Undergraduate Mathematics Research Symposium

University of Florida, Department of Mathematics

April 25, 2025

Schedule

Morning Sessions

Session 1

9:00-9:15	Connor Panish	Stochastic Fusion on Type D ASEP
9:20-9:35	Megan Sin	Modeling Malaria Immunity and Control: Dynamics, Risks, and Policy Implications
9:40-9:55	Jake Rhodes, Niccolo Turillo & Julian Carvajal	Vietoris-Rips Complexes of Ellipses
10:00-10:15	Zhengmao Zhang	Opinion Dynamics of Public Attitudes Toward the COVID-19 Vaccine
10:20 -10:45	Coffee break	

Session 2

10:45-11:00	Andersen Wall	Structured Decompositions: The Idea, Code, and Applications
11:05-11:20	Penelope Beall	Constructions of Macaulay Posets and Rings
11:25-11:40	Braden Close & Jake Rhodes	Using Differential Equations to Model Heavy Metal Bioaccumulation as part of SCUDEM IX Challenge
11:45-12:00	Madeline Berryman-Dages	Preissmann's Theorem: On the Topological Structure of Negatively Curved Space
12:05-12:20	Jianda Du	Determining the Effect of Curvature in a Mathematical Model of Cell Migration

Lunch: 12:25-1:25

Afternoon Session

Session 3

1:25-1:45	Alessandro Barletta	Complex Eigenvalues and the Dynamic Power Method with Momentum: What Could *Possibly* Go Wrong?
1:50-2:05	Arjun Singh	Connectomic analysis of age-related neurodegeneration in random matrix denoised brain networks and revealed sub-networks
2:10-2:25	Xavier Gottlieb-Young &Jada Sitchler	Modeling Seasonal Chocolate Consumption and Heavy Metal Accumulation in Children
2:30-2:45	Roberto Giuffredi	Analyzing the Emergence of Gamma Oscillations During Development

Abstracts

Session 1

1.1 Connor Panish

Mentor: Jeffrey Kuan (Texas A&M)

Title: Stochastic Fusion on Type D ASEP

Abstract: The Type D Asymmetric Simple Exclusion Process (ASEP) is a particle system involving two classes of particles. We construct a new interacting particle system where more than one particle of the same type can occupy a lattice site by performing the method of stochastic fusion developed by J. Kuan in 2019. We analyze this new interacting particle systems' generator matrix, demonstrate that as drift speed approaches infinity Type D ASEP degenerates to normal ASEP for certain communicating classes and prove that the stationary distribution does not depend on the drift speed. Furthermore, we construct Markov self-dual processes for specific drift speeds using the diagonalization of the generator.

1.2 Megan Sin

Mentors: Calistus Ngonghala & Hemaho Taboe

Title: Modeling Malaria Immunity and Control: Dynamics, Risks, and Policy Implications

Abstract: Malaria remains a significant global health challenge, with high morbidity and mortality. In endemic areas, repeated exposure improves partial immunity, leading to asymptomatic carriers with low parasitemia who act as hidden reservoirs, perpetuating transmission. This study develops a malaria transmission model that integrates immunity dynamics to examine how repeated exposure influences immunity acquisition, transitions between symptomatic and asymptomatic states, and overall transmission patterns. Our findings underscore the need for integrated vector management strategies that target both adult and immature mosquito populations. Accordingly, public health policies should prioritize sustained ITN coverage, enhanced larval control, and immunity-preserving interventions to reduce mortality and support sustained long-term malaria control.i

1.3 Jake Rhodes, Niccolo Turillo, Julian Carvajal

Mentor: Henry Adams

Title: Vietoris-Rips Complexes of Ellipses

Abstract: The Vietoris-Rips simplicial complex of a subset of a metric space X, denoted $\mathrm{VR}(X;r)$ is an abstract simplicial complex with simplices formed by by each finite subset of X with diameter less than a scale parameter $r > 0$. By examining the homotopy type of the Vietoris-Rips complex of a set at different scales, meaningful descriptions of the shape of the data can be made. Right now, the Vietoris-Rips complex at different scales is not fully understood for virtually any shape besides a circle. In this project, we extend the existing literature on ellipses. For ellipses whose semimajor axis has length less than $\sqrt{2}$, the first two nontrivial homotopy types are known. Our research for these ellipses seeks to understand the transition to the next two nontrivial homotopy

types. When the length of the semimajor axis of the ellipse is greater than $\sqrt{2}$, neither the first nontrivial homotopy type of the Vietoris-Rips complex is known, nor is the scale at which the transition occurs. In a step towards finding the first nontrivial homotopy type, we believe that we have found a closed-form solution for the scale at which the transition occurs.

1.4 Zhengmao Zhang

Mentor: Youngmin Park

Title: Opinion Dynamics of Public Attitudes Toward the COVID-19 Vaccine

Abstract: This study investigates opinion dynamics in public attitudes toward vaccination, using a modified SIR model that classifies individuals as Agree, Neutral, or Disagree. Transitions between groups are driven by interpersonal influence modeled as messaging transmission. Through equilibrium and sensitivity analyses, the model reveals how initial group sizes and asymmetric influence rates shape long-term opinion outcomes. A case study on COVID-19 vaccine hesitancy, using real survey data, shows the model's predictive accuracy and highlights the dominance of negative messaging. The model is extended to a SIRV framework to demonstrate its broader public health implications. Limitations include simplified assumptions and the exclusion of external influences, suggesting directions for future refinement.

Session 2

2.1 Andersen Wall

Mentor: James Fairbanks

Title: Structured Decompositions: The Idea, Code, and Applications

Abstract: Structured decompositions were introduced by Benjamin Bumpus as a way to study structural and algorithmic compositionality using category and graph theoretic structures. We will discuss properties of categories, the structured decomposition functor, and the Grothendieck construction. I will also present some algorithms that can be used to exploit these structures, how they work, and their complexity. I will end by presenting some applications of these current algorithms to some general problems.

2.2 Penelope Beall

Mentors: Alexandra Seceleanu, University of Nebraska-Lincoln & Nikola Kuzmanovski, University of Notre Dame

Title: Constructions of Macaulay Posets and Rings

Abstract: A ring is Macaulay-Lex iff its monomial poset interacts nicely with some total order. This property can be extended to posets in general. We will consider a few different ways to combine several posets into a new poset, and investigate to what extent each operation preserves the Macaulay property. Some of these poset operations have algebraic analogs. For example, a Cartesian product of posets corresponds to a tensor product of rings. If time and technology permits, there will be some demonstrations of the MacaulayPosets package developed for Macaulay2.

2.3 Braden Close, Jake Rhodes

Mentor: Youngmin Park

Title: Using Differential Equations to Model Heavy Metal Bioaccumulation as part of SCUDEM IX Challenge

Abstract: Research examining heavy metal concentrations in cacao products has raised concerns about potential toxicity for frequent chocolate consumers. In this study, conducted as part of SCUDEM IX Challenge, a nonlinear system of differential equations was developed to predict lead dynamics and bioaccumulation in the body. The model considers time-dependent lead concentrations in the GI tract M, bloodstream A, soft tissue S, and hard tissue H. Lead diffusion between systems follows logistic-based osmosis transport equations. Diffusion parameters were loosely selected from literature and iteratively refined to preserve model stability and ensure outputs align with surveyed values. Two primary consumption patterns, or inhomogeneities, were selected for test cases; daily "stress" and weekend "binge" consumption patterns were defined by a sinusoid and periodic step function, respectively. The model surveyed a year period, additionally considering increased consumption for American holidays and birthdays. Runge-Kutta fourth-order approximations were implemented to plot the solution curves developed via numerical methods. According to model predictions, maintaining daily chocolate consumption below 50g is unlikely to induce lead toxicity, as compared with the CDC Blood Lead Reference Value (BLRV) of 3.5 μg/dL.

2.4 Madeline Berryman-Dages

Mentor: Luca Di Cerbo

Title: Preissmann's Theorem: On the Topological Structure of Negatively Curved Space

Abstract: In this presentation we describe the properties of complete Riemannian manifolds with negative sectional curvature. Our ultimate aim is to apply these properties towards the reconstruction of a proof for Preissmann's theorem, which is stated as: "Given a compact Riemannian manifold with negative sectional curvature, every abelian subgroup of the fundamental group is infinite cyclic." Preissmann's theorem is motivated by the particular importance of the fundamental group in the case of negatively curved manifolds. This is because all higher homotopy groups of a complete and negatively curved manifold are trivial, thus all non-trivial homotopy classes can be found precisely in the fundamental group. Interestingly enough, the proof of Preissmann's theorem will contain little discussion on the fundamental group. Instead, we will work with a different albeit isomorphic group of elements called covering transformations. Covering transformations are interesting in themselves because they operate by "shuffling" the elements in each fiber of the universal covering space, which in effect preserves the covering map. In regards to Preissmann's theorem, the group of covering transformations allows us to work in the universal covering space, which, due to being simply connected, makes it possible to apply useful geometric laws and geodesic properties. Overall, Preissmann's theorem draws from a broad range of subjects in differential geometry and algebraic-topology, and rests on a long history of mathematicians who progressed the euclidean world of geometry to a framework where we can consider the algebraic and topological structures of curved space.

2.5 Jianda Du

Mentor: Tracy Stepien

Title: Determining the Effect of Curvature in a Mathematical Model of Cell Migration

Abstract: Cell migration is essential for processes such as tissue development, wound healing, and cancer metastasis. For instance, during gastrulation—an early stage of embryonic development—cell migration is crucial for the formation of germ layers that eventually develop into tissues and organs. We extend a previously established continuum mechanical model of cell migration by introducing curvature as a key factor. We investigate how curvature influences cell migration in spreading embryonic tissues of two species: the aquatic frog Xenopus laevis and the axolotl salamander Ambystoma mexicanum. Simulations are conducted with various initial tissue shapes to assess the impact of curvature. Sensitivity analysis and approximate Bayesian computation with sequential Monte Carlo (ABC-SMC) are used to evaluate the importance of incorporating curvature and to additionally determine the form of curvature dependence that best reflects the experimental data.

Session 3

3.1 Alessandro Barletta

Mentor: Sara Pollock

Title: Complex Eigenvalues and the Dynamic Power Method with Momentum: What Could *Possibly* Go Wrong?

Abstract: We begin with a brief overview of the momentum accelerated power method for finding dominant eigenvalue-eigenvector pairs. First, we look at the optimal choice of momentum parameter when all eigenvalues are real, and then we investigate what happens when some subdominant eigenvalues are complex. We conclude with a discussion of current findings and directions for future research.

3.2 Arjun Singh

Mentors: Peter Bubenik & Juan Claudio Nino

Title: Connectomic analysis of age-related neurodegeneration in random matrix denoised brain networks and revealed subnetworks

Abstract: Brain connectivity analysis plays a crucial role in understanding the structural and functional disruptions associated with aging and neurodegenerative processes. However, spurious connections and noise in connectivity matrices can obscure meaningful network features, limiting the ability to detect group-level differences in brain organization. This study investigates the application of a filtering technique derived from random matrix theory (RMT) to separate noise from true signals in functional connectivity matrices and assess its impact on detecting age-related network alterations. By systematically applying RMT filtering to fMRI data from younger and older adults, we examine its effect on graph-theoretic quantifiers compared to unfiltered data. Furthermore, we leverage RMT to identify intrinsic functional subnetworks and characterize age-related differences within these specific systems. We find that RMT filtering significantly enhances

the detection of age differences in several global metrics, notably increasing sensitivity for closeness centrality (p=0.0010) and diameter (p=0.0376) while markedly improving significance for clustering coefficient (p=0.0059). Analysis of nine RMT-derived subnetworks revealed widespread age-related reductions in network efficiency and clustering, though the specific profile of affected metrics varied considerably across subnetworks, highlighting system-specific vulnerability. This RMT-based approach, combining denoising with subnetwork identification, offers a promising direction for refining network-based biomarkers and improving the sensitivity of functional connectivity analyses in aging and related neurological disorders.

3.3 Xavier Gottlieb-Young & Jada Sitchler

Mentor: Youngmin Park

Title: Modeling Seasonal Chocolate Consumption and Heavy Metal Accumulation in Children

Abstract: Chocolate consumption in children may lead to higher levels of heavy metals in the bloodstream due to contamination in popular candy brands. Each gram of chocolate contains about 0.07 to 0.3 micrograms of lead, and children consume an estimated 1000 to 3000 grams per year. Around 50 percent of ingested lead is absorbed into the bloodstream, where it decreases over time with a half-life of about 30 days. To reflect realistic eating habits, we modeled chocolate consumption for five different countries using a mixed distribution with spikes around common holidays like Halloween, Valentine's Day, Christmas, Ramadan, Diwali, Easter, birthdays, and more. We combined the given intake patterns with an exponential decay function to estimate changes in lead concentrations in the blood over time. Our model also accounts for cadmium exposure and includes comparisons across the chosen countries using current consumption data, mapping the risks of heavy metal toxicity in children under various intake scenarios. This presentation will highlight our findings with visualizations and explain the mathematical framework we used to assess exposure and long-term health risks.

3.4 Roberto Giuffredi

Mentor: Youngmin Park

Title: Analyzing the Emergence of Gamma Oscillations During Development

Abstract: Gamma oscillations, which occur in the frequency range of 20–120 Hz, are a common feature of mammalian brains linked to cognitive and sensory processing. Experiments have shown that gamma oscillations become stronger as primates mature from infancy to adulthood [Gonzalez-Burgos et al., Cerebral Cortex, 2014], and the mechanism behind this change could be the growth of inhibitory connections onto excitatory neurons. To test this hypothesis, we study a pair of coupled neural oscillators and alter the synapses from weakly inhibitory to strongly inhibitory, to mirror the changes to inhibitory strengths during primate development. Our simulations show that the oscillators begin to synchronize as inhibition becomes stronger, and we use coupled oscillator theory to mathematically confirm this observation. We conclude that this result is consistent with the observation that gamma oscillations become stronger through development (assuming that stronger synchrony implies stronger gamma oscillations).

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