20th Annual SIAM Front Range Applied Mathematics Student Conference

Saturday, March 9th, 2024

Check-in, Welcome and Breakfast: 8:30 - 9:00

Student Commons Building, Room 4128

Breakfast sponsored by CU Denver SGA

Morning Session I: 9:00 - 10:35

Student Commons Building, Room 4125

9:00 - 9:20	Andrew Kitterman *University of Colorado, Denver*	New Surrogate Modeling Techniques
9:25 - 9:45	Max Silver *University of Colorado, Boulder*	Changing Fire Weather in Colorado: A Contrast Between Observational Data and Reanalysis Data
9:50 - 10:10	Lillian Makhoul *University of Colorado, Denver*	A Study of the Voter Model
10:15 - 10:35	Jonathon Hirschi *University of Colorado, Denver*	Data Acquisition for Wildfire Fuel Modeling

Morning Session II: 9:00 - 10:35

Student Commons Building, Room 4017

9:00 - 9:20	Michael Ernst *United States Air Force Academy*	Fractals: Where repetition makes the dimension complicated.
9:25 - 9:45	Delaney M.J. Finley *United States Air Force Academy*	Finding the Stability of Instability: Using Differential Equations to Model Bipolar Disorders
9:50 - 10:10	Julia Meilan Jess *University of Colorado, Boulder*	Source Localization in (Tree) Infection Networks. Part I
10:15 - 10:35	Devlin Costello *University of Colorado, Boulder*	Source Localization in (Tree) Infection Networks. Part II.

University of Colorado Denver
CU IN THE CITY

We gratefully acknowledge funding support from CU Denver Dept. of Mathematical and Statistical Sciences and the J.R. Woodhull/Logicon Teaching Professor of Applied Mathematics at CU Boulder.

Morning Session III: 9:00 - 10:35

Student Commons Building, Room 4113

9:00 - 9:20	Abigail Nix *University of Colorado, Denver*	Modifying Kemeny's Constant
9:25 - 9:45	Jacob Johns *University of Colorado, Denver*	An Illustrative Example of Brand Sentiment Analysis: Python and the McRib
9:50 - 10:10	Troy Johnson *University of Colorado, Colorado Springs*	Approximating rational solutions to partial differential equations using Malmquist-Takenaka rational functions
10:15 - 10:35	Dani Lisle *University of Colorado, Boulder*	Genetic Reinforcement Learning of Optimal Strategy Dynamics in Symbolic Form

10:40 - 11:00 – Coffee Break

11:00 - 12:00 – Industry Panel

Student Commons Building, Room 1600

Panel Members:

- Cat Graber, Software Engineer, *Maptek*, MAPTEK
- Travis Hunter, Senior Principal Software Engineer, *Northrop Grumman*, NORTHROP GRUMMAN
- Dan Kaslovsky, Software Architect, Cybersecurity Industry
- Valerie Yellam, Senior Systems Engineer, *Boeing*, BOEING

12:00 - 12:40 – Lunch Break

Student Commons Building, Room 1600

12:40 - 1:40 – Plenary Address

Student Commons Building, Room 1600

"Countermeasures for Infectious Diseases"

Dr. Daniel Larremore. *Associate Professor, Department of Computer Science & BioFrontiers Institute, University of Colorado Boulder*

A group picture will be taken immediately following the plenary address.

Afternoon Session I: 1:50 - 3:25

Student Commons Building, Room 4125

1:50 - 2:10	Sean Svihla *University of Colorado, Boulder*	Sparsification of Phylogenetic Covariance Matrices of Regular Trees
2:15 - 2:35	Molly McFaul *University of Colorado, Boulder*	Approximate Solutions of the KP Equation with Applications to Shallow Water Waves
2:40 - 3:00	Shuhuai Qin *Colorado State University*	A Machine Learning Integrated with In Vitro Experiments for Study of Drug Delivery from PLGA Nanoparticles
3:05 - 3:25	Johnathan Rhyne *University of Colorado, Denver*	Improvements in DLARFT in LAPACK

Afternoon Session II: 1:50 - 3:00

Student Commons Building, Room 4017

1:50 - 2:10	Jerry Wang, Jasper Shen, and Matthew Stuckenbruck *University of Colorado, Boulder*	Conditional Modeling of "Momentum" in Tennis Games
2:15 - 2:35	João Vitor de Oliveira Silva *University of Colorado, Denver*	Gaussian Process Modeling with Applications to Tumor Growth
2:40 - 3:00	Gressner Soto *University of Colorado, Boulder*	On Chaotic Non-Stationary Steady-States and Biological Processes

Industry Panel Discussion

11:00 - 12:00

Cat Graber

Software Engineer, Maptek

Cat Graber got her MS in Applied Mathematics in 2018 at University of Colorado Denver. She has worked as a software developer for Maptek, a mining software company, for 4.5 years. She fixes bugs and occasionally implements new features.

Travis Hunter

Senior Principal Software Engineer, Northrop Grumman

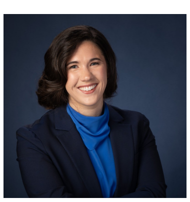
Travis Hunter is a 2011 graduate from UCCS and is currently Senior Software Engineer at Northrop Grumman. He has been a software engineer in the aerospace and defense industry since 2016, and with Northrop since 2018. Travis worked on several projects integral to the US' missile defense programs, particularly in the modeling and simulation space. He has worked on physics engines that simulate the performance and trajectories of complex missile systems for the Missile Defense Agency, as well as tactical RADAR code for several defense radar systems. His current position involves algorithm development for a new infrared satellite system. Travis's background in applied mathematics and physics allows him to successfully work with a team of other software, aerospace, and systems engineers to help design and develop mathematical models of physical systems and their environments.

Dan Kaslovsky

Software Architect, Cybersecurity Industry

Dan Kaslovsky has worked in engineering and data science for over a decade. After completing a Ph.D. in Applied Math at CU Boulder and earning an NSF Postdoctoral Fellowship, he found a home in industry building products and growing teams at cybersecurity companies. Embracing the ongoing shifts in the data and engineering fields, he has worked in many roles, including Data Scientist, Machine Learning Engineer, and Director of Software Architecture. Dan enjoys toeing the line between technical contribution and engineering leadership. He regularly interviews, hires, and mentors data scientists, engineers, and researchers and runs a consultancy where he coaches graduating students and other professionals through career transitions.

Valerie Yellam



Senior Systems Engineer, Boeing

Valerie Yellam is a Senior Systems Engineer/Team Lead for the Boeing Virtual Warfare Center's Space Analysis and Experimentation Team. Currently, she is developing high fidelity models and system CONOPS for simulations and analyses supporting a wide base of customers such as SpaceForce, DoD, and other internal Boeing groups. This position requires an excellent understanding of astrodynamics, satellite operations, and advanced sensor technologies to complete a wide range of critical efforts. Valerie holds a BA in Mathematics with a minor in Computer Science and a MS in Aeronautics with an emphasis on Space Studies. Her previous work experiences include Lead Software Engineer of the Redundant Inertial Navigation Unit for the Space Launch System and support Software Engineer for the Ground-based Midcourse Defense program.

Plenary Address

12:40 - 1:40

Countermeasures for Infectious Diseases

Daniel Larremore

Associate Professor, Department of Computer Science & BioFrontiers Institute
University of Colorado Boulder

For the applied mathematician, both vaccination and testing are fascinating infectious disease countermeasures. Why? First, their impact depends on how and when you use them, meaning that (i) their value is connected to a dynamics and (ii) there are associated optimization problems for their usage. Second, it's extremely difficult to directly estimate the effectiveness of either countermeasure at a population scale from empirical data, elevating the value of mathematical models that can predict impact from first principles. In this talk, I'll introduce and discuss such models for both vaccination and testing in the context of respiratory syncytial virus (RSV), influenza A, and SARS-CoV-2, alongside critical optimization problems: who should get the first doses of a scarce vaccine? And, how should we use the new wave of at-home rapid antigen tests for maximum impact? Finally, we'll reflect on how our understanding of the answers to these questions has changed since early 2020, and highlight a few other interesting open problems in the study of infectious disease countermeasures.

About the Speaker

Dr. Daniel Larremore is an Associate Professor in the Department of Computer Science and the BioFrontiers Institute at the University of Colorado Boulder. He is also an affiliate of the Department of Applied Mathematics at the University of Colorado Boulder, and is a member of the external faculty at the Santa Fe Institute and in the Center for Communicable Disease Dynamics at the Harvard T. H. Chan School of Public Health. His research develops mathematical methods using novel combinations of networks, dynamical systems, and statistical inference to solve problems in two main areas: infectious disease epidemiology and computational social science. Prior to joining the University of Colorado faculty, he was an Omidyar Fellow at the Santa Fe Institute 2015-2017 and a post-doctoral fellow at the Harvard T.H. Chan School of Public Health 2012-2015. He obtained his Ph.D. in Applied Mathematics from the University of Colorado Boulder in 2012, and holds an undergraduate degree in Chemical Engineering from Washington University in St. Louis. He is the recipient of the Erdös - Rényi Prize from the Network Science Society and the Alan T. Waterman Award from the National Science Foundation.

MORNING SESSION I

NEW SURROGATE MODELING TECHNIQUES

Andrew Kitterman
University of Colorado, Denver

The presenter will discuss novel methods relating to Primary Orthogonal Decomposition Mapping method; which covariance kernel to use, and how to improve computational time. Presenter will then discuss inroads being made into Data Reconstruction using POD methods; how to obtain estimates efficiently.

CHANGING FIRE WEATHER IN COLORADO: A CONTRAST BETWEEN OBSERVATIONAL DATA AND REANALYSIS DATA

Max Silver
University of Colorado, Boulder

Recent wildfires in Colorado raise the question of whether rising global temperatures have caused an increase in fire weather in Colorado. We use two datasets to address the question: "How has the occurrence of fire weather changed in Colorado" Using 21 years of observed weather conditions from a meteorological tower at the National Renewable Energy Laboratory and 66 years of ERA5 reanalysis data, we assess changing trends in Colorado fire weather. The observational data are limited in temporal extent, but they capture exact real-world conditions at a location in complex terrain. The reanalysis data are available for an extended period of time and for the entire state, but the data are of relatively coarse spatial and temporal resolution and may fail to capture extremes.

To quantify fire risk, we calculate the hot-dry-windy index (HDWI), which relies on wind speed and vapor pressure deficit. No statistically significant trend in the HDWI appears in the observational dataset. However, according to the reanalysis data, strong increasing trends in HDWI values emerge across all of Colorado. This apparent conflict between observational and reanalysis data suggests that reanalysis data may not be representative and more long-term observational datasets are required to assess fire risk.

A STUDY OF THE VOTER MODEL

Lillian Makhoul
University of Colorado, Denver

A voter model is a directed graph of nodes which hold one of m possible opinions. This graph can be represented in many different forms, however the main shape I look at in this presentation is a square lattice graph, which holds "boundary"" nodes, and each node may hold one of two opinions.

In this presentation, I will give an overview of the Classic Voter Model, put forward an alternative model I've come up with, discuss limitations I've encountered throughout this project, touch on some additional work, specifically on the Confidence Voter Model, and brief on some unanswered questions.

This project was completed under the advisory of Daniel Conus (Lehigh University).

Github Repository:
https://github.com/makhoullillian153/A-Numerical-Study-of-the-Voter-Model

DATA ACQUISITION FOR WILDFIRE FUEL MODELING

Jonathon Hirschi
University of Colorado, Denver

Wildfire modeling requires utilizing data at very different spatial scales. In my presentation, I will demonstrate building a dataset for fuel moisture modeling using spatial techniques like interpolation and downscaling to align disparate data sources at a desired location. Then, I will discuss spatiotemporal cross validation and how to meaningfully quantify model prediction error. I will demonstrate some common pitfalls related to validating spatiotemporal models using a simple fuel moisture model. Naïve approaches to cross validation that don't account for correlation in space and time can lead to data leakage issues and overly optimistic model accuracy metrics.

MORNING SESSION II

FRACTALS: WHERE REPETITION MAKES THE DIMENSION COMPLICATED

Michael Ernst
United States Air Force Academy

Julia and Mandelbrot sets show a beautiful visual of complex math, but to understand their image, we must first understand fractals. From space filling curves to iterated patterns and all natural things in between, fractals appear everywhere with multiple dimensional perspectives. In this talk, we will cover multiple examples of both natural and mathematical fractals alongside different measures for dimension.

FINDING THE STABILITY OF INSTABILITY: USING DIFFERENTIAL EQUATIONS TO MODEL BIPOLAR DISORDERS

Delaney M.J. Finley
United States Air Force Academy

Bipolar disorder is a mental disorder defined by both episodes of low depression and mania, and is classified into two categories: type one and type two. This paper focuses specifically on type two bipolar, which is unique in the fact that a person who is diagnosed with type two is one who swings back and forth between the periods of depression and mania on a regular basis, in an oscillating manner. Through the use of three different, second order nonlinear ordinary differential equations, the Van Der Pol, Lienard, and Rayleigh oscillators, we can seek to model Bipolar behavior and analyze the effects that the parameters play on both the solution and its respective limit cycles. Through the use of varied equations and parameters, we can demonstrate certain patient cases and outcomes, find equilibrium points, and analyze the stability or instability of the amplitude of a patient through the use of limit cycles.

SOURCE LOCALIZATION IN (TREE) INFECTION NETWORKS. PART I

Julia Meilan Jess
University of Colorado, Boulder

Effective source localization is crucial for public health, especially in light of the 2020 COVID-19 pandemic. This talk introduces an observed-based estimation method for source localization in tree networks (i.e., connected graphs without cycles), assuming a susceptible-infected (SI) model. Under this model, recovery is impossible once a node is infected, and the infection originates at a single unknown node at time 0, the source. It then spreads from infected to susceptible neighboring nodes, according to random time delays described by probability distributions that may depend on the identity of neighboring nodes. The only available information for estimating the source is the infection times of preselected nodes, the observers. By adapting an existing methodology based on Laplace transforms and their empirical versions, we propose a new methodology for estimating the probability that each node in the network is the true source.

This work has been partially funded by the NSF grant No. 1836914.

SOURCE LOCALIZATION IN (TREE) INFECTION NETWORKS. PART II

Devlin Costello
University of Colorado, Boulder

Building on the work presented in Part I, which discussed observation-based source localization in tree infection networks, this talk shifts focus towards applying and testing these methods on large synthetic and real networks. In particular, we present how to generate random tree networks using Prufer sequences, and how to simplify the complexity of the source localization problem presented in Part I. We also examine different strategies for addressing this problem, paying particular attention to its inherent constraints and assessing their effectiveness across a large testing suite of possible network scenarios.

This work has been partially funded by CU Boulder's Discovery Learning Apprenticeship (DLA) Program.

MORNING SESSION III

MODIFYING KEMENY'S CONSTANT

Abigail Nix
University of Colorado, Denver

In a connected graph, Kemeny's constant gives the expected time of a random walk from an arbitrary vertex x to reach a randomly-chosen vertex y. Because of this, Kemeny's constant can be interpreted as a measure of how well a graph is connected. It is generally unknown how the addition or removal of edges affects Kemeny's constant.

Inspired by the edge derivative of the normalized Laplacian, we derive the edge derivative of Kemeny's constant for several graph families. In addition, we find sharp bounds for the edge derivative of an eigenvalue of the normalized Laplacian and bounds for the edge derivative of Kemeny's constant.

AN ILLUSTRATIVE EXAMPLE OF BRAND SENTIMENT ANALYSIS: PYTHON AND THE MCRIB

Jacob Johns
University of Colorado, Denver

Brand sentiment is a vital and key aspect of marketing for corporations and organizations. A defining part of an advertising campaign is determining value added. Often, it is too costly to feasibly determine if any significant change in the public's habits occurred due to an advertisement. One solution that has been proven effective is the use of social media data. We recapitulate this by performing statistical tests on Twitter/X data regarding the 2021 rerelease of the McRib. Sentiment data is derived from tweets/posts and the Natural Language Toolkit.

APPROXIMATING RATIONAL SOLUTIONS TO PARTIAL DIFFERENTIAL EQUATIONS USING MALMQUIST - TAKENAKA RATIONAL FUNCTIONS

Troy Johnson
University of Colorado, Colorado Springs

Approximating rational solutions to partial differential equations is often difficult using traditional numerical methods such as spectral Fourier methods, due to slow (algebraic) decay of the functions. This talk will introduce the Malmquist-Takenaka (MT) functions as a suitable basis for representing rational functions. The MT functions are set of orthogonal rational functions that, importantly, can be related to the discrete Fourier transform and computed via a modified fast Fourier transform. Many examples illustrating the effectiveness of this approach will be given.

GENETIC REINFORCEMENT LEARNING OF OPTIMAL STRATEGY DYNAMICS IN SYMBOLIC FORM

Dani Lisle
University of Colorado, Boulder

We devise a framework for bridging the gap between reinforcement learning in games or systems, and strategic knowledge extraction applying reinforcement learning with genetic algorithmic mechanics to differential equations governing the behavior of agents. This builds upon previous work and differs in its application of genetically mutating equations to the reinforcement learning problem. Previous work in reinforcement learning of strategy lacks the ability to discover open-form equations with highly complex and nonlinear structures, while sparse previous work in genetically mutating equations is in applications to discovery of physical dynamics, but not to strategies or policies. This work draws from both in creating a framework to develop a generalized method for learning optimal strategy encoded as differential equations. We reinforcement learning to obtain optimal strategy dynamics directly from the rules or physics of the game or system rather than from a dataset. We explore results of the approach on simple theoretic games.

AFTERNOON SESSION I

SPARSIFICATION OF PHYLOGENETIC COVARIANCE MATRICES OF REGULAR TREES

Sean Svihla
University of Colorado, Boulder

Consider a rooted tree T where each edge e has a non-negative length $\ell(e)$. The covariance matrix C of T is the matrix with rows and columns indexed by the leaves of the tree, with entries $C(i,j) := \sum_{e \in [i \wedge j, \circ]} \ell(e)$. Namely, the entries in C represent the sums of edge lengths shared by the paths connecting any two leaves to the tree's root.

Recent research has demonstrated that the covariance matrix of a large, randomly generated binary tree becomes significantly sparse, with overwhelming probability, after a change-of-basis using the Haar-like wavelets of the tree. This work expands upon this finding to encompass the broader class of k-regular trees for any $k \geq 2$ by refining asymptotic formulas in the literature for the mean and variance of the internal path length of random k-regular trees.

This research has received partial funding from NSF grant No. 1836914.

APPROXIMATE SOLUTIONS OF THE KP EQUATION WITH APPLICATIONS TO SHALLOW WATER WAVES

Molly McFaul
University of Colorado, Boulder

Various interactions of water waves between wave-packets and background flows have previously been studied, including interactions of a linear wavepacket with an expansion wave in one spatial dimension, and interactions of a nonlinear wavepacket with an undular bore (also called a dispersive shock wave.) Here, the interaction between a two-dimensional linear wavepacket and a one-dimensional expansion wave is analyzed; special approximate solutions are found analytically for the governing partial differential equation, the Kadomtsev-Petviashvili (KP) equation. The conditions on the incident wavepacket's wave vector that leads to transmission or trapping of the wavepacket in the background mean flow are analyzed in multiple cases of interaction. The evolution of the wavepacket amplitude is also determined.

A MACHINE LEARNING INTEGRATED WITH IN VITRO EXPERIMENTS FOR STUDY OF DRUG DELIVERY FROM PLGA NANOPARTICLES

Shuhuai Qin
Colorado State University

For decades, optimization of drug delivery systems has been pivotal in biomedical research. In this talk, we report our preliminary findings from integration of machine learning (ML) and in vitro experiments for study of drug delivery from PLGA poly (lactic-co-glycolic acid) micro-/nano-particles (MPs/NPs).

For in vitro experiments, we synthesize PLGA NPs using the double emulsion solvent evaporation technique. We utilize ultraviolet-visible spectroscopy (UV-Vis) to characterize release profiles from MPs and NPs that encapsulate various types of drugs.

Machine learning methods such as linear regression (LR), Gaussian process regression (GPR), and artificial neural networks (ANN) have been used for a variety of problems, while each method has its advantages and limitations. GPR could work with small-size data and provide predictions with uncertainty.

By integrating results from applying machine learning techniques and in vitro experiments, we develop better understanding of the connection between pH values, solubility, NP sizes, and drug release profiles, especially the percentage of drug amount released during the initial burst. This work represents a new research paradigm to overcome the high costs of traditional experiments and limitations of empirical models.

This is a joint work with Yu Sun, Namul Namul, Yingli Li, Prof. Yan Vivian Li, and Prof. James Liu.

IMPROVEMENTS IN DLARFT IN LAPACK

Johnathan Rhyne
University of Colorado, Denver

The QR factorization is an integral part in many fields and is an important operation to do efficiently and accurately. The current implementation inside LAPACK constructs Q from householder vectors using a blocking scheme. As part of this blocking scheme, LARFT constructs a factor that is necessary for blocking that is called repeatedly, and we propose new schemes to speed up this part.

AFTERNOON SESSION II

CONDITIONAL MODELING OF "MOMENTUM" IN TENNIS GAMES

Jerry Wang, Jasper Shen, and Matthew Stuckenbruck
University of Colorado, Boulder

Momentum is a term that refers to the incredible ability that many sports players have to suddenly win a series of victories when they would otherwise not be expected to. The idea is that a player's repeated success can improve their performance in the short-term. It is associated with the concept of psychological momentum, which is a well-studied phenomenon in psychology associated with goal-seeking.

Within this investigation we used several statistical methods in order to quantify psychological momentum within tennis matches. We first quantified momentum as the ability to predict the next point in the game based on information from the previous volleys. We were able to measure and predict momentum by categorizing streaks of points in a row. The data was split into 70% on which the data was based, and it was tested on the other 30%. The r^2 coefficient for the model on the 30% was 0.7275, which shows that the model has a moderately high prediction power on the probability of a player scoring a point based on their streak of points. It was found that momentum increases with the number of points a player scores in a row, except after 3-4 points scored in which case it actually decreases to less than 50%.

Following that, we developed a Markov Chain based on the dependent trials model for different states of momentum. Probabilities of scoring points were modeled such that they were dependent upon the state of momentum at any given time. Through this it was observed that momentum state probabilities, as well as scoring probabilities, would approach a steady state after roughly four points scored into the future. This seems to similarly suggest that momentum does not seem to carry for more than four volleys after it is gained. The predictions from the Markov Chain were also analyzed against the real data. After converting point data into the three designated states for momentum, it was clear that the Markov chain model predicted which state the real game would be in with a reasonably low RMSE for up to five steps into the future of the given state.

Afterwards, the factors involved in the event of a momentum swing were investigated. Connecting these factors with the current number of points scored in a row by a player, the event in which a player won a break point seemed to show the strongest individual connection to an indication of a momentum swing. This factor was then translated into a probability of a momentum swing and it was discovered that there was an increase in probability of a momentum swing following the third point scored in a row.

Utilizing the models produced, we observed the existence of momentum in professional games of tennis. However, we discovered the concept of momentum being unable to consistently persist as the player continues to consecutively accrue points.

GAUSSIAN PROCESS MODELING WITH APPLICATIONS TO TUMOR GROWTH

João Vitor de Oliveira Silva
University of Colorado, Denver

Mechanistic models have been proposed in order to understand phenomena from different areas of knowledge, such as the onset and growth of tumors. Although the development of computational solution of these models is an important task, it is also essential to identity parameters which reflect experimental data of the scenario of interest. Bayesian inference is an approach which solves the latter problem, by incorporating model and data uncertainties. Considering that this process requires repeated execution of the model, this is prone to be infeasible for complex multiscale tumor growth models. This work presents a methodology to circumvent this issue with the introduction of a surrogate Gaussian Process (GP) model. We review theoretical aspects of GP, so as to define an appropriate GP for this context. As a proof of concept, the proposed approach is presented in two tumor growth models, with our results suggesting its ability in reducing the overall inference computational time without lost of accuracy.

ON CHAOTIC NON-STATIONARY STEADY-STATES AND BIOLOGICAL PROCESSES

Gressner Soto
University of Colorado, Boulder

A late-1970's contribution by Dr. K.-D. Willamowski and Dr. Otto Rössler related to a chemical reaction arrangement that is feasible able to sustain a chaotic type of non-stationary motion is examined. The arrangement of the chemical-reaction network transforms 3 distinct species into 2 distinct species, utilizing 3 transient intermediate species; the concentrations of these 3 intermediate species are the aspects of this arrangement that are able to access this sustained chaotic type of presence. There exist 2 primary objectives with this undertaking: 1) continue developing numerical tools for the analysis of more elaborate collections of non-linear differential-equations, particularly as they relate to reaction networks and 2) lay-out an initial argument for why chaotic-and-beyond type of non-stationary steady-states are not compatible with the type of motion that underlies biological activity.