The 43rd Annual Meeting

SIAM Southeastern Atlantic Section
2019

PROGRAM and ABSTRACTS

September 21–22, 2019

Knoxville, Tennessee, USA

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Knoxville, Tennessee, USA

Organized by

Department of Mathematics
University of Tennessee

Sponsored by

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Society for Industrial and Applied Mathematics

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Directions and Orientation

Address of the venue

Department of Mathematics (Ayres Hall)
University of Tennessee
1403 Circle Dr, Knoxville, TN 37916, USA

Science and Engineering Research Facility (SERF building)
University of Tennessee
1414 Circle Dr, Knoxville, TN 37916, USA

Student Union
University of Tennessee
1502 Cumberland Avenue, Knoxville, TN 37916, USA

UT Campus Parking Information

Participants staying at any of the above hotels are encouraged to walk to the conference location. On-campus hourly parking is available at Volunteer Hall Parking Garage at 1545 White Avenue, Knoxville, TN. The cost is $1.00 for every half-hour.


THE UNIVERSITY OF TENNESSEE KNOXVILLE
PARKING MAP
Student Union
Ayres Hall
SERF
Tennessee River
(FORT LOUDOUN LAKE)
Neyland Drive
Cumberland Avenue
Volunteer Boulevard
Lake Loudoun Blvd
Alcoa Highway
Henley Street
Fort Sanders Area
Circle Park
The Hill
Worlds Fair Park
Downtown Knoxville
UT Campus Area
Student Parking
Staff Area Parking
Restricted Parking
Visitor Parking
RecSports Parking Area
Staff/Visitor Parking
Staff/Student Parking
Student/Visitor Parking
Motorcycle Parking
Plug-In Electric Vehicle
Emergency Blue Phones
Interior Emergency Blue Phones
BUILDINGS & CODES
PARKING & TRANSIT SERVICES

Saturday, September 21, 2019

7.30–12.00 **Registration** (**Location**: Ayres Hall, Outside of Room 227)

7.30–8:45 **Breakfast refreshments** (**Location**: SERF, Outside of Room 307)

8.45–9.00 **Welcome and Overview** (**Location**: SERF 307)

9.00–10.00 **Plenary Talk** (**Location**: SERF 307)

Prof. Irene M. Gamba, The University of Texas at Austin

Title: **Computational issues for kinetic collisional modeling in plasma dynamics**

10.00–10.30 **Coffee Break** (**Location**: Aryes Hall, Lobby)

Mini-symposia Talks

(25 minute talk plus 5 minute for questions)

10.30–12.30: **Numerical methods and reduced-order modeling in fluid dynamics and control (Part I of II).** Chairs: *Xuping Xie* (xiex@ornl.gov), Oak Ridge National Laboratory; *Traian Iliescu* (iliescu@vt.edu), Virginia Tech

Location: Ayres Hall, Room 110

1. **High order explicit local time-stepping methods for hyperbolic conservation laws** – *Lili Ju (University of South Carolina)*
2. **Continuous data assimilation reduced order models of fluid flow** – *Leo Reholz (Clemson University)*
3. **Computation of nonlinear feedback laws from reduced-order models** – *Jeff Borggaard (Virginia Tech)*
4. **Large eddy immersed boundary computations of intracolonial coral flow fields** – *Anne Staples (Virginia Tech)*

10.30–12.30: **Data-driven and machine learning approaches for applications (Part I of II).** Chairs: *Viktor Reshniak* (reshniakv@ornl.gov), Oak Ridge National Lab; *Rick Archibald* (archibaldrk@ornl.gov), Oak Ridge National Lab; *Jae-Hun Jung* (jaehun@buffalo.edu), SUNY Buffalo

Location: Ayres Hall, Room 111

1. **Multi-Agent Consensus Equilibrium (MACE) and Imaging Applications** – *Gregery T Buzzard (Purdue University)*

2. **AI-based X-Ray CT Reconstruction for Metal Additive Manufacturing** – *Amir Koushyar Ziabari (Oak Ridge National Laboratory)*

3. **BdryGP: a new Gaussian process model for incorporating boundary information** – *Liang Ding (Simon Mak)*

4. **Bayesian Learning via Topology for Filament Network Classification** – *Farzana Nasrin (University of Tennessee)*

10.30–12.30: **Recent Advances of Modeling and Computational Methods for Multiphase Problems (Part I of II).** Chairs: *Jia Zhao* (jia.zhao@usu.edu), Utah State University; *Xiaofeng Yang* (xfyang@math.sc.edu), University of South Carolina at Columbia

Location: Ayres Hall, Room 112

1. **Some Benchmark Computations for the Functionalized Cahn-Hilliard Equation** – *Steven Wise (University of Tennessee)*

2. **Thermodynamically consistent phase-field modeling of contact angle hysteresis** – *Pengtao Yue (Virginia Tech)*

3. **Some algorithms for the mean curvature flow under topological changes** – *Yukun Li (University of Central Florida)*

4. **Efficient schemes with unconditionally energy stabilities for anisotropic phase field models** – *Xiaofeng Yang (University of South Carolina)*

10.30–12.30: **Fast Algorithms, Sparsity and Approximation (Part I of III).** Chairs: *Bosu Choi* (choibosu@utexas.edu), University of Texas at Austin; *Mark Iwen* (iwenmark@msu.edu), Michigan State University; *Armenak Petrosyan* (petrosyana@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 113

1. **Efficient Approximation of Deep ReLU Networks for Functions on Low-Dimensional Manifolds** – *Wenjing Liao (Georgia Institute of Technology)*

2. **A Scale Invariant Approach for Sparse Signal Recovery** – *Yifei Lou (University of Texas at Dallas)*

3. **Structured Sparsity Promoting Functions** – *Erin Tripp (Syracuse University)*

4. **Data-Driven Discovery of the Sparse Structure of Dynamical Systems and its application to Prediction of Limit Cycles** – *Ming Zhong (Johns Hopkins University)*

10.30–12.30: **Analysis and Simulations in Mathematical Biology Models (Part I of II).** Chairs: *Olivia Prosper* (oprosper@utk.edu), University of Tennessee; *Suzanne Lenhart* (slenhart@utk.edu), University of Tennessee

Location: Ayres Hall, Room 114

1. **Modeling the within-host dynamics of cholera** – *Jin Wang (University of Tennessee, Chattanooga)*
2. **Optimal resource allocation for a diffusing population** – *Jason Bintz (Johnson University)*
3. **Marine reserves and optimal dynamic harvesting when fishing damages habitat** – *Michael Kelly (Transylvania University)*
4. **A data-driven approach to modeling the heroin and fentanyl epidemic** – *Tricia Phillips (University of Tennessee)*

10.30–12.30: **Recent developments in nonlocal PDEs in fluids and other applications (Part I of II).** Chairs: *Changhui Tan* (tan@math.sc.edu), University of South Carolina

Location: Ayres Hall, Room 120

1. **Isentropic Approximation** – *Ronghua Pan (Georgia Institute of Technology)*
2. **Global solutions for SQG front problems** – *Qingtian Zhang (West Virginia University)*
3. **Regularity and long-time behavior for hydrodynamic flocking models** – *Trevor Leslie (University of Wisconsin, Madison)*
4. **Anticipation breeds alignment** – *Ruiwen Shu (University of Maryland)*

10.30–12.30: **Analysis and Applications of Fractional PDEs and Nonlocal Operators (Part I of III).** Chairs: *Tadele Mengesha* (mengesha@utk.edu), University of Tennessee Knoxville; *Pablo Seleson* (selesonpd@ornl.gov), Oak Ridge National Laborator; *Mitchell Sutton* (msutto11@vols.utk.edu), University of Tennessee Knoxville

Location: Ayres Hall, Room 121

1. **A Look at the Morphing Method to Blending Classical Elasticity and Peridynamics** – *Kylie Berry (Dalton State College)*
2. **New Characterizations of Sobolev and Potential Spaces** – *James Scott (University of Tennessee Knoxville)*
3. **Solvability of a System of Nonlocal Equations Related to Peridynamics** – *Tadele Mengesha (University of Tennessee Knoxville)*

4. **Modeling Material Anisotropy in Bond-Based Peridynamics** – *Pablo Seleson (Oak Ridge National Laboratory)*

10.30–12.30: **Numerical solutions for interface problems (Part I of II).** Chairs: *Yanzhao Cao* (yzc0009@auburn.edu), Auburn University; *Junshan Lin* ((jzl0097@auburn.edu), Auburn University

Location: Ayres Hall, Room 123

1. **Continuous and discontinuous Galerkin methods for non-divergence form linear elliptic PDEs** – *Xiaobing Feng (University of Tennessee)*
2. **Shape optimization methods for ill-posed Bernoulli Problem using CutFEM method** – *Cuiyu He (University of Georgia)*
3. **Stochastic gradient descent method for optimal control of SPDEs** – *Somak Das (Auburn University)*
4. **An probabilistic numerical scheme for the partial integro-differential equations in three-dimensional irregular domains** – *Minglei Yang (Auburn University)*

Contributed Talks

(25 minute talk plus 5 minute for questions)

10.30–12.30: **Contributed Talks (Part I of III).** Chair: Steve Wise (University of Tennessee)

Location: Ayres Hall, Room 124

- **Recasting the Proof of Parseval's Identity** – *Joshua M. Siktar (University of Tennessee-Knoxville)*
- **Analysis of the Bi-anisotropic Maxwell system in Lipschitz domains** – *Eric Stachura (Kennesaw State University)*
- **Peierls-Nabarro model for single edge dislocation: mathematical validation and exponential convergence to equilibrium** – *Yuan Gao (Duke University)*
- **A stage structured model with seasonality of hemlock woolly adelgid and two predatory beetle species in the GSMNP** – *Hannah Thompson (University of Tennessee-Knoxville)*

12.30–14.00 **Lunch** (**Location**: Student Union Ballroom C)

14.00–15.00 **Plenary Talk** (**Location**: SERF 307)

Prof. John A. Burns (Virginia Tech)

Title: **Mathematical & Computational Challenges in Modeling, Control, Optimization and Design of Engineered Systems**

15.00–15.30 **Coffee Break** (**Location**: Aryes Hall, Lobby)

Mini-symposia Talks

(25 minute talk plus 5 minute for questions)

15.30–17.30: **Numerical methods and reduced-order modeling in fluid dynamics and control (Part II of II).** Chairs: *Xuping Xie* (xiex@ornl.gov), Oak Ridge National Laboratory; *Traian Iliescu* (iliescu@vt.edu), Virginia Tech

Location: Ayres Hall, Room 110

1. **Non-intrusive reduced order modeling of fluid flows using deep neural networks** – *Xuping Xie (Oak Ridge National Laboratory)*
2. **Error analysis of pressure recovery for proper orthogonal decomposition based reduced order models of the Navier-Stokes equations** – *Michael Schneier (University of Pittsburg)*
3. **Data-driven variational multi-scale reduced order model** – *Birgul Koc (Virginia Tech)*
4. **Data-driven correction reduced order models for the quasi-geostrophyic equations** – *Changhong Mou (Virginia Tech)*

15.30–17.30: **Data-driven and machine learning approaches for applications (Part II of II).** Chairs: *Viktor Reshniak* (reshniakv@ornl.gov), Oak Ridge National Laboratory; *Rick Archibald* (archibaldrk@ornl.gov), Oak Ridge National Laboratory; *Jae-Hun Jung* (jaehun@buffalo.edu), SUNY Buffalo

Location: Ayres Hall, Room 111

1. **MultiGrid Adaptive Reduction of Data on Unstructured Grids** – *Ben Whitney (Oak Ridge National Laboratory)*
2. **Learning with Information Theoretic Criteria** – *Qiang Wu (Middle Tennessee State University)*
3. **A Deep Learning Method for Inverse Scattering Problem** – *He Yang (Augusta University)*
4. **Topological data analysis and convolutional neural network for the time-series data analysis** – *Jae-Hun Jung (SUNY Buffalo)*

15.30–17.30: **Recent Advances of Modeling and Computational Methods for Multiphase Problems (Part II of II).** Chairs: *Jia Zhao* (jia.zhao@usu.edu), Utah State University; *Xiaofeng Yang* (xfyang@math.sc.edu), University of South Carolina at Columbia

Location: Ayres Hall, Room 112

1. **Mixed finite element methods for a stochastic Cahn-Hilliard equation** – *Yi Zhang (University of North Carolina at Greensboro)*
2. **An optimal-order error estimate of the lowest-order ELLAM-MFEM approximation to miscible displacement in three space dimensions** – *Xiangcheng Zheng (University of South Carolina)*
3. **A level-set method for moving contact line problems with comparison to phase-field simulations** – *Jiaqi Zhang (Virginia Tech)*
4. **Arbitrarily High-order Unconditionally Energy Stable Schemes for Thermodynamically Consistent Gradient Flow Models** – *Jia Zhao (Utah State University)*

15.30–17.30: **Fast Algorithms, Sparsity and Approximation (Part II of III).** Chairs: *Bosu Choi* (choibosu@utexas.edu), University of Texas at Austin; *Mark Iwen* (iwenmark@msu.edu), Michigan State University; *Armenak Petrosyan* (petrosyana@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 113

1. **Sparsity of Supports of Measures Minimizing Integral Energy Functionals** – *Oleksandr (Alex) Vlasiuk (Florida State University)*
2. **Compressive Sensing of Multiband Signals Using Discrete Prolate Spheroidal Sequences** – *Santhosh Karnik (Georgia Institute of Technology)*
3. **A Compressive Sensing Approach to Cluster Extraction** – *Daniel McKenzie (University of Georgia)*
4. **Dimension-Independent Sparse Fourier Transform** – *Amir Zandieh (EPFL)*

15.30–17.30: **Analysis and Simulations in Mathematical Biology Models (Part I of II).** Chairs: *Olivia Prosper* (oprosper@utk.edu), University of Tennessee; *Suzanne Lenhart* (slenhart@utk.edu), University of Tennessee

Location: Ayres Hall, Room 114

1. **Combinatorial optimization for ecological conservation** – *Lakmali Weerasena (University of Tennessee, Chattanooga)*

2. **Agent-based and continuous models of locust hopper bands** – *Christopher Strickland (University of Tennessee)*

3. **Human movement and vector-borne diseases** – *Omar Saucedo (Virginia Tech)*

4. **Optimal control of harvest timing in a discrete model** – *Danielle Burton (University of Tennessee)*

15.30–17.30: **Recent developments in nonlocal PDEs in fluids and other applications (Part II of II).** Chairs: *Changhui Tan* (tan@math.sc.edu), University of South Carolina

Location: Ayres Hall, Room 120

1. **The minimum speed of traveling wave to some reaction-diffusion systems** – *Yuanwei Qi (University of Central Florida)*

2. **Wave breaking in a class of non-local conservation laws** – *Yongki Lee (Georgia Southern University)*

3. **Uniqueness and non-uniqueness of steady states of aggregation-diffusion equations** – *Xukai Yan (Georgia Institute of Technology)*

4. **Suppression of Chemotactic collapse through fluid-mixing and fast-splitting** – *Siming He (Duke University)*

15.30–17.30: **Analysis and Applications of Fractional PDEs and Nonlocal Operators (Part II of III).** Chairs: *Tadele Mengesha* (mengesha@utk.edu), University of Tennessee Knoxville; *Pablo Seleson* (selesonpd@ornl.gov), Oak Ridge National Laborator; *Mitchell Sutton* (msutto11@vols.utk.edu), University of Tennessee Knoxville

Location: Ayres Hall, Room 121

1. **A Reproducing Kernel Enhanced Approach for Peridynamic Solutions** – *Marco Pasetto (Oak Ridge National Laboratory)*

2. **A Nonlocal Feature Driven Exemplar-Based Image Inpainting** – *Viktor Reshniak (Oak Ridge National Laboratory)*

3. **Nonlocal Transport in Fluid and Plasma Physics Systems** – *Diego Del-Castillo-Negrete (Oak Ridge National Laboratory)*

4. **On the Phase Separation in a Nonlocal Cahn-Hilliard Variational Inequality** – *Olena Burkovska (Oak Ridge National Laboratory)*

15.30–17.30: **Innovations and implementations of numerical methods for time dependent problems (Part I of II).** Chairs: *Zachary Grant* (grantzj@ornl.gov), Oak Ridge National Laboratory; *Hoang Tran* (tranha@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 122

1. **Implicit and Explicit Parallel Error Inhibiting Schemes** – *Zachary J. Grant (Oak Ridge National Laboratory)*
2. **Second-order, loosely coupled methods for fluid-poroelastic material interaction** – *Oyekola Oyekole (University of Notre Dame)*
3. **New class of high-order methods for multi-rate differential equations** – *Vu Thai Luan (Mississippi State University)*
4. **Numerical Techniques for Atmospheric Modeling on Accelerators** – *Mathew Norman (Oak Ridge National Laboratory)*

15.30–17.30: **Numerical solutions for interface problems (Part II of II).** Chairs: *Yanzhao Cao* (yzc0009@auburn.edu), Auburn University; *Junshan Lin* ((jzl0097@auburn.edu), Auburn University

Location: Ayres Hall, Room 123

1. **A spatially second order alternating direction implicit (ADI) method for solving three dimensional parabolic interface problems** – *Shan Zhao (University of Alabama)*
2. **Optimal random interface problems on solar panel designs** – *Han Werner Van Wyk (Auburn University)*
3. **On the equations of poroelasticity – recent advances** – *A. J. Meir (Southern Methodist University)*
4. **A direct nonlinear filtering method for parameter estimation** – *Feng Bao (Florida State University)*

Contributed Talks

(25 minute talk plus 5 minute for questions)

15.30–17:30: **Contributed Talks (Part II of III).** Chair: Steve Wise (University of Tennessee)

Location: Ayres Hall, Room 124

- **Quadrature by two expansions: evaluating laplace layer potentials using complex polynomial and plane wave expansions** – *Lingyun Ding (University of North Carolina at Chapel Hill)*
- **Continuous Data Assimilation from Scattered Spatial Observations in Time Dependent PDEs** – *Tong Wu (Tulane University)*
- **Viscous Transport in Eroding Porous Media** – *SHANG-HUAN CHIU (Florida State University)*
- **Image reconstruction via edge-masked regularization** – *Victor Churchill (Dartmouth College)*

17.30–19:00: Reception and Poster Session (Location: 3rd and 4th floor of Ayres Hall)

Sunday, September 22, 2019

7.45–8:30 **Breakfast refreshments** (**Location**: SERF, Outside of Room 307)

8.30–9.30 **Plenary Talk** (**Location**: SERF 307)

Prof. Max Gunzburger, Florida State University

Title: **Four "better" ways to solve the Navier-Stokes equations: simulation of Richardson pair dispersion, ensemble discretization methods, an auxiliary equation approach for UQ, and filtered regularizations**

9.30–10.00 **Coffee Break** (**Location**: Aryes Hall, Lobby)

Mini-symposia Talks

(25 minute talk plus 5 minute for questions)

10.00–12.00: **Advances in stable and robust machine learning: theory and practice (Part I of I).** Chairs: *Joseph Daws Jr.* (jdaws@vols.utk.edu), The University of Tennessee, Knoxville

Location: Ayres Hall, Room 110

1. **High-dimensional function approximation with ReLU deep neural networks** – *Nicholas Dexter (Simon Frasier University)*
2. **Stable tensor neural networks (t-NNs): A matrix-mimetic, multidimensional framework for rapid deep learning** – *Elizabeth Newman (Emory University)*
3. **Neural network integral representations on the sphere for the ReLU activation function** – *Armenak Petrosyan (Oak Ridge National Laboratory)*
4. **Distributed Robust Subspace Recovery** – *Vahan Huroyan (The University of Arizona)*

10.00–12.00: **Modeling and Surrogate Modeling Techniques Based on Structured and Random Approaches (Part I of I).** Chairs: *Miroslav Stoyanov* (stoyanovmk@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 111

1. **Hybrid sampling methods for Partial Differential Equations with Multiscale Uncertain Coefficients** – *Hans-Werner van Wyk (Auburn University)*

2. **Interpolatory HDG methods for nonlinear PDEs** – *Yangwen Zhang (University of Delaware)*
3. **Radiation Source Localization Using Surrogate Models for 3-D Monte Carlo Transport Physics Simulations** – *Jared Cook (North Carolina State University)*
4. **Adaptive interpolation method for periodic functions with finite differentiability** – *Miroslav Stoyanov (Oak Ridge National Laboratory)*

10.00–12.00: **Mathematical Modeling of Biological Systems (Part I of I).** Chairs: *Lale Asik* (lale.asik@ttu.edu), Texas Tech University; *Annabel Meade* (aemeade@ncsu.edu), NC State University

Location: Ayres Hall, Room 112

1. **Population model for the decline of** *Homalodisca vitripennis* **(Hemiptera: Cicadellidae) over a ten-year period** – *Annabel Meade (NC State University)*
2. **A Mathematical Model to Determine T-cell Behavior with Cancer Chimeric Antigen Receptor (CAR) Therapies** – *Celia Schacht (NC State University)*
3. **Pathogen Mutation in a Vector-borne Disease Model** – *Praachi Das (NC State University)*
4. **The Effects of Excess Food Nutrient Content on a Tri-trophic Food Chain Model in the Aquatic Ecosystem** – *Lale Asik (Texas Tech University)*

10.00–12.00: **Fast Algorithms, Sparsity and Approximation (Part III of III).** Chairs: *Bosu Choi* (choibosu@utexas.edu), University of Texas at Austin; *Mark Iwen* (iwenmark@msu.edu), Michigan State University; *Armenak Petrosyan* (petrosyana@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 113

1. **Sparse harmonic transform: best s-term approximation guarantees for high-dimensional functions in sublinear-time** – *Bosu Choi (University of Texas at Austin)*
2. **Linear Convergence of Accelerated Generalized Conditional Gradient Algorithms in Spaces of Measures** – *Konstantin Pieper (Oak Ridge National Laboratory)*
3. **Weak Phase Retrieval and Phaseless Reconstruction** – *Dorsa Ghoreishi (University of Missouri)*
4. **Natural Greedy Algorithm: Constructing Reduced Bases in Banach Spaces** – *Anton Dereventsov (Oak Ridge National Laboratory)*

10.00–12.00: **Application of high-order methods to problems in astrophysics (Part I of I).** Chairs: *M. Paul Laiu* (laiump@ornl.gov), Oak Ridge National Laboratory; *Eirik Endeve* (endevee@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 114

1. **Solving the Conformally Flat Einstein Equations with Finite Elements and Spherical Harmonics** – *Nick Roberts (University of Tennessee)*

2. **A Discontinuous Galerkin Method for General Relativistic Hydrodynamics in thornado** – *Samuel J. Dunham (Vanderbilt University)*

3. **Bounded Runge-Kutta Discontinuous Galerkin Method for Neutrino Transport in CCSN Simulations** – *Ran Chu (University of Tennessee)*

4. **Nonlinear solvers for two-species neutrino-matter interactions in core-collapse supernovae simulations** – *M. Paul Laiu (Oak Ridge National Laboratory)*

10.00–12.00: **Analysis and Applications of Fractional PDEs and Nonlocal Operators (Part III of III).** Chairs: *Tadele Mengesha* (mengesha@utk.edu), University of Tennessee Knoxville; *Pablo Seleson* (selesonpd@ornl.gov), Oak Ridge National Laborator; *Mitchell Sutton* (msutto11@vols.utk.edu), University of Tennessee Knoxville

Location: Ayres Hall, Room 121

1. **Discretization of Fractional Boundary Value Problems Using Split Operator Local Extension Problems** – *John Paul Roop (North Carolina A&T State University)*

2. **Regularity of the Solution to Fractional Diffusion, Advection, Reaction Equations on a Bounded Interval in $\mathbb{R}^1$** – *Vincent J. Ervin (Clemson University)*

3. **A New Theory of Fractional Differential Calculus and Fractional Sobolev Spaces** – *Mitchell Sutton (University of Tennessee Knoxville)*

4. **TBA** – *TBA*

10.00–12.00: **Innovations and implementations of numerical methods for time dependent problems (Part II of II).** Chairs: *Zachary Grant* (grantzj@ornl.gov), Oak Ridge National Laboratory; *Hoang Tran* (tranha@ornl.gov), Oak Ridge National Laboratory

Location: Ayres Hall, Room 122

1. **Asymptotic preserving schemes on kinetic models with singular limits** – *Changhui Tan (University of South Carolina)*

2. **Variable stepsize, variable order methods for PDEs** – *Victor DeCaria (Oak Ridge National Laboratory)*

3. **A hybrid model for simulating sprouting angiogenesis in bio-fabrication** – *Yi Sun (University of South Carolina)*

Contributed Talks

(25 minute talk plus 5 minute for questions)

10.00–12:00: **Contributed Talks (Part III of III).** Chair: Steve Wise (University of Tennessee)

Location: Ayres Hall, Room 124

- **An Agent-Based Model Simulating Wolf Domestication by Natural Selection** – *David C. Elzinga (University of Tennessee, Knoxville)*
- **Mathematically Modeling the Immune Response of Celiac Disease** – *Cara J. Sulyok (University of Tennessee, Knoxville)*
- **Moving mesh finite element simulation for phase-field modeling of brittle fracture** – *Xianping Li (Arizona State University)*
- **The Quest for Missing Component: Dualities in Hybrid Optimal Control** – *Ali Pakniyat (Georgia Institute of Technology)*

ABSTRACTS

Plenary Talks

Speaker: Prof. Irene M. Gamba (The University of Texas at Austin)

Title: Computational issues for kinetic collisional modeling in plasma dynamics

Abstract: Kinetic collisional models describe transport properties of probability distributions in an statistical framework. Such models have interacting forms that are of non-local multi-linear nature ranging from the Boltzmann equation derived from classical billiard models to the Landau equation, the associate one for Coulomb interactions, as much as electron transport in mesoscales. In this overview lecture, we will focus on different computational and analytical issues regarding conservation, positivity propagation, as much as deviation from equilibrium due to rough boundary data, and discuss spectral conservative schemes and FEM based approach. Applications range from classical elastic theory of single or multi-species (mixtures) models for rarefied gases, as well as electron transport in nano scale channels. These models share a common computational framework that relies in the structure of their weak formulations in connection with conservation properties with their statistical observable (or macroscopic) states.

Speaker: Prof. John A. Burns (Virginia Tech)

Title: Mathematical & Computational Challenges in Modeling, Control, Optimization and Design of Engineered Systems

Abstract: In his famous 1986 Bell Communications Research Lecture titled "*You and Your Research*", Richard Hamming said,

"*If you do not work on an important problem, it's unlikely you'll do important work. It's perfectly obvious*".

What is not so obvious is how to determine what problems are important and why they are important. What is clear, but not often recognized, is that applied & computational mathematics has become the enabling science for most modern breakthroughs and advances in scientific discoveries and technology developments. Mathematical algorithms enable the development of computational engineering software required for model based development and provide the engines that drive data analytics and machine learning. Applications can and should play a key role in deciding the importance of research in mathematics. In this talk I discuss past mistakes and present some emerging applications in design, optimization and control of complex engineering systems. I will close with advice for young researchers and some predictions about future directions.

Speaker: Prof. Max Gunzburger (Florida State University)

Title: Four "better" ways to solve the Navier-Stokes equations: simulation of Richardson pair dispersion, ensemble discretization methods, an auxiliary equation approach for UQ, and filtered regularizations

Abstract: The facetious and self-serving title refers to four approaches for Navier-Stokes simulations. The first involves the analysis, numerical analysis, and an efficient implementation strategy for a recently proposed fractional Laplacian closure model that accounts for Richardson pair dispersion observed in turbulent flows. The

second is the exploitation of accurate and widely applicable ensemble methods in settings in which multiple inputs need to be processed, as may be the case for uncertainty quantification, reduced-order modeling, and control and optimization. The third addresses the lack of regularity of solutions and the resultant loss of accuracy of approximations in the case of white or weakly correlated additive noise forcing. The fourth involves filtered spectral viscosity and hierarchical finite element methods for regularized Navier-Stokes equations.

Mini-symposia Talks

(25 minute talk plus 5 minute for questions)

Application of high-order methods to problems in astrophysics

Organizers: *M. Paul Laiu* (laiump@ornl.gov), Oak Ridge National Lab; *Eirik Endeve* (endevee@ornl.gov), Oak Ridge National Lab

Abstract
Core-collapse supernovae and compact binary mergers are astrophysical events responsible for heavy element synthesis and emission of photon, neutrino, and gravitational wave signals. Harvesting insights into the physical processes driving these events relies heavily on models requiring extreme-scale, high-fidelity computing. These models solve a coupled system of equations for self-gravity, hydrodynamics, and neutrino transport. Our ability to model these events with satisfactory realism relies, in part, on advances in multi-physics and multi-scale algorithms, novel discretization techniques, and fast solvers. This mini-symposium features presentations by researchers working on the application of high-order methods to various astrophysics model components.

Part I of I (Sunday, 10:00–12:00):

- **Speaker:** *Nick Roberts* (jrober50@vols.utk.edu), University of Tennessee,

  Title: Solving the Conformally Flat Einstein Equations with Finite Elements and Spherical Harmonics

  Abstract: Core Collapse Supernovae (CCSNe) are the deaths of massive stars. Due to the high densities and energies involved in the CCSN explosion, relativistic effects become non-trivial. The Conformally Flat Approximation (CFA) to General Relativity reformulates the Einstein Equations into a set of five coupled elliptic equations for the metric terms. We present a new scheme for solving the CFA metric equations consisting of an expansion using spherical harmonic functions and continuous radial finite elements.

- **Speaker:** *Samuel J. Dunham* (samueljdunham@gmail.com), Vanderbilt University,

  Title: A Discontinuous Galerkin Method for General Relativistic Hydrodynamics in thornado

  Abstract: We are developing a solver for the general relativistic hydrodynamics equations assuming a conformally-flat approximation, a discontinuous Galerkin (DG) method for spatial discretization, and an explicit strong-stability-preserving Runge-Kutta method for temporal discretization. The solver makes use of AMReX for parallel-capabilities. Our solver has been benchmarked against several challenging test-problems, and results from these problems will be presented, along with a discussion of the DG method and two limiters necessary for the high-order methods.

- **Speaker:** *Ran Chu* (rchu@vols.utk.edu), University of Tennessee,

  Title: Bounded Runge-Kutta Discontinuous Galerkin Method for Neutrino Transport in CCSN Simulations

  Abstract: This talk summaries our recent work on the development of bounded implicit-explicit (IMEX) time integrator for discontinuous Galerkin (DG) methods approximating neutrino transport in core-collapse supernova (CCSN) simulations. To model the neutrino transport in CCSN, a robust and efficient method that preserves the restrictions on the solution with diffusion accuracy is desired. Here we propose a class of IMEX schemes where the collision term is treated implicitly and the high-order DG method for the convection term is treated explicitly.

- **Speaker:** *M. Paul Laiu* (laiump@ornl.gov), Oak Ridge National Laboratory,

  Title: Nonlinear solvers for two-species neutrino-matter interactions in core-collapse supernovae simulations

  Abstract: Efficient numerical schemes are needed for high-fidelity simulations of neutrino transport in nuclear astrophysics applications, where the dominating computational cost is in modeling neutrino-matter interactions. We compare various iterative solvers for nonlinear systems arising from neutrino-matter interactions due to emission and absorption, scattering, and pair processes, which couple the neutrino transport and the matter equations. Numerical results are reported and analyzed on a multi-group two-moment model employing discontinuous Galerkin phase-space discretization and implicit-explicit time integration.

Numerical solutions for interface problems

Organizers: *Yanzhao Cao* (yzc0009@auburn.edu), Auburn University; *Junshan Lin* ((jzl0097@auburn.edu), Auburn University

Abstract
This minisymposium focuses on recent development on numerical methods for partial differential equations, especially those with interfacial conditions.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Xiaobing Feng* (xfeng@utk.edu), University of Tennessee

  Title:Continuous and discontinuous Galerkin methods for non-divergence form linear elliptic PDEs

  Abstract: In this talk I shall present some newly developed continuous Galerkin (CG or finite element) methods and discontinuous Galerkin (DG) methods for approximating strong solutions of a class of linear elliptic PDEs in non-divergence form whose leading coefficients are only continuous or even only belong to the space of vanishing mean oscillation (VMO). Such PDEs are building blocks of fully nonlinear Hamilton-Jacobi-Bellman equations arising from stochastic optimal control and financial mathematics. The proposed numerical methods can use either C^0 or L^2 finite element spaces, they are simple to implement and can be done using standard finite element or DG codes. On the other hand, the convergence analysis of the methods is quite involved and very technical, it requires to establish finite element

and DG discrete Calderon-Zygmund estimates, which will be discussed in detail in the talk. Numerical experiments will be presented to demonstrate the effectiveness of the proposed CG and DG methods.

- **Speaker:** *Cuiyu He* (Cuiyu.He@uga.edu), University of Georgia

  Title: Shape optimization methods for ill-posed Bernoulli Problem using CutFEM method

  Abstract:

  This paper introduces and compares three types shape derivative (SD) for the ill-posed Bernoulli problem, also sometimes referred to as an "inverse obstacle problem". For the ill-posed Bernoulli problem, the Cauchy datum is known on the mixed boundary and only Dirichlet data is known on the free (unknown) boundary. To localize the free boundary, the shape derivative is used to drive the initial guess of free boundary through the optimal direction that minimize the cost functional. In the vast literature the classical surface-based SD are more preferred due to its lower computation cost and easy representation. However, shown that the volume based SD requires less regularity and has been proven to possess certain superconvergence properties. We note that the classical volume- and surface-based SDs are equivalent when analyzing in the continuous level. However, the equivalence no longer hold in the discrete level and both forms become inexact. For comparison, we also derive the exact volume-based SD by solely analyzing the discrete system. It has shown in our numerics that those two volume-based SDs performs similarly. What's more, we also introduce a new surface-based SD that is also exact, has much simpler representation and can be easily obtained based on the

  nite element method with boundary correction on the free boundary. Numerical experiments using our surface-type exact SD have shown similar or even better convergence rates comparing to the volume-type SDs.

- **Speaker:** *Somak Das* (ajmeir@mail.smu.edu), Auburn University

  Title: Stochastic gradient descent method for optimal control of SPDEs

  Abstract: Most of our contemporary mathematical models are based on partial differential equations. However, the varied levels of randomness pose difficulties for such systems to be accurately modeled using deterministic partial differential equations. In such settings we use stochastic partial dierential equations to incorporate the randomness. To determine the optimal control for the stochastic system in this project, we adopt the stochastic gradient descent algorithm . With vast data-sets being customary for training of most machine learning algorithms, the stochastic gradient descent method is one of the efficient ways to obtain the optimal control. Another class of algorithms, adaptive gradient, has also widespread applications in large scale stochastic optimizations. The algorithm adjusts its step-size at every iteration depending on the current gradient value unlike stochastic gradient where we need to re-tune the step-size manually. In this talk we show the results obtained from these algorithms.

- **Speaker:** *Minglei Yang* (mzy0020@tigermail.auburn.edu), Auburn University

  Title: An probabilistic numerical scheme for the partial integro-differential equations in three-dimensional irregular domains

  Abstract: The partial integro-differential equations (PIDEs) have been applied in a wide variety of application, including, e.g., contaminant ow in groundwater, the dynamics of financial markets and plasma physics. In this talk I will present a stable and efficient probabilistic numerical scheme for initial value PIDEs, which can work in high-dimensional irregular domains. Analysis of the approximation errors of the proposed schemes and several numerical examples will be presented to verify the accuracy and effectiveness of our approach.

Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Shan Zhao* (szhao@ua.edu),

  Title: A spatially second order alternating direction implicit (ADI) method for solving three dimensional parabolic interface problems

  Abstract: A new matched alternating direction implicit (ADI) method is proposed in this paper for solving three-dimensional (3D) parabolic interface problems with discontinuous jumps and complex interfaces. This scheme inherits the merits of its ancestor for two-dimensional problems, while possesses several novel features, such as a non-orthogonal local coordinate system for decoupling the jump conditions, two-side estimation of tangential derivatives at an interface point, and a new Douglas-Rachford ADI formulation that minimizes the number of perturbation terms, to attack more challenging 3D problems

- **Speaker:** *Han Werner Van Wyk* (hzv0008@auburn.edu), Auburn University

  Title: Optimal random interface problems on solar panel designs

  Abstract: Random rough textures can increase the absorbing efficiency of solar cells by trapping the optical light and increasing the optical path of photons, and in turn increases the effectiveness of solar panels. In this talk, I will briefly describe the mechanism and the mathematical modeling of thin film solar cells to start with. Then I will describe how to use mathematical shape control methods to optimally design of random rough surfaces in thin-film solar cells.

- **Speaker:** *A. J. Meir* (ajmeir@mail.smu.edu), Southern Methodist University

  Title: On the equations of poroelasticity – recent advances

  Abstract: Poroelasticity is a complex coupled multiphysics phenomenon. The equations of poroelasticity (a coupled system of pde) model and predict the mechanical behavior of fluid-infiltrated porous media. Their significance comes from the fact that many natural substances, e.g., rocks, soils, clays, shales, biological tissues, and bones, as well as man-made materials, e.g., foams, gels, concrete, water-solute drug carriers, and ceramics, are all elastic porous materials (hence poroelastic).

  I will give an overview of the equations of poroelasticity and their mathematical analysis, suggest the use of finite element based numerical methods for efficiently and accurately approximating solutions of model problems in poroelasticity, and discuss some observations, recent research directions, and possible extensions.

- **Speaker:** *Feng Bao* (fbao@fsu.edu), Florida State University,

  Title: A direct nonlinear filtering method for parameter estimation

  Abstract: Parameter estimation is an important research topic in data assimilation. In this paper, a novel parameter estimation method is introduced, where the parameter is considered as the state process in a nonlinear filtering problem and the state model that contains the parameter is used to construct a pseudo-observation. This approach is named the direct filter method since nonlinear filter algorithms are used to estimate the parameter directly without estimating the state model as part of the solution in the nonlinear filtering problem. Numerical experiments are carried out to examine the effectiveness and accuracy of the direct filter method

Recent developments in nonlocal PDEs in fluids and other applications

Organizers: *Changhui Tan* (tan@math.sc.edu), University of South Carolina

Abstract
This mini-symposium focuses on recent developments in the theory of nonlocal partial differential equations and their applications in fluid dynamics, as well as other fields including hyperbolic conservation laws, kinetic theory and mathematical biology. The main topics include well-posedness theory, quantitative properties and long-time behaviors of the solutions of the equations, singularity formations and other relevant issues.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Ronghua Pan* (panrh@math.gatech.edu), Georgia Institute of Technology

  Title: Isentropic Approximation

  Abstract: In the study of compressible flows, the isentropic model was often used to replace the more complicated full system when the entropy is near a constant. This is based on the expectation that the corresponding isentropic model is a good approximation to the full system when the entropy is sufficiently close to the constant. We will discuss the mathematical justification of isentropic approximation in Euler flows and in Navier-Stokes-Fourier flows. This is based on the joint work with Y. Chen and J. Jia.

- **Speaker:** *Qingtian Zhang* (qingtian.zhang@mail.wvu.edu), West Virginia University,

  Title: Global solutions for SQG front problems

  Abstract: We consider a family of patch-like solutions of surface quasi-geostrophic (SQG) equation, where the patch may be unbounded. We derive the equations of the contour dynamics under different geometrical situations and prove that the initial value problems have unique local smooth solutions. Under a smallness assumption on the initial data, with the help of the dispersive estimate, we are able to prove the global existence of the solutions for SQG front problem.

- **Speaker:** *Trevor Leslie* (tleslie2@wisc.edu), University of Wisconsin, Madison,

  Title: Regularity and long-time behavior for hydrodynamic flocking models

  Abstract: In this talk, we will discuss wellposedness theory and the long-time behavior for various Euler Alignment models on the 1D torus. We will show that for large times, the deviation from a uniform flock can be controlled by an auxiliary quantity that depends only on the initial data. We will also consider some issues that arise when the problem is posed on the full real line rather than the periodic setting.

- **Speaker:** *Ruiwen Shu* (rshu@cscamm.umd.edu), University of Maryland,

  Title: Anticipation breeds alignment

  Abstract: We study the large-time behavior of systems driven by radial potentials, which react to *anticipated* positions, $\mathbf{x}^\tau(t) = \mathbf{x}(t) + \tau\mathbf{v}(t)$ with anticipation increment $\tau > 0$. As a special case, such systems yield the celebrated Cucker-Smale model for alignment, coupled with pairwise interactions. Viewed from this perspective, such anticipated-driven systems are expected to emerge into *flocking* due to alignment of velocities, and *spatial concentration* due to confining potentials. We treat both the discrete dynamics and large crowd hydrodynamics, proving the decisive role of anticipation in driving such systems with attractive potentials into velocity alignment and spatial concentration. We also study the concentration effect near equilibrium for anticipated-based dynamics of pair of agents governed by attractive-repulsive potentials.

Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Yuanwei Qi* (yuanwei.qi@ucf.edu), University of Central Florida,

  Title: The minimum speed of traveling wave to some reaction-diffusion systems

  Abstract: In this talk, I shall present some recent results on existence of minimum speed to two types of reaction-diffusion systems which have important applications in Mathematical Biology. This is a joint work with Xinfu Chen and Guirong Liu.

- **Speaker:** *Yongki Lee* (yongkilee@georgiasouthern.edu), Georgia Southern University,

  Title: Wave breaking in a class of non-local conservation laws

  Abstract: In this talk, we discuss threshold conditions for wave breaking in a class of non-local conservation law with concavity changing flux. From a class of non-local conservation laws, the Riccati-type ODE system that governs a solution's gradient is obtained. The changes in concavity of the flux correspond to the sign changes in the leading coefficient functions of the ODE system. We identify the blow-up condition of this structurally generalized Riccati-type ODE. The method is illustrated via the Whitham-type equation with nonlinear drift and the traffic flow models with nonlocal-concave-convex flux.

- **Speaker:** *Xukai Yan* (xukai.yan@math.gatech.edu), Georgia Institute of Technology,

  Title: Uniqueness and non-uniqueness of steady states of aggregation-diffusion equations

  Abstract: In this talk ,we discuss a nonlocal aggregation equation with degenerate diffusion, which describes the mean-field limit of interacting particles driven by nonlocal interactions and localized repulsion. When the interaction potential is attractive, it is previously known that all stationary solutions must be radially decreasing up to a translation, but uniqueness (for a given mass) within this class was open, except for some special interaction potentials. For general attractive potentials, we show that the uniqueness/non-uniqueness criteria are determined by the power of the degenerate diffusion, with the critical power being $m = 2$. In the case $m \geq 2$, we show the stationary solution for any given mass is unique for any attractive potential, by tracking the associated energy functional along a novel interpolation curve. In the case $1 < m < 2$, we construct examples of smooth attractive potentials, such that there are infinitely many radially decreasing stationary solutions of the same mass. This is a joint work with Matias Delgadino and Yao Yao.

- **Speaker:** *Siming He* (simhe@math.duke.edu), Duke University,

  Title: Suppression of Chemotactic collapse through fluid-mixing and fast-splitting

  Abstract: The Patlak-Keller-Segel equations (PKS) are widely applied to model the chemotaxis phenomena in biology. It is well-known that if the total mass of the initial cell density is large enough, the PKS equations exhibit finite time blow-up. In this talk, I present some recent results on applying additional fluid flows to suppress chemotactic blow-up in the PKS equations. These are joint works with Jacob Bedrossian and Eitan Tadmor.

Numerical methods and reduced-order modeling in fluid dynamics and control

Organizers: *Xuping Xie* (xiex@ornl.gov), Oak Ridge National Laboratory; *Traian Iliescu* (iliescu@vt.edu), Virginia Tech

Abstract
In this minisymposium, we will discuss some recent developments of numerical and model reduction methods in fluid dynamical systems with applications. The speakers in this minisymposium will present their new research findings in control, turbulent fluid flows, and machine learning applications.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Lili Ju* (ju@math.sc.edu), University of South Carolina,

  Title: High Order Explicit Local Time-Stepping Methods for Hyperbolic Conservation Laws.

  Abstract: In this talk we present and analyze a general framework for constructing high order explicit local time stepping (LTS) methods for hyperbolic conservation laws. In particular, we consider the model problem discretized by Runge-Kutta discontinuous Galerkin (RKDG) methods and design LTS algorithms based on the strong stability preserving Runge-Kutta (SSP-RK) schemes, that allow spatially variable time step sizes to be used for time integration in different regions of the computational domain. The proposed algorithms are of predictor-corrector type, in which the interface information along the time direction is first predicted based on the SSP-RK approximations and Taylor expansions, and then the fluxes over the region of the interface are corrected to conserve mass exactly at each time step. Following the proposed framework, we detail the corresponding LTS schemes with accuracy up to the fourth order, and prove their conservation property and nonlinear stability for the scalar conservation laws. Numerical experiments are also presented to demonstrate excellent performance of the proposed LTS algorithms.

- **Speaker:** *Leo Reholz* (rebholz@clemson.edu), Clemson University,

  Title: Continuous data assimilation reduced order models of fluid flow.

  Abstract: We propose, analyze, and test a novel continuous data assimilation reduced order model (DA-ROM) for simulating incompressible flows. While ROMs have a long history of success on certain problems with recurring dominant structures, they tend to lose accuracy on more complicated problems and over longer time intervals. Meanwhile, continuous data assimilation (DA) has recently been used to improve accuracy and, in particular, long time accuracy in fluid simulations by incorporating measurement data into the simulation. This paper synthesizes these two ideas, in an attempt to address inaccuracies in ROM by applying DA, especially over long time intervals and when only inaccurate snapshots are available. We prove that with a properly chosen nudging parameter, the proposed DA-ROM algorithm converges exponentially fast in time to the true solution, up to discretization and ROM truncation errors. Finally, we propose a strategy for nudging adaptively in time, by adjusting dissipation arising from the nudging term to better match true solution energy. Numerical tests confirm all results, and show that the DA-ROM strategy with adaptive nudging can be highly effective at providing long time accuracy in ROMs.

- **Speaker:** *Jeff Boggaard* (jborggaard@gmail.com), Virginia Tech,

  Title: Computation of nonlinear feedback laws from reduced-order models

  Abstract: Not available

- **Speaker:** *Anne Staples* (staplesa@vt.edu), Virginia Tech,

  Title: Large eddy immersed boundary computations of intracolonial coral flow fields

Abstract: Corals are sessile and rely on the surrounding ocean flow to obtain nutrients. Here, we perform three-dimensional immersed-boundary simulations of the flow through a single Pocillopora meandrina colony. We demonstrate that the passive geometric features of the branching colony produce highly vortical internal flows. This enhances mass transfer at the interior of the colony and compensates almost exactly for average flow speed reductions there of up to 64%, resulting in the advection time scale remaining roughly constant throughout the colony

Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Xuping Xie* (xiex@ornl.gov), Oak Ridge National Laboratory,

  Title: Non-intrusive reduced order modeling of fluid flows using deep neural networks.

- **Speaker:** *Michael Schneier* (MHS64@pitt.edu), University of Pittsburg,

  Title: Error Analysis of Pressure Recovery for Proper Orthogonal Decomposition based Reduced Order Models of the Navier-Stokes Equations

  Abstract: For incompressible flow models, the pressure term serves as a Lagrange multiplier to ensure that the incompressibility constraint is satisfied. In engineering applications, the pressure term is necessary for calculating important quantities based on stresses like the lift and drag. For reduced order models (ROMs) generated via a Proper Orthogonal Decomposition (POD), it is common for the pressure to drop out of the equations and produce a velocity-only ROM. To recover the pressure, many techniques have been numerically studied in the literature; however, these techniques have undergone little rigorous analysis. In this work, we examine two of the most popular approaches: pressure recovery through the Pressure Poisson equation and recovery via the momentum equation through the use of a supremizer stabilized velocity basis. We examine the challenges that each of these approaches faces and prove stability as well as convergence results for the supremizer stabilized approach. We also investigate numerically how these different methods behave.

- **Speaker:** *Birgul Koc* (birgul@vt.edu), Virginia Tech,

  Title: Data-Driven Variational Multi-Scale Reduced Order Model.

  Abstract: Not available

- **Speaker:** *Changhong Mou* (cmou@vt.edu), Virginia Tech,

  Title: Data-Driven Correction Reduced Order Models for the Quasi-Geostrophyic Equations.

  Abstract: Not available

Fast Algorithms, Sparsity and Approximation

Organizers: *Bosu Choi* (choibosu@utexas.edu), University of Texas at Austin; *Mark Iwen* (iwenmark@msu.edu), Michigan State University; *Armenak Petrosyan* (petrosyana@ornl.gov), Oak Ridge National Laboratory

Abstract
Reconstruction algorithms of high dimensional signals (e.g., functions) often suffer from the curse of dimensionality. One popular means of circumventing this potentially crippling problem is to invoke sparsity assumptions and assume, for example, compressibility in a given basis. This approach has proven widely successful in the mathematics, computer science, and engineering communities in the form of compressive sensing and sparse approximation. The goal of this mini-symposium is to present recent work on new sparse reconstruction methods and related computational algorithms. It will cover topics such as convex and non-convex optimization methods, graph clustering methods for sparse recovery, continuous domain sampling, multidimensional sparse problems, and sparse Fourier algorithms.

Part I of III (Saturday, 10:30–12:30):

- **Speaker:** *Wenjing Liao* (wliao60@gatech.edu), School of Mathematics, Georgia Institute of Technology

  Title: Efficient Approximation of Deep ReLU Networks for Functions on Low-Dimensional Manifolds

  Abstract: Classical approximation theory of neural networks implies that, in order to achieve a fixed approximation accuracy of a given function, the network size must grow exponentially with respect to the dimension of the input variable. In practical applications, data are often in a high-dimensional space but exhibit low-dimensional structures. The network size used in practice is significantly smaller than the one predicted by theory. To explain the gap between theory and practice, we model data as point clouds on a low-dimensional manifold. I will present an efficient approximation theory of deep ReLU networks for functions supported on low-dimensional manifolds. We constructed a ReLU network for such function approximation where the size of the network grows exponentially with respect to the intrinsic dimension of the manifold. This work is joint with Minshuo Chen, Haoming Jiang, Tuo Zhao (Georgia Institute of Technology).

- **Speaker:** *Yifei Lou* (yifei.lou@utdallas.edu), Department of Mathematical Sciences, University of Texas at Dallas

  Title: A Scale Invariant Approach for Sparse Signal Recovery

  Abstract: I will talk about the ratio of the L_1 and L_2 norms, denoted as L_1/L_2, to promote sparsity. Due to the non-convexity and non-linearity, there has been little attention to this scale-invariant model. Compared to popular models in the literature such as the L_p model for $p \in (0, 1)$ and the transformed L_1 (TL1), this ratio model is parameter free. Theoretically, we present a strong null space property (sNSP) and prove that any sparse vector is a local minimizer of the L_1/L_2 model provided with this sNSP condition. We also reveal the relationship between L_1/L_2 and L_1-αL_2, based on which we propose three numerical algorithms to minimize this ratio model. The experimental results demonstrate the proposed approaches are comparable to the state-of-the-art methods in sparse recovery and work particularly well when the ground-truth signal has a high dynamic range. In addition, a variant of the L_1/L_2 model to apply on the gradient is also discussed with a proof-of-concept example of the MRI reconstruction.

- **Speaker:** *Erin Tripp* (eetripp@syr.edu), Syracuse University

  Title: Structured Sparsity Promoting Functions

  Abstract: In this talk, we will give a brief overview of our work on sparsity promoting functions (SPF) for regularization methods. We provide a simple definition of SPF which captures the essential characteristics of well-known penalties like the ℓ_0 and ℓ_1 norms. We then give a simple construction of semi-convex SPF from convex SPF and discuss their properties. In particular, we look at how the induced SPF inherits structure from its parent function. This structure then allows us to apply a variety

of algorithms to solve SPF-penalized minimization problems. We conclude with some discussion of applications to denoising.

- **Speaker:** *Ming Zhong* (mzhong5@jhu.edu), Department of Applied Mathematics & Statistics, Johns Hopkins University

  Title: Data-Driven Discovery of the Sparse Structure of Dynamical Systems and its application to Prediction of Limit Cycles

  Abstract: We further the investigation of the nonparametric inference approach in [1]. for learning interaction laws from observing various kinds of agent-based dynamical systems by applying it to more complex dynamics with more advanced interaction laws. Moreover, we show that our estimators can empirically predict the diverse limit cycles of those dynamical systems. The dynamical systems which we are studying are highly compressible, therefore we are able to represent the dynamical system with only its generator function and initial conditions. Although the dynamical data is obtained before limit cycles appear, we are still able to accurately predict the existence of limit cycles and other characteristic information. Furthermore, we are able to learn from observed data the more elaborate structure of the interaction laws, namely the parametric form of the interaction laws. The learned estimators can lead to discovery and deeper understanding of the underlying physics.

  [1]: F. Lu, M. Zhong, S. Tang, and M. Maggioni, Nonparametric inference of interaction laws in systems of agents from trajectory data, Proceedings of the National Academy of Sciences on June 28th, 2019.

Part II of III (Saturday, 15:30–17:30):

- **Speaker:** *Oleksandr (Alex) Vlasiuk* (vlasiuk@math.fsu.edu, ovlasiuk@fsu.edu), Department of Mathematics, Florida State University

  Title: Sparsity of Supports of Measures Minimizing Integral Energy Functionals

  Abstract: We discuss the properties of probability measures on the unit sphere, minimizing energies of the form $\iint_{\mathbb{S}^d} F(x \cdot y)\, d\mu_x d\mu_y$ for a continuous kernel F. It has been established recently that the finiteness of the positive part of Gegenbauer expansion of F guarantees existence of discrete minimizers. This and other conditions that imply discreteness in the case of mildly repulsive kernels are presented. For a class of energies of the form $F = |x \cdot y|^p$, $0 < p \notin 2\mathbb{N}$, minimizers are shown to have empty interior of the support.

- **Speaker:** *Santhosh Karnik* (skarnik1337@gatech.edu), School of Electrical and Computer Engineering, Georgia Institute of Technology

  Title: Compressive Sensing of Multiband Signals Using Discrete Prolate Spheroidal Sequences

  Abstract: CS is often motivated as an alternative to Nyquist-rate sampling. However, there is a significant gap between the discrete, finite-dimensional CS framework and the problem of acquiring a continuous-time, multiband signal from compressed measurements. One must utilize a dictionary in which a vector of samples of a multiband signal has a sparse approximation. Perhaps the most naïve approach is using a dictionary with discrete Fourier transform (DFT) vectors. However, due to the "spectral leakage" phenomenon, multiband signals do not have an approximately sparse representation in the DFT dictionary, or even in an overcomplete DFT dictionary. In this talk I will discuss one approach to bridging this gap by exploiting the discrete prolate spheroidal sequences (DPSS's), a collection of functions that provide an efficient representation for discrete signals that are perfectly timelimited and nearly bandlimited. By modulating and merging the DPSS basis – also known as the Slepian basis – we obtain a dictionary for which most vectors of sampled multiband signals have a sparse approximation. This

dictionary can be readily exploited by standard CS algorithms. Unfortunately, due to the high computational complexity of projecting onto the Slepian basis, this representation is often overlooked in favor of the fast Fourier transform (FFT). In this talk I will also describe novel fast algorithms for working with the Slepian basis elements, with a complexity comparable to the FFT.

- **Speaker:** *Daniel McKenzie* (mckenzie@math.uga.edu), Department of Mathematics, University of Georgia

  Title: A Compressive Sensing Approach to Cluster Extraction

  Abstract: : In this talk we discuss how to use techniques from compressive sensing to design a cluster extraction algorithm by treating the cluster indicator vector as a sparse solution to a linear system involving the graph Laplacian. We show that our algorithm, which we call SingleClusterPursuit, has computational complexity $O(d_{\max} n \log(n))$ where $d_{\max}$ represents the largest vertex degree in the graph. We verify numerically that it runs quickly and accurately on large data sets, both synthetic and real. We prove that, for a large class of probabilistic models of graphs with clusters, which includes the popular stochastic block model, the fraction of vertices misclassified by SingleClusterPursuit goes to zero as the size of the cluster goes to infinity.

- **Speaker:** *Amir Zandieh* (amir.zandieh@epfl.ch), Computer and Communication Sciences, EPFL

  Title: Dimension-Independent Sparse Fourier Transform

  Abstract: The Discrete Fourier Transform (DFT) is a fundamental computational primitive, and the fastest known algorithm for computing the DFT is the FFT (Fast Fourier Transform) algorithm. One remarkable feature of FFT is the fact that its runtime depends only on the size N of the input vector, but *not on the dimensionality of the input domain*: FFT runs in time $O(N \log N)$ irrespective of whether the DFT in question is on $\mathbb{Z}_N$ or $\mathbb{Z}_n^d$ for some $d > 1$, where $N = n^d$.

  The state of the art for Sparse FFT, i.e. the problem of computing the DFT of a signal that has at most k nonzeros in Fourier domain, is very different: all current techniques for sublinear time computation of Sparse FFT incur an exponential dependence on the dimension d in the runtime. In this paper, we give the first algorithm that computes the DFT of a k-sparse signal in time poly$(k, \log N)$ *in any dimension* d, avoiding the curse of dimensionality inherent in all previously known techniques. Our main tool is a new class of filters that we refer to as *Adaptive Aliasing Filters*: these filters allow isolating frequencies of a k-Fourier sparse signal using $O(k)$ samples in time domain and $O(k \log N)$ runtime per frequency, in any dimension d.

  We also investigate natural average case models of the input signal: **(1)** worst case support in Fourier domain with randomized coefficients and **(2)** random locations in Fourier domain with worst-case coefficients. Our techniques lead to an $\widetilde{O}(k^2)$ time algorithm for the former and an $\widetilde{O}(k)$ time algorithm for the latter.

Part III of III (Sunday, 10:00–12:00):

- **Speaker:** *Bosu Choi* (choibosu@utexas.edu), Oden Institute for Computational Engineering and Sciences, University of Texas at Austin.

  Title: Sparse Harmonic Transform: Best s-Term Approximation Guarantees for High-Dimensional Functions in Sublinear-Time

  Abstract: In this talk we will discuss fast and memory efficient numerical methods for learning the best s term approximation of functions of many variables in terms of bounded orthonormal tensor product bases. Such functions appear in many applications including, e.g., various Uncertainty Quantification

(UQ) problems involving the solution of parametric PDE that are approximately sparse in Chebyshev or Legendre product bases.

More concretely, let $\mathcal{B}$ be a finite Bounded Orthonormal Product Basis (BOPB) of cardinality $|\mathcal{B}| = N$. Herein we will develop methods that rapidly approximate any function f that is nearly sparse in the BOPB, that is, f of the form

$$f(\mathbf{x}) \approx \sum_{b \in \mathcal{S}} c_b \cdot b(\mathbf{x})$$

with $\mathcal{S} \subset \mathcal{B}$ of $|\mathcal{S}| = s$ is much less than N. Our method has a runtime of just $(s \log N)^{O(1)}$, uses only $(s \log N)^{O(1)}$ function evaluations on a fixed and nonadaptive grid, and not more than $(s \log N)^{O(1)}$ bits of memory.

This and the similarly reduced sample and memory requirements set our algorithm apart from previous works based on standard compressive sensing algorithms such as basis pursuit which typically store and utilize full intermediate basis representations of size $\Omega(N)$ during the solution process. Besides these theoretical guarantees, also the empirical performance of our method improves over previous approaches. In particular, the enhanced memory efficiency allows us to tackle much larger problem sizes than in previous works.

This is joint work with Mark Iwen (Michigan State University) and Toni Volkmer (Chemnitz University of Technology)

- **Speaker:** *Konstantin Pieper* (pieperk@ornl.gov), Computational and Applied Mathematics Group, Oak Ridge National Laboratory

  Title: Linear Convergence of Accelerated Generalized Conditional Gradient Algorithms in Spaces of Measures

  Abstract: A class of generalized conditional gradient algorithms for the solution of sparse optimization problem in spaces of Radon measures is presented. The method iteratively inserts additional Dirac-delta functions and optimizes the corresponding coefficients. Under general assumptions, a sub-linear $\mathcal{O}(1/k)$ rate in the objective functional is obtained, which is sharp in most cases. To improve efficiency, one can fully resolve the finite-dimensional subproblems occurring in each iteration of the method. We provide an analysis for the resulting procedure: under a structural assumption on the optimal solution, a linear $\mathcal{O}(\zeta^k)$ convergence rate is obtained locally. We illustrate the theoretical results for problems arising in the context of sparse source identification and optimal sensor design. This is a joint work with Daniel Walter, RICAM, Linz.

- **Speaker:** *Dorsa Ghoreishi* (dg8w6@mail.missouri.edu), Department of Mathematics, University of Missouri

  Title: Weak Phase Retrieval and Phaseless Reconstruction

  Abstract: Phase retrieval and phaseless reconstruction for Hilbert space frames is a very active area of research. Recently, it was shown that these two concepts are equivalent. In this project, we make a detailed study on weakening the above mentioned concepts to weak phase retrieval and phaseless reconstruction. Here we will prove three surprising results: (1) Weak phaseless reconstruction is equivalent to phaseless reconstruction. i.e. it never was weak; (2) Weak phase retrieval is not equivalent to weak phaseless reconstruction; (3) Weak phase retrieval requires at least 2m-2 vectors in an m-dimensional Hilbert space. We also give several examples illustrating the relationship between these concepts.

- **Speaker:** *Anton Dereventsov* (dereventsova@ornl.gov), Computational and Applied Mathematics Group, Oak Ridge National Laboratory

Title: Natural Greedy Algorithm: Constructing Reduced Bases in Banach Spaces

Abstract: The goal of a reduced basis method is to find an approximating subspace for a given set of elements. We present the Natural Greedy Algorithm — a novel way of constructing reduced bases in Banach spaces that utilizes the norming functionals of the basis elements in order to project onto subspaces. Such an approach allows for a significantly simpler basis construction as compared to the classical Greedy Algorithm, which commonly computes projections by solving a high-dimensional minimization problem. As it turns out, the performance of the Natural Greedy Algorithm is similar to that of the Greedy Algorithm in terms of both theoretical and numerical results, while the realization of the latter is substantially more computationally expensive in general. In addition, we compare our algorithm to the other two popular reduced bases techniques: the Proper Orthogonal Decomposition and the Empirical Interpolation Method.

Analysis and Simulations in Mathematical Biology Models

Organizers: *Olivia Prosper* (oprosper@utk.edu), University of Tennessee; *Suzanne Lenhart* (slenhart@utk.edu), University of Tennessee

Abstract
This session will showcase models with a variety of biological applications, ranging from immunology of cholera to spatial-temporal models for fishery populations and vector-borne disease. The types of models include ordinary differential equations, partial differential equations, and discrete equations. The models are mechanistic and data driven. Featured techniques include stability analysis, optimization, optimal control and sensitivity analysis.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Jin Wang* (jin-wang02@utc.edu),University of Tennessee, Chattanooga

  Title: Modeling the within-host dynamics of cholera

  Abstract: We perform a study on the within-host dynamics of cholera using mathematical models based on differential equations. Our goal is to gain quantitative understanding of the development of the pathogens inside the human body and the potential impact on the disease transmission and spread at the population level. We focus our attention on the analysis of the within-host interaction among the pathogenic bacteria, viruses, and immune responses. Additionally, we present some numerical simulation results to demonstrate the analytical finding.

- **Speaker:** *Jason Bintz* (jasonbintz@gmail.com), Johnson University, TN

  Title: Optimal resource allocation for a diffusing population

  Abstract: The spatial distribution of resources can have a strong effect on the overall abundance of a diffusing population. We investigate the optimal distribution of resources for given initial and boundary conditions. Population dynamics are represented by a parabolic partial differential equation with density dependent growth and resources are represented through their space- and time-varying influence on

the growth function. We consider both local and total constraints on resource allocation. The goal is to maximize the abundance of the population while minimizing the cost of resource allocation. After characterizing the optimal control in terms of the state population and the adjoint functions, we illustrate several scenarios numerically.

- **Speaker:** *Michael Kelly* (mikelly@transy.edu), Transylvania University, Lexington KY

  Title: Marine Reserves and Optimal Dynamic Harvesting When Fishing Damages Habitat

  Abstract: Marine fisheries are a significant source of protein for many human populations. In some locations, however, destructive fishing practices have negatively impacted the quality of fish habitat and reduced the habitat's ability to sustain fish stocks. Improving the management of stocks that can be potentially damaged by harvesting requires improved understanding of the spatiotemporal dynamics of the stocks, their habitats, and the behavior of the harvesters. We develop a mathematical model for both a fish stock as well as its habitat quality. Both are modeled using nonlinear, parabolic partial differential equations, and density-dependence in the growth rate of the fish stock depends upon habitat quality. The objective is to find the dynamic distribution of harvest effort that maximizes the discounted net present value of the coupled fishery-habitat system. The value derives both from extraction (and sale) of the stock and the provisioning of ecosystem services by the habitat. Optimal harvesting strategies are found numerically. The results suggest that no-take marine reserves can be an important part of the optimal strategy and that their spatiotemporal configuration depends both on the vulnerability of habitat to fishing damage and on the timescale of habitat recovery when fishing ceases.

- **Speaker:** *Tricia Phillips* (tphill30@vols.utk.edu), University of Tennessee

  Title: A Data-Driven Approach to Modeling the Heroin and Fentanyl Epidemic

  Abstract: A preliminary report will be given on the formulation and analysis of a heroin/fentanyl epidemic model. This model, consisting of a system of ordinary differential equations, aims to better understand the dynamics between prescription opioid use, prescription opioid addiction, heroin/fentanyl addiction, and recovery from opioid addiction.

Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Weerasena, Lakmali* (lakmali-weerasena@utc.edu), University of Tennessee, Chattanooga,

  Title: Combinatorial Optimization for Ecological Conservation

  Abstract: Conservation biologists and wildlife managers are challenged with designing protected area networks optimal for biodiversity conservation. Although protection of extensive wildlands with the full assemblage of native species in large population sizes is the ecologically prudent solution, such targets are unrealistic due to limitations in funds and other resources. Thus, the development of conservation prioritization models is imperative so that limited lands can be effectively used for biodiversity conservation. These prioritization models should ensure the long-term protection of species. In this study, we have developed an efficient bi-objective mathematical model to address this issue. We show that this model is a generalization to classical multi-objective set covering problem which is one of the representative NP-hard combinatorial optimization problems. We propose a novel algorithm to approximate the Pareto set of the proposed model. We analyzed the trade-off the objective functions and the performances of the algorithm using real and hypothetical test data.

- **Speaker:** *Christopher Strickland* (cstric12@utk.edu), University of Tennessee

  Title: Agent-based and Continuous Models of Locust Hopper Bands

Abstract: Presentation Abstract Locusts gather by the millions to feed on crops, destroying fields of agricultural produce. As juveniles, wingless locusts march together and form a variety of patterns including wave fronts. We examine this collective propagation through two models: an agent-based model and a set of partial differential equations. The agent-based model is directly linked to individual behavior with respect to resource availability and differs from previous such models in that direct locust-to-locust interactions are not involved. The PDE model yields insight into the collective, analytic behavior of the aggregate group. In this talk, I will introduce both models and some of the conclusions we have been able to draw in the context of data from the biological literature and parameter sensitivity analysis.

- **Speaker:** *Omar Saucedo* (osaucedo@vt.edu), Virginia Tech

  Title Human movement and vector-borne diseases

  Abstract: With travel becoming more frequent across the world, it is important to understand how spatial dynamics impact the spread of diseases. Human movement plays a key part on how a disease can be distributed as it enables a pathogen to invade a new environment and helps the persistence of a disease in locations that would otherwise be isolated. In this project, we explore how spatial heterogeneity combines with mobility network structure to influence vector-borne disease dynamics by using cellphone data from Namibia. In addition, we derived an approximation for the domain reproduction number for a n-patch SIR Ross-MacDonald model using a Laurent series expansion. Lastly, we will analyze the sensitivity equations with respect to the domain reproduction number to determine which parameters should be targeted for intervention strategies.

- **Speaker:** *Danielle Burton* (dburton3@vols.utk.edu), University of Tennessee

  Title: Optimal harvesting strategies in discrete population models

  Abstract: Management decisions regarding harvest are complicated and important. In the difference equation setting, many order of events cases have been studied. Hiromi Señor's proposed a model to study the timing of harvest between breeding seasons by taking a convex combination of the order of events cases reproduce-harvest and harvest-reproduce. We derive a new model that mechanistically incorporates harvest timing and share some preliminary numerical results.

Mathematical Modeling of Biological Systems

Organizers: *Lale Asik* (lale.asik@ttu.edu), Texas Tech University; *Annabel Meade* (aemeade@ncsu.edu), NC State University

Abstract
The scope of this special session covers many methods for modeling and analyzing biological systems. It shows how to use predictive mathematical models to acquire and analyze knowledge about ecological and epidemiological systems. It also provides a unique opportunity for researchers to present their recent results, to interact and exchange scientific ideas, and to collaborate in a productive and sustained way.

Part I of I (Sunday, 10:00–12:00):

- **Speaker:** *Annabel Meade* (aemeade@ncsu.edu), Center for Research in Scientific Computation, NC State University, Raleigh, NC, USA

  Title: Population model for the decline of *Homalodisca vitripennis* (Hemiptera: Cicadellidae) over a ten-year period

  Abstract: The glassy-winged sharpshooter, *Homalodisca vitripennis*, is an invasive pest which presents a major economic threat to the grape industries in California. We create a time and temperature-dependent mathematical model to analyze aggregate *H. vitripennis* population data from a 10-year study, during which *H. vitripennis* decreased significantly. Recently a common enemy of *H. vitripennis*, certain mymarid parasitoid species including *Cosmocomoidea ashmeadi* and *Cosmocomoidea morrilli*, have been studied to use in place of insecticides as a control method.

- **Speaker:** *Celia Schacht* (cmschach@ncsu.edu), Center for Research in Scientific Computation, NC State University, Raleigh, NC, USA

  Title: A Mathematical Model to Determine T-cell Behavior with Cancer Chimeric Antigen Receptor (CAR) Therapies

  Abstract: Many problems in mathematical biology deal with longitudinal, yet aggregate data. In order to understand better this type of data, we investigate it through an example in which aggregate data is used in relation with chimeric antigen receptor therapy, or CAR T therapy, which utilizes the body's immune system to fight cancer by genetically modifying T-cells to recognize cancerous cells. We investigate this type of therapy by modeling the flow of T-cells in the tumor, blood, and spleen of a cancerous body with a set of ordinary differential equations that utilize laws of mass balance. Different types of CAR T therapy have a different effect on antigen recognition, so we focus on the parameter which alters the flow of T-cells between the blood and tumor. Our goal is to fit our model to both aggregate and sparse data collected from mice at the Moffitt Cancer Center using iterative least-squares inverse problems and to inform future data collection using optimal design.

- **Speaker:** *Praachi Das* (pdas2@ncsu.edu), Department of Mathematics, NC State University, Raleigh, NC, USA

  Title: Pathogen Mutation in a Vector-borne Disease Model

  Abstract: Recent years have seen vector-borne viral diseases such as dengue, chikungunya, and Zika become rising sources of global public health concern. The worldwide incidence of dengue has been estimated to have doubled in the last 20 years, and chikungunya incidence has expanded to over 50 countries leading to millions of cases of the disease. Prior research has linked pathogen mutation and subsequent increase in transmission efficiency via a secondary vector, such as *Ae. albopictus*, as a significant contributing factor. This change in disease vector brings about the possible spread of infection to areas where the primary vector, *Ae. aegypti*, the population is either low or absent – a phenomenon which was previously less likely. The effects of pathogen mutation on the probability of disease emergence have previously been mathematically analyzed in a model which indicated that occasional mutation events could lead to the evolution of the original pathogen strain to have an $R_0 >$ the threshold value of 1. This could result in the successful emergence of disease even when the original pathogen is incapable of causing an outbreak. We implement this concept in creating a branching process theory-based mathematical model for vector-borne diseases investigating the influence of their two-step transmission cycle and pathogen mutation on the probability of disease emergence. This model is a step towards a better understanding of these dynamics of disease emergence with regard to pathogen evolution, and our results have the potential to influence preventative and control measures that are currently taken against mosquito-borne diseases.

- **Speaker:** *Lale Asik* (lale.asik@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX, USA

  Title: The Effects of Excess Food Nutrient Content on a Tri-trophic Food Chain Model in the Aquatic Ecosystem

  Abstract: Recent discoveries in ecological stoichiometry have indicated that food quality in terms of the phosphorus:carbon ratio affects predators whether the imbalance involves insufficient or excess nutrients. This phenomenon is called the "stoichiometric knife-edge." In this study, we develop and analyze a three-trophic-level food chain model that captures this phenomenon. The model tracks two essential elements, carbon, and phosphorus, in each species. We analyze the dynamics of the system, such as boundedness and positivity of the solutions, existence, and stability conditions of boundary and internal equilibria. Through numerical simulations and bifurcation analyses, we observe the switching of the dynamics of the system between periodic oscillations and chaos. Our findings also show that nutrient-rich food consumption causes (direct or indirect) adverse effects on species.

Advances in stable and robust machine learning: theory and practice

Organizers: *Joseph Daws Jr.* (jdaws@vols.utk.edu), The University of Tennessee, Knoxville

Abstract

Despite the impressive successes of neural networks and other models on difficult machine learning tasks, most models suffer from some well-documented struggles, especially when deployed on a large scale. For example, very deep networks are susceptible to adversarial attacks and overfitting. Such issues may be alleviated by conceptualizing stability and robustness for these models. This minisymposium reports on recent results which improve performance by addressing the stability and robustness of machine learning.

Part I of I (Sunday, 10:00–12:00):

- **Speaker:** *Nicholas Dexter* (nicholas_dexter@sfu.ca), Simon Frasier University,

  Title: High-dimensional function approximation with ReLU deep neural networks

  Abstract: Over the past decade, advances in software architectures and specialized hardware have enabled *machine learning* (ML) with *deep neural networks* (DNNs) to achieve impressive results on many historically challenging problems, e.g., image classification, autonomous vehicles, and speech recognition. Driving these successes is the modern ubiquity of large-scale data sets for training and feature detection, and methods for their processing and meta-data capture, a data-science paradigm referred to as *big data*. DNNs are also increasingly being applied to problems in the sciences, such as approximating solutions to *partial differential equations* (PDEs) defined on high-dimensional domains. Recent theoretical results on DNNs show that such architectures allow for the same approximation rates as best in class schemes such as "hp-adaptive" finite element and spectral approximations in norms relevant to PDE problems.

  However, despite these results, many open questions related to obtaining such approximations in practice remain. In this talk we present results on the application of a standard DNN architecture, namely the

fully-connected feedforward neural network with ReLU activation function $\sigma(x) = \max\{x, 0\}$, to the problem of finding an approximation to a function f, defined on a compact domain $\mathcal{U} \subset \mathbb{R}^d$, from a set $(x_i, f(x_i))_{i=1}^m$ of points and function values. We also present results on the existence of a DNN and training procedure which performs as well as *compressed sensing* (CS) for high-dimensional function approximation in terms of accuracy and sample complexity. Hence, to provide a comparison, we include results obtained with CS on the same problems. In particular, our results highlight key issues of stability in the training process and the amount of data required to obtain an approximation.

- **Speaker:** *Elizabeth Newman* (elizabeth.newman@emory.edu), Emory University,

  Title: Stable tensor neural networks (t-NNs): A matrix-mimetic, multidimensional framework for rapid deep learning

  Abstract: As data have become more complex to reflect multi-way relationships in the real world, new techniques have become essential to reveal latent content. In this talk, we will merge two popular methods to uncover these complex relationships in data: neural networks which reveal nonlinear relationships and tensors which exploit high-dimensional correlations. Hence, we call our framework a tensor neural network (t-NN).

  The foundation of our t-NNs is a matrix-mimetic multidimensional algebra based on the $*_M$-product. In this talk, we will briefly outline this family of tensor-tensor products and describe the parametric advantages of designing neural networks in this high-dimensional space. In the remainder of the talk, we will describe differential-equations-inspired neural network architectures which give rise to a notion of network stability. The matrix-mimeticity of our t-NN algebra enables us to extend this notion of stability to higher dimensions and exploit the parametric advantages of working in a tensor algebra. We will conclude with some preliminary numerical experiments to illustrate the advantages of using t-NNs over equivalent matrix-based designs.

- **Speaker:** *Armenak Petrosyan* (Speaker1Email), Oak Ridge National Lab,

  Title: Neural network integral representations on the sphere for the ReLU activation function.

  Abstract: We present neural network integral representations as a generalization of shallow artificial neural networks. For the ReLU activation function, we derive an explicit reconstruction formula on the unit sphere under finite L_1 norm assumption on the outer weights. We further extend our theory to deep networks by introducing ResNet type integral representations.

- **Speaker:** *Vahan Huroyan* (vahanhuroyan@math.arizona.edu), The University of Arizona,

  Title: Distributed Robust Subspace Recovery

  Abstract: We propose an iterative algorithm together with its theoretical analysis for the multi-way matching problem. The input of the multi- way matching problem includes multiple sets, with the same number of objects and noisy measurements of fixed one-to-one correspondence maps between the objects of each pair of sets. Given only noisy measurements of the mutual correspondences, the multi-way matching problem asks to recover the correspondence maps between pairs of them. The desired output includes the original fixed correspondence maps between all pairs of sets. Our proposed algorithm iteratively solves a non-convex optimization formulation for the multi-way match- ing problem. We prove that for specific noise model, if the initial point of our proposed iterative algorithm is good enough, the algorithm linearly converges to the unique solution. Furthermore, we show how to find such an initial point. Numerical experiments demonstrate that our method is much faster and more accurate than the state-of-the-art methods.

Recent advances of modeling and computational methods for multiphase problems

Organizers: *Jia Zhao* (jia.zhao@usu.edu), Utah State University; *Xiaofeng Yang* (xfyang@math.sc.edu), University of South Carolina at Columbia

Abstract
Multiphase problems arise in a wide range of computational science and engineering applications. They are ubiquitous in the universe. How to develop thermodynamically consistent description of the multiphase phenomena and How to develop appropriate numerical strategies and computational methods to efficiently solve the multiphase problems are pressing issues in the research community. In this mini-symposium, experts in modeling and computation are invited to share their recent advances in studying multiphase problems and relevant applications. It serves as a platform for advancing modeling and numerical strategies in the related field.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Steven Wise* (swise1@utk.edu), The University of Tennessee,

  Title: Some Benchmark Computations for the Functionalized Cahn-Hilliard Equation

  Abstract: In this talk, I will give some computational results using a variety of time-stepping schemes and solvers to approximate solutions to the Functionalized Cahn-Hilliard Equation, a challenging nonlinear and sixth-order parabolic PDE modeling membrane dynamics. We compare linear IMEX, energy stable, BDF2, Backward Euler, and SAV-type schemes on some benchmark tests. The early results are interesting. There has been an explosion of papers on energy stable and linearized schemes. Most people think energy stable is *always* better, and linear energy stable is even better still. But are these methods the most efficient when a predetermined accuracy is wanted? Who's gonna win? Come out and see.

- **Speaker:** *Pengtao Yue* (ptyue@vt.edu), Virginia Tech,

  Title: Thermodynamically consistent phase-field modeling of contact angle hysteresis

  Abstract: In the phase-field description of moving contact line problems, the two-phase system can be described by free energies, and the constitutive relations can be derived based on the the second law of thermodynamics. In this talk, we will introduce a novel boundary condition for contact-angle hysteresis by exploiting wall energy relaxation, which allows the system to be in non-equilibrium at the contact line. This method captures pinning, advancing, and receding automatically without the explicit knowledge of contact-line velocity and contact angle. The microscopic dynamic contact angle is computed as part of the solution instead of being imposed. Furthermore, the formulation satisfies a dissipative energy law, where the dissipation terms all have their physical origins. Based on this energy law, we develop a finite-element discretization that is at least unconditionally energy-stable for matched density and zero hysteresis. In the end, we will provide some numerical results including benchmarks.

- **Speaker:** *Yukun Li* (Yukun.Li@ucf.edu), University of Central Florida,

  Title: Some algorithms for the mean curvature flow under topological changes

  Abstract: The mean curvature flow has broad applications in a few scientific and engineering areas, and the topological changes are the most usual scenarios, such as the process of cell fusion and division, the process of alloy coarsening and separation, and so on. The level set formulations of the mean curvature flow and most geometric flows are fully nonlinear partial differential equations. To avoid solving the fully nonlinear partial differential equations with low regularity, we use the energy minimization

approach to solve the mean curvature flow with topological changes. We propose an energy penalized minimization algorithm and a multilevel minimization algorithm, and we apply these methods to the benchmark problems we constructed and many random problems. We verify that these algorithms are capable of handling topological changes of the mean curvature flow very well. The energy minimization approach in this paper might be similarly extended to the computation of other geometric flows, i.e., the Hele Shaw flow, multiphase flows, and many coupled flows of the mean curvature flow/Hele Shaw flow and fluid flows.

- **Speaker:** *Xiaofeng Yang* (xfyang@math.sc.edu), University of South Carolina,

  Title: Efficient schemes with unconditionally energy stabilities for anisotropic phase field models

  Abstract: We consider numerical approximations for anisotropic phase field models, by taking the anisotropic Cahn-Hilliard/Allen-Cahn equations with their applications to the faceted pyramids on nanoscale crystal surfaces and the dendritic crystal growth problems, as special examples. The main challenge of constructing numerical schemes with unconditional energy stabilities for these type of models is how to design proper temporal discretizations for the nonlinear terms with the strong anisotropy. We combine the recently developed IEQ/SAV approach with the stabilization technique, where some linear stabilization terms are added, which are shown to be crucial to remove the oscillations caused by the anisotropic coefficients, numerically. The novelty of the proposed schemes is that all nonlinear terms can be treated semi-explicitly, and one only needs to solve some coupled/decoupled, but linear equations at each time step. We further prove the unconditional energy stabilities rigorously, and present various 2D and 3D numerical simulations to demonstrate the stability and accuracy.

Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Yi Zhang* (y_zhang7@uncg.edu), University of North Carolina at Greensboro,

  Title: Mixed finite element methods for a stochastic Cahn-Hilliard equation

  Abstract: We propose a fully discrete finite element method for the stochastic Cahn-Hilliard equation with gradient-type multiplicative noises. Strong convergence with rates will be discussed. Numerical experiments are also provided to illustrate the performance of the method. This is joint work with Xiaobing Feng and Yukun Li.

- **Speaker:** *Xiangcheng Zheng* (xz3@email.sc.edu), University of South Carolina,

  Title: An optimal-order error estimate of the lowest-order ELLAM-MFEM approximation to miscible displacement in three space dimensions

  Abstract: An optimal-order error estimate for the lowest-order ELLAM-MFEM time stepping procedure for the coupled system of time-dependent nonlinear partial differential equations modeling miscible displacement that moves through the three-dimensional subsurface porous media is proved, under a practically reasonable time-step constraint of Delta t = O(h). In the procedure, the Eulerian-Lagrangian localized adjoint method (ELLAM) and the mixed finite element method (MFEM) are used to solve the transport equation and the pressure equation, respectively. This mathematically justi es the numerical advantages of the ELLAM-MFEM solution procedure.

- **Speaker:** *Jiaqi Zhang* (zjiaqi@vt.edu), Virginia Tech,

  Title: A level-set method for moving contact line problems with comparison to phase-field simulations

  Abstract: We will present an efficient method to implement contact angle hysteresis in the level-set framework. The stress singularity is alleviated by Ren and E's (2007) version of generalized Navier boundary condition (GNBC), which is further modified to account for contact angle hysteresis. The

modified GNBC automatically captures the different states of the contact line, i.e., advancing, receding, and stationary, and the contact line is evolved naturally by the flow field. There is no need to solve extra equations or switch to a no-slip boundary condition to keep the contact line immobile. Numerical results of our method agree well with experimental and theoretical results. Since Ren and E's GNBC is very similar to the original GNBC (Qian et al., 2003) for the phase-field method, we will also show comparisons between the level-set and phase-field methods in terms of formulations and computations.

- **Speaker:** *Jia Zhao* (jia.zhao@usu.edu), Utah State University,

  Title: Arbitrarily High-order Unconditionally Energy Stable Schemes for Thermodynamically Consistent Gradient Flow Models

  Abstract: We present a systematical approach to developing arbitrarily high order, unconditionally energy stable numerical schemes for thermodynamically consistent gradient flow models that satisfy energy dissipation laws. Utilizing the energy quadratization (EQ) method, We formulate the gradient flow model into an equivalent form with a corresponding quadratic free energy functional. Based on the equivalent form with a quadratic energy, we adopt the Gaussian collocation method to discretize the equivalent form with a quadratic energy, arriving at an arbitrarily high-order scheme for gradient flow models. Schemes derived using both approaches are proved rigorously to be unconditionally energy stable. Numerical results will be shown to illustrate their accuracy and effectiveness.

Data-driven and machine learning approaches for applications

Organizers: *Viktor Reshniak* (reshniakv@ornl.gov), Oak Ridge National Laboratory; *Rick Archibald* (archibaldrk@ornl.gov), Oak Ridge National Laboratory; *Jae-Hun Jung* (jaehun@buffalo.edu), SUNY Buffalo

Abstract
A growing amount of available data in recent years has accelerated the efforts of a research community in an attempt to incorporate this knowledge into scientific and engineering models. This naturally presents new challenges in both theoretical description and practical implementation of such data-driven models. The goal of this mini-symposium is to provide a platform for the discussion between theoretical and applied researchers which can help to narrow the gap between theory and practice.

Part I of II (Saturday, 10:30–12:30):

- **Speaker:** *Gregery T Buzzard* (buzzard@purdue.edu), Purdue University,

  Title: Multi-Agent Consensus Equilibrium (MACE) and Imaging Applications

  Abstract: The Plug-&-Play method was introduced as a way to use advanced non-parametric denoising algorithms such as BM3D and CNNs as prior models in inverse problems and has found many applications since then. In this talk, I'll describe a generalization of P&P called Multi-Agent Consensus Equilibrium (MACE). MACE addresses two limitations of P&P. First, it allows for the introduction of multiple prior or data terms or agents. These agents may, for example, represent multiple uncertain priors, or multiple uncertain data models. Second, MACE defines regularized inversion in terms of balance equations rather than optimization. This allows for a much more general framework of well-defined

inverse operators with potentially superior performance. I'll describe the MACE framework and give several example uses, including ways of integrating physical modeling with neural networks. This is joint work with Charlie Bouman, Stanley Chan, and several of our graduate students.

- **Speaker:** ***Amir Koushyar Ziabari****, Singanallur Venkatakrishnan, Michael Kirka, Ryan Dehoff, Philip Bingham, and Vincent Paquit* (ziabariak@ornl.gov), ORNL,

  Title: AI-based X-Ray CT Reconstruction for Metal Additive Manufacturing

  Abstract: Non-destructive evaluation (NDE) of additively manufactured (AM) parts is important to understand the impact of various process parameters and qualifying the final quality of the built part. X-ray computed tomography (XCT) has played a critical role for rapid NDE and characterization of additively manufactured (AM) parts. Long scan times, metal artifacts, noisy reconstruction in analytical methods and low speed of high-quality iterative reconstruction methods, are the key challenges limiting XCT for rapid inspection of a large number of parts that may be manufactured on a given day. Here, we present a novel AI-based algorithm to rapidly obtain high-quality XCT reconstructions of AM parts. We discuss how using the CAD models further enhances our X-ray CT reconstruction technique beyond the state-of-the-art.

- **Speaker:** *Liang Ding,* ***Simon Mak****, C. F. Jeff Wu* (simontszfung.mak@duke.edu), Duke University,

  Title: BdryGP: a new Gaussian process model for incorporating boundary information

  Abstract: Gaussian processes (GPs) are widely used as surrogate models for emulating computer code, which simulate complex physical phenomena. In many problems, additional boundary information (i.e., the behavior of the phenomena along input boundaries) is known beforehand, either from governing physics or scientific knowledge. While there has been recent work on incorporating boundary information within GPs, such models do not provide theoretical insights on improved convergence rates. To this end, we propose a new GP model, called BdryGP, for incorporating boundary information. We show that BdryGP not only has improved convergence rates over existing GP models (which do not incorporate boundaries), but is also more resistant to the "curse-of-dimensionality" in nonparametric regression. Our proofs make use of a novel connection between GP interpolation and finite-element modeling.

- **Speaker:** ***Farzana Nasrin****, Cassie P. Micucci and Vasileios Maroulas* (fnasrin@utk.edu), UTK,

  Title: Bayesian Learning via Topology for Filament Network Classification

  Abstract: For cells of living organisms, active transportation of ingredients is vital. Defects in this transportation have been linked to various disorders. A crucial step to investigate the biophysical mechanisms that are responsible for this transpiration in cells is to accurately classify possible mechanisms underlying intracellular transport. This work focuses on classifying filament networks via topology by simply relying on their features such as the empty space and connectedness. Persistent homology is a tool for learning about the geometrical/topological structures by detecting different dimensional hole and storing their appearance disappearance scales in persistence diagrams. We propose a Bayesian framework that adopts independent and identically distributed cluster point process characterization of persistence diagrams. This framework provides flexibility to estimate simultaneously the posterior cardinality and intensity by utilizing this general point process and by adopting techniques from the theory of marked point processes. We present a closed form of the posterior intensity and cardinality under the assumption of conjugate families of Gaussian mixtures and binomials. Based on this form, we apply an effective Bayes factor classification algorithm on filament networks data of plant cells.

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Part II of II (Saturday, 15:30–17:30):

- **Speaker:** *Ben Whitney* (whitneybe@ornl.gov), ORNL,

  Title: MultiGrid Adaptive Reduction of Data on Unstructured Grids

  Abstract: We present a mathematical framework that enables the adaptive compression of scientific field data while controlling the loss as measured in a variety of norms. The technique is used to ensure that user-supplied quantities of interest are preserved to within a user-prescribed tolerance. The compression algorithms are based on a stable decomposition we call the multilevel splitting. We introduce this splitting and give efficient algorithms for its computation on both structured tensor product grids and general unstructured meshes. In addition to the theory underlying the method we discuss recent work towards integration of the package, called MGARD, into the I/O system ADIOS and a number of example applications.

- **Speaker:** ***Qiang Wu*** (qiang.wu@mtsu.edu), Middle Tennessee State University,

  Title: Learning with Information Theoretic Criteria

  Abstract: Learning with information theoretic criteria, namely, the maximum correntropy criterion (MCC) and the minimum error entropy (MEE), has been shown successful in a variety of applications. It is particularly powerful to handle data contaminated by outliers or heavy tailed noises. To theoretically justify the effectiveness of these two information theoretic criteria, we studied the consistency of MCC and MEE based machine learning algorithms. We showed that, with appropriate parameter selection strategies, these algorithms can effectively learn both mean regression function and modal regression function. We also proved some no-free-lunch theorems which indicate that, in some scenarios, there must be some sacrifice of information contained in the data in order to achieve high prediction accuracy.

- **Speaker:** *He Yang* (hyang1@augusta.edu), Augusta University,

  Title: A Deep Learning Method for Inverse Scattering Problem

  Abstract: In this talk, we will present a deep learning method for solving the inverse scattering problem with far-field data. The method can be used to construct a fitting ball that covers the unknown scatterer. Numerical results show that our proposed method can solve the problem efficiently without the knowledge of the noise level in the far-field data. This is joint work with Dr. Jun Liu.

- **Speaker:** ***Jae-Hun Jung****, Dongjin Lee and Christopher Bresten* (jaehun@buffalo.edu), Ajou University and SUNY Buffalo,

  Title: Topological data analysis and convolutional neural network for the time-series data analysis

  Abstract: Detection of anomalous patterns or the existence of significant signals in time-series data is an important application. In this talk, we propose to concatenate topological data analysis (TDA) and convolutional neural networks (CNN) to improve the signal detection problem performed by CNN analysis only. The applications include Earth polar motion data and gradational wave data.

Modeling and Surrogate Modeling Techniques Based on Structured and Random Approaches

Organizers: *Miroslav Stoyanov* (stoyanovmk@ornl.gov), Oak Ridge National Laboratory

Abstract
The computational complexity of problem in modern science and engineering presents unprecedented challenges to modeling in terms of preserving accuracy and fidelity while reducing the computational cost. Whether using a discretization scheme to a model described by partial differential equations or using a surrogate model to reduce the complexity of an existing (discrete) approximation, efficient methods often have to rely on combinations of structured (interpolatory) grids and random sampling.

Part I of I (Sunday, 10:00–12:00):

- **Speaker:** *Hans-Werner van Wyk* (hzv0008@auburn.edu), Auburn University,

  Title: Hybrid sampling methods for Partial Differential Equations with Multiscale Uncertain Coefficients

  Abstract: The viability of efficient interpolatory sampling methods, used to approximate statistical quantities of interest related to uncertain physical systems, is limited by the complexity of the underlying parameter space. Monte Carlo sampling methods on the other hand, while less efficient, have an accuracy that depends only on the sampled quantity's variance. In this talk, we combine these two sampling methods in a complementary way, by splitting the parameter space into a low-complexity/high-variance component that can be resolved by means of interpolatory surrogates, and a high-complexity/low-variance part for which Monte Carlo sampling is well-suited. We show how this hybrid method reduces the overall computational cost and demonstrate its features with the help of a few computational experiments.

- **Speaker:** *Yangwen Zhang* (ywzhangf@udel.edu), University of Delaware,

  Title: Interpolatory HDG methods for nonlinear PDEs.

  Abstract: In this work, we propose a new Interpolatory hybridizable discontinuous Galerkin (Interpolatory HDG) method for some nonlinear PDEs. We adopt ideas from the Interpolatory finite element method and extend to the HDG method. The resulting Interpolatory HDG method is applicable for more general nonlinear PDEs, and we obtained optimal convergence rates. However, we lost the superconvergence after an element-by-element processing. We present recent work to recover the superconvergence.

- **Speaker:** *Jared Cook* (jacook8@ncsu.edu), North Carolina State University,

  Title: Radiation Source Localization Using Surrogate Models for 3-D Monte Carlo Transport Physics Simulations

  Abstract: Locating special nuclear materials (SNM) in a 3-D urban environment is of critical importance and presents significant computational challenges. High-fidelity radiation transport simulations, such as Monte Carlo N-Particle (MCNP), provide a reasonable prediction of what one would expect in a real world scenario. Since MCNP is computationally expensive, we construct surrogate models to emulate the high-fidelity response. The surrogate models provide an efficient framework for performing Bayesian inference using Markov Chain Monte Carlo (MCMC) methods. We estimate the posterior distribution of the source location and intensity using this MCMC approach.

- **Speaker:** *Miroslav Stoyanov* (stoyanovmk@ornl.gov), Oak Ridge National Laboratory,

  Title: Adaptive Interpolation Method for Periodic Functions with Finite Differentiability

  Abstract: We consider adaptive sparse grid interpolation applied to periodic functions, the motivating application is molecular potential energy surfaces models where the inputs describe angles between atoms and hence the response is periodic to the (unknown) degree of differentiability. Approximation uses a basis of trigonometric polynomials which preserves periodicity. The effectiveness of the

method in high dimension depends on identifying the optimal combination of polynomial powers, i.e., the polynomials with dominant coefficients. The coefficients are computed from a multidimensional fast-Fourier-transform, and the decay rate is inferred from a fit to a quasi-optimal estimate for the best approximation space.

Analysis and Applications of Fractional PDEs and Nonlocal Operators

Organizers: *Tadele Mengesha* (mengesha@utk.edu), University of Tennessee Knoxville; *Pablo Seleson* (selesonpd@ornl.gov), Oak Ridge National Laboratory; *Mitchell Sutton* (msutto11@vols.utk.edu), University of Tennessee Knoxville

Abstract
The mini-symposium for Analysis and Applications of Fractional PDEs and Nonlocal Operators will give researchers and students a glimpse into the world of fractional and nonlocal operators, constitutive models, governing equations, and numerical methods. With topics ranging from fractional calculus to applications in materials science and image processing, this series of presentations will give attendees a wide perspective of current developments in fractional PDEs and nonlocal operators.

Part I of III (Saturday, 10:30–12:30):

- **Speaker:** *Kylie Berry* (kberry@daltonstate.edu), Dalton State College

  Title: A Look at the Morphing Method to Blending Classical Elasticity and Peridynamics

  Abstract: In this talk, I will discuss a particular energy-based blended model. This model was proposed in 2012 and is known in the existing literature as the ?morphing framework?[1]. It was proposed as a way to model material behavior and deformation under forces, that could capture discontinuous deformations accurately while remaining computationally cost effective. By looking through the lens of differential equations and functional analysis, properties analogous to ones that are well-known for the Laplace equation are established which ultimately enable us to prove well-posedness of the considered problem. This, further allows us to solve the problem using the finite element method. The convergence rate of the finite element solution to the true solution is explored in the case of smooth solutions. These rates are compared with the classical and peridynamic convergence rates.

  Additionally, I will present some analysis that shows that the size of this ghost force is dependent on the smoothness of the blending function and the ratio of the length of the blending region to the material horizon, δ.

  [1] G. Lubineau, Y. Azdoud, F. Han, Ch. Rey and A. Askari (2012). A morphing strategy to couple non-local to local continuum mechanics. Journal of Mechanics and Physics of Solids, v. 60(6), pp. 1088-1102.

- **Speaker:** *James Scott* (jscott66@vols.utk.edu), University of Tennessee Knoxville

  Title: New Characterizations of Sobolev and Potential Spaces

  Abstract: We show that a class of spaces of vector fields whose semi-norms involve the magnitude of ?directional? difference quotients is in fact equivalent to the class of fractional Sobolev spaces. The

equivalence can be considered a Korn-type characterization of fractional Sobolev spaces. We additionally show that the class of vector-valued Bessel potential spaces can be characterized by a Marcinkiewicz-type integral that is ? pointwise ? smaller than the classical Marcinkiewicz integral, and does not resemble other classes of potential-type integrals found in the literature. In applications, these results are used to better understand spaces of vector fields associated to a strongly coupled system of nonlocal equations related to a continuum model of peridynamics. This talk is comprised of joint work with Tadele Mengesha.

- **Speaker:** *Tadele Mengesha* (mengesha@utk.edu), University of Tennessee Knoxville

  Title: Solvability of a System of Nonlocal Equations Related to Peridynamics

  Abstract: I will present recent results on solvability of a system of equations that is used in a nonlocal model in mechanics. The nonlocal model is made up of a strongly coupled system of integral equations and is a nonlocal analogue of the Navier-Lame? system of classical elasticity. We will discuss the well-posedness of the system as well as demonstrate optimal local Sobolev regularity of solutions. Connections between the associated nonlocal energy spaces and corresponding classical function spaces will be established. Conditions that imply compact embedding of these spaces in classical spaces will be given. This is a joint work with Jimmy Scott.

- **Speaker:** *Pablo Seleson* (selesonpd@ornl.gov), Oak Ridge National Laboratory

  Title: Modeling Material Anisotropy in Bond-Based Peridynamics

  Abstract: The peridynamic theory of solid mechanics is a nonlocal reformulation of classical continuum mechanics suitable for material failure and damage simulation. As opposed to the classical theory, constitutive models in peridynamics do not require spatial differentiability of displacements, which allows for a natural representation of material discontinuities, such as cracks. Applications in peridynamics to date cover a wide range of engineering problems; however, the majority of those applications employ isotropic material models. In this presentation, we will present a framework for modeling anisotropic media in bond-based peridynamics. The framework is able to accommodate any of the symmetry classes in classical linear elasticity. We will discuss modeling restrictions and specializations to two-dimensional problems.

Part II of III (Saturday, 15:30–17:30):

- **Speaker:** *Marco Pasetto* (mpasetto@eng.ucsd.edu), Oak Ridge National Laboratory

  Title: A Reproducing Kernel Enhanced Approach for Peridynamic Solutions

  Abstract: The most common discretization method for peridynamic models used in engineering problems is the node-based meshfree approach. This method discretizes peridynamic domains by a set of nodes, each associated with a nodal cell with a characteristic volume, leading to a particle-based description of continuum systems. The behavior of each particle is then considered representative of its cell. This limits the convergence rate to the first order. In this work we introduce a reproducing kernel (RK) approximation to the field variables in the peridynamic equations to increase the order of convergence of peridynamic numerical solutions. The numerical results demonstrate improved convergence rates in linear peridynamic problems using the proposed method.

- **Speaker:** *Viktor Reshniak* (reshniakv@ornl.gov), Oak Ridge National Laboratory

  Title: A Nonlocal Feature Driven Exemplar-Based Image Inpainting

  Abstract: We present a nonlocal variational image completion technique which admits simultaneous inpainting of multiple structures and textures in a unified framework. The recovery of geometric structures

is achieved by using general convolution operators as a measure of behavior within an image. These are combined with a nonlocal exemplar-based approach to exploit self-similarity of an image in the selected feature domains and to ensure the inpainting of textures. We also introduce an anisotropic patch distance metric to allow for better control of the feature selection within an image and present a nonlocal energy functional based on this metric. Finally, we derive an optimization algorithm for the proposed variational model and examine its validity experimentally with various test images.

- **Speaker:** *Diego Del-Castillo-Negrete* (delcastillod@ornl.gov), Oak Ridge National Laboratory,

  Title: Nonlocal Transport in Fluid and Plasma Physics Systems

  Abstract: Understanding transport is critical to many arears of science and engineering. Problems of particular interest to this presentation include transport in fluids in the presence of coherent structures and transport in high temperature plasmas in controlled nuclear fusion. We will discuss experimental, theoretical, and numerical evidence indicating that in these systems local (diffusive) transport models might not be applicable in some regimens. We will also present a class of non-local models to describe the observed non-diffusive transport.

- **Speaker:** *Olena Burkovska* (burkovska@fsu.edu), Oak Ridge National Laboratory,

  Title: On the Phase Separation in a Nonlocal Cahn-Hilliard Variational Inequality

  Abstract: We consider a nonlocal Cahn-Hilliard model with a double-well obstacle potential on a bounded domain, which is motivated by the problem of phase separation in copolymer melts. We consider the case when both local and nonlocal operators appear in the model and are complemented with nonlocal boundary flux conditions, which are analogous to the local Neumann boundary conditions. We analyze structural properties of the solution and derive suitable discretization techniques. In contrast to the local Cahn-Hilliard problem, which always leads to a diffuse interface, the proposed nonlocal model can lead to a strict separation into pure phases of the substance for nontrivial interactions. Concretely, we show that a sharp interface can already occur for a certain critical (non-zero) value of the interface parameter. Here, the choice of the obstacle potential plays an important role in our analysis, since it guarantees the strict separation into pure phases. Mathematically, we pose the problem as a coupled system involving a set of parabolic variational inequalities, which at each time instance can be restated as a constrained optimization problem. We provide preliminary numerical experiments to verify our theoretical results and to conduct a comparative study of the nonlocal problem and its local counterpart. This talk is comprised of joint work with Max Gunzburger.

Part III of III (Sunday, 10:00–12:00):

- **Speaker:** *John Paul Roop* (jproop@ncat.edu), North Carolina A&T State University

  Title: Discretization of Fractional Boundary Value Problems Using Split Operator Local Extension Problems

  Abstract: Partial differential equations which include nonlocal operators have recently become a major focus of mathematical and computational research. The efficient computational implementation of a nonlocal operator remains an important question. In this talk, we review some of the developments in the numerical analysis of fractional PDE. We introduce an operator splitting approach to the discretization of nonlocal boundary value problems. It has been shown that the fractional Laplacian in $\mathbb{R}^d$ is identical to equivalent local extension problem in $\mathbb{R}^{d+1}$ with a nonlinear Neumann boundary condition. Computational experiments are presented using finite differences and meshless methods.

- **Speaker:** *Vincent J. Ervin* (vjervin@clemson.edu), Clemson University

  Title: Regularity of the Solution to Fractional Diffusion, Advection, Reaction Equations on a Bounded Interval in $\mathbb{R}^1$

  Abstract: The regularity of the solution to a differential equation plays an important role in constructing optimal approximation schemes to the equation. Of interest in this presentation is the regularity of the solution to the fractional diffusion, advection, reaction equation:

$$-D\left(rD^{-(2-\alpha)} + (1-r)D^{-(2-\alpha)*}\right)Du(x) + b(x)Du(x) + c(x)u(x) = f(x)\,, \quad x \in (0,1)\,, \tag{1}$$

$$\text{subject to } u(0) = u(1) = 0\,, \tag{2}$$

where $1 < \alpha < 2$, and $0 \leq r \leq 1$.

Equations (1),(2), with $r = 1/2$, $b(x) = c(x) = 0$ represents the fractional Laplace equation. Recently regularity results and an optimal order finite element approximation scheme for the fractional Laplace equation were given by Acosta and Borthagaray [1]. This work was extended to the fractional Laplace equation with convection and reaction terms by Hao and Zhang in [2], where they also presented an optimal order spectral approximation scheme.

In this presentation we discuss generalizations of [1] and [2] to (1),(2).

  [1] G. Acosta and J.P. Borthagaray. A fractional Laplace equation: Regularity of solutions and finite element approximations. SIAM J. Numer. Anal., 55(2):472–495, 2017.

  [2] Z. Hao and Z. Zhang. Optimal regularity and error estimates of a spectral Galerkin method for fractional advection-diffusion-reaction equations. Preprint 2018.

- **Speaker:** *Mitchell Sutton* (msutto11@vols.utk.edu), University of Tennessee Knoxville,

  Title: A New Theory of Fractional Differential Calculus and Fractional Sobolev Spaces

  Abstract: In this talk I shall present a new theory of weak fractional differential calculus and fractional Sobolev spaces. The crux of this new theory is the introduction of a weak fractional derivative concept which is a natural generalization of integer order weak derivatives, it also helps to unify multiple existing fractional derivative concepts. Various calculus rules including a fundamental theorem of calculus are established and connections to existing fractional derivatives are also obtained. Based on the weak fractional derivative concept, new fractional order Sobolev spaces will be introduced and many important properties, such as density theorem, extension theorem and trace theorem, of those Sobolev spaces will be established. Moreover, relationships with existing fractional Sobolev spaces will be discussed. This is a joint work with Xiaobing Feng of the University of Tennessee at Knoxville.

Innovations and implementations of numerical methods for time dependent problems

Organizers: *Zachary Grant* (grantzj@ornl.gov), Oak Ridge National Laboratory; *Hoang Tran* (tranha@ornl.gov), Oak Ridge National Laboratory

Abstract
This mini-symposium focuses on recent advances in the numerical treatment of differential equations with applications to PDEs and stochastic models. This class of problems include conservation laws, reaction-diffusion problems, and stochastic oscillators, among others. Special emphasis is placed on the design and analysis of accurate and optimized numerical methods, as well as their efficient implementations. The mini-symposium also aims at promoting and enhancing collaborations between researchers with interest in the above-mentioned topics.

Part I of II (Saturday, 15:30–17:30):

- **Speaker:** *Zachary J. Grant* (grantzj@ornl.gov), Oak Ridge National Laboratory,

  Title:Implicit and Explicit Parallel Error Inhibiting Schemes

  Abstract: It is well known that classic time stepping methods globally lose one order of accuracy in comparison to its local truncation error due to an accumulation of the errors over time. However it was shown in the work by Gottlieb and Ditkowski that by using a block multi-step approach with carefully chosen coefficients it is possible to impact the interaction between the local truncation errors of the varying schemes and so inhibit the growth of the global error. These methods are known as Error Inhibiting Schemes (EIS). This strategy allows one to achieve higher orders of accuracy than one would originally expect, and suggests a new approach to create high order methods. In this work we extend the EIS formulation to explicit and implicit methods which have global errors two orders of accuracy higher than their local truncation errors. We then use this theoretical understanding to construct new methods of varying orders that also enjoy many desirable properties such as A-stability, L-stability, and low cost error estimators.

- **Speaker:** *Oyekola Oyekole* (ooyekole@nd.edu), University of Notre Dame,

  Title:Second-order, loosely coupled methods for fluid-poroelastic material interaction

  Abstract: This work focuses on modeling the interaction between an incompressible, viscous fluid and a poroviscoelastic material. The fluid flow is described using the time-dependent Stokes equations, and the poroelastic material using the Biot model. The viscoelasticity is incorporated in the equations using a linear Kelvin-Voigt model. We introduce two novel, non-iterative, partitioned numerical schemes for the coupled problem. The first method uses the second-order backward differentiation formula (BDF2) for implicit integration, while treating the interface terms explicitly using a second-order extrapolation formula. The second method is the Crank-Nicolson and Leap-Frog (CNLF) method, where the Crank-Nicolson method is used to implicitly advance the solution in time, while the coupling terms are explicitly approximated by the Leap-Frog integration. We show that the BDF2 method is unconditionally stable and uniformly stable in time, while the CNLF method is stable under a CFL condition. Both schemes are validated using numerical simulations. Second-order convergence in time is observed for both methods. Simulations over a longer period of time show that the errors in the solution remain bounded. Cases when the structure is poroviscoelastic and poroelastic are included in numerical examples. This is joint work with Martina Bukac.

- **Speaker:** *Vu Thai Luan* (luan@math.msstate.edu), Mississippi State University,

  Title: New class of high-order methods for multi-rate differential equations

Abstract: In this talk, we derive a new class of high-order accurate methods for multirate time integration of systems of ordinary differential equations. More precisely, starting from an explicit exponential Runge?Kutta method of the appropriate form, we derive a multirate algorithm to approximate the action of the matrix exponential through the definition of modified 'fast' initial-value problems. These fast problems may be solved using any viable solver, enabling multirate simulations through use of a subcycled method. Due to this structure, we name these as Multirate Exponential Runge?Kutta (MERK) methods. In addition to showing how MERK methods may be derived, we provide rigorous convergence analysis, showing that for an overall method of order p, the fast problems corresponding to internal stages may be solved using a method of order p?1, while the final fast problem corresponding to the time-evolved solution must use a method of order p. Numerical simulations are then provided to demonstrate the convergence and efficiency of MERK methods with orders three through five on a series of multirate test problems. This is a joint work with D. R. Reynolds and R. Chinomona.

- **Speaker:** *Mathew Norman* (normanmr@ornl.gov), Oak Ridge National Laboratory,

  Title: Numerical Techniques for Atmospheric Modeling on Accelerators

  Abstract: Modern parallel computing architectures favor accelerator devices such as GPUs because they provide increased computational capability with reduced power requirements compared to more traditional CPUs. Accelerators are at their core vector machines that rely heavily on thread switching, latency hiding, and reduced local cache and register capacities compared to CPU architectures. Because of this, we need new algorithms that reduce data movement and increase the local computations done on data once it is fetched from memory. This talk covers a range of algorithmic choices that simultaneously improve computational efficiency, accuracy, and robustness for atmospheric modeling. This includes both spatial and temporal operators, and choices are unique to the challenges of atmospheric modeling.

Part II of II (Sunday, 10:00–12:00):

- **Speaker:** *Changhui Tan* (tan@math.sc.edu), University of South Carolina,

  Title: Asymptotic preserving schemes on kinetic models with singular limits

  Abstract: In this talk, I will discuss a class of kinetic models with mono-kinetic hydrodynamic limits. Due to the singular limit, standard asymptotic-preserving (AP) schemes lose accuracy when the parameter is close to the limit. To overcome such difficulty, we introduce a velocity scaling method that transforms the singular limit to a non-singular one, and build AP schemes on the transformed systems. As an example, I will present kinetic swarming models and the corresponding AP schemes based on velocity scaling. This is a joint work with Alina Chertock and Bokai Yan.

- **Speaker:** *Victor DeCaria* (decariavp@ornl.gov), Oak Ridge National Laboratory,

  Title: Variable stepsize, variable order methods for PDEs

  Abstract: Variable stepsize, variable order (VSVO) methods are the methods of choice to efficiently solve a wide range of ODEs with minimal work and assured accuracy. However, VSVO methods have limited impact in complex applications due to their computational complexity and the difficulty to implement them in legacy code. We address the computational complexity with cheap post-processing techniques to produce solutions of different orders. These new methods also do not require intrusive modifications to existing codes.

- **Speaker:** *Yi Sun* (yisun@math.sc.edu), University of South Carolina,

  Title: A hybrid model for simulating sprouting angiogenesis in bio-fabrication

Abstract: We present a 2D hybrid model to study sprouting angiogenesis of multicellular aggregates during vascularization in bio-fabrication. This model is developed to describe and predict the time evolution of angiogenic sprouting from endothelial spheroids during tissue or organ maturation in a novel bio-fabrication technology–bio-printing. Here we employ typically coarse-grained continuum models (reaction-diffusion systems) to describe the dynamics of vascular-endothelial-growth-factors, a mechanical model for the extra-cellular matrix based on the finite element method and couple a cellular Potts model to describe the cellular dynamics.

Contributed Talks

(25 minute talk plus 5 minute for questions)

Part I of III (Saturday, 10:30–12:30):

- **Speaker:** *Joshua M. Siktar* (jsiktar@vols.utk.edu), University of Tennessee-Knoxville

  Title: Recasting the Proof of Parseval's Identity

  Abstract: We generalize aspects of Fourier Analysis from intervals on $\mathbb{R}$ to bounded and measurable sets in $\mathbb{R}^n$. In doing so, we obtain a few interesting results. The first is a new proof of the famous Integral Cauchy-Schwarz Inequality. The second is a restatement of Parseval's Identity that doubles as a representation of integrating bounded and measurable functions over bounded and measurable subsets of any dimension of real numbers. We also include additional integral inequalities that are elementary in nature as applications of these two results, in particular studying the convergence of Fourier Series in L^p spaces.

- **Speaker:** *Eric Stachura* (eric.stachura@kennesaw.edu), Kennesaw State University

  Title: Analysis of the Bi-anisotropic Maxwell system in Lipschitz domains

  Abstract: We discuss well-posedness of an initial boundary value problem for the time dependent, bi-anisotropic Maxwell system in a Lipschitz domain. In such a setting there are 8 material parameters, which are allowed to depend on space and time. We in particular taken into account memory effects and impose nonzero Dirichlet boundary data. Similar results in higher order Sobolev spaces are obtained as well, assuming the material parameters satisfy a certain multiplier property.

- **Speaker:** *Yuan Gao* (yuangao@math.duke.edu), Duke University
  Co-authors: *Jian-Guo Liu* (jliu@math.duke.edu), Duke University

  Title: Peierls-Nabarro model for single edge dislocation: mathematical validation and exponential convergence to equilibrium

  Abstract: Materials defects such as dislocations are important line defects in crystalline materials and they play essential roles in understanding materials properties like plastic deformation. In this talk, we study the relaxation process of Peierls-Nabarro dislocation model, which is a gradient flow with singular nonlocal energy and double well potential describing how the materials relax to its equilibrium with

the presence of a dislocation. The difficulties of this problem rising from bistable profile in R which naturally leads to a singular nonlocal energy. We first perform mathematical validation of the PN models by rigorously establishing the relationship between the PN model in the full space and the reduced problem on the slip plane in terms of both governing equations and energy variations. Then we present spectral analysis for nonlocal Schordinger operator and show the dynamic solution to Peierls-Nabarro model will converge exponentially to a shifted steady profile which is uniquely determined.

- **Speaker:** *Hannah Thompson* (hthomp15@vols.utk.edu), University of Tennessee-Knoxville
  Co-authors: *Suzanne Lenhart* (slenhart@utk.edu), University of Tennessee- Knoxville;
  Gregory Wiggins (wiggybug@utk.edu), University of Tennessee- Knoxville

  Title: A stage structured model with seasonality of hemlock woolly adelgid and two predatory beetle species in the GSMNP

  Abstract: The hemlock woolly adelgid, an invasive species, has greatly impacted populations of hemlock trees in the eastern US. Two biological control predators of the adelgid have been found coexisting on adelgid infested trees, but little is known about the interaction of the predators and their joint impact on adelgid populations in natural settings. Using data collected in the Great Smoky Mountains National Park, we model the population dynamics of the adelgid and the two predators with a system of ordinary differential equations.

Part II of III (Saturday, 15:30–17:30):

- **Speaker:** *Lingyun Ding* (dingly@live.unc.edu), University of North Carolina at Chapel Hill

  Title: Quadrature by two expansions: evaluating laplace layer potentials using complex polynomial and plane wave expansions

  Abstract: The recently developed quadrature by expansion (QBX) technique accurately evaluates the layer potentials with a singular, weakly or nearly singular, or even hypersingular kernels in the integral equation reformulations of partial differential equations. The idea is to form a local complex polynomial or partial wave expansion centered at a point away from the boundary to avoid the singularity in the integrand, and then extrapolate the expansion at points near or even exactly on the boundary. We derive new representations of the Laplace layer potentials using both the local complex polynomial and plane wave expansions. Unlike in the QBX, the local complex polynomial expansion in the new quadrature by two expansions (QB2X) method only collects the far-field contributions and its number of expansion terms can be analyzed using tools from the classical fast multipole method. The plane wave type expansion in the QB2X method better captures the layer potential features near the boundary. The internal connections of the layer potential with its density function and curvature on the boundary are explicitly revealed in the plane wave expansion and its error is bounded by the Fourier extension errors.

- **Speaker:** *Tong Wu* (twu2@tulane.edu), Tulane University
  Co-authors: *James M Hyman* (mhyman@tulane.edu), Tulane University;
  Humberto C. Godinez (hgodinez@lanl.gov), Los Alamos National Laboratory;
  Vitaliy Gyrya (vitaliy_gyrya@lanl.gov), Los Alamos National Laboratory

  Title: Continuous Data Assimilation from Scattered Spatial Observations in Time Dependent PDEs

  Abstract: We introduce one new continuous data assimilation algorithm based on the AOT data assimilation algorithm, which is using the dynamic feedback control, which is construct based on the governing PDE and the observed data not only at the current local state, but also the data in a short future, which

provides better feedback locally and leads a faster convergence rate. We have tested our algorithm on a number of test problems, including 1D KPP-Burgers' equation, 1D Kuramoto-Sivashinsky equation, and 2D shallow water equations.

- **Speaker:** *SHANG-HUAN CHIU* (schiu@fsu.edu), Florida State University.
  Co-authors: *BRYAN D. QUAIFE* (bquaife@fsu.edu), Florida State University;
  M. N. J. MOORE (mnmoore2@fsu.edu), Florida State University.

  Title: Viscous Transport in Eroding Porous Media

  Abstract: Erosion is a fluid-mechanical process that is present in many geological phenomena such as groundwater flow. We present a boundary integral equation formulation to simulate two-dimensional erosion of a porous media. A numerical challenge to simulate low porosities is accurately resolving the interactions between nearly touching eroding bodies. We present a Barycentric quadrature method to resolve these interactions and compare its accuracy with the standard trapezoid rule. To reduce the computational time, we develop a hybrid method that combines the Barycentric quadrature rule and an accelerated version of the trapezoid rule. We compute the velocity, vorticity, and tracer trajectories in the geometries that include dense packings of 20, 50, and 100 eroding bodies. Similar to our previous work [1], we observe quickly expending channels between close bodies, flat faces developing along the regions of near contact, and bodies eventually vanishing. Finally, having computed tracer trajectories, we characterize the transport inside of eroding geometries by computing and analyzing the tortuosity and anomalous dispersion rates. We present the validation of the tortuosities based on two different definitions and apply a reinsertion method to compute asymptotic anomalous dispersion rates.

  [1]B. D. Quaife *et al.*, J. Comput. Phys. **375**, 1 (2018).

- **Speaker:** *Victor Churchill* (Victor.A.Churchill.GR@dartmouth.edu), Dartmouth College
  Co-authors: *Rick Archibald* (archibaldrk@ornl.gov), Oak Ridge National Laboratory;
  Anne Gelb (annegelb@math.dartmouth.edu), Dartmouth College.

  Title: Image reconstruction via edge-masked regularization

  Abstract: We present a reconstruction method for edge-sparse images that uses approximate edge locations to enforce a sparsity penalty more precisely than standard ℓ_1 regularization methods. Specifically, an edge detection informs a reconstruction where ℓ_2 regularization is applied away from edges. Since the difficulty of the problem is effectively shifted from reconstruction to edge detection, we also discuss several methods for detecting edges from data that are acquired as non-uniform Fourier samples as in synthetic aperture radar.

Part III of III (Sunday, 10:00–12:00):

- **Speaker:** *David C. Elzinga* (delzinga@vols.utk.edu), University of Tennessee, Knoxville
  Co-authors: *Ryan Kulwicki* (Ryan.Kulwicki@valpo.edu), Valparaiso University;
  Samuel Iselin (siselin3@gatech.edu), Georgia Institute of Technology;
  Alex Capaldi (Alex.Capaldi@valpo.edu), Valparaiso University.

  Title: An Agent-Based Model Simulating Wolf Domestication by Natural Selection

  Abstract: The prevailing theory of the domestication of the modern dog is that domestication occurred over two periods. While there exists substantial evidence that artificial selection drove the more recent domestication period, the main cause of the earlier period remains unknown. One proposed theory, the

proto-domestication hypothesis, suggests that wolves domesticated themselves through entirely natural selective forces as they scavenged human settlements. This hypothesis has come under scrutiny as the relatively short time period of domestication would suggest additional forces of evolution to be necessary. We present an agent-based model of evolution of a single trait, a measure of human tolerance, in wolves to test the plausibility of the proto-domestication hypothesis within such time constraints. We use Hartigan's Dip Test for Unimodality to measure if and when divergence of populations occurred. We conclude that our model indicates the proto-domestication hypothesis is plausible within realistic time constraints.

- **Speaker:** *Cara J. Sulyok* (csulyok@vols.utk.edu), University of Tennessee, Knoxville
Co-authors: *Judy Day* (judyday@utk.edu), University of Tennessee, Knoxville;
Suzanne Lenhart (slenhart@utk.edu), University of Tennessee, Knoxville.

  Title: Mathematically Modeling the Immune Response of Celiac Disease

  Abstract: Celiac disease is a hereditary autoimmune disease that affects approximately 1 in 133 Americans. After ingesting the protein gluten, a patient with celiac disease may experience a range of unpleasant symptoms while small intestinal villi, essential to nutrient absorption, are destroyed in an immune process. The only known treatment for this disease is a lifelong gluten-free diet and there is currently no drug treatment. This preliminary work provides a mathematical framework to better understand the immunological mechanisms in celiac disease. The model will be able to analyze various theories behind the progression of this disease by capturing the dynamics of a healthy subject and a patient with celiac disease.

- **Speaker:** *Xianping Li* (Xianping.Li@asu.edu), Arizona State University
Co-authors: *Weizhang Huang* , (whuang@ku.edu) University of Kansas
Fei Zhang , (fzhang_cup@outlook.com) China University of Petroleum-Beijing
Shicheng Zhang , (zhangsc@cup.edu.cn) China University of Petroleum-Beijing .

  Title: Moving mesh finite element simulation for phase-field modeling of brittle fracture

  Abstract: A moving mesh finite element method is studied for the numerical solution of a phase-field model for brittle fracture. Three regularization methods are proposed to smooth out the decomposition of the strain tensor, which can effectively improve the convergence of Newton's iteration without compromising the accuracy of the numerical solution. Our method is able to adaptively concentrate the mesh elements around propagating cracks and handle multiple and complex crack systems.

- **Speaker:** *Ali Pakniyat* (pakniyat@gatech.edu), Georgia Institute of Technology

  Title: The Quest for Missing Component: Dualities in Hybrid Optimal Control

  Abstract: We revisit the notion of feedback as a ubiquitous policy structure in systems and control theory, and argue that a feedback law purely in state is not necessarily optimal. By studying examples of deterministic and stochastic hybrid systems, we remark that a general control policy depends on both the past information and future predictions about the process and, hence, a reduction to feedback structure jointly in the state and a "dual" variable requires the pair to summarize both the past and the future. Viewing the two fundamental results in optimal control theory from a duality perspective, we show that duality relationship holds in the Minimum Principle (MP) between the finite dimensional spaces of state variations and of co-state (adjoint) processes, and in Dynamic Programming (DP) between the infinite dimensional spaces of measures and of continuous functions. We present new version of the MP and DP for deterministic and stochastic hybrid systems and illustrate their implementation on analytic and practical examples. For numerical solution methodologies, we study the three classes of (a) generally

nonlinear, (b) linear quadratic, and (c) polynomial systems where, for the latter case in particular, we can employ sum-of-squares techniques.

Poster Session

(Saturday 17:30 – 19:00)

- **Presenter**: *Sundar Tamang* (sundar11@uab.edu), University of Alabama at Birmingham

  Title: A Model for Currency Exchange Rates

  Abstract: The catastrophic economic events like, oil price shock in 1973, the 9/11 event in 2001, stock market crash in October, 1987 and crash in late 2008 etc, impacted the US economy without warning from sharp downturns to actual market crashes. And the current economic theory and statistical models are not enough to analyze those events. So, for constituting the models to predict and recovery of US economy with major factors: commodities, stock, bond and currency, I am going to predict and recover the currency exchange rates using models "Stochastic Differential Equations" with predicting trend of exchange rates by system of delay differential equations and recovering of volatility of exchange rates by using inverse problem in "Dupire's Equations" which is obtained from "Black-Scholes Equations".

- **Presenter**: *Ashley Gannon, Bryan Quaife* Florida State University

  Title: Semi-Permeable Deformable Membranes in a Viscous Fluid

  Abstract: Aquaporins are channels located in the cell membrane that facilitate the movement of water into and out of a cell. These channels facilitate water transport at a higher rate than osmosis through the lipid bilayer. Studies have demonstrated that osmosis plays a role in cell movements. We apply a high-order boundary integral equation method to simulate the movements of a single vesicle with a semi-permeable deformable membrane in various Stokesian flows.

- **Presenter**: *Jesse Buffaloe* (jbuffal1@vols.utk.edu), The University of Tennessee, Knoxville;
  Brandon Barker (barker49@msu.edu), Michigan State University;
  David Pochik (dpochik@vols.utk.edu), The University of Tennessee, Knoxville
  Co-author: *Eirik Endeve* (endevee@ornl.gov), Oak Ridge National Laboratory

  Title: Application of the Discontinuous Galerkin Method to Supernova Hydrodynamics in `thornado`

  Abstract: Realistic simulations of core-collapse supernovae require multi-dimensional and high-fidelity descriptions of the relevant physics. To this end, a new code (`thornado`) is being developed which makes use of the discontinuous Galerkin method. We highlight algorithmic considerations and results from `thornado` in the context of the standing accretion shock problem and the use of a nuclear equation of state. This testing suggests success in these domains, while future efforts will focus on combining the work from multiple fronts, along with the implementation of adaptive mesh refinement using the AMReX framework.

- **Presenter**:*Ali Pakniyat* (pakniyat@gatech.edu), Georgia Institute of Technology
  Co-authors: *Ramanarayan Vasudevan* (ramv@umich.edu), University of Michigan

  Title: A Convex Duality Approach to Optimal Control of Killed Markov Processes

  Abstract: A general class of optimal control problems is studied for stochastic systems governed by con trolled Itô differential equations on compact state spaces where the process is killed (i.e. switched to

zero dynamics) upon arrival on the boundary of the domain. Using the notion of occupation measures, it is shown that the original problem is embedded in a convex linear program on the space of Radon measures and, since the embedding is tight, the optimal solution of both the original and the convex relaxation problems are equal. By exploiting the dual relationship between the space of continuous functions and of measures, the value function is identified as the upper envelope of the smooth sub-solutions of the Hamilton-Jacobi problem. Using the denseness of polynomials on compact domains and employing Putinar's Positivstellensatz, a numerical algorithm is formulated for fast approximation of the value function.