The Twenty-Eighth Annual Nebraska Conference for Undergraduate Wisdom in Mathematics

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POSTER ABSTRACTS

Posters by Undergraduate Students

Zoe Balson, Appalachian State University
Timeless Tunes: A Statistical Analysis of Structural Features Predicting Classic Status in Popular Music

What makes a song become a "classic", consistently appealing to listeners throughout time? Do timeless, commercially successful pieces of music have structural similarities in their composition? We investigate this question by accessing data from top Billboard charts over the past 80 years, intentionally choosing songs we categorize as either "classic" or "ephemeral". We then identify and measure variables such as melodic simplicity, originality, and singability, using the Music21 Python-based toolkit to perform a statistical analysis comparing the two groups of songs.

Ang Barrett, Northeastern University
Aspects of Matrix Lie Groups with a View Toward Spinors

This project investigates the intricate relationships between various matrix Lie groups and their corresponding Lie algebras, in particular from the point of view of quaternionic representations. The goal of this investigation is to gain insights into spinors and their geometric and algebraic foundations. Taking a ground up approach, we go through a development of foundational Lie theory to work through the various facets of relationships between low-dimensional matrix Lie groups. The culmination of this inquiry is an introduction to spinors, exploring how the previously developed algebraic and geometric insights over a pathway to understanding spinor representations. This systematic approach illuminates the foundational connections between matrix Lie groups, Lie algebras, and spinor theory.

Teresa Bean, Saint Mary's College
Deep Learning in Image Classification Models

Deep learning is often regarded as a 'black box' for data, with the internal mechanisms remaining opaque. To better understand these processes we developed an image classification model trained on 33,000 photos we collected of 16 campus locations, including academic buildings, dormitories, the athletic center, student center, and lake. Our dataset was divided into three subsets: the training data for the model learning, the validation data to assess and refine during learning training, and the testing set to evaluate final model performance. We analyzed model logic by using Tensor Board visualizations, heat maps, and SoftMax scores to interpret our model's behavior and improve testing accuracy. By tuning hyperparameters within our convolutional neural network and utilizing the Keras library, our model achieved a testing accuracy of 93.7% across the 16 locations.

Shreshty Budakoti, Penn State University
A Diffusion-Based Framework for Designing Molecules in Flexible Protein Pockets

The design of molecules for flexible protein pockets represents a significant challenge in structure-based drug discovery, as proteins often undergo conformational changes upon ligand binding. While deep learning-based approaches have shown promise in molecular generation, they typically treat protein pockets as rigid structures, limiting their ability to capture the dynamic nature of protein-ligand interactions. Here, we introduce YuelDesign, a novel diffusion-based generative framework developed to address this challenge through mathematical modeling of molecular dynamics. YuelDesign employs a fully connected graph representation to encode protein pocket flexibility, combining geometric and topological information through adjacency matrices and spatial embeddings. The diffusion process, grounded in stochastic differential equations, iteratively de-noises atomic coordinates to model the probabilistic evolution of molecular structures. A specialized bond reconstruction module, formulated as an optimization step, ensures chemical validity and minimizes synthetic complexity. Our results demonstrate that YuelDesign generates molecules with favorable drug-likeness, low synthetic complexity, and diverse chemical functional groups, including some not present in the training data. Redocking analysis reveals that the generated molecules exhibit docking energies comparable to native ligands.

Linh Bui, Denison University
Predicting Voter Turnout and Election Outcomes at the Precinct Level

In the United States, polling data are collected at the state level, but election results vary substantially within states (e.g., between rural and urban areas). Unlike polls, election results are often available at the precinct level, and these fine-scale data can provide insight into how primary elections, general elections, and voter turnout are related at a granular level. Using primary and general data at the precinct level for past presidential races, we aim to explore a voter dynamics model that quantifies turnout behaviour, contributing to a deeper understanding of electoral prediction beyond polling.

Nicole Caldwell, Drake University
Ecosystem Impacts of Organic Pest Management Practices in Midwest Apple Orchards

Considering the push in recent years for organically produced fruit, orchards are seeing an increasing struggle to effectively manage pest populations using alternative and sustainable methods. This is of particular concern in apple orchards, where damage caused by the codling moth (Cydia pomonella) is often severe. Recent studies indicate that promoting natural predator populations, such as bats, can help alleviate pest management stress as well as contribute to biodiversity goals. The focus of this research is the "Driftless Region" of the Midwest due to its unique landscape and emphasis on fruit production. An agent-based modeling approach is utilized to study the long-term effects that increased bat populations have on the ecosystems surrounding apple orchards, as well as interactions with other forms of organic pest control.

Clara Campos Correa de Araujo, DePaul University
Numerical Computation of Dirichlet Eigenvalues of Grid Domains

This research explores the mathematical field of spectral geometry to analyze how the first ten Dirichlet eigenvalues of a given grid domain-related to the first ten resonant frequencies produced by a drumhead of the same shape-change as the grid domain changes. The data is obtained through mathematical computation done in the platform FreeFEM, where the Dirichlet eigenvalues of an input domain are computed. An analysis is carried to compare the normalized eigenvalues of different grid domains, where it is observed that for the cases examined: adding one small square to a large square domain generally increases each of the first ten normalized eigenvalues; adding this small square to the edges of the domain increases these normalized eigenvalues more than when adding it to the middle region; the lowest normalized eigenvalues are usually found in domains with a certain degree of symmetry.

Amanda Castillo-Lopez, Colorado School of Mines
Quantifying River Hydrological Regimes through Hydrograph Power Spectral Density Analysis to Improve Flood Risk Understanding

Devastating floods underscore the need for a more comprehensive understanding of flood risks. The generation of river floods partially depends on river hydrologic regimes reflected in hydrograph shapes. To develop an understanding of these hydrologic regimes, we created metrics that distinguish hydrograph shapes according to how the river discharge data informs different patterns of geomorphological work. After an initial analysis of hydrographs from rivers around the world, we determined that grouping the rivers by drainage size or hydroclimate type did not effectively distinguish rivers by magnitude and frequency of flood events. We developed a mathematical grouping method which independently focuses on flood magnitude-frequency relationships. While variance is a compelling metric for discharge variability, it does not preserve information about variability at different time scales. Instead, we decided to dissect this measure by using a Power Spectral Density (PSD) analysis. PSD quantifies how variance at different time scales affects the overall variance and thus allows us to identify and use K-means clustering to group rivers by river discharge patterns that repeat over different lengths of time. By developing quantitative metrics to classify rivers based on magnitude and frequency of flood events, we will ultimately develop a more nuanced understanding of flood extremes–including event magnitude, duration and intensity–and their role in driving geomorphic change.

Cosette Clinton, Western Washington University
Reliable Student's t-Based Approximate Odds Ratio Confidence Interval

The odds ratio, which compares the probabilities of success against the probabilities of failures as a ratio, is frequently used in the two-sample setting to quantify the treatment effect of dichotomous outcomes. Due to its importance, the odds ratio appears in various fields of study such as epidemiology, biostatistics, economics, medical research, and psychology. As the odds ratio is considered a key measure of effect size, it is crucial to be able to provide a reliable confidence interval for the odds ratio; however, its coverage probability performance tends to vary significantly depending on factors such as sample sizes and true probabilities of success. Moreover, simulation studies for odds ratio confidence intervals typically limit the true odds ratio to be between 1 and 10, an undesirable restriction for research in social sciences where an odds ratio of 20 or higher is common. To construct a confidence interval which is robust to these factors and applicable for a wider range of true odds ratio values, we demonstrate how the delta method can be applied to derive a Student's t-based approximate confidence interval. Then, by applying the cell count adjustment method of Gart to the derived confidence interval, we show its relative advantages to the Agresti-Min exact confidence interval which is recommended in recent simulation studies.

Rylee Coney, Gonzaga University
A Decomposition of Linear Recurrences in Terms of Jordan Forms

Given an nth order linear recurrence relation with its associated companion matrix A, the sequence generated by the recurrence relation can also be generated using the associated Jordan form. The Jordan form has a block form, which allows a certain decomposition of the sequence. It is possible that the decomposition will allow properties of the sequence to be studied, in terms of sequences generated by the individual blocks of the Jordan form. This was motivated by an earlier work in which uniform distribution properties of sequences from linear recurrence relations over finite fields was studied.

Isha Diddi, Colorado State University
Mapping Disparities: The Intersection of Rurality, Wealth, and Health in Colorado

Socioeconomic indicators can often influence physical well-being: the amount of wealth one has can make it easier or harder to afford healthcare, a minority-populated town may have a smaller healthcare system, a decreased average educational level can lead to practicing less preventative care, etc. This study investigated whether being classified as "rural" exemplified these vulnerabilities, specifically in Colorado. To begin this study, public health and economic indicators for Colorado counties such as per capita personal income, employer contributions for government social insurance, percentage of uninsured individuals, and mortality rates were compiled and analysed. Using t-tests, socio-demographic indicators were compared between rural and urban populations to determine statistically significant differences in vulnerabilities among these groups. Following the analyses, relevant literature and national and local trends were reviewed to identify existing patterns and support new trends revealed by the data. As rural populations often go unnoticed, addressing these disparities is crucial to promoting healthcare equity. Strengthening rural healthcare ultimately improves public health for all.

Brianna Dysinger, University of Central Oklahoma
Diversity Comparisons within Publicly Funded K-12 Schools

Charter schools, despite receiving public funding, oftentimes do not have to adhere to the same regulations as public schools. This study considers the racial makeup of public schools within the Oklahoma City Metro. By using multiple diversity measures from ecology, enrollment demographics are analyzed to identify possible racial or ethnic biases. The findings aim to assess whether deregulation inside publicly funded institutions impacts racial diversity.

Genesis Encarnacion, Mount Mary University
Defunding Sexual Healthcare: A Topological Investigation of Resource Accessibility

Topological Data Analysis (TDA) is a mathematical tool that uses concepts from topology to study the shape of data, revealing features such as holes and clusters that may be overlooked by more commonly used methods of analyzing data. In this study we used TDA, specifically a tool known as persistent homology, where we use simplicial complexes to describe features that persist, such as holes, to explore gaps in access to reproductive healthcare in California. Our analysis focuses on the distribution of Planned Parenthood clinics and Federally Qualified Health Centers (FQHCs), which provide essential reproductive health care services. We manually collected the locations of Planned Parenthood clinics through the Planned Parenthood website and used data from the California Department of Health Care Access and Information to identify FQHCs. Applying TDA techniques, such as persistence diagrams and the Vietoris-Rips complex, we examined how access to care may change in response to *Medina v. Planned Parenthood South Atlantic*, a recent Supreme Court decision that blocks the use of Medicaid at Planned Parenthood clinics. We look at the holes which represent gaps in health care coverage both with Planned Parenthood locations and with the possible removal of all locations. Our findings can highlight areas where healthcare access is most vulnerable and demonstrate how TDA can be used to analyze spatial inequalities in public health.

Anastasia Eriksen, University of Nebraska-Lincoln
Mathematical Modeling of Earth's Magnetic Field in the North Atlantic

This study investigates the oceanic crust in the Northern Atlantic north of Iceland, focusing on the actively spreading Kolbeinsey Ridge and the now-extinct Ægir Ridge. These ridges offer insight into the evolution of Earth's magnetic field and tectonic activity. By developing a mathematical model of the magnetic anomalies associated with both ridges and comparing the modeled field to observed data, this research aims to clarify how the Kolbeinsey and Ægir ridges evolved through time. The results will contribute to understanding the relationship between oceanic crust formation and the reversal history of Earth's magnetic field.

Nayda Farnsworth, Colgate University
4-dimensional Tic-Tac-Toe: Establishing a New Lower Bound on $HJ(4,2)$

At first glance, tic-tac-toe may seem unexciting, often ending in a tie. However, the Hales-Jewett theorem transforms this simple game into a rich combinatorial phenomenon. What if we extend the game board to higher dimensions? How large does the dimension need to be to avoid a draw? This is captured by $HJ(n,m)$, the minimal dimension of a hypercube such that any coloring of its cells with m colors contains a monochromatic combinatorial line of length n. In 2014, Hindman and Tressler showed that $HJ(3,2) = 4$ and established a lower bound $HJ(4,2) > 5$. This work builds on their approach to establish a new lower bound on $HJ(4,2)$. We encode the Hales-Jewett problem as a Boolean satisfiability problem and use heuristic SAT solvers, combined with high-performance parallel computing, to efficiently search the problem space. We show the combinatorial setup, the Boolean encoding, our computational methods, and present improved lower bounds on $HJ(4,2)$ and $HJ(3,3)$.

Katharine Franklin, Gonzaga University
Graph Pebbling

Graph Pebbling is a combinatorial game played on a fixed graph $G = (V,E)$. The game begins with Player One deciding how many pebbles to play with. Player Two then chooses a target vertex (V) and distributes Player One's pebbles across the graph. Player One must then maneuver the pebbles, where each move consumes one pebble to shift another along an edge (E), until a pebble reaches the target. We also explore an alternative order of play: Player One selects both the number and placement of pebbles, while Player Two chooses the target vertex only afterward. In either case, the challenge is for Player One to guarantee success despite Player Two's adversarial choices. By comparing these scenarios across different families of graphs, we uncover how the interplay between pebble placement, adversarial targeting, and graph structure shapes the difficulty of the game.

Krrish Ghindani, University of Nebraska-Lincoln
Digitizing the American Priesthood: Spatial, Temporal, and Sociological Analysis of Clerical Records, 1888-Present

This project constructs a comprehensive, machine-readable dataset of U.S. Catholic priests from 1888 to the present, combining digitized clerical directories, parish records, and diocesan reports. Using OCR-based text extraction and spatial mapping, we document over a century of changes in the geography and demographics of the American priesthood. The dataset enables two classes of analysis: (1) an institutional study of how church administrative practices–such as reassignment of clergy–affect community outcomes, and (2) a sociological study of the priesthood as a mechanism for immigrant integration and social mobility. The initial phase, presented here, focuses on data pipeline development, validation of 1970-1990 records, and visualization of spatial distribution across decades. This foundation supports future research on institutional accountability, demographic change, and the evolving role of religion in American life.

Leah Glasser, Pitzer College
A Compartmental Model for Annual Blue Whale Migration

Blue whales (Balaenoptera musculus), a keystone species, exhibit a linear migration pattern from Southern waters near Chilean North Patagonia in the summer to warmer Northern breeding grounds near the Galapagos in the winter. We modified our base compartmental model of animal migration patterns to apply specifically to the blue whale population off the Western coast of South America. Using Berkeley Madonna, we looked at variations of parameters to best describe this population's behavior. This model could be employed to predict where the whale population will be concentrated at certain times of the year, and help mitigate human impacts on the whales.

Megan Gilbert, Gonzaga University
Mosaic Knots and Unknotting Numbers

The unknotting number is typically examined on simple projections of knots onto a flat surface, but we also examine unknotting on mosaic knot diagrams, redefining the unknotting number as the number of crossing tile changes needed produce the unknot. We show that using hexagon tiles to unknot will produce a lower unknotting number for knots with classical unknotting numbers greater than one.

Kate Harvey, Colorado School of Mines
Numerical Approximation for Singular Integrals Arising from Topological Defects in Ambient Real Space

Vortex filaments are fundamental structures in fluid dynamics whose motion is governed by singular integral equations. Central to this description is the Biot-Savart integral (BSI), which diverges near the filament and presents challenges for numerical simulation. This project explores computational approaches for approximating the BSI and modeling the resulting filament dynamics. Algorithms were implemented in Python to discretize space curves, stabilize near-singular behavior, and visualize curve evolution under self-induced flow. This project looked at four different meshes: a ring, a Kelvin ring, a Hasimoto soliton, and a perturbed ring. The results highlight how numerical strategies influence both the stability and accuracy of vortex simulations, with broader implications for understanding complex fluid dynamics.

Alison Hill, Washburn University
Methods for Optimizing Breeding Expectations in Pokémon JRPG

Pokémon is an extremely popular Japanese role playing game in which players take on the role of trainers to capture and battle creatures called Pokémon. In Generation II, the franchise introduced the breeding mechanic which allows players to breed two compatible Pokémon as a means to obtain specific characteristics such as egg moves, natures, hidden abilities, and individual values. There are various held items such as the Destiny Knot, Everstone, and Power Items, which act to influence the outcomes of different breeding scenarios. This study looks at the various components that influence the statistical outcomes of breeding, and ways to maximize the use of those components to influence desired outcomes.

Jayleen Jiang, Mount Holyoke College
Balancing Efficiency and Fairness in EV Charging Infrastructure: A Multi-Objective Optimization Approach

The rapid growth of electric vehicles has created an urgent need for charging infrastructure that is both efficient and equitable. This project develops an optimization framework to determine where new charging stations should be placed, integrating real-world road networks, population data, and public safety considerations. Using Seattle as a case study, we model realistic travel times based on road graphs from OpenStreetMap and design a multi-objective cost function that balances three goals: improving efficiency by minimizing population-weighted travel time, promoting fairness by reducing the maximum travel time for any neighborhood, and ensuring safety by avoiding proximity to schools. Because the problem is NP-hard, we implement a three-step heuristic algorithm that combines K-Means clustering to narrow candidate sites, a greedy selection process for initial placement, and local search refinement to optimize the final configuration. The resulting plan identifies 15 charging locations that achieve 97% citywide coverage within a 15-minute drive and greatly reduce inequality in access. Together, these findings show how combining optimization techniques with equity-based metrics can guide more sustainable and socially responsible urban infrastructure planning.

Taylore Keesler, University of Central Florida
Bayesian Wind Farm Optimization

Maximizing the annual energy production of large-scale wind farms is a challenging black-box optimization problem. Each candidate layout requires an expensive wind-farm simulation, gradient information is unavailable, and strict geometric constraints on turbine spacing and site boundaries must be satisfied. We investigate constrained Bayesian Optimization (BO) algorithms for efficiently exploring the design space of the Wind Farm Layout Optimization (WFLO) problem. We begin by evaluating standard BO with Expected Improvement and Lower Confidence Bound acquisition functions on benchmark problems. For the WFLO task, we compare four constrained BO strategies: (1) a BO baseline with IPOPT constraint handling, (2) a Hybrid BO-IPOPT method, (3) Scalable Constrained Bayesian Optimization (SCBO), and (4) FuRBO (Feasibility-Driven Trust Region BO), a trust-region approach that adapts to the feasible set. We also experiment with custom covariance kernels designed to exploit the geometry of turbine layouts. Empirical results demonstrate that FuRBO and the Hybrid BO-IPOPT method consistently outperform SCBO and the BO baseline, identifying feasible layouts with significantly higher annual energy production.

Mack Kona, Cal Poly Humboldt
Multiscale Mathematical Modeling of Microglial Responses to Metabolic and Cytokine Signals in the Brain

Microglia are the brain's resident immune cells, dynamically responding to both inflammatory cytokines and metabolic cues from their environment. Understanding how local molecular signals shape microglial behavior and influence interactions with neurons and astrocytes is key to uncovering mechanisms of neuroinflammation and neurodegeneration. We applied two distinct modeling approaches. First, we constructed a system of ordinary differential equations describing intracellular signaling pathways that regulate key transcription factors. This model captures transitions between proinflammatory and homeostatic microglia phenotypes (states). We then implemented an agent-based model representating populations and interaction of microglia, neurons, and astrocytes. Model rules allow cell-cell communication and response. This framework allows a multi-scale exploration of how neurodegeneration emerges.

Sophie Kramer, Washburn University
Optimal Battle Strategies in Pokémon JRPG

Pokémon Diamond is a turn-based JRPG released in September of 2006. In *Pokémon Diamond*, players collect Pokémon to build a team and fight in battles to ultimately become the Pokémon champion. This project focuses on determining the ideal team of Pokémon to defeat the champion in *Pokémon Diamond*. Built-in game statistics including base statistics of Pokémon and battle statistics are taken into consideration when determining the ideal team. This project also determines the ideal strategies to defeat the champion and how to expand these strategies into other areas.

Linh Le, Nebraska Wesleyan University
The Science of Brewing Coffee: Novel Apparatus

Brewing the perfect cup of coffee requires remarkably close attention to detail as well as consideration of multiple scientific factors that affect the taste of the coffee. Inspired by the vacuum reflux distillation apparatus which served as a coffee maker in "Breaking Bad", our goal was to demonstrate our scientific expertise in controlling the brewing process by using our self-built brewing apparatus; a complex setup including glass flasks and tubes that provides an elaborate way to make coffee via vacuum pressure and precise high temperature control. We conducted a permutation test using bootstrapping to test the significance of the feedback collected about the coffee from students, faculty, and staff on Nebraska Wesleyan University campus and modified the coffee as fit. We found out that by passing water over grounds at such elevated temperatures while stirring, we can extract the molecules responsible for the flavor assuming the absence of rapid degradation of those flavor molecules by the oxygen present in the air (a process that chemists use a Soxhlet extractor to replicate). Every coffee sample's caffeine quantification extracted with Soxhlet was grouped into two categories: change in brew time and change in ground mass to calculate the corresponding rate of change. From that, we were able to determine whether brew time affected caffeine quantification better than ground mass in this apparatus.

Paris Lewis, North Carolina State University
Distinguishing Stochastic Fluctuations from Deterministic Population Dynamics

Chaos in ecological systems poses a fundamental challenge to long-term prediction and conservation planning, as even small differences in initial conditions can lead to drastically different outcomes. Traditional methods for detecting chaos, such as those based on Lyapunov exponents (LEs), yield mixed results against increasing levels of noise in field data. We address a critical gap in the literature: quantifying the extent to which prediction error is due to deterministic variance versus stochastic noise. We show how to assess the reliability of the LEs by quantifying the proportion of forecast error due to noise. We introduce an ensemble-based framework that perturbs observed initial conditions and propagates forecasts through a local surrogate model to estimate the contribution of deterministic divergence, intrinsic stochasticity, and measurement error to total forecast variance. Additionally, we explore applications of this framework within ecological data, evaluating the reliability of the LE for different dynamical systems. Preliminary results suggest that increasing levels of stochastic noise require disproportionately greater measurement uncertainty to account for the observed dynamics through deterministic models. Our approach offers new tools for understanding the limits of predictability in complex ecological systems and for distinguishing between intrinsic unpredictability and noise-driven variation in population dynamics.

Sydney Lipton, Grand Valley State University
Evaluating Integrals Using the Bracket Method

We will show the application of the integration method known as the bracket method. This method is for evaluating definite integrals over the half-line $[0, \infty)$ based on the expansion of the integrand as a power series. The advantage of establishing this method is that we can evaluate these "bracket series" with a small number of rules. We will be illustrating the application of this method via examples with Bessel functions, demonstrating its simplicity and flexibility.

Emma Lombardo, Saint Mary's College
Using Ordinary Differential Equations to Model Fat-Cell Differentiation

Adipogenesis is the process by which precursor cells develop into mature adipocytes, or fat-storing cells. We strived to better understand the basic process in which precursor cells decide to either stay a precursor cell or become a fat cell. We expanded an existing deterministic model of the transcriptional network of adipogenesis to include a module for adiponectin production, an insulin-sensitizing hormone secreted by adipocytes. We analyzed two possible implementations for the adiponectin module. For each model, we calculated the relative local sensitivity of adiponectin and lipid droplets (fat) to various sets of synthesis and decay parameters. This allowed us to quantify the sensitivity of adiponectin and lipid droplet steady states and maximum values to parameter variability in our two proposed models.

Raina Majumder, Colorado School of Mines
Data-Driven Discovery of Nonlinear Oscillators with SINDy-SHRED

The topic of dynamical systems is relevant in the face of advancing, predictive technology with various applications present within and outside the field of mathematics. This growing relevance also calls attention to the intersection of using dynamical systems as a way to gain predictive power over various natural phenomena, and as a result, we find ourselves in the midst of a growing topic of discussion surrounding the use of data analysis and processing in combination with dynamical systems. The SINDy-SHRED (Sparse Identification of Nonlinear Dynamics with SHallow REcurrent Decoder Network) algorithm takes real-world, spatiotemporal data and integrates sensing and model identification using a shallow recurrent decoder network. Essentially described as "go-pro physics", we have used this algorithm to try and replicate results of dynamical systems modeling weakly-coupled, non-linear oscillators from prior work. We will show various obstacles faced while using the SINDy-SHRED algorithm, the benefits of using the SINDy-SHRED algorithm, and what our next steps will be moving forward with this project.

Trinity Millier, Pacific University
Alternatives to Fisher's Analysis of Variance In the Case of Violated Assumptions

Fisher's Analysis of Variance (ANOVA) is a widely used and relied upon test to compare means across groups in many fields. To use this test, one must meet its assumptions of approximate normality and homogeneity of variance. As a double major in Mathematics and Psychology, I see firsthand how samples rarely meet these assumptions exactly. Type 1 error rate is affected when these assumptions are violated, creating an unreliable test. In cases like these, alternative tests can be more powerful and more reliable than Fisher's ANOVA. I will discuss Welch's ANOVA for heterogeneity of variance, permutation tests for violations of normality and small sample sizes, as well as other tests for variance conditions. I hope to apply this research to the real studies I run as a Psychology student.

Nora Nelson Laird, Colorado College
Simulating Single Transferable Voting for the Colorado House of Representatives

Social choice theory research demonstrates that single transferable voting (STV) results in more proportionally representative legislative bodies. We aim to understand how using multi-member districts and ranked ballots with STV would affect the representation of political parties in the Colorado House of Representatives. We investigated this objective by producing 10,000 multi-member districting plans of Colorado, generating ranked ballots for each of these plans using returns from the 2022 Colorado attorney general race, and simulating STV using these ballots. Our simulated STV elections for the Colorado House of Representatives gave more proportional representation for Democrats and Republicans than the current first-past-the-post system. Future research should explore how the implementation of STV would influence the representation of racial and ethnic groups in the Colorado General Assembly to provide guidance on electoral reform in the state.

Jenny Nguyen, Denison University
Predicting Voter Turnout and Election Outcomes at the Precinct Level using Data Science and Statistical Modeling

Election forecasting in the US is a multi-billion dollar industry. Most forecasters rely on increasingly unreliable polling data and demographic information to predict election outcomes, usually at large spatial scales (e.g., counties or states). Here, we use presidential primary data at the finest spatial scale (precinct level) to predict general election results, without relying on polling or demographic data. Using election results from the 2016 US presidential election in several states, we find that election results are the least predictable in low-turnout precincts. Surprisingly, we also find that the winning party in the general election tends to have underperformed compared with its primary vote share.

Uyen Nguyen, Denison University
Computational Verification of the Generalized Riemann Hypothesis

This project presents a rigorous, end-to-end pipeline for verifying the Generalized Riemann Hypothesis for quadratic Dirichlet L-functions up to a finite height. The workflow uses SageMath for discriminant arithmetic and archimedean precomputation, lcalc for high-precision zero enumeration, and Python for orchestration and fault-tolerant parallelism. Command-line parameters include discriminant ranges, target height eta, zero-interval half-width epsilon, and truncation limits for logarithmic-derivative approximations, enabling efficient, fault-tolerant, massively parallel execution. Two explicit numerical assumptions are maintained: zero-list accuracy at 10^{-5} and sufficient floating-point accuracy for all evaluations. Applied to all fundamental discriminants with $|d| < 10^6$, the pipeline certifies that every nontrivial zero with imaginary parts between 0 and 12.0 lies on the critical line. Verification cost is modeled by the minimal number of zeros required up to height eta: $N_\eta(d)$ is well approximated by $a_\eta \times \log|d| \times \log\log|d| + b_\eta \times \log|d| + c_\eta$, with $a_\eta > 0, b_\eta < 0$, and coefficients that empirically grow approximately quadratically with eta. The workflow is fully reproducible, and the design is extensible to larger $|d|$, higher eta, and stronger numerical guarantees, providing a transparent foundation for pushing the computational frontier in number theory.

Abigail Nigro, Mount Holyoke College
Topological Data Analysis Techniques in Genetic Stock Identification of Chinook Salmon

The Southern Resident Killer Whale (SRKW) is an endangered species of orca living off the coast of the Pacific Northwest and has evolved to eat primarily Chinook salmon. The survival of the SRKW is contingent on ensuring the continued availability of this food source. As Chinook salmon are important culturally, ecologically, and economically, conservation efforts depend on precise identification of what geographic and temporal genetic stocks of salmon are being consumed by the SRKW. Scientists can only use non-invasive methods to study the SRKW, which means that the individual genetic stocks of salmon must be identified through fecal samples which contain a mixture of individuals. We utilized the tools of topological data analysis to identify viable techniques to differentiate between these genetic stocks. The techniques we explored include computing persistent homology and utilizing the Mapper algorithm. Several of our approaches worked well on certain mock datasets. However, we found the assumptions used to create those datasets do not always hold for real-world data. Better understanding of salmon genomics is required to assess whether our techniques generalize to data drawn from actual salmon.

Hannah Paulson, Furman University
Garden Solitaire

Garden Solitaire is a solo turn-based game where the score is determined by the final arrangement of cards on the table. We examined different strategies to maximize score as well as how likely those strategies were to succeed with a random deck. We determined several approaches and compared how often each one can happen and how well they score. We manually tested a variety of arrangements and methods of discarding cards, which helped find strategies that do better than just playing randomly. Along the way, we increased our best score with improved arrangements.

Dionne Phan, Denison University
Mathematics of Machine Learning: Exploring How Neural Networks Learn

The paper introduces and compares three methods, which are Physics-Informed Neural Networks (PINNs), Neural Tangent Kernel (NTK), and Physics-Informed Kernel Learning (PIKL), to solve a partial differential equation (PDE) problem. Specifically, we focus on the one-dimensional diffusion PDE. PINNs are a promising method because they take advantage of the high expressive power of neural networks by embedding physical governing equations into the training of a neural network. However, PINNs suffer from optimization instabilities and hyperparameter sensitivity. The NTK framework provides a theoretical explanation for these issues by linearizing training dynamics, but its practical application is limited by the unrealistic assumption of infinite-width networks and ill-conditioned kernel matrices. We use PIKL as a robust and efficient alternative that embeds physical knowledge directly into a closed-form kernel design, avoiding the need for gradient-based optimization. Our experiments demonstrate that PIKL consistently outperforms both PINN and NTK in terms of accuracy, stability, and provides natural uncertainty quantification. We also use the kernel on PIKL to quantify error and uncertainty. The kernel structure of PIKL also provides a natural and straightforward way to quantify error and uncertainty through the posterior mean and variance of the underlying Gaussian Process.

Sela Raisl, Cal Poly Humboldt
see **Mack Kona**

Katherine Rodbell, Colorado College
see **Nora Nelson Laird**

Pablo Rodriguez Cabrero, Doane University
Beyond the Birth Certificate: Visualizing a Century of Naming Data

This project explores how data visualization and statistical analysis can reveal cultural patterns hidden within more than a century of U.S. baby-naming data. Using records from the U.S. Social Security Administration (1880-2024), we analyzed nearly every recorded baby name by year, state, sex, and frequency. Visualizations illustrate both timeless and trendy names, highlighting shifts in popularity across regions and generations. We quantified name "complexity" using Scrabble scores, examined the dynamics of unisex names and names that have switched genders, and investigated how cultural events, politics, and religion have shaped naming trends over time. By transforming millions of names into interpretable graphics, this study demonstrates how data visualization can illuminate the evolving landscape of American identity through something as personal–and as universal–as a name.

Bridget Rozema, Grand Valley State University
see **Sydney Lipton**

Jose Sánchez Menchén, University of Richmond
The Search for Generalized Denniston Partial Difference Sets

A partial difference set (PDS) in a finite group G is a subset $D \subset G$ with the property that the multiset of differences $\{d_1 d_2^{-1} : d_1, d_2 \in D\}$ represents elements of D and of $G \setminus D$ a fixed number of times. Our work focuses on a particular family of PDSs in non-elementary abelian groups called Denniston PDSs. In this poster, we present various strategies for constructing PDSs in an effort to identify them in groups where their existence was previously unknown. Key components of our research include the study of Character Theory, Coding Theory, and Cyclotomic Classes. This work began at the University of Richmond in Summer 2025 in collaboration with Dr. Jim Davis and our research team: Sally Brouhard, Jacob Martin, Beckett Rebele-Henry, Sammie Ritchie, Pepe Sánchez Menchén, and Dan Schwarz.

Dan Schwarz, University of Richmond
see **Jose Sánchez Menchén**

Beatrice Shea, United States Air Force Academy
The SPIN Polynomial: A Quantum-Inspired Invariant of Pseudoknots

The theory of knots studies embeddings of circles in three-dimensional space up to continuous deformations. In recent years the notion of a pseudoknot–a knot diagram in which some crossings are left unresolved-has emerged as a natural framework for modeling systems with incomplete information. Classical invariants of knots such as the Jones polynomial do not immediately extend to pseudoknots because the uncertainty encoded by precrossings must be resolved before evaluation. In this paper we introduce the Shea Pseudoknot INvariant polynomial (SPIN), a quantum-inspired invariant of pseudoknots. The SPIN polynomial is defined as a phase-weighted expectation of the Jones polynomial over all classical resolutions, where the weights are determined by Gauss diagram labels motivated by spin-$\frac{1}{2}$ quantum systems. We provide a self-contained introduction to classical knot theory and the Jones polynomial, define pseudoknots and their associated invariants, and establish the invariance of the SPIN polynomial under both classical and pseudo-Reidemeister moves. Skein relations, behavior under mirror image and connected sum, and explicit computations for small pseudoknots are derived. We show that the SPIN polynomial specializes to a pseudo-modified Jones polynomial at parameter $t = 1$, interpret t as a quantum interference parameter, and suggest future directions including categorification and applications to quantum computation.

Shreya Sinha, Princeton University
The Non-Orientable Four-Ball Genus of a New Infinite Family of Torus Knots

We extend previous work by using a combination of band surgeries and known bounds to compute $\gamma_4\big(T\big(4n, (2n \pm 1)^2 + 4n - 2\big)\big) = 2n - 1$ for all $n \geq 1$. We further generalize this result by showing that $\gamma_4(T(4n + 2k,\, n(4n + 2k) - 1)) = \gamma_4(T(4n + 2k,\, (n + 2)(4n + 2k) - 1)) = 2n - 1 + k$ for all $n \geq 1$ and $k \geq 0$. All knots in this family are counterexamples to Batson's conjecture.

Katie Smela, Colorado College
Modeling Quorum Sensing Dynamics Using Stochastic Differential Equations

Quorum sensing is a process of intercellular communication that enables bacteria to ascertain population density and coordinate group behaviors through the release and detection of signaling molecules, often in response to environmental stimuli. This project investigates the stochastic dynamics of quorum sensing using two non-linear models of cellular activation, each differing in the mechanism of deactivation: one assumes linear deactivation while the other incorporates non-linear dependence on signal molecule concentration. To analyze these models, we apply a Fokker-Planck framework to approximate the long-term probability distributions of the number of actively quorum sensing cells. We further estimate mean first passage times to characterize the likelihood of spontaneous switching between steady-state population sizes of quorum sensing cells. Additionally, we calculate splitting probabilities to determine the favored steady state once the population reaches the system's unstable equilibrium. By examining system behavior across different population scales, this research highlights how noise influences bistable quorum sensing dynamics and provides insight into the stability and robustness of collective bacterial decision-making. We conclude that noise-driven switching is unobservable in simulation in large-scale populations and the lower steady state is heavily biased by the system.

Emmerson Taylor, Park University
Structure Constants for the Universal Enveloping Superalgebras of Lie Superalgebras of Dimension Four and Smaller

Given a Lie superalgebra, $L = L_0 \oplus L_1$, over $\mathbb{R}$ or $\mathbb{C}$, the universal enveloping superalgebra of L, $\mathbf{U}(L)$, encompasses all noncommutative polynomials with coefficients from the field, where the variables are the basis elements of L. $\mathbf{U}(L)$ is also equipped with the graded commutator bracket, that is, for $x \in L_m$ and $y \in L_n$, where $n, m \in \{0, 1\}$, $xy = (-1)^{mn}yx + [x, y]$ in $\mathbf{U}(L)$. This relation gives us a way to "straighten" or reorder products of basis elements. The Poincaré Birkhoff-Witt (PBW) Theorem implies that every element of $\mathbf{U}(L)$ can be written uniquely as a linear combination of products of elements of L in any fixed order, where the odd basis vectors have power 0 or 1. The coefficients of the resulting linear combination are referred to as the structure constants. The goal of our research was to derive straightening identities in $\mathbf{U}(L)$ where L has dimension four and smaller, using Backhouse's classification of such Lie superalgebras, in order to find their structure constants. We formulated and proved closed formulas for the structure constants of many of these superalgebras.

Alice Tesser, Rollins College
Admissions Data as a Window into Students Food Insecurity and Equity

The research explores the extent to which students feel pressured to conceal their experiences with food insecurity and examines whether these challenges are adequately recognized and addressed by the student body and institutional support systems. The study was motivated by a broader conversation about the potential of using admissions data to address social justice issues on campus. Specifically, it explores how such data can reveal students' past experiences and perceptions of food insecurity, guide administrations in informed policy implementation, and foster a more equitable, inclusive academic environment. The results indicate a significant association between the percentage of Free and Reduced-Price Lunch program participation at students' high schools and their enrollment at a small private liberal arts college. To explore how this relationship has evolved, we analyze admissions data from two critical years: 2019 (pre-pandemic) and 2023 (post-pandemic). This comparative analysis examines shifting student food insecurity concerns and their effects on admissions at a small private liberal arts college. Furthermore, our findings emphasize the value of school-specific data over aggregated county-level statistics. Particularly, our results underscore the impact of school zoning policies versus ZIP code boundaries, demonstrating that a school's official zone may better capture the socioeconomic realities affecting its students than broader regional identifiers.

Anh Trinh, College of Saint Mary
A hybrid Gompertz-Hill Model to Predict Tumor Volume Changes

In recent years, there has been an increasing demand for statistical algorithms to predict tumor growth and support proactive approaches in cancer treatments. In this project, we investigated several classical models of tumor dynamics including Gompertz, exponential, logistic, Spratt, Bertalanffy, and the Hill equation. Among these, previous studies have shown that the Gompertz model was most accurate in predicting dynamic organism growth, and the Hill equation (dose-response curve) best described chemotherapy effectiveness in tumor regression. However, these two frameworks have not been combined to bridge their strengths. Our project introduces a hybrid Gompertz-Hill model to estimate both the growth and decay of tumor volume following chemotherapy treatment over time. We further analyze this new equation using dimensional analysis, steady-state behavior, sensitivity analysis, and mean squared error comparisons with NCI data to assess its predictivity. Finally, we discuss the applications of this new model in biology and mathematics.

Anna Tymoshenko, Pacific University Oregon
Mathematical Modeling of Accessibility-Aware Routes for Indoor Navigation

This project applies mathematical modeling to improve accessibility in indoor navigation systems. Campus buildings are represented as weighted graphs, where edges correspond to paths characterized by multiple cost factors such as distance, slope, and accessibility. The model employs multi-criteria optimization to identify routes that balance efficiency with inclusivity, allowing for personalized path recommendations based on user needs. By adjusting weighting schemes, the study examines how different priorities affect route selection and overall path quality. This work demonstrates how applied mathematics can inform the design of equitable and efficient navigation tools such as Campus Compass, an indoor navigation application developed as part of my computer science capstone project.