SUnMaRC 2026

Southwestern Undergraduate Mathematics Research Conference

April 17–19, 2026

Lumberjack Mathematics Center (LMC)

Northern Arizona University • Flagstaff, AZ

Unless otherwise noted, all events take place in the LMC.

Friday, April 17

5:00–6:30 PM Arrival, Welcome & Pizza! *(LMC Lobby, second floor of the SAS Building)*

PLENARY TALK · 6:30–7:30 PM · LMC

Dr. Kurt Herzinger

My Journey from Numerical Semigroups to Combinatorial Games

7:30–9:00 PM Problem Session I *(LMC Lobby)*

Saturday, April 18

9:00 AM — Morning Sessions (Parallel)

Session 1 — Room 201A | *Chair: Gina Nabours*

9:00–9:20 AM **Gabriella Stewart & Zane Padgett** — *NAU*

New Results on Digraphs with Constant Cover Pebbling Numbers, Part I

The cover pebbling number of a graph is the minimum number of pebbles needed so that from any initial arrangement of the pebbles, after a series of pebbling moves, there is at least one pebble on every vertex. We will present new results on various families of directed graphs whose single vertex cover pebbling numbers are constant.

9:25–9:45 AM **Gabriella Stewart & Zane Padgett** — *NAU*

New Results on Digraphs with Constant Cover Pebbling Numbers, Part II

The cover pebbling number of a graph is the minimum number of pebbles needed so that from any initial arrangement of the pebbles, after a series of pebbling moves, there is at least one pebble on every vertex. We will present new results on various families of directed graphs whose single vertex cover pebbling numbers are constant.

9:50–10:10 AM **Brandon Wang & Eli Perrine** — *ASU*

Partial Results in Hub Cover Pebbling Number for High Minimum Degree Graphs

A hub set in a graph G is a set U of vertices such that any two vertices outside U are connected by a path whose internal vertices lie in U. The hub cover pebbling number of a graph G is the least non-negative integer such that from all distributions of that many pebbles over the vertices of G, it is possible via pebbling moves to place at least one pebble on each element of some hub cover. We assume such graphs G have high minimum degree and find the best upper bound for the hub cover pebbling number.

10:10–10:30 AM *Break*

10:30–10:50 AM **Niko Koers** — *UNM*

Pushing the Spirit of Base Fibonacci

Motivated by Zeckendorf's theorem and its many generalizations, we survey a hierarchy of systems of numeration, from classical complete integer sequences and Fibonacci codes up to more abstract digit languages. We then return to selected layers and discuss results, especially regarding the structure of the space of complete sequences, and the growth rates of complete sequences in mixed radix systems.

Session 2 — Room 201 | *Chair: Jerry Galley*

9:00–9:20 AM **Ernesto Morales Carrasco** — *UNM*

Stopping Measles in Its Tracks: An Age-Structured SEIR-MV Model of Declining Vaccination, Waning Immunity, and Catch-Up Strategies

Measles remains one of the most transmissible infectious diseases known, and declining vaccination coverage has renewed the threat of large-scale outbreaks in communities once considered protected. The 2025 New Mexico measles outbreak originating in west Texas illustrates how localized coverage gaps can seed wider epidemics. This work develops a deterministic age-structured SEIR-MV compartmental model parameterized to the New Mexico population to project future measles outbreak dynamics under four scenarios: baseline fixed vaccination coverage, declining routine coverage, targeted catch-up vaccination campaigns, and imported infections. Under fixed coverage, the model produces inter-epidemic intervals of approximately 27 years, with the initial transient case distribution approximating the 2025 outbreak data. When coverage declines at 0.9 percentage points per year, the first outbreak advances to year 12, peak infectious prevalence increases 3-fold, and the system transitions to endemic transmission by mid-century. Sensitivity analysis of five catch-up strategies reveals that adult first-dose campaigns achieve full epidemic suppression at approximately 500-550 vaccinations per year, while second-dose boosting of partially-immune individuals confers no measurable benefit. These findings support prioritizing restoration of first-dose routine coverage above the 95% herd immunity threshold, with adult first-dose catch-up campaigns as the highest-yield supplementary intervention.

9:25–9:45 AM **Brandon Gallegos** — *UNM*

Why Humanity Needs a Definition

This presentation begins with Georg Cantor's claim that in mathematics "the art of posing a question must be held of higher value than solving it," and uses that thesis as a way of thinking about what mathematics is and why it matters.

Rather than treating mathematics as a finished collection of results, the talk emphasizes the courage and creativity involved in questioning what seems obvious, intuitive, or settled. Cantor's work on infinity serves as a central example of mathematics moving beyond ordinary intuition, while the history of Euclid's fifth postulate illustrates how new mathematical worlds can open when an old assumption is no longer treated as untouchable. From that act of questioning came non-Euclidean geometry, and eventually the geometric framework that made general relativity possible. The central argument is that major mathematical advances often begin not with answers, but with the refinement, persistence, and seriousness of a question.

9:50–10:10 AM **Shaurya Chauhan** — *University of Arizona*

Simulated Adaptive Optical Super-Resolution Imaging

When optically imaging distant light sources such as exoplanets and stars, or incredibly close microscopic systems, the resolution of a classical imaging system is fundamentally limited by the Rayleigh Criterion. This criterion mathematically denotes a "minimum pair-wise separation" that two sources can be resolved. These systems are often at high relative contrast differences in brightness, and can be denoted as "constellations." In these constellations, so-called "direct-imaging" methods can be vastly outperformed by viewing the imaging problem in the context of quantum mechanics. Spatial-mode-demultiplexing (SPADE) is a quantum measurement scheme that instead of measuring photon arrivals at the image plane, decomposes the light field into a set of orthogonal spatial modes. There exists a fundamental limit on the gathered information determined by the Fisher Information of the scene, and it can be shown that choosing certain bases of orthogonal modes for spatial-mode sorting can saturate these theoretical limits, corresponding to a more accurate estimation of the constellation. By running various Python simulations of the proposed measurement scheme titled Dynamic SPADE, which runs mode-sorting iteratively in two distinct orthonormal bases, PAD (PSF-adapted) and YKL (Yuen-Kennedy Lax), the validity of an iterative estimation protocol optimized for relative brightness estimation and emitter positions is explored.

10:10–10:30 AM *Break*

10:30–10:50 AM **Alex Shah** — *University of Arizona*

Survival Analysis in Plant Phenology

Spring leafout timing in deciduous trees matters for carbon cycling, ecosystem function, and climate adaptation. Predicting leafout has proven to be difficult: simple regression approaches require fixing a seasonal temperature window ahead of time, risk including climate data that postdates the biological event, and collapse leafout into a single endpoint when it is really the end stage of a longer physiological sequence. This study fits a Cox Proportional Hazards model with time-varying covariates to citizen science observations of Eastern redbud (Cercis canadensis) recorded through the USA National Phenology Network's Nature's Notebook platform from 2012 to 2024. Each plant-year observation is expanded into daily time steps following the counting process convention, with covariate values updated at each step and records truncated at the observed leafout day. Time-varying covariates include cumulative growing degree days accumulated above a base threshold and cumulative chill units.

Session 3 — Room 221A | *Chair: Scott Akin*

9:00–9:20 AM **Jinwoo Choi** — *University of Arizona*

Transfer Analysis for Univ. Arizona Football Team (Churn Analysis)

This study investigates the use of daily physical tracking metrics (Catapult data) to predict whether a college football player will enter the transfer portal. Because the dataset was limited to 71 players with severely imbalanced data, the Synthetic Minority Over-sampling Technique (SMOTE) and Stratified 5-Fold Cross-Validation were utilized to prevent model bias and overfitting. Through Forward Feature Selection, the dataset was optimized down to three key indicators: Average Player Load Per Minute, Season Max Velocity, and Home Latitude. This revealed that a player's physical intensity, peak athleticism, and geographic distance from home are significantly stronger predictors of transferring than bulk practice volume. Four machine learning algorithms were evaluated on this final feature set, with XGBoost achieving 83% accuracy, a 0.754 ROC/AUC, and a leading precision of 0.677.

9:25–9:45 AM **Vanya Murzin** — *ASU*

Can Graph Theory Analysis of Brain Networks Characterize Differences in Connectivity Between Brain Regions in Alzheimer's Patients Versus Control

9:50–10:10 AM **Canyon Clark** — *NAU*

Comparing Metropolis–Hastings and Hamiltonian Monte Carlo for Parameter Inference in Mechanistic Epidemiological Models

Accurate forecasting of infectious diseases is essential for informing public health interventions and resource allocation. In this work, we propose a hybrid framework that combines a deep neural network (DNN) with Markov Chain Monte Carlo (MCMC) methods for parameter inference in an SIHR epidemiological model. We decompose the transmission rate into a baseline component and a time-varying external forcing. A fixed baseline transmission parameter is inferred via MCMC, while a DNN is used to learn time-dependent external forcing driven by covariates such as weather conditions and social determinants of health. We investigate two MCMC approaches: the widely used

Metropolis-Hastings (MH) algorithm and the gradient-based Hamiltonian Monte Carlo (HMC) method. We compare MH and HMC across several performance metrics, including convergence speed, estimation accuracy, computational cost, and acceptance rate. Our results demonstrate that HMC consistently outperforms MH on the parameter inference of the SIHR model.

10:10–10:30 AM *Break*

10:30–10:50 AM **Abbas Hamid** — *CSU*

The Cross Between Math and Music

This presentation explores the relationship between mathematics and music. Beginning with foundational concepts in music theory, we examine how pitch, scales, and chords are structured using numerical relationships. We then investigate tuning systems, highlighting how different mathematical approaches, such as equal temperament and just intonation, impact musical sound. The discussion continues with frequency and harmony, showing how simple ratios produce consonance through the harmonic series. Rhythm and meter are analyzed through the lens of fractions and patterns in time. Finally, we introduce the concept of sets in music, demonstrating how mathematical set theory and modular arithmetic can be used to analyze and transform musical structures.

10:50–11:00 AM *Break*

PLENARY TALK · 11:00 AM–12:00 PM · LMC

Dr. Hiram Beltrán-Sánchez

Implausibility of Radical Life Extension in Humans in the 21st Century

12:00–1:30 PM Lunch *(Hot Spot at the Union)*

1:30 PM — Afternoon Sessions (Parallel)

Session 4 — Room 201A | *Chair: David Deville*

1:30–1:50 PM **Owen Davis & Vaughn Wilmer** — *NAU*

Seymour Vertices in Toroidal Grid Graphs, Part 1

Let G be a simple connected digraph with oriented edges. A great deal of research analyzes Seymour vertices in G, originally to determine rankings in round-robin tournaments, as a vertex v corresponds to a strong player if its second out-neighborhood is large. We present new results on numbers of Seymour vertices in toroidal grid graphs. This is a two-part presentation.

1:55–2:15 PM **Owen Davis & Vaughn Wilmer** — *NAU*

Seymour Vertices in Toroidal Grid Graphs, Part 2

Let G be a simple connected digraph with oriented edges. A great deal of research analyzes Seymour vertices in G, originally to determine rankings in round-robin tournaments, as a vertex v corresponds to a strong player if its second out-neighborhood is large. We present new results on numbers of Seymour vertices in toroidal grid graphs. This is a two-part presentation.

2:20–2:40 PM **Alex Shin** — *ASU*

1-D Domain Wall Analysis of Graphene

Recent analysis of graphene and its multilayer forms have emerged as the most studied materials due to exceptional mechanical and electrical properties. The moire lattices created from graphene host superconductivity, correlated insulator states, and flat electronic bands at different angles. When two graphene layers are placed above each other, the resulting lattice undergoes structural relaxation that creates a one-dimensional domain wall due to the interactions of weak and elastic energy. These walls are narrow localized ridges that separate commensurate regions of AB and AA stacking. Within the system being analyzed, the Lennard-Jones interlayer potential creates a registry dependent energy whose minima corresponds to favorable stacking configurations, analogous to the Frenkel-Kontorova model where deformable elastic bonds compete with the periodic energy landscape of a fixed substrate.

2:40–3:00 PM *Break*

3:00–3:20 PM **Aldo Morelli** — *UNM*

Relationships between Bond, Invasion, and First Passage Percolation

For the past 75 years, percolation models have been studied both for their mathematical content and their applicability in modeling phenomena in many scientific fields. In this presentation we provide brief introductions to the models of bond, invasion, and first passage percolation, and describe some of their connections.

3:25–3:45 PM **Billy Lippincott** — *NAU*

Numerical Bifurcation Analysis of a Coupled Nonlinear System of Differential Equations

We study a coupled system of ordinary and partial differential equations motivated by applications in areas such as population dynamics and fluid dynamics. Understanding the structure of solution branches for such systems is important because bifurcations can suggest new physical or biological behaviors as a parameter varies. To compute solutions numerically, we use finite-difference matrices together with Newton's method, and we apply a tangent continuation method to trace bifurcation curves as a system parameter changes. Our computations numerically show the existence of multiple bifurcation branches, including high-energy branches, for the system. In addition, we classify the Morse index of each solution, which helps identify changes in stability and provides a way to investigate the possible existence of secondary branches.

Session 5 — Room 201 | *Chair: Matt Fazio*

1:30–1:50 PM **Tegan Keen** — *CSU*

On the Identifiability of Leak Compartments in Linear Compartmental Models

In many applications, including in ecology and pharmacokinetics, linear compartmental models are used to model transfer between compartments which may represent populations, drug concentration, etc. Such models are represented by directed graphs in which the edges represent the transfers between compartments. An important feature of such models is the identifiability degree, which summarizes the extent to which it is possible to recover the transfer rates from noiseless experimental data. In this presentation, we investigate the effects of adding leaks (edges directed out of the model) on the identifiability degree. We show that in a model represented by a strongly connected graph, if exactly one leak is in the same compartment as an output, then that leak parameter is uniquely identifiable.

1:55–2:15 PM **Weslee Nguyen** — *University of Arizona*

Topological Data Analysis in Decoding Systems Neuroscience

Systems neuroscience studies how behavior emerges from the coordinated activity of large neuronal populations. Modern recording techniques can measure thousands of neurons simultaneously, producing high-dimensional and noisy datasets. Despite this complexity, neuronal activity is often constrained to low-dimensional geometric structures. Topological Data Analysis (TDA) provides a framework to recover this underlying structure to understand neural population dynamics. This talk will give an introduction to algebraic topology and TDA with no prior background assumed. There will be an application to the neural basis of orienting behaviors of echolocating bats, and end with a reflection on the importance of early undergraduate involvement in research.

2:20–2:40 PM **Noah Plant** — *NAU*

Designing Quantum Algorithms to Maximize Fisher Information

Quantum information theory represents a new paradigm for understanding information and is an active area of ongoing research within mathematics. Practical applications of quantum information rely on quantum networks consisting of interconnected quantum devices that can be represented by graphs and are subject to errors that degrade quantum information. In this project, we present a novel approach for characterizing entire quantum networks using only local information, while incorporating real-world constraints such as network topology and noise. In particular, we demonstrate that properties of a quantum network can be inferred through violations of the CHSH inequality, allowing for network characterization without global access to the system. These results provide a practical framework for analyzing emerging quantum networks, offering insight into how and where errors accumulate within a network.

2:40–3:00 PM *Break*

3:00–3:20 PM **Josh DeLand** — *ASU*

Recurrent Neural Networks for Localized Chaotic Flows

Nonlinear dynamical systems are prevalent in nature, science and engineering; however, the underlying governing equations or states may not be exactly known. In many cases, the data collected is only from a localized region in space and/or time. This results in a need for emerging tools that can analyze data that has already been collected and make predictions for how it will continue to behave and develop. In this presentation, we test the utility of recurrent neural networks (RNNs) to make predictions for different chaotic systems when only trained on a localized region of data. The models were first tested on chaotic attractors such as the Lorenz Attractor, then used on both a periodic and chaotic flow past a cylinder. Results show that when a sufficiently sophisticated deep neural network is developed, the RNNs can accurately generate short-term predictions based on the localized regions it trains on.

3:25–3:45 PM **Chayton Castruita** — *UNM*

The Cyclic Nature of Differential Powers of Ideals in Semigroup Rings

Normal affine semigroup rings are finitely generated algebras whose monomial elements are represented as the integer lattice intersecting a convex cone. The differential power is a relatively new tool in commutative algebra that categorizes elements of an ideal based on the differential operators acting on them. In this presentation we use a ring of differential operators called the Weyl algebra to construct differential operators on affine semigroup rings, then we define the differential power through these operators. Along the way we encounter a way to simplify the calculation of differential powers using the semigroup lattice's geometric structure and use it to describe the asymptotic behavior of differential powers of principal ideals in affine semigroup rings.

Session 6 — Room 221A | *Chair: Hannah Prawzinsky*

1:30–1:50 PM **Christine Le & Brendan Phoebe** — *University of Arizona*

Optimal Strategies and Probabilistic Search in Battleship

Battleship is a game in which players take turns hunting for each other's ships on a 10x10 grid. It tests each player's ability to make strategic guesses despite high uncertainty. The optimal strategy against random layouts involves a probabilistic approach, where a cell is assigned a number equal to the number of possible layouts in which that cell is occupied. The cell with the highest number is then targeted, and the strategy repeats for the next turn. However, using this strategy without sampling can be computationally expensive. This study aims to test neural networks and their ability to approach the optimal strategy, testing different training parameters like number of generations, number of candidates, and number of games per candidate. By comparing performance across these different settings, inferences can be made on the most computationally effective ways to train a neural network for the game of Battleship.

1:55–2:15 PM **Jing Luo & Kishan Bhatnagar** — *ASU*

Modeling the Sexually Active Community

Currently, there is limited research on the demographic dynamics of sexually active populations and no existing models that estimate entry and cessation rates independently of mortality. This study introduces a mass-balance framework that captures changes in the sexually active population through a cohort-based inflow-outflow model, explicitly incorporating cessation. To test the mathematical theories behind this approach, we developed a discrete model that integrates U.S. Census Bureau population estimates, Social Security Administration actuarial life tables, and published sexual activity rates for individuals aged 15 to 44 to depict the sexually active population from 2010 to 2018. Our discrete model evolves through six state variables calculating the rates of cessation while accounting for four distinct mathematical scenarios to prevent impossible negative rates. This discrete model serves as a proof of concept for a continuous framework capable of estimating sexually active population dynamics using available demographic data.

2:20–2:40 PM **Jack Cerullo** — *UNM*

Building the Optimal Team: Axiomatic and Data-Driven Approaches

2:40–3:00 PM *Break*

3:00–3:20 PM **Hope Winsor** — *CSU*

Colorado Performance Framework: Educational Quality or a Measure of Money?

3:25–3:45 PM **Lekha Shrivastava** — *ASU*

Precision Under Pressure: A Comparative Analysis of Nine PLS1 Variants in Image Restoration under Multi-Model Noise Gradients

Partial Least Squares (PLS) regression serves as a computationally efficient, "white-box" alternative to deep learning for image deconvolution in hardware-constrained environments. While PLS variants are well-documented in one-dimensional chemometrics, their numerical stability and breakdown points in two-dimensional image restoration remain under-researched. This study benchmarks the nine PLS1 algorithms identified by Andersson (2009) to identify their operational limits in high-resolution visual data. The experimental framework utilizes a constant Gaussian blur kernel applied to a dual-domain dataset of 1,000 images (DIV2K and NASA/Hubble). To simulate real-world impairment, 135 unique testing scenarios were constructed by subjecting blurred images to three noise models (Gaussian, Poisson, and Salt & Pepper) across a five-level intensity gradient ranging from 1% to 50%. Performance is evaluated using Structural Similarity (SSIM), Peak Signal-to-Noise Ratio (PSNR), and computational latency.

3:45–4:00 PM *Break*

PLENARY TALK · 4:00–5:00 PM · LMC

Dr. Kathryn Bryant

The Math of AI Hallucinations

5:00–6:30 PM Dinner *(Hot Spot at the Union)*

6:30–8:00 PM Problem Session II *(LMC Lobby)*

Sunday, April 19

9:30 AM — Morning Sessions (Parallel)

Session 7 — Room 201A | *Chair: Casey Malone*

9:30–9:50 AM **Shaye Fordring, Seb Pardo & Elenor Rushall** — *NAU*

Enumeration of Pattern-Avoiding Cayley Permutations via Species

Any permutation of {1, 2, ..., n} may be written in one-line notation as a sequence of entries representing the result of applying the permutation to the identity. If p and q are two permutations, then p is said to contain q as a pattern if some subsequence of the entries of p has the same relative order as all the entries of q; otherwise p is said to avoid q. One of the first notable results in the field of permutation patterns was MacMahon's 1915 proof that the Catalan numbers count 123-avoiding permutations. We study pattern avoidance in the context of signed Cayley permutations. Introduced by Mor and Fraenkel in 1983, a Cayley permutation is a finite sequence of positive integers that includes at least one copy of each integer between one and its maximum value. We explore pattern avoidance in signed Cayley permutations with the aim of providing species, exponential generating series, and counting formulas.

9:55–10:15 AM **Rowdy Fordney** — *NAU*

Jumping Random Checkers

This research project investigated combinatorial aspects of a game of chance inspired by an old casino game called "Cash King Checkers." The problem is based on a checkerboard where red kings are placed on three white squares in the first row of the board, and a pre-chosen number of black checkers are randomly distributed to other white squares. Only the kings move, and their moves consist of completing as many jumps of black checkers as possible. The goal was to determine the frequency of the number of jumps given the random allocation of black checkers. To count possibilities, the larger problem was partitioned into cases and each was counted separately. Discoveries include general formulas for the number of arrangements resulting in one, two, three, and four jumps on the 6x6 board, and a general algorithm to count the number of configurations leading to zero jumps after b checkers are dropped, regardless of board size.

10:15–10:35 AM *Break*

10:35–10:55 AM **Norman Boyd** — *UNM*

Randomized Least Squares Solvers for Randomized Fourier Neural Networks

Random Fourier Neural Networks (rFNNs) are a neural network architecture that can learn high-frequency and multiscale structure by training with repeated overdetermined least squares solves arising from Markov Chain Monte Carlo frequency sampling. In practice, these least squares problems account for most of the computational cost of training, which motivates the search for faster solvers. In this work, randomized sketching methods are studied for the regularized least squares problems that arise in one training iteration of an rFNN. Three sketching-based approaches are compared: Sketch-and-Solve, Sketch-and-Precondition, and Iterative Sketching. The results show that Sketch-and-Precondition and Iterative Sketching maintain errors consistent with the regularization level across a broad range of sketch dimensions while often outperforming Householder QR in runtime.

Session 8 — Room 201 | *Chair: Calder Evans*

9:30–9:50 AM **Megan He** — *ASU*

Cyclotomic Polynomials and Density of Related Diophantine Equations

We give background definitions and an introduction to cyclotomic polynomials. We dissect Beiter's work with the midterm coefficient of the pq-th cyclotomic polynomial and how it connects to the two Diophantine equations. Previous work studied those two equations $ax + by = (a - 1)(b - 1)/2$ and $ax + by + 1 = (a - 1)(b - 1)/2$ for relatively prime numbers a and b. We build on their problems for future investigation, namely, investigating the density of pairs corresponding to each equation.

9:55–10:15 AM **Ryan Grimm** — *CSU*

Counting Covers: A Case Study of Problem Solving in Higher-Level Math

The Hurwitz number counts, up to isomorphism, the number of covers of a Riemann surface of a certain genus, holding constant the ramification profile of such a cover. With this information alone, the Hurwitz number is effectively incalculable beyond simple examples. However, through translating the problem first to monodromy representations, then to representation theory, Hurwitz numbers become significantly more practical computations. Examining Hurwitz numbers as a case study provides insight into much of the modern approach of mathematics: analyzing the intersections of fields to gain insight. Higher-level mathematics today conducts research by translating problems through different fields to gain the advantages those other fields provide. This research was conducted through review of relevant literature and academic interviews with mathematics faculty.

10:15–10:35 AM *Break*

10:35–10:55 AM **TBD** —

TBD

11:00 AM–12:00 PM Lunch & Conference Closure *(Sandwiches!)*

Problem Competition Open Hours

Friday: 7:30–9:00 PM · Saturday: 6:30–8:00 PM