2021 MIDWEST NUMERICAL ANALYSIS DAY

October 29-30, 2021

MISSOURI S&T

Mathematics and Statistics

Program for Midwest Numerical Analysis Day 2021

Sponsored By

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Missouri University of Science and Technology:
Office of the Vice Chancellor of Research and Innovation
College of Arts, Sciences, and Business
Department of Mathematics and Statistics
Missouri Institute of Computational and Applied Mathematical Sciences
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Important Notices

If the zoom meeting of one parallel session is down due to some uncontrollable reason, we will immediately start to use the following backup zoom meeting:

zoom meeting ID: 992 1472 0176
zoom link: https://umsystem.zoom.us/j/99214720176

Backup parallel session room: Silver & Gold 201.

Discussion rooms for in-person participants: Burgess 202, Mark Twain 205, Shamrock Room 210.

Section I: Conference Schedule
(US Central Time)

- **Friday, October 29, 2021 (Online presentations only)**

12:30pm-4:30pm: Havener Center, Wiese Second Level Atrium
Registration

1:00pm —1:10pm: Havener Center, St. Pat's Ballroom 206 C
Opening
zoom meeting ID: 939 0062 7477
zoom link: https://umsystem.zoom.us/j/93900627477
Chair: Xiaoming He

1:10pm—2:50pm: Parallel Sessions

PS1: Havener Center, St. Pat's Ballroom 206 C
zoom ID: 939 0062 7477
zoom link: https://umsystem.zoom.us/j/93900627477
Chair: Yanzhi Zhang/Xiaoming He

1:10pm—1:35pm
Speaker: Dexuan Xie, University of Wisconsin-Milwaukee
Title: An Effective Finite Element Iterative Method for Solving an Improved Poisson–Nernst–Planck Ion Channel Model

1:35pm—2:00pm
Speaker: Sarah Locke, Eastern Kentucky University
Title: A New Approach to Proper Orthogonal Decomposition with Difference Quotients

2:00pm—2:25pm
Speaker: John Carter, Missouri S&T
Title: Second Order Ensemble Method for Evolutionary MHD Equations at Small Magnetic Reynolds Number

2:25pm—2:50pm
Speaker: Thu Thi Anh Le, Kansas State University
Title: Imaging of 3D objects with experimental data using orthogonality sampling methods

PS2: Havener Center, Carver/Turner 204
zoom ID: 968 9936 9032
zoom link: https://umsystem.zoom.us/j/96899369032
Chair: Steve Gao

1:10pm—1:35pm
Speaker: Lei Wang, University of Wisconsin-Milwaukee
Title: Krylov subspace/treecode method for correlated random displacements in Brownian dynamics simulations

1:35pm—2:00pm
Speaker: Birgul Koc, University of Seville
Title: Verifiability of the Data-Driven Variational Multiscale Reduced Order Model

2:00pm—2:25pm
Speaker: Ying Li, University of Florida
Title: An Artificial Compressibility CNLF Method for the Stokes-Darcy Model and Application in Ensemble Simulations

2:25pm—2:50pm
Speaker: Aleksei Sorokin, Illinois Institute of Technology
Title: QMCPy, a Quasi-Monte Carlo Software Framework

2:50pm—3:10pm: Havener Center, St. Pat's Ballroom 206 A, B
Break for coffee

3:10pm—5:15pm: Parallel Sessions

PS3: Havener Center, St. Pat's Ballroom 206 C
zoom ID: 939 0062 7477
zoom link: https://umsystem.zoom.us/j/93900627477
Chair: Yanzhi Zhang/Daoru Han

3:10pm—3:35pm
Speaker: ZhiQiang Chen, University of Missouri-Kansas City
Title: Statistical Resilience Distance Framework and Application to Engineering Structures and Infrastructure Systems

3:35pm—4:00pm
Speaker: Haroldo Chacon, Missouri S&T
Title: Predicting Multiple-Site Damage of Fuselage Structures by Employing Monte Carlo Simulation Technique

4:00pm—4:25pm
Speaker: Min-Jhe Lu, Illinois Institute of Technology
Title: Nonlinear simulation of vascular tumor growth with chemotaxis and the control of necrosis

4:25pm—4:50pm
Speaker: Yijin Gao, Iowa State University
Title: Numerical solution for effective mass time-dependent Schrödinger equation

4:50pm—5:15pm
Speaker: Jue Yan, Iowa State University
Title: Cell-average based neural network method for partial differential equations

PS4: Havener Center, Carver/Turner 204
zoom ID: 968 9936 9032
zoom link: https://umsystem.zoom.us/j/96899369032
Chair: Steve Gao

3:10pm—3:35pm
Speaker: Jun Sur Richard Park, University of Iowa
Title: Learning the G-limits in homogenization problems via physics informed neural networks

3:35pm—4:00pm
Speaker: Lauren M. White, Kansas State University
Title: Frictionless indentation of a rigid stamp into a half-space

4:00pm—4:25pm
Speaker: Pedro H. A. Anjos, Illinois Institute of Technology
Title: Electrically-controlled self-similar evolution of viscous fingering patterns in radial Hele-Shaw flows

4:25pm—4:50pm
Speaker: Jay Mayfield, Iowa State University
Title: A Green's Function Method for Wave Problems

4:50pm—5:15pm
Speaker: Mustafa Danis, Iowa State University
Title: A direct discontinuous Galerkin method with interface correction for Navier-Stokes equations

- Saturday, October 30, 2021 (either in-person or online presentations)

8:00am: Havener Center, Wiese Second Level Atrium
Registration and morning coffee

8:30am—8:40 am: Havener Center, St. Pat's Ballroom 206 C
Welcome
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Xiaoming He

8:40am—9:30 am: Havener Center, St. Pat's Ballroom 206 C
Plenary speaker: Wolfgang Bangerth, Colorado State University
Title: Simulating Complex Flows in The Earth Mantle
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Xiaoming He

9:30am—10:20am: Havener Center, St. Pat's Ballroom 206 C
Plenary speaker: Yassine Boubendir, New Jersey Institute of Technology
Title: Iterative Solvers Based on Domain Decomposition Methods For Acoustic Problems
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Daozhi Han

10:20am—10:50am: Havener Center, St. Pat's Ballroom 206 A, B
Break for coffee

10:50am—12:30pm: Parallel Sessions

PS5: Havener Center, St. Pat's Ballroom 206 C
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Xiaoming He/Yanzhi Zhang

10:50am—11:15am
Speaker: Weizhang Huang, University of Kansas
Title: A surface moving mesh PDE method

11:15am—11:40am
Speaker: Mary Barker, Washington University in St. Louis
Title: A nonconforming method for the 2D vector Laplacian

11:40am—12:05pm
Speaker: Xu Zhang, Oklahoma State University
Title: A High-Order Immersed C0 Interior Penalty Method for Biharmonic Interface Problems

12:05pm —12:30pm
Speaker: Yue Cao, Illinois Institute of Technology
Title: Moving Boundary Problem with Variable Coefficients

PS6: Havener Center, Carver/Turner 204
zoom ID: 961 6501 7515
zoom link: https://umsystem.zoom.us/j/96165017515
Chair: Steve Gao

10:50am—11:15am
Speaker: Shuhao Cao, Washington University in St. Louis
Title: Galerkin Transformer

11:15am—11:40am
Speaker: Xuan Gu, University of Arkansas
Title: Uncertainty Quantification for Rayleigh-Taylor Instability

11:40am—12:05pm
Speaker: James Burton, University of Arkansas
Title: A Random Choice Method of the Glimm's Scheme

12:05pm—12:30pm
Speaker: Xuejian Li, Missouri S&T
Title: Numerical analysis and efficient algorithms for solving variational data assimilation problem

PS7: Havener Center, Missouri/Ozark 207
zoom ID: 928 5368 7490
zoom link: https://umsystem.zoom.us/j/92853687490
Chair: Daozhi Han

10:50am—11:15am
Speaker: Taige Wang, University of Cincinnati
Title: Forced oscillations of viscous Burger's equation posed on bounded domains

11:15am—11:40am
Speaker: John Singler, Missouri S&T
Title: On Optimal Pointwise in Time Error Bounds and Difference Quotients for Proper Orthogonal Decomposition

11:40am—12:05pm
Speaker: Azzah Alshekhi, University of Missouri-Kansas City
Title: Cubic Spline Least Squares Method for Computing Stationary Density Function of Frobenius-Perron Operator

12:05am—12:30pm
Speaker: Yanwei Zhang, Missouri S&T
Title: Applications of Machine Learning Techniques to Geophysical Problems

PS8: Havener Center, Meramec/Gasconade 208
zoom ID: 941 1075 6020
zoom link: https://umsystem.zoom.us/j/94110756020
Chair: Daoru Han

10:50am—11:15am
Speaker: Weimin Han, University of Iowa
Title: Mixed finite element method for a Navier-Stokes hemivariational inequality

11:15am—11:40am
Speaker: Chunmei Wang, University of Florida
Title: A New Primal-Dual Weak Galerkin Method for Elliptic Interface Problems with Low Regularity Assumptions

11:40am—12:05pm
Speaker: Zhen Chao, University of Michigan -Ann Arbor
Title: An improved ion channel finite element mesh generation scheme

12:05pm—12:30pm
Speaker: Ahmed Al-Taweel, University of Arkansas at Little Rock
Title: A stabilizer free weak Galerkin finite element method with Supercloseness of order two

12:30—1:50pm: Havener Center, St. Pat's Ballroom 206 A, B
Lunch buffet or contactless meal box

1:50—2:00pm: Havener Center, St. Pat's Ballroom 206 C
Announcements
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: John Singler

2:00—2:50pm: Havener Center, St. Pat's Ballroom 206 C
Plenary speaker: Tao Lin, Virginia Tech
Title: Immersed Finite Element Methods and Applications
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: John Singler

2:50—3:40pm: Havener Center, St. Pat's Ballroom 206 C
Plenary speaker: Petronela Radu, University of Nebraska – Lincoln
Title: Nonlocal Models in Dynamic Fracture, Diffusion, and Machine Learning
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Yanzhi Zhang

3:40—4:10pm: Havener Center, St. Pat's Ballroom 206 A, B
Break for coffee

4:10—5:50pm: Parallel Sessions

PS9: Havener Center, St. Pat's Ballroom 206 C
zoom meeting ID: 970 5332 5503
zoom link: https://umsystem.zoom.us/j/97053325503
Chair: Xiaoming He/Yanzhi Zhang

4:10pm—4:35pm
Speaker: Yang Yang, Michigan Technological University
Title: The reinterpreted discrete fracture model

4:35pm—5:00pm
Speaker: Ryan Holley, University of Arkansas
Title: High-order WENO Schemes for Richtmyer-Meshkov Instability of an air/SF_6 interface

5:00pm—5:25pm
Speaker: Zachary Miksis, University of Notre Dame
Title: A sparse grid fast sweeping WENO method for Eikonal equations

5:25pm—5:50pm
Speaker: Zichao Jin, Illinois Institute of Technology
Title: A Kernel-Free Boundary Integral Method for Two-Dimensional Magnetostatic Problems

PS10: Havener Center, Carver/Turner 204
zoom ID: 961 6501 7515
zoom link: https://umsystem.zoom.us/j/96165017515
Chair: Steve Gao

4:10pm—4:35pm
Speaker: Shiping Zhou, Missouri S&T
Title: Numerical studies on the high-order fractional Laplacian

4:35pm—5:00pm
Speaker: David Lund, Missouri S&T
Title: Strong and Weak Scaling Performance of the Parallel Immersed Finite Element Particle-in-Cell (PIFE-PIC) Framework

5:00pm—5:25pm
Speaker: Hanli Wu, Missouri S&T
Title: Impacts of Lightweight Aggregates Interlayers for Air Convection Embankment on Pavement Thermal Profile and Pavement Performance in Alaskan Permafrost Regions

5:25pm—5:50pm
Speaker: Jianxun Zhao, Missouri S&T
Title: Kinetic particle modeling of plasma charging and dust transport near the lunar terminator

PS11: Havener Center, Missouri/ Ozark 207
zoom ID: 928 5368 7490
zoom link: https://umsystem.zoom.us/j/92853687490
Chair: Daozhi Han

4:10pm—4:35pm
Speaker: Songting Luo, Iowa State University
Title: Numerical Solutions for Time-Dependent Schrodinger Equations

4:35pm—5:00pm
Speaker: Cheng Wang, University of Massachusetts Dartmouth
Title: Structure-preserving, energy stable numerical schemes for a liquid thin film coarsening model

5:00pm—5:25pm
Speaker: Xiaoxia Tang, Illinois Institute of Technology
Title: A Phase Field Model for Vesicle Growth or Shrinkage and Nonlinear Multigrid Simulation

5:25pm—5:50pm
Speaker: Qing Cheng, Purdue University
Title: Constructing positivity and bound-preserving schemes based on Lagrange Multiplier approach

PS12: Havener Center, Meramec/Gasconade 208
zoom ID: 941 1075 6020
zoom link: https://umsystem.zoom.us/j/94110756020
Chair: Daoru Han

4:10pm—4:35pm
Speaker: Yixuan Wu, Missouri S&T
Title: Unified mesh free pseudospectral methods for solving classical and fractional PDEs

4:35pm—5:00pm
Speaker: Anh Vo, University of Nebraska-Lincoln
Title: Convergence of Solutions of the Nonlocal Conservation-Diffusion law

5:00pm—5:25pm

Speaker: Senbao Jiang, Illinois Institute of Technology

Title: High-order Corrected Trapezoidal Quadrature Rules for Functions with Fractional Singularities

5:25pm—5:50pm

Speaker: Trung Truong, Kansas State University

Title: A numerical method for solving the inverse scattering problem for 3D bi-anisotropic periodic structures

6:00pm—8:00pm: Havener Center, St. Pat's Ballroom 206 A, B

Dinner buffet or contactless meal box

Section II: Abstracts for Plenary Presentations

(Sorted alphabetically by last name)

Talk Title: Simulating complex flows in the Earth mantle
Speaker Name: Wolfgang Bangerth
Affiliation: Colorado State University
Email: bangerth@colostate.edu

Abstract: On long enough time scales, the Earth mantle (the region between the rigid plates at the surface and the liquid metal outer core at depth) behaves like a fluid. While it moves only a few centimeters per year, the large length scales nevertheless lead to very large Rayleigh numbers and, consequently, very complex and expensive numerical simulations. At the same time, given the inaccessibility of the Earth mantle to direct experimental observation implies that numerical simulation is one of the few available tools to elucidate what exactly is going on in the mantle, how it affects the long-term evolution of Earth's thermal and chemical structure, as well as what drives and sustains plate motion.

I will here review the approach we have taken in building the state-of-the-art open source solver ASPECT (see http://aspect.geodynamics.org) to simulate realistic conditions in the Earth and other celestial bodies. ASPECT is built using some of the most widely used and best software libraries for common tasks, such as deal.II for mesh handling and discretization, p4est for parallel partitioning and rebalancing, and Trilinos for linear algebra. In this talk, I will focus on the choices we have made regarding the numerical methods used in ASPECT, and in particular on the interplay between higher order discretizations on adaptive meshes, linear and nonlinear solvers, optimal preconditioners, and approaches to scale to thousands of processor cores. All of these are necessary for simulations that can answer geophysical questions.

Talk Title: Iterative solvers based on domain decomposition methods for acoustic problems
Speaker Name: Yassine Boubendir
Affiliation: New Jersey Institute of Technology
Email: boubendi@njit.edu

Abstract: Domain decomposition algorithms have several advantages for modern day simulations. Among these, domain decomposition methods allow for highly parallelizable computations and they also easily enable the coupling of dissimilar numerical schemes. Following a brief description of these methods for the Helmholtz equation, we will focus on one major difficulty of these techniques which is the choice of the transmission conditions. In addition, we will describe the treatment of the so-called cross- points problem in the case of nodal finite element methods. Then, we will explain how to design efficiently boundary/finite elements coupling algorithms. Numerical experiments are presented to validate these methods.

Talk Title: Immersed finite element methods and applications
Speaker Name: Tao Lin
Affiliation: Virginia Tech
Email: tlin@vt.edu

Abstract: Interface problems appear in numerical simulations over domains consisting of multiple materials that result in discontinuous coefficients in the involved partial differential equations (PDEs), and solutions to these PDEs often lack regularity across the material interfaces. This deficiency of the global regularity requires traditional finite element (FE) methods to use fitted meshes in which each element essentially contains one of the materials; otherwise, the performance of a FE method cannot be guaranteed. Fitted meshes are unstructured in general unless material interfaces have trivial geometries. The immersed finite element (IFE) methods are non-traditional FE methods that can utilize interface-independent meshes to solve interface problems; hence, if desired, they can use structured/Cartesian meshes even for interfaces with non-trivial geometries. In this talk, after a brief introduction of IFE methods, we will present some new ideas for constructing IFE functions with features such as (1). they can handle non-homogeneous jump conditions; (2). they can use higher degree polynomials; (3). they can be extended to 3D interface problems; (4). they can deal with interface problems for modelling multiphysics. Some applications will be presented to demonstrate features of IFE methods.

Talk Title: Nonlocal models in dynamic fracture, diffusion, and machine learning
Speaker Name: Petronela Radu
Affiliation: University of Nebraska – Lincoln
Email: pradu@unl.edu

Abstract: Nonlocal frameworks have empowered mathematical modelers with new tools to capture phenomena with discontinuous, singular, or irregular behavior, which are encountered in many applications. While classical models in continuum mechanics employ operators that inherently assume (at least some) smoothness for solutions, nonlocal operators employ integral operators which expand the space of possible solutions to allow even discontinuous functions. While the engineering and scientific computation communities have been using nonlocal models in an increasingly large number of applications, the theoretical investigations are still in their early stages of development. As numerical simulations have been plagued by many issues (such as computational costs, stability, convergence behavior that is dependent on the interaction between the mesh size and the nonlocal horizon of interaction) there is a clear need to advance the rigorous mathematical work. The presentation will focus on some the challenges and opportunities offered by nonlocal models, as well as on some of recent progress that we have made at theoretical level, as well as in numerical simulations. I will conclude with a discussion of nonlocality in machine learning from a couple of different perspectives.

Section III: Abstracts for Parallel Sessions

(sorted alphabetically by last name)

Talk Title: Cubic Spline Least Squares Method for Computing Stationary Density Function of Frobenius-Perron Operator

Speaker Name: Azzah Alshekhi
Affiliation: University of Missouri Kansas City
Email: aaa8hd@mail.umkc.edu

Abstract: Using a sequence of cubic spline functions and the idea of the least squares method, we approximate the unique stationary density function of Frobenius-Perron operator associated with a transformation S from the interval [0,1] into itself, where the transformation S is measurable and nonsingular. We expect to have faster convergence rate than the previous work done using a sequence of constant, linear, or quadratic spline functions.

Talk Title: A stabilizer free weak Galerkin finite element method with supercloseness of order two

Speaker Name: Ahmed Al-Taweel
Affiliation: University of Arkansas at Little Rock
Email: asaltaweel@ualr.edu

Abstract: The weak Galerkin (WG) finite element method is an effective and flexible general numerical technique for solving partial differential equations. A simple weak Galerkin finite element method is introduced for second-order elliptic problems. First, we have proved that stabilizers are no longer needed for this WG element. Then we have proved the supercloseness of order two for the WG finite element solution. The numerical results confirm the theory.

Talk Title: Electrically-controlled self-similar evolution of viscous fingering patterns in radial Hele-Shaw flows

Speaker Name: Pedro H. A. Anjos
Affiliation: Illinois Institute of Technology
Email: pamorimanjos@iit.edu

Abstract: Time-dependent injection strategies are commonly employed to control the number of viscous fingers emerging at the interface separating two fluids during radial displacement in Hele-Shaw flows. Here we demonstrate theoretically that such a usual controlling method is significantly improved by taking advantage of an electro-osmotic flow generated by applying an external electric field. More specifically, under the coupled action of time-varying electric currents and injection rates, we design a strategy capable of controlling not only the number of fingers emerging at the interface but also when (and if) the self-similar evolution occurs. In addition, the level of instability of the n-fold fingered patterns can also be tuned. This improved control over the interfacial features cannot be realized by the sole consideration of a time-varying injection rate.

Perturbative second-order mode-coupling approach and boundary integral simulations confirm that the validity and effectiveness of the controlling protocol go beyond the linear regime.

Talk Title: A nonconforming method for the 2D vector Laplacian
Speaker Name: Mary Barker
Affiliation: Washington University in St. Louis
Email: marybarker@wustl.edu

Abstract: A hybridizable, nonconforming method for the 2D vector Laplacian is introduced that generalizes the P1-nonconforming method introduced by Brenner, Cui, Li, and Sung in 2008. Some a priori error estimates are given and numerical results that illustrate optimal convergence for problems with low regularity

Talk Title: A Random Choice Method of the Glimm's Scheme
Speaker Name: James Burton
Affiliation: University of Arkansas
Email: jmb100@uark.edu

Abstract: Numerical methods for the solution of hyperbolic partial differential equations concerns shock formation and propagation. In order to solve the Euler equations of compressible fluid dynamics, stable, accurate and robust algorithms for shock computations are needed. In our numerical simulations of compressible multiphase flows in 1D, we use Glimm's scheme because of its good algorithmic properties, especially near discontinuities. However, this scheme is difficult to extend to multidimensional hyperbolic problems. Glimm's scheme using the random choice method (RCM), is revisited to investigate convergence properties using low-discrepancy sampling methods. A set of van der Corput sampling sequences and its generalized version Halton sequences are used to determine the sensitivity of the random variables to the approximated solutions. A detailed study is performed to find the optimal choice in sampling sequence. Numerical solutions on the various meshes using different sequences are performed to determine the optimal sampling choice with a good convergence property.

Talk Title: Galerkin Transformer
Speaker Name: Shuhao Cao
Affiliation: Washington University in St. Louis
Email: s.cao@wustl.edu

Abstract: Transformer in "Attention Is All You Need" is now THE ubiquitous architecture in every state-of-the-art model in Natural Language Processing (NLP), such as BERT. At its heart and soul is the "attention mechanism". We apply the attention mechanism the first time to a data-driven operator learning problem related to partial differential equations. Inspired by Fourier Neural Operator which showed a state-of-the-art performance in parametric PDE evaluation, an effort is put together to explain the heuristics of, and to improve the efficacy of the attention mechanism. It is demonstrated that the widely-accepted "indispensable" softmax normalization in the scaled dot-product attention is sufficient but not necessary. Without the softmax normalization, the approximation capacity of a linearized Transformer variant can be proved to be on par with a Petrov-Galerkin projection layer-wise. Some simple changes mimicking projections in Hilbert spaces are applied to the attention mechanism, and it helps the final model achieve remarkable accuracy in operator learning tasks with unnormalized data, surpassing the evaluation accuracy of the classical Transformer applied directly by 100 times. Meanwhile in all experiments, the newly proposed simple attention-based operator learner, Galerkin Transformer, shows significant improvements in both speed and evaluation accuracy over its softmax-normalized counterparts.

Talk Title: Moving Boundary Problem with Variable Coefficients.

Speaker Name: Yue Cao
Affiliation: Illinois Institute of Technology
Email: ycao33@hawk.iit.edu

Abstract: We present a method to compute moving interface problems whose coefficients in governing equations are variables. Variable coefficient could be non-homogeneous viscosity in Hele-Shaw problem or uptake rate in tumor growth problems. We apply KFBIM (kernel-free boundary integral method) to compute velocity of the interface. It does not require analytical form of the Green's function and could solve variable coefficient elliptic partial differential equations. Another unique feature is that we develop explicit and implicit methods to evolve the interface. Both methods have no restriction on time step regardless of stiffness. The methods are second order accurate in space and time.

Talk Title: Second Order Ensemble Method for Evolutionary MHD Equations at Small Magnetic Reynolds Number

Speaker Name: John Carter
Affiliation: Missouri University of Science & Technology
Email: jachdm@mst.edu

Abstract: We study a second order ensemble method for fast computation of an ensemble of MHD flows at small magnetic Reynolds number. Computing an ensemble of flow equations with different input parameters is a common procedure for uncertainty quantification in many engineering applications, for which the computational cost can be prohibitively expensive for nonlinear complex systems. We propose an ensemble algorithm that requires only solving one linear system with multiple right-hands instead of solving multiple different linear systems, which significantly reduces the computational cost and simulation time. Comprehensive stability and error analyses are presented proving conditional stability and second order in time convergent.

Numerical tests are provided to illustrate theoretical results and demonstrate the efficiency of the proposed algorithm.

Talk Title: Predicting Multiple-Site Damage of Fuselage Structures by Employing Monte Carlo Simulation Technique.

Speaker Name: Haroldo Chacon
Affiliation: Graduate Student, Aerospace Engineering – Missouri University of Science and Technology
Email: hcbd6@umsystem.edu

Abstract:
Multiple-Site Damage is the most common source of Widespread Fatigue Damage found in aircraft fuselage structures. This type of damage represents a threat to structural integrity and continued airworthiness of aging aircraft fleet. The current aviation regulatory agencies require the establishment of maintenance actions to preclude widespread fatigue in structural areas susceptible to multiple-site damage. Therefore, an understanding of its progression, and the development of analytical tools to prevent its onset becomes important to assess structural integrity and comply with airworthiness standards. A reliable and efficient numerical methodology to perform multiple site damage assessment in fuselage riveted panels was developed and presented. Monte Carlo simulation technique was employed to calculate the distribution of fatigue initiation lives and probabilistic crack propagation accounting for multiple adjacent crack scenarios. Stress intensity factors were computed by applying compounding method based on classical solutions. The numerical results obtained via numerical simulation were compared against previously published test data. Fatigue crack initiation and crack propagation lives agreed with the experimental results. Finally, cumulative probability function was used to establish maintenance actions required to preclude widespread fatigue damage.

Talk Title: An improved ion channel finite element mesh generation scheme

Speaker Name: Zhen Chao
Affiliation: University of Michigan -Ann Arbor
Email: zhench@umich.edu

Abstract: To solve an ion channel model by the finite element method, one of the most important tasks is to generate an interface fitted unstructured tetrahedral mesh for a box simulation domain. Actually, it is very difficult to construct such a mesh due to the irregular shape of proteins. In addition, to handle different boundary and interface conditions, equations are defined in different regions, we need to mark triangular surface meshes on the inter- faces/boundaries and tetrahedra meshes in different regions. In this talk, I will describe an improved algorithms and implementations for generating these meshes, and numerical tests for showing the robustness and efficiency of our mesh generation package are presented.

Talk Title: Statistical Resilience Distance Framework and Application to Engineering Structures and Infrastructure Systems
Speaker Name: ZhiQiang Chen
Affiliation: University of Missouri, Kansas City
Email: chenzhiq@umsystem.edu

Abstract: Engineered systems provide services that further support human life, social, and economic activates. One trend in designing and managing an engineering system is to assess a system in terms of resilience, namely, to characterize how the system adapts to and recovers from an extreme event. Towards this goal, many qualitative methods exist, e.g., scorecards-based rating; nonetheless, the development of quantitative assessment of engineered resilience is still in its infancy stage. In addition, resilience assessment differs from the previous reliability-or risk-based assessment in that the notion of resilience spans not only physical variables but ones from the socioeconomic, organizational, and technological dimensions, which often define the degree of resourcefulness and determine the rate of system recovery. In this work, we will review the current engineering resilience assessment approach and point out the lack of a theoretical basis for comparing resilience objectively. To this end, we have developed a statistical resilience distance framework that aims to provide tools to evaluate resilience migration, quantify the benefits of a technical countermeasure, and assess the effects of high-level decision-making and resourcefulness. Applications of this framework for river-crossing bridges and rural power distribution systems will be discussed.

Talk Title: Constructing positivity and bound-preserving schemes based on Lagrange Multiplier approach
Speaker Name: Qing Cheng
Affiliation: Purdue University
Email: cheng573@purdue.edu

Abstract: In the talk, I will introduce a new Lagrange multiplier approach to construct efficient and accurate positivity/bound and/or mass preserving schemes for a class of semi-linear and quasi-linear parabolic equations. We establish stability results under a general setting, and carry out an error analysis for second-order positivity/bound preserving schemes. We apply our approach to several typical PDEs which preserve positivity/bound and/or mass. We also present some numerical results to validate our approach.

Talk Title: A direct discontinuous Galerkin method with interface correction for Navier-Stokes equations
Speaker Name: Mustafa Danis
Affiliation: Iowa State University, Department of Mathematics
Email: danis@iastate.edu

Abstract: We present a new direct discontinuous Galerkin method with interface correction (DDGIC) for 2D compressible Navier-Stokes equations. The new DDGIC method is based on the observation that the nonlinear diffusion of Navier-Stokes equations can be represented as a certain combination of multiple individual diffusion processes corresponding to each equation and conserved variable in the system. This new representation significantly simplifies the numerical viscous flux such that it only requires employing the simple direct DG numerical flux formula to compute the gradients of the conserved variables at the element interfaces. We also present how the new method can be used for the scalar nonlinear diffusion equations as well as a more complicated system of equations with nonlinear diffusion. We also demonstrate the high order of accuracy of the new DDGIC method for several numerical experiments.

Talk Title: A New Approach to Proper Orthogonal Decomposition with Difference Quotients
Speaker Name: Sarah Locke Eskew
Affiliation: Eastern Kentucky University
Email: sarah.locke@eku.edu

Abstract: In a recent work [B.\ Koc et al., SIAM J.\ Numer.\ Anal., 2021], the authors showed that including difference quotients (DQs) is necessary in order to prove optimal pointwise in time error bounds for proper orthogonal decomposition (POD) reduced order models of the heat equation. In this talk, we introduce a new approach to including DQs in the POD procedure. Instead of computing the POD modes using all of the snapshot data and DQs, we only use the first snapshot along with all of the DQs and special POD weights. We show that this approach retains all of the numerical analysis benefits of the standard POD DQ approach, while using a POD data set that has half the number of snapshots as the standard POD DQ approach, i.e., the new approach is more computationally efficient. We illustrate our theoretical results with numerical experiments.

Talk Title: Numerical solution for effective mass time-dependent Schrödinger equation
Speaker Name: Yijin Gao
Affiliation: Iowa State University
Email: yjgao@iastate.edu

Abstract: We will present asymptotic methods for simulating effective mass time-dependent Schrödinger equation. The Huygens' principle is used as the time propagator for the wave function where the Green functions are approximated by asymptotic approximations. The perfectly matched layer method is incorporated to restrict the computation onto a bounded domain of interest. Also we consider the stability of the first and second order scheme. Numerical examples are presented to verify the result.

Talk Title: Uncertainty Quantification for Rayleigh-Taylor Instability
Speaker Name: Xuan Gu

Affiliation: Department of Mathematical Sciences, University of Arkansas, Fayetteville, AR 72701, USA
Email: xuangu@uark.edu

Abstract: The influence of initial conditions on the evolution of the hydrodynamic instabilities has been investigated through laboratory experiments. and simulations over several decades. In this talk, we present the computational framework developed to investigate the effect of initial conditions on the growth rate of Rayleigh-Taylor Instability (RTI) which occurs when the light fluid is accelerated into the heavier fluid. The framework is used to determine the sensitivity of the growth rate with respect to the input parameters on the numerical simulations of flows using a front tracking method. Ensemble data consist of paired sets of input parameters and simulation output results. In the preparation of paired input parameters, the min-max range is specified for values such as Atwood number, gravity and pressure at the interface. Front tracking based computational fluid dynamics (CFD) code is ran for the paired input parameters in order to collect output for the post-processing stage to perform the global sensitivity analysis. The framework couples the Uncertainty Quantification Toolkit (UQTk) C++/python open source library and the CFD code for the sensitivity analysis. We present numerical results to show a large ensemble data to present the influence of initial conditions on the growth rate of RTI.

Talk Title: Mixed finite element method for a Navier-Stokes hemivariational inequality
Speaker Name: Weimin Han
Affiliation: University of Iowa
Email: weimin-han@uiowa.edu

Abstract: The hemivariational inequality of the stationary Navier-Stokes equations (NS hemivariational inequality) models the motion of a viscous incompressible fluid in a bounded domain, subject to a nonsmooth and nonconvex slip boundary condition. The incompressibility constraint is treated through a mixed formulation. Solution existence and uniqueness results are provided. The mixed finite element method is applied to solve the NS hemivariational inequality and error estimates are derived. Numerical results are reported to illustrate the optimal convergence order predicted by the error analysis.

Talk Title: High-order WENO Schemes for Richtmyer-Meshkov Instability of an air/SF_6 interface
Speaker Name: Ryan Holley
Affiliation: University of Arkansas
Email: rh027@uark.edu

Abstract: Turbulent mixing due to Richtmyer-Meshkov Instability (RMI) occurs in a wide range of science and engineering applications such as supernova explosions and inertial confinement fusion. The experimental, theoretical and numerical studies help us to understand the RMI mechanism on these important problems. In this talk, we will present the algorithmic features used for the numerical simulations of RMI and the numerical effects of the high-order Weighted Essentially Non-Oscillatory (WENO) schemes on the two-dimensional RMI of an air/SF_6 interface. The single-mode shock-tube experiments of Collins and Jacobs (2002) are used to setup the initial conditions of our numerical simulations. The numerical simulations are performed using high-order WENO scheme to evaluate the asymptotic growth rate of the mixing zone. For validation and verification purpose, we compare our numerical results with the experiment and investigate the convergence properties of flow fields under mesh refinement through three-level resolutions (coarse-medium-fine) before and after re-shock. We also study the effect of artificial compression method to the WENO scheme on the computation of shocks and contact discontinues.

Talk Title: A surface moving mesh PDE method

Speaker Name: Weizhang Huang
Affiliation: Department of Mathematics, University of Kansas
Email: whuang@ku.edu

Abstract: We will present a surface moving mesh method for general surfaces with or without explicit parameterization. The method is an extension of the moving mesh partial differential equation (MMPDE) method that has been developed for bulk meshes. The surface moving mesh equation is defined as the gradient system of a meshing energy function, with the nodal mesh velocities being projected onto the underlying surface. Like the bulk mesh situation, we show that any mesh generated by the surface moving mesh method remains nonsingular if it is so initially. Moreover, a surface meshing energy function is presented based on mesh equidistribution and alignment. The main challenges in the development come from the fact that the Jacobian matrix of the affine mapping between the reference element and a simplicial surface element is not square. It is emphasized that the method is developed directly on surface meshes, making no use of any information on surface parameterization. It utilizes surface normal vectors to ensure that the mesh vertices remain on the surface while moving, and also assumes that the initial surface mesh is given. The new method can apply to general surfaces with or without explicit parameterization since the surface normal vectors can be computed based on the current mesh. A selection of two- and three-dimensional examples will be presented.

Talk Title: High-order Corrected Trapezoidal Quadrature Rules for Functions with Fractional Singularities

Speaker Name: Senbao Jiang
Affiliation: Illinois Institute of Technology
Email: sjiang23@hawk.iit.edu

Abstract: We introduce and analyze a high-order quadrature rule for evaluating the two-dimensional singular integrals of the forms \begin{align*} I = \int_{\mathbb{R}^2}\phi(x)\frac{x_1^2}{|x|^{2+\alpha}} \d x, \quad 0< \alpha < 2 \end{align*} where $\phi\in C_c^N$ for $N\geq 2$. This type of singular integrals and its quadrature rule appear in the numerical discretization of Fractional Laplacian in the non-local Fokker-Planck Equations

in 2D. The quadrature rule is adapted from O. Marin et al, they are trapezoidal rules equipped with correction weights for points around singularity. We prove the order of convergence is $2p+4-\alpha$, where $p\in\mathbb{N}_{0}$ is associated with total number of correction weights. Although we work in 2D setting, we mainly formulate definitions and theorems in $n\in\mathbb{N}$ dimensions for the sake of clarity and generality.

Talk Title: A Kernel-Free Boundary Integral Method for Two-Dimensional Magnetostatic Problems

Speaker Name: Zichao Jin
Affiliation: Illinois Institute of Technology
Email: zjin10@hawk.iit.edu

Abstract: In this research, a kernel-free boundary integral method for solving variable coefficients elliptic partial differential equations in a doubly-connected domain is presented. The KFBIM does not require an explicit form of Green's function for the quadrature, instead, it computes boundary or volume integrals by solving an equivalent interface problem on Cartesian mesh. The problems defined in doubly-connected domain is decomposed into two separate interface problems. Then the integrals are evaluated using a Krylov subspace iterative method in a finite difference framework. The KFBIM is applied to solve a two-dimensional magnetostatic problem, the geometry of the problem is a ring shape, which is usually used as a ring core or toroidal inductor or transformer. The PDEs of the electromagnetic problem is derived and shown and the results is compared with the FEM which is a standard numerical method in engineering area in accuracy and efficiency.

Talk Title: Verifiability of the Data-Driven Variational Multiscale Reduced Order Model

Speaker Name: Birgul Koc
Affiliation: University of Seville
Email: birkoc@alum.us.es

Abstract:
In this paper, we focus on the mathematical foundations of reduced order model (ROM) closures. First, we extend the verifiability concept from large eddy simulation to the ROM setting. Specifically, we call a ROM closure model verifiable if a small ROM closure model error (i.e., a small difference between the true ROM closure and the modeled ROM closure) implies a small ROM error. Second, we prove that a data-driven ROM closure (i.e., the data-driven variational multiscale ROM) is verifiable. Finally, we investigate the verifiability of the data-driven variational multiscale ROM in the numerical simulation of the Burgers equation and a two-dimensional flow past a circular cylinder at Reynolds numbers Re=100 and Re=1000.

Talk Title: Imaging of 3D objects with experimental data using orthogonality sampling methods

Speaker Name: Thu Thi Anh Le
Affiliation: Kansas State University
Email: thule@ksu.edu

Abstract:
We consider the electromagnetic inverse scattering problem that aims to reconstruct the location and shape of an unknown object from the electromagnetic field scattered by that object. It has applications in radar and nondestructive testing. In this talk, we investigate a modified version of the Orthogonality Sampling Method (OSM) for Maxwell's equations. This modification allows the method to work with more types of polarization associated with the data. Numerical results testing against 3D experimental data from the Fresnel institute will be presented. The results show that the modified OSM performs better than its original version in real data verification. This is joint work with Dinh-Liem Nguyen, Hayden Schmidt, and Trung Truong.

Talk Title: Numerical analysis and efficient algorithms for solving variational data assimilation problem

Speaker Name: Xuejian Li
Affiliation: Mathematics and Statistics department, Missouri S&T
Email: xlcdt@umsystem.edu

Abstract: In this report we use a second order parabolic interface equation as an example to show a full picture of the variational data assimilation(VDA) for linear partial differential equations. By using Tikhonov regularization we formulate the data assimilation problem into an optimization problem. Existence, uniqueness, and stability of the optimal solution are established. The standard adjoint operation is utilized to derive the first order continuous optimality system. For numerically solving, a finite element method and the backward Euler scheme are designed in the space and temporal discretization. The optimal convergence rate is demonstrated by recovering the Galerkin orthogonality and other uncertainties. Furthermore, due to the extreme computational cost in VDA, we focus more on reducing the CPU memory requirement and simulation time by developing a variety of efficient algorithms. Finally, numerical results are provided to validate the proposed method.

Keywords— data assimilation, Second order parabolic interface equation, finite element method, optimization, gradient descent, time parallel

Talk Title: An Artificial Compressibility CNLF Method for the Stokes-Darcy Model and Application in Ensemble Simulations

Speaker Name: Ying Li
Affiliation: University of Florida
Email: yli7@ufl.edu

Abstract: We propose and analyze an efficient, unconditionally stable, second order convergent, artificial compressibility Crank--Nicolson leap-frog (CNLFAC) method for numerically solving the Stokes--Darcy equations. The method decouples the fully coupled Stokes--Darcy system into two smaller subphysics problems, which reduces the size of the linear systems to be solved, at each time step, and allows parallel computing of the two subphysics problems. It also decouples the computation of the velocity and pressure in the free flow region. The pressure only needs to be updated at each time step without solving a Poisson equation, avoiding pressure errors in boundary layers due to imposing artificial boundary conditions. We prove that the method is unconditionally long time stable and second order convergent. We also propose an unconditionally stable ensemble algorithm based on the CNLFAC method. The ensemble algorithm results in a common coefficient matrix for all realizations and consequently allows the use of efficient direct or iterative solvers to reduce the computational cost. Numerical experiments are provided to illustrate the second order convergence and unconditional stability of the CNLFAC method. Moreover, the CNLFAC ensemble algorithm is demonstrated to reduce the computational time of a Crank--Nicolson leap-frog nonensemble algorithm by 95% in our tests.

Talk Title: Nonlinear simulation of vascular tumor growth with chemotaxis and the control of necrosis

Speaker Name: Min-Jhe Lu
Affiliation: Department of Applied Mathematics, Illinois Institute of Technology
Email: mlu19@hawk.iit.edu

Abstract: In this work, we develop a sharp interface tumor growth model to study the effect of both the intratumoral structure using a controlled necrotic core and the extratumoral nutrient supply from vasculature on tumor morphology. We first show that our model extends the benchmark results in the literature using linear stability analysis. Then we solve this generalized model numerically using a spectrally accurate boundary integral method in an evolving annular domain, not only with a Robin boundary condition on the outer boundary for the nutrient field which models tumor vasculature, but also with a static boundary condition on the inner boundary for pressure field which models the control of tumor necrosis. The discretized linear systems for both pressure and nutrient fields are shown to be well-conditioned through tracing GMRES iteration numbers. Our nonlinear simulations reveal the stabilizing effects of angiogenesis and the destabilizing ones of chemotaxis and necrosis in the development of tumor morphological instabilities if the necrotic core is fixed in a circular shape. When the necrotic core is controlled in a non-circular shape, the stabilizing effects of proliferation and the destabilizing ones of apoptosis are observed. This is a joint work with Professor Wenrui Hao, Chun Liu, John Lowengrub and Shuwang Li.

Talk Title: Strong and Weak Scaling Performance of the Parallel Immersed Finite Element Particle-in-Cell (PIFE-PIC) Framework

Speaker Name: David Lund
Affiliation: Missouri S&T

Email: dclgzb@mst.edu

Abstract: This study focuses on a recently developed particle simulation code package PIFE-PIC, which is a novel three-dimensional (3-D) Parallel Immersed-Finite-Element (IFE) Particle-in-Cell (PIC) simulation model for particle simulations of plasma-material interactions. This framework is based on the recently developed non-homogeneous electrostatic IFE-PIC algorithm, which is designed to handle complex plasma-material interface conditions associated with irregular geometries using a Cartesian-mesh-based PIC. Three-dimensional domain decomposition is utilized for both the electrostatic field solver with IFE and the particle operations in PIC to distribute the computation among multiple processors. Two different simulations were ran to validate PIFE-PIC and to profile the parallel performance of the code package. The first is a simulation of the orbital-motion-limited (OML) sheath of a dielectric sphere immersed in a stationary plasma using the strong scaling approach. The second is a simulation of the plasma interaction near a flat surface and the resulting physical 1-D photoelectron sheath using the weak scaling approach.

Talk Title: Numerical Solutions for Time-Dependent Schrodinger Equations
Speaker Name: Songting Luo
Affiliation: Iowa State University
Email: luos@iastate.edu

Abstract: The time-dependent Schrodinger equations is challenging to solve numerically despite its wide applications in various areas. This talk will discuss numerical techniques for solving the time-dependent Schrodinger equations with perfectly matched layers. Operator-splitting methods will be adopted to transfer the equation into sub-equations such that one sub-equation is solvable by usual ODE solvers, and the other sub-equation that involves the kinetic operator will be solved by either a Krylov subspace based pseudo-spectral method or an asymptotic time propagator that utilizes asymptotic Green's functions. Numerical example will be presented to demonstrate the methods.

Talk Title: A Green's Function Method for Wave Problems
Speaker Name: Jay Mayfield
Affiliation: Iowa State University
Email: jmayfiel@iastate.edu

Abstract: We present an effective asymptotic Green's function method for propagating the waves through the wave equation. The wave is first split into its forward-propagating and backward-propagating parts. Following that, the method, which combines the Huygens' principle and the geometrical optics approximations, is designed to propagate the forward-propagating and backward-propagating waves, where an integral with Green's functions that is based on the Huygens' principle is used to propagate the waves, and the Green's functions are approximated by the geometrical optics approximations. Upon obtaining analytic approximations for the phase and

amplitude in the geometrical optics approximations through short-time Taylor series expansions, a short-time propagator for the waves is derived and the resulting integral can be evaluated efficiently by fast Fourier transform after appropriate lowrank approximations. The short-time propagator can be applied repeatedly to propagate the waves for a long time. In order to restrict the computation onto a bounded domain of interest, the perfectly matched layer technique with complex coordinate stretching transformation is incorporated. Numerical experiments are presented to demonstrate the proposed method.

Talk Title: A sparse grid fast sweeping WENO method for Eikonal equations
Speaker Name: Zachary Miksis
Affiliation: University of Notre Dame
Email: zmiksis@nd.edu

Abstract: Fixed-point fast sweeping methods are a class of explicit iterative methods developed in the literature to efficiently solve steady state solutions of hyperbolic PDEs. They are explicit and do not involve inverse operation of any nonlinear local system. Hence they are robust and flexible, and have been combined with high order WENO schemes to solve various hyperbolic PDEs in the literature. For multidimensional nonlinear problems, high order fixed-point fast sweeping WENO methods still require quite large amount of computational costs. We apply sparse-grid techniques, an effective approximation tool for multidimensional problems, to reduce the computational costs of fixed-point fast sweeping WENO methods. Here we focus on a robust Runge-Kutta (RK) type fixed-point fast sweeping WENO scheme with third order accuracy for solving Eikonal equations, an important class of static Hamilton-Jacobi (H-J) equations. Numerical experiments on solving multidimensional Eikonal equations and a more general static H-J equation are performed to show that the sparse grid computations of the scheme achieve large savings of CPU times, and at the same time maintain comparable accuracy and resolution with those on corresponding regular single grids. This work is by Zachary Miksis and Yong-Tao Zhang

Talk Title: Learning the G-limits in homogenization problems via physics-informed neural networks
Speaker Name: Jun Sur Richard Park
Affiliation: University of Iowa
Email: junsur-park@uiowa.edu

Abstract: Multiscale equations with scale separation can be approximated by the corresponding homogenized equations with slowly varying homogenized coefficients (G-limits). The traditional homogenization techniques typically rely on the periodicity of the multiscale coefficients, thus finding the G-limits requires some other approaches in more general settings. We consider the inverse problem of recovering the G-limits and the corresponding homogenized solution from given data. In this work, we develop an efficient physics-informed neural networks (PINNs) algorithm for the inverse problem. We demonstrate that our approach could produce desirable approximations to the G-limits and, consequently, homogenized solutions.

Talk Title: QMCPy, a Quasi-Monte Carlo Software Framework
Speaker Name: Aleksei Sorokin
Affiliation: Illinois Institute of Technology
Email: asorokin@hawk.iit.edu

Abstract: Quasi-Monte Carlo (QMC) methods are used in many scientific applications to perform efficient, high dimensional numerical integration. This talk will describe the elements within QMCPy, an open source, Python library that implements research from across the QMC community into a cohesive, extensible framework. We overview the architecture of good QMC software and provide examples illustrating how our package categorizes these principles into an extensible object oriented framework. Specifically, we will overview the point generators, variable transforms (also known as importance sampling), and guaranteed approximation algorithms available in QMCPy.

Talk Title: On Optimal Pointwise in Time Error Bounds and Difference Quotients for Proper Orthogonal Decomposition
Speaker Name: John Singler
Affiliation: Mathematics and Statistics, Missouri University of Science and Technology
Email: singlerj@mst.edu

Abstract: We resolve several long-standing issues dealing with optimal pointwise in time error bounds for proper orthogonal decomposition (POD) reduced order modeling of the heat equation. We show that including difference quotients (DQs) yields optimal POD reduced order model error bounds, and not including DQs yields suboptimal error bounds.

Talk Title: A Phase Field Model for Vesicle Growth or Shrinkage and Nonlinear Multigrid Simulation
Speaker Name: Xiaoxia Tang
Affiliation: Illinois Institute of Technology
Email: xtang15@hawk.iit.edu

Abstract: We present a phase field model for vesicle growth or shrinkage based on osmotic pressure that arises due to a chemical potential gradient. The model consists of an Allen-Cahn-like equation, which describes the phase field evolution, a Cahn-Hilliard-like equation, which simulates the fluid concentration, and a Stokes-like equation, which models the flow. It is mass conserved and surface area constrained during the membrane deformation. Conditions for vesicle growth or shrinkage are analyzed via the common tangent construction. We develop the numerical computing in two-dimensional space using a nonlinear multigrid method comprised of a standard FAS method for the Allen-Cahn and Cahn- Hilliard part, and the Vanka smoothing strategy for the

Stokes part. Convergence tests that suggest a O(t+h^2) accuracy of the solver are performed. We also demonstrate the growth and shrinkage effects graphically and numerically which turns out agree with the conditions analyzed via the common tangent construction.

Talk Title: A numerical method for solving the inverse scattering problem for 3D bi-anisotropic periodic structures

Speaker Name: Trung Truong
Affiliation: Kansas State University
Email: trungt@ksu.edu

Abstract: Direct and inverse scattering problems for three-dimensional bi-anisotropic periodic structures governed by the full Maxwell equation have various applications, especially in the study of photonic crystals. However, most of the existing works are concerned with the case of isotropic structures. Also, the presence of three matrix-valued coefficients that characterize physical properties of the bi-anisotropic periodic scatterers makes the problems technically challenging. Moreover, inverse problems involving periodic structures are known to be highly ill-posed. In this talk, we provide a rigorous justification of the Factorization method for the shape reconstruction of such structures, which utilizes properties of the corresponding integro-differential equation. We also present numerical examples to show efficiency of the method as a numerical tool to solve the inverse problem. This is joint work with Dinh-Liem Nguyen.

Talk Title: Convergence of Solutions of the Nonlocal Conservation-Diffusion law

Speaker Name: Anh Vo
Affiliation: University of Nebraska-Lincoln
Email: anh.vo@huskers.unl.edu

Abstract: Nonlocal models have been more widely studied as an alternative method to study PDE models with discontinuity. Nonlocal interaction is finite long-range interaction between particles. A topic that is undergoing rigorous investigation is the convergence of nonlocal models to local counterparts. In my presentation, I will present the convergence of nonlocal divergence operators and the nonlocal Laplacian operator to their local operators. Then I will present the convergence of solutions of the nonlocal conservation-diffusion equation to the solutions of its local counterparts.

Talk Title: Structure-preserving, energy stable numerical schemes for a liquid thin film coarsening model

Speaker Name: Cheng Wang
Affiliation: University of Massachusetts Dartmouth
Email: cwang1@umassd.edu

Abstract: Positivity preserving, energy stable numerical schemes are proposed and analyzed for the droplet liquid film model, with a singular Leonard-Jones energy potential involved. Both the first and second order accurate temporal algorithms are considered. In the first order scheme, the convex potential and the surface diffusion terms are implicitly, while the concave potential term is updated explicitly. Furthermore, we provide a theoretical justification that this numerical algorithm has a unique solution, such that the positivity is always preserved for the phase variable at a point-wise level. Moreover, an unconditional energy stability of the numerical scheme is derived, without any restriction for the time step size. In the second order numerical scheme, the BDF temporal stencilis applied, and an alternate convex-concave decomposition is derived, so that the concave part corresponds to a quadratic energy. In turn, the combined Leonard-Jones potential term is treated implicitly, and the concave part the is approximated by a second order Adams-Bashforth explicit extrapolation, and an artificial Douglas-Dupont regularization term is added to ensure the energy stability. The unique solvability and the positivity-preserving property for the second order scheme are similarly established. In addition, optimal rate convergence analysis is derived for both numerical schemes. A few numerical simulation results are also presented.

Talk Title: A New Primal-Dual Weak Galerkin Method for Elliptic Interface Problems with Low Regularity Assumptions

Speaker Name: Chunmei Wang
Affiliation: University of Florida
Email: chunmei.wang@ufl.edu

Abstract: This speaker will introduce a new primal-dual weak Galerkin (PDWG) finite element method for second order elliptic interface problems with ultra-low regularity assumptions on the exact solution and the interface and boundary data. It is proved that the PDWG method is stable and accurate with optimal order of error estimates in discrete and Sobolev norms. In particular, the error estimates are derived under the low regularity assumption of $u\in H^{\delta}(\Omega)$ for $\delta>1/2$ for the exact solution u. Extensive numerical experiments are conducted to provide numerical solutions that verify the efficiency and accuracy of the new PDWG method.

Talk Title: Krylov subspace/treecode method for correlated random displacements in Brownian dynamics simulations

Speaker Name: Lei Wang
Affiliation: University of Wisconsin, Milwaukee
Email: wang256@uwm.edu

Abstract: A Krylov subspace/treecode method is applied to accelerate the calculation of correlated random displacements needed for hydrodynamic interactions in Brownian dynamics simulations. The hydrodynamic interactions are given by the Rotne-Prager-Yamakawa tensor in 3D. The spectral Lanczos decomposition method is used to compute the product of the square root of the diffusion tensor with a Gaussian random vector. The barycentric Lagrange treecode is used to

compute the matrix-vector product needed at each step of the iteration. Numerical results are presented for random particles in a cube and particles representing ribosome system.

Talk Title: Forced oscillations of viscous Burger's equation posed on bounded domains
Speaker Name: Taige Wang
Affiliation: University of Cincinnati
Email: taige.wang@uc.edu

Abstract: We establish the wellposedness of periodic solutions for 1D viscous Burgers equation posed in Sobolev spaces $H^s[0; 1]$ where s lies in [0, 2], when a periodic external force is applied. In detail, asymptotical periodicity is proved, then the periodic solution is achieved by selecting a suitable initial data to generate a entire solution

Talk Title: Frictionless indentation of a rigid stamp into a half-space
Speaker Name: Lauren M. White
Affiliation: Kansas State University
Email: laurenmwhite@ksu.edu

Abstract: Material properties at nanoscale exhibit size-dependent behavior which can be attributed to the influence of surfaces and interfaces on the properties of materials. Due to this, contact problems at nanoscale have to take into account surface energy. In this talk, we consider an isotropic half-space subjected to nanoscale contact with a rigid punch. The surface energy in the Steigmann-Ogden form is used to model the half-space while linear elasticity is used to model the bulk of the material. The nanoindentation problem is solved using Boussinesq's displacement potentials and Hankel integral transforms. The problem is reduced to a single integral equation, the character of which is studied, and a numerical method of solution to the corresponding integral equation using Gauss-Chebyshev quadrature is presented.

Talk Title: Impacts of Lightweight Aggregates Interlayers for Air Convection Embankment on Pavement Thermal Profile and Pavement Performance in Alaskan Permafrost Regions
Speaker Name: Hanli Wu
Affiliation: Missouri University of Science and Technology
Email: hwvfn@mst.edu

Abstract: Crushed-rock air convection embankment (ACE) has been used to mitigate pavement distresses caused by climatic extremes in permafrost regions for more than three decades. To overcome the shortage of the crushed rocks needed for ACE in Alaska, this study proposes using the lightweight cellular concrete as a cost-effective alternative material. The performance of six selected pavement structures, including a typical Alaskan asphalt pavement and five pavements

reinforced with different paving interlayers (i.e., silty sand/gravel, crushed rocks, cellular concrete, foam glass aggregates, and lightweight expanded clay aggregates) were investigated. Pavement thermal analyses using TEMPS and ANSYS Fluent were performed to predict the heat transfer patterns and thermal performance of each case. Pavement performance analyses using viscoelastic-based FlexPAVE™ and the elastic-based Alaska Flexible Pavement Design program were conducted to evaluate the long-term performance and structural stability of subgrade soil. The results showed that the lightweight aggregates ACEs improved cooling performance more effectively than the crushed-rock ACE. The lightweight aggregates interlayers could maintain desired thermal insulation in summer and enhance the cooling effect in winter. The modeling results identified the high potential of using lightweight aggregates as alternative ACE materials to improve pavement's service life and subgrade stability.

Talk Title: The reinterpreted discrete fracture model
Speaker Name: Yang Yang
Affiliation: Michigan Technological University
Email: yyang7@mtu.edu

Abstract: In this talk, we construct the reinterpreted discrete fracture model for flow simulation of fractured porous media containing flow blocking barriers on non-conforming meshes. The methodology of the approach is to modify the traditional Darcy's law into the hybrid-dimensional Darcy's law where fractures and barriers are represented as Dirac-delta functions contained in the permeability tensor and resistance tensor, respectively. This model is able to account for the influence of both highly conductive fractures and blocking barriers accurately on non-conforming meshes. The local discontinuous Galerkin (LDG) method is employed to accommodate the form of the hybrid-dimensional Darcy's law and the nature of the pressure/flux discontinuity. The performance of the model is demonstrated by several numerical tests.

Talk Title: Unified mesh free pseudospectral methods for solving classical and fractional PDEs
Speaker Name: Yixuan Wu
Affiliation: Dr. Yanzhi Zhang (My advisor from the mathematics and statistics department of Missouri University of Science and Technology)
Email: ywx7c@umsystem.edu

Abstract: In the recent decade, fractional partial differential equations (PDEs) have been well recognized for their ability to describe anomalous diffusion phenomena in many complex systems, including turbulence, biomedicine and quantum mechanics. Many mathematical models include both classical and fractional Laplacians to describe such a phenomenon. Compared to the classical Laplacian, numerical methods for the fractional Laplacian still remain limited. Additionally, the existing methods have to solve classical and fractional problems separately.

In this talk, I will present a novel meshfree pseudospectral method based on the generalized inverse multiquadric or Gaussian radial basis functions. Our method unifies the discretization of classical

and fractional Laplacians and also bypasses numerical approximation to the hypersingular integral of fractional Laplacian. Our method is simple and easy when handling complex geometries and local refinements, and its computer program implementation remains the same for high dimension. Moreover, two approaches of selecting shape parameters, including condition number indicated method and random-perturbed method, are studied to avoid the ill-conditioning issues when using large number of points.

Talk Title: An Effective Finite Element Iterative Method for Solving an Improved Poisson Nernst–Planck Ion Channel Model
Speaker Name: Dexuan Xie
Affiliation: Department of Mathematical Sciences, University of Wisconsin-Milwaukee
Email: dxie@uwm.edu

Abstract: Over the past decades, significant progress has been made in the development of ion channel models by using a system of Poisson-Nernst-Planck equations (PNP), which is a system of strongly coupled nonlinear partial differential equations. However, how to develop effective finite element algorithms for solving PNP ion channel models remains an interesting research topic. In this talk, I will report an effective finite element iterative algorithm for solving an improved PNP ion channel model, which we construct using a membrane surface charge density and Neumann/periodic boundary value conditions in order to reflect charge effect from membrane and membrane influence from the outside of a simulation box domain. This algorithm has been implemented as a software package for an ion channel protein in a mixture solution of multiple ionic species. Numerical results will be presented to demonstrate the convergence and performance of the iterative algorithm for a voltage-dependent anion-channel protein in a solution of up to four ionic species.

Talk Title: Cell-average based neural network method for partial differential equations
Speaker Name: Jue Yan
Affiliation: Iowa State University
Email: jyan@iastate.edu

Abstract: In this talk, we present the cell-average based neural network (CANN) method for partial differential equations. The CANN method is motivated by finite volume scheme and is based on the integral or weak formulation of partial differential equations. A simple feed forward network is forced to learn the solution average evolution between two neighboring time steps. Offline supervised training is carried out to obtain the optimal network parameter set, which uniquely identifies one finite volume like neural network method. Once well trained, the network method is implemented as an explicit finite volume method. Different to traditional numerical methods, our method can be relieved from the explicit scheme CFL stability small time step size restriction and can adapt to almost any large time step size for solution evolution in time. First order of convergence is observed for parabolic and fourth order PDEs and second order of convergence is observed for hyperbolic and dispersive and fifth order PDEs. The cell-average based neural

network method can sharply evolve contact discontinuity with almost zero numerical diffusion introduced. Shock and rarefaction waves are well captured for nonlinear hyperbolic conservation laws.

Talk Title: A High-Order Immersed C0 Interior Penalty Method for Biharmonic Interface Problems
Speaker Name: Xu Zhang
Affiliation: Oklahoma State University
Email: xzhang@okstate.edu

Abstract: We introduce a high-order immersed C0 interior penalty method is for solving biharmonic interface problems on unfitted mesh. The P2 and P3 immersed finite element (IFE) spaces are constructed to accommodate biharmonic interface conditions in the least-squares sense. Basic properties of the new IFE spaces such as unisolvence and partition of unity are analyzed. A C0 interior penalty scheme with the new IFE space is proposed to solve the biharmonic interface problems. We proved the well-posedness of the discrete problem. Extensive numerical experiments show optimal convergence in L2, H1 and H2 norms. This is joint work with Yuan Chen.

Talk Title: Applications of Machine Learning Techniques to Geophysical Problems
Speaker Name: Yanwei Zhang
Affiliation: Missouri University of Science and Technology
Email: yzcd4@umsystem.edu

Abstract: In order to understand the internal structure of the Earth and detect earthquakes, tens of thousands of seismic stations have been deployed around the world since the early 1960s. A huge amount of seismic waveform data have been collected from these stations, resulting in challenges in processing and analyzing the data in a timely manner. Therefore, by taking the recent revolution in Artificial Intelligence and especially Machine Learning (ML), developing more reliable and efficient methods for data processing is an essential task in geophysical research. Here, we established Convolutional Neural Networks (CNNs) to solve two Geophysical problems: auto classification of event types (earthquakes, collapses, and explosions) and auto ranking of shear wave splitting (SWS) measurements from seismic waveforms. Both CNNs are trained by human-verified datasets. Comparing with human works, the results reveal that the CNNs can achieve 94.4% accuracy to classify event types in Shandong Province, China, and produce a time reduction of about 80% in ranking SWS measurements with only missing 1.2% human accepted measurements. When some constraints are applied, the splitting parameters of SWS measurements show a high similarity with human-determined measurements.

Talk Title: Kinetic particle modeling of plasma charging and dust transport near the lunar terminator

Speaker Name: Jianxun Zhao
Affiliation: Missouri University of Science and Technology
Email: JZ32K@mst.edu

Abstract: This study presents a modeling investigation of plasma charging and dust transport near the lunar surface at the terminator region. The motions of charged dust grains are governed by the ambient electrostatic fields, together with the Moon's gravitational force. The electrostatic field is obtained through numerical simulations of plasma interactions with a fully kinetic finite-difference particle-in-cell (FD-PIC) code. The code has been validated by the comparison between a 1-D numerical results and the semi-analytical solutions. This study can be used to support potential lunar surface activities by providing a simulation of electrostatic and dust environment within the photoelectron sheath.

Talk Title: Numerical studies on the high-order fractional Laplacian

Speaker Name: Shiping Zhou
Affiliation: Department of Mathematics and Statistics, Missouri University of Science and Technology
Email: szb5g@umsystem.edu

Abstract: In this talk, we will present a numerical method for the high-order fractional Laplacian. First, we will discuss the different definitions of the high-order fractional Laplacian $(-\Delta)^{(\alpha/2)}$, with $2<\alpha<4$, in comparison to the celebrated fractional Laplacian($0<\alpha<2$). We will then propose a novel numerical method for the high-order fractional Laplacian operator. Numerical results will be presented in approximating the operator in solving the Poisson problems. It shows that our method has a 2nd-order accuracy, and if $\alpha=3$ the accuracy can achieve the 3rd-order.

Section IV: List of Participants (Both in-person and online)

(sorted alphabetically by last name; more than sixty students and postdocs)

Akim Adekpedjou, Missouri S&T

Abdullah Al Moinee, Missouri S&T

Ahmed Al-Taweel, University of Arkansas at Little Rock

Azzah Alshekhi, University of Missouri Kansas City

Hussam Alshekhi, University of Missouri Kansas City

Pedro H. A. Anjos, Illinois Institute of Technology

Mahboub Baccouch, University of Nebraska at Omaha

Wolfgang Bangerth, Colorado State University

Mary Barker, Washington University in St. Louis

Amlan K. Barua, Indian Institute of Technology Dharwad

Bo Bi, Missouri S&T

Hunter Boswell, Missouri S&T

Yassine Boubendir, New Jersey Institute of Technology

Guy Easton Brawley, Missouri S&T

James Burton, University of Arkansas

Jia Cai, Huaiyin Normal University

Shuhao Cao, Washington Univ in St. Louis

Yue Cao, Illinois Institute of Technology

John Austin Carter, Missouri S&T

Haroldo Chacon, Missouri S&T

Zhen Chao, University of Michigan – Ann Arbor

Yuan Chen, Ohio State University

ZhiQiang Chen, University of Missouri - Kansas City

Qing Cheng, Purdue University

Stephen Clark, Missouri S&T

Mustafa Danis, Iowa State University

Tuhin Kanti Das, Missouri S&T

Lucas Delibas, University of Missouri-Kansas City

Emmanuel Masavo Djegou, Missouri S&T

Sarah Locke Eskew, Eastern Kentucky University

Stephen S. Gao, Missouri S&T

Yijin Gao, Iowa State University

Mahdi Gharehbaygloo, Missouri S&T

Xuan Gu, University of Arkansas

Ruchi Guo, University of California, Irvine

Daoru Han, Missouri S&T

Daozhi Han, Missouri S&T

Weimin Han, University of Iowa

Md Fahim Hasan, Missouri S&T

Xiaoming He, Missouri S&T

Ryan Holley, University of Arkansas

Michael Hood, Northern Illinois University

Scott Hootman-Ng, University of Nebraska-Lincoln

Tamas Horvath, Oakland University

Wenqing Hu, Missouri S&T

Weizhang Huang, University of Kansas

Saqib Hussain, Texas A&M International University

Matt Insall, Missouri S&T

Yan Jia, Missouri S&T

Nan Jiang, University of Florida

Senbao Jiang, Illinois Institute of Technology

Zichao Jin, Illinois Institute of Technology

Tulin Kaman, University of Arkansas

Fritz Keinert, Iowa State University

Sarah Sarfaraz Khan, Missouri S&T

DongHyun Kim, Missouri S&T

Birgul Koc, University of Seville

Robert Krasny, University of Michigan

Thu Thi Anh Le, Kansas State University

Shuwang Li, Illinois Institute of Technology

Xuejian Li, Missouri S&T

Ying Li, University of Florida

Chuanjun Liu, Missouri S&T

James Liu, Colorado State University

Kelly Liu, Missouri S&T

Tao Lin, Virginia Tech

Min-Jhe Lu, Illinois Institute of Technology

David Lund, Missouri S&T

Songting Luo, Iowa State University

Sayantan Majumdar, Missouri S&T

Zachary Miksis, University of Notre Dame

Connor Murphy, Northern Illinois University

Jason Murphy, Missouri S&T

Jawad A. M. Najjar, Northern Illinois University

Kacper Ostalowski, Northern Illinois University

Omer Oztoprak, Northern Illinois University

Jun Sur Richard Park, University of Iowa

Michael Pieper, University of Nebraska Lincoln

Petronela Radu, University of Nebraska-Lincoln

V. A. Samaranayake, Missouri S&T

Jyoti Saraswat, Thomas More University

Steven Sierra, Oklahoma State University

John Singler, Missouri S&T

Aleksei Sorokin, Illinois Institute of Technology

Ze Sun, Missouri S&T

Joseph Braxton Stubblefield, University of Arkansas

Dongliang Tan, Changchun University of Science and Technology

Jifu Tan, Northern Illinois University

Xiaoxia Tang, Illinois Institute of Technology

Trung Truong, Kansas State University

Emily Vines， University of Arkansas-Fort Smith

Anh Vo, University of Nebraska-Lincoln

Cheng Wang, University of Massachusetts Dartmouth

Chunmei Wang, University of Florida

Lei Wang, University of Wisconsin, Milwaukee

Taige Wang, University of Cincinnati

Yumeng Wang, Missouri S&T

Pu Wang, The Boeing Company

Lauren White, Kansas State University

Charuka Dilhara Wickramasinghe, Wayne State University

Hanli Wu, Missouri S&T

Sung-Heng Wu, Missouri S&T

Yixuan Wu, Missouri S&T

Dexuan Xie, University of Wisconsin-Milwaukee

Jue Yan, Iowa State University

Yang Yang, Michigan Technological University

Zhe Yu, Harbin Institute of Technology/Shenzhen

Youxin Yuan, Missouri S&T

Bangwei Zhang, The Boeing company

Fan Zhang, Missouri S&T

Xu Zhang, Oklahoma State University

Yanwei Zhang, Missouri S&T

Yanzhi Zhang, Missouri S&T

Jianxun Zhao, Missouri S&T

Shiping Zhou, Missouri S&T

Qiao Zhuang, Worcester Polytechnic Institute

Section V: Organizing Committee

Committee Chair:
Xiaoming He (Missouri S&T, Department of Mathematics and Statistics)

Committee Members:
Steve Gao (Missouri S&T, Department of Geosciences and Geological and Petroleum Engineering)

Daoru Han (Missouri S&T, Department of Mechanical and Aerospace Engineering)

Daozhi Han (Missouri S&T, Department of Mathematics and Statistics)

Nan Jiang (University of Florida, Department of Mathematics)

John Singler (Missouri S&T, Department of Mathematics and Statistics)

Pu Wang (The Boeing Company, St. Louis)

Yanzhi Zhang (Missouri S&T, Department of Mathematics and Statistics)

Section VI: Midwest Numerical Analysis Day

The **Midwest Numerical Analysis Day (MWNADay)** is a forum for researchers at all stages of their careers, mainly from the Midwest, to exchange ideas in numerical analysis, scientific computing and related application areas. Participation of graduate students is strongly encouraged.

Steering Committee of MWNADay

Kendall Atkinson (University of Iowa, Department of Mathematics)

Mahboub Baccouch (University of Nebraska at Omaha, Department of Mathematics)

Weimin Han (University of Iowa, Department of Mathematics)

Xiaoming He (Missouri S&T, Department of Mathematics and Statistics)

Weizhang Huang (University of Kansas, Department of Mathematics)

Fritz Keinert (Iowa State University, Department of Mathematics)

Shuwang Li (Illinois Institute of Technology, Department of Applied Mathematics)

Jie Shen (Purdue University, Department of Mathematics)

Dexuan Xie (University of Wisconsin – Milwaukee, Department of Mathematical Sciences)

Section VII: Missouri University of Science and Technology

150 year of excellence in innovation
And we're just getting started.

Missouri University of Science and Technology (Missouri S&T) was founded in 1870, during the height of the Industrial Revolution, to educate the builders and makers of that era. Known then as the Missouri School of Mines and Metallurgy (MSM) and later as the University of Missouri-Rolla (UMR), today's Missouri S&T is a leading STEM-focused university built on a proud heritage of discovery and innovation.

S&T is expanding its excellence in innovation today thanks to the generous **$300 million donation** from the late Fred Kummer, a 1955 graduate, and his wife June. It is the largest single gift to any university, public or private, in the state of Missouri. Learn more at **KummerInstitute.mst.edu**.

We are investing in our infrastructure, too, with a new master plan, an $18 million arrival district, and an envisioned $200 million manufacturing technology and innovation campus. Learn more about this progress at **masterplan.mst.edu**.

Missouri S&T offers 101 degrees in 40 different areas of study, from mathematics and statistics to business, computer science, education, engineering, information technology, the physical and social sciences, and the humanities and liberal arts. Known for its outstanding return on investment, S&T was named the top-value public engineering university of 2021 by College Factual.

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Missouri S&T | Mathematics and Statistics

math@mst.edu

(573) 341-4641

202 Rolla Building
400 W. 12th St.
Rolla, MO 65409-0020