Rose-Hulman
Undergraduate Mathematics Conference

March 28, 2026

ROSE-HULMAN
INSTITUTE OF TECHNOLOGY

Department of Mathematics
Terre Haute, Indiana

Welcome

Welcome to the 41ˢᵗ Rose-Hulman Undergraduate Mathematics Conference. This conference serves as an opportunity to highlight the research being done by undergraduate students which involves the use of mathematics. Students and faculty performing research across a wide spectrum are brought together by our shared interest in the mathematical sciences. Today is an opportunity to celebrate the accomplishments of those who are presenting, to encourage those for whom research is on the horizon, to broaden our knowledge among new and old friends, and to meet and converse others who also have a passion for all things mathematical. We have a great program this weekend.

Invited Speakers

Our speakers this year have some beautiful and interesting applications of mathematics to discuss. Dr. Matthew Wright, Associate Professor at St. Olaf College, will talk about applications of mathematics to fairness and apportionment. Dr. Jenny Quinn, Executive Director of the Seattle Universal Math Museum, will discuss mathematical ideas of size, geometry, combinatorics, and more.

Contributed Papers

The focal point of the weekend is the contributed student talks. We have almost thirty student presentations today. Regardless of your mathematical interests, we are certain you will find something that appeals to you. We are grateful to all those students who are willing to share their work with us during the conference. We are excited to host you this weekend, and we hope you enjoy the conference!

MAA Press Books

The American Mathematical Society, publisher of the Mathematical Association of America's books series, has donated the books that are on display at the conference. Please check out the book display on the first floor of the Fowler Academic Building.

Conference attendees can use the code below to save 25% on any purchase at the AMS bookstore through April 4. There are some great textbooks for nearly all undergraduate mathematics courses, books for self-study and enrichment, as well as those to read just for fun! Books authored by both of the Invited Speakers are featured.

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Rose-Hulman Undergraduate Math Journal

The Rose-Hulman Undergraduate Math Journal is devoted entirely to papers written by undergraduates on topics related to mathematics. Although the authors need not be undergraduates at the time of submission or publication, the work must have been completed before graduation. The journal is distributed freely in an electronic format from the journal's web site.

In order to maintain a high level of exposition, each paper is sponsored by a mathematician familiar with the student's work and each paper is refereed. The editor-in-chief makes the final decision for publication. The journal is sponsored by the Mathematics Department at Rose-Hulman Institute of Technology.

To each of our presenters, we hope you will consider publishing your research. Should you choose to consider the Rose-Hulman Undergraduate Math Journal, please visit the journal's website for more information

Phone: 812.877.8302
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ℝose-Hulman Undergraduate Mathematics Journal

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Schedule

Saturday

Donuts, Coffee, and Math

8:30 - 9:00am, Fowler Academic Building Lobby
On-site registration will be available just inside the entrance to the Fowler Academic building. Name tags for pre-registered participants will be available in room J101, the first room on your right as you enter. We will have donuts and coffee available as you start your day on the second floor of the Fowler Academic Building (FAB).

Introductory Remarks

9:00am Myers Hall M137
Official Welcome and start to the conference – Ellen Goldey, Provost.

Plenary Speaker

9:10 - 10:10am, Myers Hall M137 Dr. Matthew Wright, What is big? Understanding geometric notions of size.

Morning Contributed Student Talks

10:20 - 11:55am, FAB J202, J204, J206, J208
Due to the volume of student presentations, we are excited to have four parallel sessions of student talks conveniently next door to each other on the second floor of the Fowler Academic Building.

FAB J202

Time	Presenter	Title
10:20 - 10:35	William Wisniewski	Applying the Combinatorial Nullstellensatz To Integer-Magic Labelings; Hartke Magicness
10:40 - 10:55	Lucas Waite	Bipartite Extremal Numbers of Trees
11:00 - 11:15	Haoyu Tang, Arha Gatram, Srujan Roplekar	Eigenvector Preferential Attachment Networks
11:20 - 11:35	Alexander Bastien	On Link-Irregular Digraphs

FAB J204

Time	Presenter	Title
10:20 - 10:35	Mia Pesavento	Machine Learning-Guided Quota Optimization for Sorority Recruitment Matching
10:40 - 10:55	Joshua Tiffany	Augmentation and Adaptive Iterative Training for Multilabel ECG Classification
11:00 - 11:15	Lydia Wright	Estimating Missing Observations in Replicated Two-Way Fixed-Effects Linear Models
11:20 - 11:35	Gabriel Silva	Adaptive Kalman Filtering and Correlated Noise: Dynamic Process-Noise Covariance Scaling for Financial Time Series Forecasting

FAB J206

Time	Presenter	Title
10:20 - 10:35	Tyler Petersen and Alexandra Raloff	A Generalized Dimensional Construction of Vertex Algebroids Associated with Cyclic Leibniz Algebras
10:40 - 10:55	Alexa Renner	Multiplication and the 2-Independence Property in Expansions of the Ordered Group of Integers
11:00 - 11:15	Tan Le	Value Sets of Reversed Dickson Polynomials over Finite Fields
11:20 - 11:35	Alexa Renner	Prime Graphs of Infinite Groups
11:40 - 11:55	Sylvia Webster	Small Carmicheal Numbers

FAB J208

Time	Presenter	Title
10:20 - 10:35	Swechchha Adhikari	Constructing Monogenic Fields of Cryptographic Size
10:40 - 10:55	Dheeran Wiggins	Locality via (co)limits in an infinite spin chain
11:00 - 11:15	Elijah Berry	Searching for Optimal Symplectic Maps
11:20 - 11:35	Pritesh Thakur	Studying the threshold of ZX and ZY surface codes under anisotropic noise using correlated matching

Lunch

12:00pm - 12:55pm, New Academic Building Lobby
We will have a catered hot bar with a variety of options to meet most dietary restrictions and needs. Feel free to enjoy wherever you would like on campus. This will be available on the second floor of the Fowler Academic building, on the same level as the student talks.

Afternoon Contributed Student Talks

1:00 - 2:20pm, FAB J202, J204, J206, and J208
Due to the volume of student presentations, we are excited to have four parallel sessions of student talks conveniently next door to each other.

FAB J202

Time	Presenter	Title
1:00 - 1:15	Michael Morris	Spectrum of the Basilica Schreier Graphs
1:20 - 1:35	Ghaya Mtimet	From Historical Puzzles to Grammatical Constraints: Circular Partitions, Generalized Run-Length Encodings, and Polynomial-Time Decidability
1:40 - 1:55	Amol Bansal	A New Algorithm for Reducing Exceedance in Generalized (n,kn) Catalan-Type Lattice Paths
2:00 - 2:15	Uy (Herry) Vo	Dickson Polynomials and Self-reciprocal Polynomials

FAB J204

Time	Presenter	Title
1:00 - 1:15	Aaditya Trivedee	A Bayesian Network Approach for analyzing intergenerational income persistence in the United States
1:20 - 1:35	Trenton Jeffers	Improving Student Success in Calculus through Student Feedback
1:40 - 1:55	Matthew Tolbert	Isolating Biases to Treatments in the Bradley-Terry Model
2:00 - 2:15	Jake Schwaderer, Mia Pesavento, Angelika Elderbrook, Alexander Bastien	Predicting Tennis Matches: Topological and Graph-Theoretic Approaches

FAB J206

Time	Presenter	Title
1:00 - 1:15	Julia Williamson	Sliding a convex set under a convex function
1:20 - 1:35	Anna Myers	Explorations of Alternative Definitions in Derivatives
1:40 - 1:55	Chenzixi Zhao	Harmonic Measure and Symbolic Dynamics: Distribution of Geometric Addresses on the Basilica Julia Set
2:00 - 2:15	Casey Ward	Inverse Problems in Geometric Optics

FAB J208

Time	Presenter	Title
1:00 - 1:15	Prasun Panthi and Min Heo	A Coupled Entry-Ablation Model and an Inverse Method for Cosmic Dust
1:20 - 1:35	Jonas Liang	Mathematical Frameworks for Cross-Scale Evolutionary Dynamics
1:40 - 1:55	Julia Biesiada	Modeling Pericyte Regulation of Retinal Blood Flow in Glaucoma
2:00 - 2:15	Katie Nguyen	Seasonal Forcing in Predator–Prey Differential Equation Models

Plenary Speaker

2:30 - 3:30pm, Myers Hall M137
Dr. Jenny Quinn, What the Pfaff?

Closing Remarks

3:30 - 3:35pm, Myers Hall M137

Abstracts

Plenary Speakers

What is big? Understanding geometric notions of size St. Olaf College
9:10-10:10am, Myers Hall, M137

How do we quantify the size of geometric objects? Depending on the context or application, the question "How big is it?" may have various answers, even with regard to the same object. For certain classes of geometric objects, a theorem by Hugo Hadwiger classifies all possible notions of size. Hadwiger's Theorem relies on the intrinsic volumes, which generalize concepts of length, area, and volume. In this talk, I will introduce the intrinsic volumes and explain Hadwiger's Theorem, with a view towards applications and computation. In other words, this talk will explain, subject to mild assumptions, all possible geometric notions of size.

Controlling the seemingly unmanageable
Jenny Quinn, Seattle Universal Math Museum
2:30 PM - 3:30 PM in Myers Hall, M137

It is likely you are familiar with the determinant function on a square matrix. But do you know about the Pfaffian? Donald Knuth once said "Pfaffians are more fundamental than determinants." So what the Pfaff is a Pfaffian?

Spoiler alert: Pfaffians are defined on skew-symmetric matrices and can be thought of as the square root of the determinant. This talk explores combinatorial interpretations of Pfaffians, determinants, and the connections between them. It showcases sign reversing involutions, a powerful and often underappreciated combinatorial method, and has guest appearances from knot theory and game theory.

Morning Undergraduate Speakers

Applying the Combinatorial Nullstellensatz To Integer-Magic Labelings; Hartke Magic-ness
William Wisniewski, Illinois Wesleyan University
10:20 - 10:35 AM in FAB J202

In this project we are using Computational Experimentation methods to identify whether or not graphs contain a magic labeling. This method is computing the Hartke polynomial of a graph, and then using the Combinatorial Nullstellensatz to detect if that graph has an integer-magic labeling. Our goal is to prove that for any graph of order 6 and beyond, there is a graph of that order which has a magic labeling that is detectable via its Hartke polynomial. As the order of the graph grows, the required computation grows, therefore we perform a qualitative analysis on smaller order graphs by examining the substructures and how they interact with each other. The goal is to gain insight into the Hartke polynomial of larger order graphs built with these same substructures.

Machine Learning-Guided Quota Optimization for Sorority Recruitment Matching
Mia Pesavento, University Of Evansville
10:20 - 10:35 AM in FAB J204

This project develops an integrated data-driven framework for multi-round sorority recruitment, where approximately 100 potential new members (PNMs) are matched to three chapters through a structured three-round process governed by the Release Figure Methodology (RFM). The framework consists of three components: a Random Forest binary classifier trained on historical registration data to generate PNM-chapter compatibility scores; integer linear programs to determine optimal invitation quotas for Rounds 2 and 3 that balance fairness, coverage, and efficiency objectives; and the Deferred Acceptance algorithm for final matching. Applied to five years of recruitment data from a small Midwestern university, the algorithm replicates actual 2025 recruitment outcomes with a 96.4% individual-level agreement rate and a 100% match rate across 56 PNMs, while optimized invitation quotas closely align with actual coordinator decisions in both rounds. The framework is deployed as an interactive Shiny web application enabling recruitment coordinators to implement these methods in practice, demonstrating how classical matching theory combined with machine learning and optimization can improve decision-making in small constrained matching markets.

A Generalized Dimensional Construction of Vertex Algebroids Associated with Cyclic Leibniz Algebras
Tyler Petersen and Alexandra Raloff, Illinois State University
10:20 - 10:35 AM in FAB J206

We investigate the algebraic structure of the vertex A-algebroids B in the case where B is a cyclic, non-Lie left Leibniz algebra and A is a unital commutative associative algebra. We begin by reviewing foundational properties of cyclic Leibniz algebras and vertex algebroids, as well as existing classifications of vertex algebroids associated with non-Lie cyclic left Leibniz algebras in dimensions two and three. Building on these known low-dimensional cases, we identify structural patterns and

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algebraic constraints that lead to a generalized construction valid in arbitrary finite dimensions. This work provides a systematic framework for extending previously established classifications and clarifies the dimensional behavior of vertex algebroids arising from cyclic Leibniz structures.

Constructing Monogenic Fields of Cryptographic Size
Swechchha Adhikari, Brigham Young University
10:20 - 10:35 AM in FAB J208

Dating back to the 1960s, research has been conducted on classifying monogenic number fields, yet a complete characterization still remains unknown. Such fields at cryptographic sizes would be useful for RLWE cryptography, which currently relies on a family of abelian monogenic number fields called cyclotomic fields. In this work, we construct number fields of large degree by iteratively applying a polynomial transformation. We first discuss the necessary and sufficient conditions for our transformed polynomial to be irreducible by constructing a reverse transformation. Then we derive a simplified formula for the discriminant of the resulting polynomial and establish the criteria under which the associated number fields are monogenic.

Bipartite Extremal Numbers of Trees
Lucas Waite, Kenyon College
10:40 - 10:55 AM in FAB J202

Extremal Graph Theory is a field which studies how constraints on large relationship structures can force the existence of a specific substructure. For example, one might be interested in how many pairs of people in a room of 12 can be friends if there is no friend-group of 4 people. This is a relatively new field with many open problems. My research is related to the famous erdos-sos conjecture on the extremal number of trees: an analogue question was posed in a recent paper, and I present new lower bounds and conjectures on this analogue and show that this conjecture holds in many cases. I am in the process of publishing a paper on these results with Professor Aydin Nuh at Kenyon College and Professor Cory Palmer at University of Montana.

The improvement past my initial summer work comes largely from generalizing the concept of k-minimality, a powerful tool often applied in sparse graph settings to give structural restraints. This perspective is powerful in reducing the problem of the bipartite extremal number with fixed part sizes. I define a bipartite graph G, the union of U and V to be (u,v)-minimal if it is bipartite and has e(G)¿—U—(u-1)+—V—(v-1), yet every subgraph of G fails this edge condition. On its own, under this framework one is able to embed many trees with a simple greedy embedding. I further observed that one may do better by fixing that —U— is at least —V— or vice versa, naturally introducing concepts of $(u, v)^R$ and $(u, v)^L$-minimality. Under this model one is able to get either a long chain of minimal subgraphs or an immediate embedding of all desired trees, allowing for weaker embedding conditions. In particular this argument is sufficient to show that random trees have bipartite extremal numbers matching my conjecture with high probability. The full ramifications of introducing new minimality types are not yet fully clear, and it is possible that this method is alone sufficient to solve the bipartite problem for general trees. This is exciting, as the Erdős–Sós conjecture is historically impenetrable by such methods, yet a strongly related problem may turn out to be approachable. In fact, the bipartite extremal numbers of trees can be used to show the truth of Erdős–Sós for some trees through random bipartitioning arguments.

Augmentation and Adaptive Iterative Training for Multilabel ECG Classification
Joshua Tiffany, Illinois State University
10:40 - 10:55 AM in FAB J204

The electrocardiogram (ECG) is widely used to detect and monitor cardiac conditions such as arrhythmias and conduction disorders. Deep learning has enabled automated ECG interpretation systems to be built from minimally preprocessed signals, but progress is constrained by two common limitations of public ECG datasets: small sample sizes and severe class imbalance. These factors make rare conditions difficult to learn and reduce model reliability in clinical use.
This work presents two complementary strategies to address extreme imbalance in multilabel ECG classification. First, we apply morphology-preserving signal transformations to expand the effective training set while maintaining clinically meaningful waveform structure. Second, we introduce an adaptive iterative training procedure that updates class weights and class-specific augmented sample counts at each iteration based on per-class validation F1 scores. By continuously reallocating emphasis toward underperforming labels, the training process explicitly targets difficult and rare conditions as learning evolves.
Experiments show that morphology-aware augmentation improves detection for most conditions compared with baselines using standard imbalance-handling methods. The adaptive iterative procedure provides additional gains in challenging conditions, though it can reduce performance on some other labels, indicating a trade-off that must be managed. Overall, the results demonstrate that combining clinically faithful augmentation with performance-driven adaptive training can significantly improve multilabel ECG classification under limited data and extreme class imbalance. This is joint work with Dr. Qi Zhang.

Multiplication and the 2-Independence Property in Expansions of the Ordered Group of Integers
Alexa Renner, Rose-Hulman Institute of Technology
10:40 - 10:55 AM in FAB J206

We present results on definability and model-theoretic wildness in certain expansions of the ordered group of integers. Specifically, we prove that the theory of certain expansions of the ordered group of integers by a unary predicate interpreted as a set enumerated by a sequence certain type of linear nonhomogeneous recurrence relation has the 2-independence property and is undecidable based on the roots of the corresponding characteristic polynomial, and we also show that such structures do or do not define multiplication in certain cases based on the multiplicity of roots of unity as roots of the characteristic equation.

Locality via (co)limits in an infinite spin chain
Dheeran Wiggins, University of Illinois
10:40 - 10:55 AM in FAB J208

Quantum error correction is a rather young field, born of the goal for quantum computation to be "fault-tolerant." In the contemporary perspective, errors are viewed in the information-theoretic language of noisy quantum channels on the *-algebra of bounded operators on a Hilbert space, following Knill and Laflamme. By considering a class of errors generated by the Pauli spin matrices, Gottesman developed an algebraic formalism by considering the subspaces fixed by so-called

stabilizer subgroups. Yet, such algebraic treatments are usually reserved for quantum systems of finite-dimension. We instead consider a system with countably many spin-1/2 sites, constructing a Pauli group that acts on the corresponding separable Hilbert space. Using this algebraic construction, we present an infinite-dimensional analogue of Gottesman's stabilizer formalism. We then show that our infinite Pauli group locally behaves like its finite counterparts in a precise sense.

Eigenvector Preferential Attachment Networks

Haoyu Tang, Arha Gatram, and Srujan Roplekar, University of Illinois
11:00 - 11:15 AM in FAB J202

The degree preferential attachment network model was popularized by [Barabási and Albert, 1999] to model real world networks. However, degree is a local centrality measure, whereas the global influence of vertices is important in some applications.
Adami et al. [2024] aimed to remedy this by introducing eigenvector centrality based preferential attachment. In this model, the attachment probabilities are determined by the Perron-Frobenius eigenvector of the graph's adjacency matrix.
Our present work includes simulations revealing the the existence, uniqueness, and stability of the superhub, the max degree vertex, and demonstrates asymptotic superhub degree growth dwarfing the rest of the vertices. We also provide numerical evidence for the sublogarithmic growth of graph diameter.
This is joint work with Arha Gatram, Haoyu Tang, Srujan Roplekar, Shuwei Zhang, Neeladri Maitra, Taegu Kang, and Jaya Manthripragada.

Estimating Missing Observations in Replicated Two-Way Fixed-Effects Linear Models

Lydia Wright, Butler University
11:00 - 11:15 AM in FAB J204

This study develops analytic estimators for single and multiple missing observations in replicated two-way fixed-effects linear models by minimizing squared error loss. The proposed method provides computationally efficient and robust solutions, validated through numerical optimization and simulation studies evaluating bias, variance, MAE, and MSE under varying replication and missingness patterns. Results demonstrate strong performance and flexibility, with potential extensions to more complex factorial and high-dimensional models.

Value Sets of Reversed Dickson Polynomials over Finite Fields

Tan Le, Knox College
11:00 - 11:15 AM in FAB J206

Let p be an odd prime and F_p be the finite field with p elements. We investigate value sets of reversed Dickson polynomials over finite fields. While previous literature often focuses on finding permutation polynomials—where the size of the value set is equal to p—our research examines the opposite extreme: cases where the size of the value set is very small.
We explicitly classify the integer indices n for which the value set has cardinality exactly two. We prove that for specific families of n determined by p, the value set consists precisely of the elements 1, 2 or 1, -1. Moreover, we examine the distribution of possible value set sizes for a given

prime p and discuss open questions regarding the existence of polynomials with specific value set cardinalities."

Searching for Optimal Symplectic Maps
Elijah Berry, University of Illinois
11:00 - 11:15 AM in FAB J208

A fundamental result in symplectic geometry is Gromov's non-squeezing theorem, which implies that while all symplectic maps are volume-preserving, they are subject to ""rigidity"" constraints that ordinary volume-preserving maps are not. A central challenge in the field is determining the optimal symplectic embedding of a given region into a ball of minimal radius. For example, McDuff and Schlenk (2012) showed that the four-dimensional ellipsoid E(1,2) cannot be symplectically embedded into any ball smaller than B(2).
This project develops a computational optimization framework to search for explicit symplectic embeddings. We approximate the space of symplectic maps using Henon-like polynomial maps, which provide a flexible yet rigorous basis for the search. By applying a gradient descent algorithm to minimize the distance of a mapped boundary from the origin, we can numerically approximate optimal embeddings. Our results demonstrate that this framework successfully recovers known theoretical lower bounds for ellipsoids and provides a tool for exploring embedding capacities in more complex, non-standard regions.
This is a joint work with Alex Ware, Tianyang Ma, Eleven Yan, Aline Leite, Yefei Zhang, and Ely Kerman.

On Link-Irregular Digraphs
Alexander Bastien, University of Evansville
11:20 - 11:35 AM in FAB J202

We introduce the concept of link-irregular digraphs, a generalization of link-irregularity in simple graphs. A digraph is said to be link-irregular if no two vertices have isomorphic directed links. We provide some analogous results from link-irregular graphs, and we develop some new results. In particular, we prove the existence of such graphs by showing that a link-irregular digraph exists on n vertices if and only if $n \geq 5$. We prove some structural properties of link-irregular digraphs including results regarding edge bounds and the planarity of these digraphs. Additionally, we will introduce some special cases of link-irregular digraphs and present a conjecture regarding some of these special cases.

Adaptive Kalman Filtering and Correlated Noise: Dynamic Process-Noise Covariance Scaling for Financial Time Series Forecasting
Gabriel Silva, Loyola University Chicago
11:20 - 11:35 AM in FAB J204

The Kalman filter is one of the most influential algorithms for recursive estimation in noisy systems, with applications spanning aerospace navigation to financial forecasting. At its core, it is a state-space framework grounded in Bayesian inference that produces both point estimates of latent states and measures of uncertainty. While financial markets present an appealing domain for

Kalman filtering, practical applications remain limited because the standard filter assumes Gaussian disturbances and fixed noise covariances; assumptions frequently violated by regime shifts, volatility clustering, and heavy-tailed return distributions. A central limitation is the specification of the process-noise covariance matrix Qt, which governs how uncertainty enters the state dynamics. Typically treated as fixed or estimated via maximum likelihood over rolling windows, Qt adapts slowly to structural market changes, leading to persistent forecast errors during regime transitions. This paper proposes a lightweight scaling mechanism that dynamically adjusts Qt using a dynamic factor gt derived from the normalized innovation squared (NIS). Unlike Mehra's classical covariance moment-matching approach, which relies on iterative optimization, our method directly scales the covariance matrix in the correct direction using recent innovation statistics to respond rapidly to regime changes. We evaluate this approach within a two-factor state-space framework inspired by the Schwartz–Smith commodity pricing model, comparing four specifications: a baseline Kalman filter, the proposed g-scaling model, Mehra's method, and a combined specification. Results demonstrate that the proposed g-scaling mechanism yields an 18% increase in both RMSE and MAE efficiency relative to Mehra's specification, with approximately half of the gain arising independently of Mehra's structure, confirming that the two methods capture complementary sources of misspecification. Distributional testing via the Kolmogorov–Smirnov test shows that the baseline Kalman filter fails chi-squared alignment, while all augmented models pass. The combined model reduces tail misspecification by 66% relative to the standard filter and improves Mehra's tail calibration by 20%, achieving the closest empirical coverage to the theoretical 95% threshold.

Prime Graphs of Infinite Groups
Alexa Renner, Rose-Hulman Institute of Technology
11:20 - 11:35 AM in FAB J206

The prime graph of a finite group G is the graph with vertex set the set of prime divisors of —G— and an edge between vertices p and q if and only if there exists an element g of G with order $o(g) = pq$. Given a finite nonabelian simple group T, a group G is T-solvable if there exists a composition series of G such that every composition factor is either abelian or isomorphic to T. In this paper, we introduce the prime graph of an infinite group, the graph with vertex set {o(g): g is an element of G and o(g) is prime} and an edge between vertices p and q if and only if there exists an element g in G with order pq, and generalize results on the prime graphs of finite solvable and T-solvable groups to results on the prime graphs of members of certain classes of infinite solvable and T-solvable groups.

Studying the threshold of ZX and ZY surface codes under anisotropic noise using correlated matching
Pritesh Thakur, Brandeis University
11:20 - 11:35 AM in FAB J208

The main working mechanism of quantum error correction codes is to perform continuous stabilizer measurements on the data qubits to get error syndromes without disturbing their encoded state. Threshold is a critical physical error rate below which increasing the code distance exponentially suppresses the logical failure. Thus, using a proper surface code and decoder combination to maximize threshold is a central problem in fault-tolerant quantum computation. Here, we analyze

ZX and Clifford-deformed ZY surface codes using correlated matching. For each code, we consider rotated and unrotated lattice geometries under two distinct CNOT orderings for syndrome extraction circuits. Using circuit-level noise models, we perform large-scale Monte Carlo simulations and decode using correlated minimum-weight perfect matching on weighted decoding graphs. Threshold values are extracted using finite-size scaling analysis by fitting logical error rates across multiple code distances. Our results show that Clifford deformation shows near-invariant logical thresholds despite additional syndrome information using correlated matching. CNOT ordering redistributes error protection asymmetrically between X and Z memories. These findings show how group-theoretic code structure, graphs and probabilistic scaling analysis determine the behavior of fault-tolerant codes under realistic noise.

Small Carmicheal Numbers
Sylvia Webster, Butler University
11:40 - 11:55 AM in FAB J206

Carmichael numbers are composite numbers that satisfy Fermat's Little Theorem. It is believed that there are Carmichael numbers with exactly d prime factors for any d ¿ 2. We present an algorithm to find the smallest Carmichael number with exactly d prime factors. We implemented this algorithm and extended the table of known examples to d = 36, 37, 38, and 39 prime factors.

Afternoon Undergraduate Speakers

Spectrum of the Basilica Schreier Graphs
Michael Morris, Rose-Hulman Institute of Technology
1:00 - 1:15 PM in FAB J202

We study the spectral properties of the Laplacian on the Schreier graphs associated with the Basilica group, the iterated monodromy group of the polynomial $z^2 - 1$. This group plays a central role in the theory of self-similar amenable but not elementary amenable automaton groups. We build heavily on the results of Brzoska, Jarvis, George, Rogers, and Teplyaev [2019] about subgraphs of the Basilica to the full sequence of Basilica graphs by developing a new recursive framework for computing their characteristic polynomials. Our analysis reveals a simple underlying dynamical system and proves approximation results for the Kesten-von-Neumann-Serre (KNS) spectral measure.

A Bayesian Network Approach for analyzing intergenerational income persistence in the United States
Aaditya Trivedee, Knox College
1:00 - 1:15 PM in FAB J204

This paper investigates the causal mechanisms underlying intergenerational income persistence in the United States. A causal Bayesian network is constructed to map the probabilistic dependencies between parental background and child economic outcomes. A score-based structure learning algorithm with tiered causal constraints is implemented to identify the most significant pathways of

status transmission. Specifically, causal mediation analysis is utilized to decompose the intergenerational income gap into direct parental transfers and indirect effects mediated through human capital accumulation. Furthermore, a heterogeneity analysis is performed to test whether the network topology of opportunity differs significantly by race and sex. The findings provide a structural decomposition of inequality of opportunity, isolating the specific extent to which geographic and demographic rigidities constrain the education channel as a vehicle for upward mobility.

Sliding a convex set under a convex function
Julia Williamson, Loyola University Chicago
1:00 - 1:15 PM in FAB J206

An existing form of approximating a non-differentiable function, f, is to slide a convex set, A, along the graph of f and take the lower boundary to form a differentiable function g. Our work reveals that sliding a convex set, A, under the graph of f gives the same approximation function, g, as sliding the set A-A along f. Additionally, sliding a convex set, A, under f is the same as sliding -A under f, or A-A along f. Due to this, if A is smooth from above or below, the approximation function g is essentially differentiable.

A Coupled Entry-Ablation Model and an Inverse Method for Cosmic Dust
Prasun Panthi and Min Heo, Wabash College
1:00 - 1:15 PM in FAB J208

Cosmic dust preserved in terrestrial strata provides a filtered record of incoming micrometeoroid flux, as particles undergo deceleration, heating, and mass loss during atmospheric entry. Recovering the original size distribution from stratigraphic observations constitutes an ill-posed inverse problem requiring a physically accurate forward model.
We present a coupled dynamical system governing three-dimensional particle motion, velocity, temperature, and mass evolution, incorporating gravity, aerodynamic drag, radiative cooling, and threshold-driven ablation. The stiff, nonlinear coupling between mass loss, drag, and heating is handled numerically through large simulation sweeps over initial radii, velocities, and entry angles, yielding a transfer map that characterizes the atmospheric filtering of incoming particles. This map exposes sharp survival boundaries and stabilization regimes where rapid cooling prevents full vaporization.
The inverse step is formulated as a nonnegative least-squares problem, reconstructing the incoming flux distribution consistent with observed strata data. The complete pipeline , from nonlinear dynamical modeling through numerical simulation to constrained inversion, offers a systematic framework for micrometeoroid flux reconstruction with applications to planetary science and atmospheric entry studies.

From Historical Puzzles to Grammatical Constraints: Circular Partitions, Generalized Run-Length Encodings, and Polynomial-Time Decidability
Ghaya Mtimet, University of Evansville
1:20 - 1:35 PM in FAB J202

Motivated by a historical combinatorial problem that resembles the well-known Josephus prob-

lem, we investigate circular partitions, formulate problems in deterministic finite automata, and develop algorithms to solve problems in this context. The historical problem involves arranging individuals on a circle and eliminating every k-th person until a desired group remains. We analyze both removal and non-removal approaches to circular partitioning, establish con- ditions for balanced partitions, and present explicit algorithms. We introduce generalized run- length encodings over partitioned alphabets to capture alternating letter patterns and compute their cardinalities using Stirling numbers of the second kind. Connecting these combinatorial structures to formal language theory, we formulate an existence problem: given a context-free grammar over a dictionary and block-pattern constraints on letters, does a valid sentence exist? We prove decidability in polynomial time by showing block languages are regular and applying standard parsing techniques. Complete algorithms with complexity analysis are provided and validated through implementation on both historical and synthetic instances.

Improving Student Success in Calculus through Student Feedback
Trenton Jeffers, Prairie View A&M University
1:20 - 1:35 PM in FAB J204

This study examines how modern technology and study habits affect students' success in Calculus I, identifying ways to build a stronger foundation and improve passing rates. The survey consisted of multiple-choice and open-ended questions and was sent to all Calculus 1 students enrolled during the 2025 Fall semester. We will discuss results pertaining to students' use of technology in the class, their study skills/habits, and their use of assessment feedback from their professors and instructors. We will also discuss how these findings on the use of technology and feedback from assignments can be used to improve student success in Calculus I and higher-level courses.

Explorations of Alternative Definitions in Derivatives
Anna Myers, Ohio Northern University
1:20 - 1:35 PM in FAB J206

The classical derivative defines a linear derivation on the algebra of differentiable functions, characterized by additivity and the Leibniz rule. In this work, we investigate a modified limit based operator defined by

D*f(a)= limit as x approaches a of $[(f(x))^2 - (f(a))^2]/(x - a)$ whenever the limit exists.

We prove that if f is differentiable at a, then D*f(a) = 2f(a) f'(a) illustrating that D* coincides with the derivative of f^2. This representation allows for a systematic structural comparison with the classical derivative, revealing that D* is nonlinear even if f and g are D*-differentiable, the sum f+g may not be. Moreover, the operator exhibits degeneracy at points where f(a)=0, meaning D* f(a) can vanish even when the classical derivative does not.

Through chosen examples, we illustrate these behaviors. For instance, the function that is rational at 1 and irrational at -1 is D*-differentiable at 0 with the value of 0, while the classical derivative does not exist. Similarly, for f(x)=|x|, D*f(0)=0 remains continuous even though f'(0) fails to exist.

These results demonstrate that D* provides a concrete example of how modifying the limit construction alters the algebraic structure of differentiation. Ultimately, the operator highlights the essential role of linearity in classical calculus and offers a framework for exploring nonlinear modifications of differential operators.

Mathematical Frameworks for Cross-Scale Evolutionary Dynamics
Jonas Liang, University of Illinois
1:20 - 1:35 PM in FAB J206

Understanding how cooperation emerges and persists in structured populations requires linking individual-level strategic interactions with population-level evolutionary forces. In this work, we study cross-scale evolutionary dynamics using stochastic multilevel selection models inspired by the Traulsen–Nowak framework. Individuals within groups interact via two-strategy evolutionary games, while groups compete based on their internal composition of cooperators and defectors. We first analyze finite-population dynamics using a system of ordinary differential equations for groups of size two, capturing the interaction between within-group selection favoring defection and between-group selection favoring cooperation. Stability analysis reveals conditions under which group-level selection overcomes individual-level temptation, allowing cooperative groups to persist. Numerical simulations illustrate how increasing group selection strength shifts the population toward higher cooperation. To study the infinite-population limit, we derive a partial differential equation describing the evolution of the density of groups over cooperator fractions. The resulting PDE balances individual-level replicator dynamics with between-group competition. Using numerical finite-volume methods and analytical arguments, we show that in the Stag Hunt game, sufficiently strong group selection drives the population toward the socially optimal all-cooperator state. Stochastic simulations of the underlying Traulsen–Nowak process validate the continuum predictions despite finite-population fluctuations. Together, these results provide a unified stochastic-to-continuum framework connecting finite-population models and infinite-population limits, clarifying how cooperation can emerge from multilevel evolutionary pressures across scales.

A New Algorithm for Reducing Exceedance in Generalized (n,kn) Catalan-Type Lattice Paths
Amol Bansal, Marquette High School
1:40 - 1:55 PM in FAB J202

Catalan numbers count many combinatorial objects, including lattice paths from (0,0) to (n,n) that stay on or below the diagonal y=x. Classical proofs of the Catalan formula often rely on the notion of exceedance, which counts upward steps that lie strictly above this diagonal.
In this talk, I study exceedance reduction for lattice paths on an (n,kn) grid, where the boundary is given by the line y=kx. I present a uniform local algorithm that reduces exceedance by exactly one while preserving the endpoints of the path. Each step of the algorithm modifies only a small portion of the path, and repeated applications systematically eliminate exceedance.
I outline the geometric reasoning that proves the correctness of the procedure and illustrate how the algorithm works through examples. The method applies uniformly for all values of k and provides a structured way to transform paths that cross the boundary into paths that remain on or below it.
I also briefly discuss a possible interpretation of the algorithm in a simplified financial model, where exceedance represents temporary overexposure and the reduction process corresponds to stepwise risk correction.

Isolating Biases to Treatments in the Bradley-Terry Model
Matthew Tolbert, Hillsdale College

1:40 - 1:55 PM in FAB J204

In the Bradley-Terry model, a judge is considered to compare two treatments to determine which is superior. By aggregating many such comparative judgements, a maximum likelihood estimate can be used to compute approximate strengths for each treatment considered. However, if a judge is known to be biased, it can be hard to measure whether that bias is due to mishandling certain kinds of comparisons or considering certain treatments. I present four metrics—some original and others variants of known metrics for the Bradley-Terry model or in psychometrics—to measure these specific kinds of biases that a judge can display.
These metrics can then be applied in psychometrics to measure the accuracy of using a LLM-based comparative judgements to estimate question difficulty. If a judge is presented with many pairs of questions and asked to choose the harder one, the weights in the Bradley-Terry model can correspond linearly with the difficulties in the psychometric Rasch model. After accounting for the general skill of a judge, however, a LLM-based judge still manifests bias. The above-found metrics show that the LLM's bias is not isolated to particular types of questions or comparisons but rather due to a broader failure to fit the model.

Harmonic Measure and Symbolic Dynamics: Distribution of Geometric Addresses on the Basilica Julia Set
Chenzixi Zhao, Purdue University
1:40 - 1:55 PM in FAB J206

Julia sets are a particular class of fractals that occur by considering complex dynamical systems. The symbolic dynamics of specific Julia sets, such as the Basilica, can be structurally defined through foundational geometric addresses and replacement rules. To this end, our goal is to investigate the distribution of these addresses on the Basilica, specifically evaluating the probability that a randomly selected point yields a specific address sequence at the n-th position for n greater than or equal to 2. To answer this question, we apply the Riemann Mapping Theorem to pull back the harmonic measure from the unit circle to the Basilica, visualizing it through external rays. Furthermore, we introduce a fractal function to map the resulting 1/4, 1/2, 1/4 measure distribution given by our method to a uniform 1/3, 1/3, 1/3 distribution.

Modeling Pericyte Regulation of Retinal Blood Flow in Glaucoma
Julia Biesiada, Indiana University Indianapolis
1:40 - 1:55 PM in FAB J208

Glaucoma, a leading cause of irreversible blindness worldwide, has been closely associated with impaired retinal blood flow. To understand the mechanisms of glaucomatous disease, several theoretical models have been developed to simulate the impact of elevated intraocular pressure (IOP) and impaired retinal blood flow on tissue oxygenation. While our recent models account for oxygen transport and flow regulation mechanisms, they do not include the role of pericytes. Pericytes are the primary regulators of blood flow in retinal capillaries (where smooth muscle cells are absent) and play an essential role in maintaining vascular tone and homeostasis. Increased levels of lactate and nitric oxide in blood lead to capillary dilation (via pericyte relaxation), while increased endothelin-1 levels cause capillary constriction (via pericyte contraction). In this work, we extend a previously established compartmental model of retinal blood flow to account for the

effects of capillary pericyte regulation as oxygen demand or intraluminal pressure are varied. Pericytes are predicted to allow for increased flow at high levels of oxygen demand but contribute to a reduced capacity for autoregulation over a range of physiologically relevant pressures . Ultimately, this framework provides a more comprehensive approach to understanding contributors to glaucomatous damage beyond the effects of elevated IOP.

Dickson Polynomials and Self-reciprocal Polynomials
Uy (Herry) Vo, Knox College
2:00 - 2:15 PM in FAB J202

Dickson polynomials of the first kind were introduced by Leonard Eugene Dickson in 1890s in the context of investigating polynomials that induce permutations of finite fields. They have many notable algebraic properties and are widely used in cryptography, coding theory and polynomial research. The introduction of Dickson polynomials of the (k+1)th kind in 2012 unified earlier approaches, offering new insights into the behavior over different algebraic structures. Self-reciprocal polynomials are polynomials whose coefficients form a palindrome. They play a very important role in coding theory as well as in the development of efficient factorization algorithms. We investigate self-reciprocal polynomials arising from Dickson polynomials of the (k+1)-th kind over Z and Z_p, where p is prime. Our results reveal clear connections between the index of the polynomial, the parameter k, and the characteristic of the underlying field.

Predicting Tennis Matches: Topological and Graph-Theoretic Approaches
Alexander Bastien, Angelika Elderbrook, Mia Pesavento, and Jake Schwaderer, University of Evansville
2:00 - 2:15 PM in FAB J204

In this joint presentation, we apply topological data analysis and graph-theoretic methods to predict professional tennis match outcomes using 65,885 ATP matches from 2000–2025. Our first approach constructs competitive networks and extracts features through persistent homology using lower-star filtration, originally achieving a 61% accuracy with a XGBoost classifier. We then updated the model adding more inputs, leading us to achieve a 66% prediction accuracy with a Random Forest classifier. We compare four topological summary methods (VAB, HNAV, HW-NAV, OW-HNPV) and demonstrate that network topology alone, without official player rankings, achieves 64% accuracy, showing that mathematical structure captures meaningful competitive patterns. Our second approach uses a modified Katz similarity index, achieving 62% accuracy. Algorithmic optimizations enable large-scale analysis to be feasible. This represents the first application of persistent homology to tennis prediction and demonstrates how mathematical techniques extract practical insights from sports data.

Inverse Problems in Geometric Optics
Casey Ward, Purdue University
2:00 - 2:15 PM in FAB J206

The analogy between Fermat's last principle and the principle of stationary action provides a unique perspective for tackling problems in geometric optics. Working through the mathematics

of the Hamiltonian formalism allows one to derive a relationship between the refractive index of a medium and optical path length known as the eikonal equation. The eikonal equation is a first-order nonlinear partial differential equation that has applications spanning fields in the physical sciences, such as seismology, electro-physiology, and a myriad of others. However, a consequence of nonlinearity is that the problem can pose substantial challenges when developing a robust theory or an efficient numerical method for the general case.

The purpose of this work is to investigate the eikonal equation in the context of tomographic reconstruction. That is, given the observed optical path lengths, we intend to try to reconstruct the medium in question by solving the inverse problem. We also intend to explore the structure of solutions to the forward problem when considered in the context of reconstructive tomography problems.

Seasonal Forcing in Predator–Prey Differential Equation Models
Katie Nguyen, Knox College
2:00 - 2:15 PM in FAB J206

This project studies predator–prey population dynamics using differential equation models that incorporate seasonal forcing. The Lotka–Volterra predator–prey model is known as the predator-prey equations, a pair of first order nonlinear differential equations. While standard models assume constant environmental conditions, this research uses a periodic function to take the four seasons into account, reflecting real-world changes in birth rates and food availability. For each season, a unique initial environment generates different functions of the population of rabbits and foxes.