Diffusion Equations and Systems

Yurij Salmaniw

Oxford University

Friday, May 30, 2025 @ 11:10 AM

Nonlocal aggregation-diffusion equations have emerged as a fundamental mean-field approximation for large interacting particle systems, with applications spanning, for example, opinion dynamics, statistical mechanics, physics, synchronisation, and mathematical biology. While much research has focused on their qualitative properties: existence, uniqueness, linear stability analysis, and long-time behavior, understanding their quantitative structure remains a key challenge: What patterns form? Under which conditions do they emerge? Are phase transitions continuous or discontinuous? How do these transitions influence other properties of the solution(s)? I am interested in the rigorous treatment of such questions from an analytical perspective, using tools from bifurcation theory. In this talk, I will present a bifurcation analysis applied to some nonlocal aggregation-diffusion equations with applications in ecology, focusing on three recent efforts. The first couples a scalar nonlocal aggregation-diffusion equation (population dynamics) with an ordinary differential equation (a 'spatial map' for the population). In the second case, we study a similar problem that can be transformed from a two-equation PDE-ODE system into a three-equation parabolic-elliptic-ODE system while maintaining the stability and solution structure properties. Finally, I will present some preliminary results for a fully nonlocal two-species aggregation-diffusion system and some current progress toward understanding the global bifurcation structure of these problems from a numerical point of view. Together, these examples highlight the versatility of a robust bifurcation analysis in understanding precise solution behavior of complex nonlocal PDE models and the different (but related) ways these tools can be applied depending on the problem of interest.
These works are joint with: Dr. Di Liu, Prof. Jonathan Potts, Prof. Junping Shi, Prof. Hao Wang, Prof. Jose Carrillo, and Antonio Villares.

The equations of nature reveal the nature of equations

Jim Yorke

University of Maryland

Friday, May 30, 2025 @ 1:40 PM

We need tools to explain why some networks are robust to perturbations, but others are vulnerable to bifurcations, changes. Differential equations and graph theory has been used as ubiquitous tools by scientists in the studying a vast group of networks. Even though there is an extensive literature available on studying linear system of equations using graphs and matrices, the interactions between network members in most cases are nonlinear. We began this investigation to understand ecological networks. There was much more written about stability of ecosystems than about the question of whether the ecosystem had a robust equilibrium. Some ecological networks can have a steady state that depends on the system improbably being perfectly balanced, where arbitrarily small changes result in the absence of a steady state. We find that some networks can have robust steady states and others cannot and we can tell what the difference independent of the actual details of the equations. We do not address the question of stability of robust solutions, but our theory opens the door to such investigations. To understand this problem we had to attack a much broader question: How do we know if a system of N equations in N unknowns, F(X) = C has a robust solution. That is, if some X and C satisfy the equation and arbitrarily small changes in C still have solutions. It is surprising to us how general our solution is that we came up with. This structure leads in some cases to ecological systems with multiple Lyapunov functions

Infinitesimal Homeostasis

Martin Golubitsky

Ohio State University

Friday, May 30, 2025 @ 3:00 PM

Homeostasis occurs when a system output remains approximately constant on variation of a system input. A typical example occurs when the internal body temperature of a warm-blooded mammal remains approximately constant on variation of the ambient temperature. We define infinitesimal homeostasis as points where the derivative of output with respect to input vanishes.

Fred Nijhout, Mike Reed, and Janet Best observed that homeostasis occurs frequently in biochemical networks. We note that homeostasis can sometimes be found by searching for infinitesimal homeostasis. In this talk we review how network architecture can lead to different kinds of infinitesimal homeostasis and discuss how a version of network pattern formation can be associated with each kind of infinitesimal homeostasis.

This is joint work with Fernando Antoneli, Will Duncan, Joe Huang, Jaxian Jin, Ian Stewart, and Yangyang Wang.

The Brin Mathematics Research Center

The Brin Mathematics Research Center is a research center that sponsors activity in all areas of pure and applied mathematics and statistics. The Brin MRC was funded in 2022 through a generous gift from the Brin Family. The Brin MRC is part of the Department of Mathematics at the University of Maryland, College Park.

Activities sponsored by the Brin MRC include long programs, conferences and workshops, special lecture series, and summer schools. The Brin MRC provides ample opportunities for short-term and long-term visitors that are interested in interacting with the faculty at the University of Maryland and in experiencing the metropolitan Washington DC area.

The mission of the Brin MRC is to promote excellence in mathematical sciences. The Brin MRC is home to educational and research activities in all areas of mathematics. The Brin MRC provides opportunities to the global mathematical community to interact with researchers at the University of Maryland. The center allows the University of Maryland to expand and showcase its mathematics and statistics research excellence nationally and internationally.

List of Participants

Lauren Childs, Virginia Tech
Stanca Ciupe, Virginia Tech
Nick Cogan, Florida State University
Daniel Cooney, University of Illinois, Urbana-Champaign
Roberto De Leo , Howard University
Bill Fagan, University of Maryland
Ulrike Feudel, University of Oldenburg
Nir Gavish, Technion Institute of Technology
John Glasser, Emory University
Martin Golubitsky, Ohio State University
Abba Gumel, University of Maryland
Katharine Gurski, Howard University
Maria Gutierrez, University of Cambridge
Wenrui Hao, Pennsylvania State University
Kathleen Hoffman, University of Maryland Baltimore County
Sana Jahedi, University of Maryland
Thomas Jun Jewell, University of Oxford
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Doron Levy, University of Maryland
Jean Lubuma, University of Witwatersrand
Marron McConnell, University of Maryland
Arnaja Mitra, University of Maryland
Steve Munch, University of California, Santa Cruz
Salihu Musa, University of Maryland
Alice Oveson, University of Maryland
Binod Pant, Northeastern University
Soyoung Park, University of Maryland
Amy Patterson, University of Maryland
Alex Safsten, University of Maryland
Yurij Salmaniw, Oxford University
Jonathan Simon, University of Maryland
John Vandermeer, University of Michigan
Joshua Weitz, University of Maryland

Jim Yorke, University of Maryland
Kejia Zhang, University of Maryland