

TriCAMS 2025 Poster Presentations and Abstracts

Zihao Yu- Electro-hydrodynamics modeling of liquid-metal droplets with electrochemical oxidation

Eutectic Gallium-Indium (EGaIn) is a room-temperature liquid metal with tunable surface tension and complex interfacial dynamics under applied electric fields. Due to its high electrical conductivity, fluidity, and low toxicity, EGaIn has gained significant interest for applications in robotics, electronics, and biomedical devices. In this work, we consider the dynamics of an EGaIn droplet immersed in a NaOH electrolyte on a flat substrate. A one-dimensional lubrication model is developed for the film thickness of the liquid metal and the oxide concentration at the EGaIn/NaOH interface. This model incorporates Marangoni effects, bulk surface tension, modified intermolecular forces, and an electrochemical oxidation flux determined by a two-dimensional multiphase electric field model. Using the coupled model, we numerically study the spatiotemporal evolution of the droplet shape and the surface oxide concentration under various electric potential boundary conditions. We demonstrate fundamental droplet behaviors such as wetting, dewetting, and directional transport. Furthermore, the simulations reveal that complex dynamics, including droplet coalescence and splitting, can be achieved by altering boundary voltages over time, offering a potential framework for programmable liquid metal manipulation.

Elly Do- An Adaptive Black-Box Algorithm for Hierarchically Semi-Separable Matrix Compression and Factorization

TBD

Troy Larsen- Total HSIC: A New Index for Global Sensitivity Analysis

Global sensitivity analysis (GSA) is a fundamental component of uncertainty quantification used to identify which input parameters most influence a model's output. Traditional methods, such as variance-based Sobol' indices, are limited because they only capture influence that manifests through variance and assume statistical independence of inputs. This can lead to inaccurate sensitivity scores, particularly when dealing with complex, non-linear dependencies.

We propose an alternative approach using the Hilbert-Schmidt Independence Criterion (HSIC). Unlike variance-based methods, HSIC is a non-parametric measure that captures general statistical dependence, including non-linear and higher-order effects, by embedding probability distributions into Reproducing Kernel Hilbert Spaces (RKHS). Our findings demonstrate that this approach offers a compelling and flexible alternative to traditional GSA methods, capable of detecting a wider range of statistical dependencies.

Julia Sanger -Tailored identifiability analysis approaches for model reduction with applications to fibrin polymerization

In wound healing, fibrin polymerization plays an essential role in clot retraction. We consider techniques for data driven and computational modeling of the polymerization of fibrinogen into fibrin matrix as mediated by thrombin, which can be represented as a system of ordinary differential equations with reaction rates as parameters. Our approaches enable investigation of relationships between tunable system properties and functional outcomes. We combine randomized initialization, parameter estimation, and local sensitivity based identifiability techniques to develop a tailored approach for model reduction.

The randomized approach allows for examination of model behavior over several realizations and yields candidates for model reduction via consistently non-influential parameters. A reduced model is identified systematically, and consistently identifiable parameters are estimated and compared across experimental designs.

Jessie Chen- Optimal Sensor Placement for Gaussian Processes using Column Subset Selection

Gaussian processes use data measured at a finite number of sensor locations to reconstruct a spatially dependent function with quantified uncertainty. However, since one can only deploy a finite number of sensors, it is important to determine how to optimally place the sensors to minimize a measure of the uncertainty in the reconstruction. We consider the Bayesian D-optimality criterion to determine the optimal sensor locations by choosing k sensors from a candidate set of m sensors. Since this is an NP-hard problem, our approach uses sensor placement as a column subset selection problem (CSSP) on the covariance matrix, computed using the kernel function on the candidate sensor points. We propose an algorithm that uses the Golub-Klema-Stewart framework (GKS) to select sensors and provide an analysis of lower bounds on the D-optimality of these sensor placements. To reduce the computational cost in the GKS step, we propose and analyze randomized Nyström approximations on the kernel matrix. We demonstrate the performance of our method on two applications: fiber coating dynamics and sea surface temperature.

Sam Thornton- A Multi-Region SEIR Model Incorporating Inter-County Mobility and Time-Dependent Transmission Dynamics

TBD

Madhumita Roy- Two-Point Boundary Value Problems for Quasi-Monotone Dynamical Systems

In this talk we will study the existence of minimal solutions to two-point boundary value problems for quasi-monotone dynamical systems. Specifically, the pointwise infimum of all supersolutions is shown to coincide with the minimal solution. This result is then applied to establish a non-uniqueness result for strong stable solutions to a class of mean field games with a continuum of players.

Harshit Bhatt- Adaptive randomized methods for Hessian Approximation

Inverse problems constrained by partial differential equations (PDEs) are ubiquitous, arising from geophysics and medical imaging to climate modeling. Solving such problems efficiently often requires second-order optimization methods that rely on the Hessian of the data misfit functional. However, for large-scale discretizations, explicitly forming or storing the Hessian is computationally expensive or even infeasible. In this work, we develop adaptive matrix-free strategies to approximate the Gauss–Newton Hessian using hierarchical and randomized techniques.

Zihao Yu- Electro-hydrodynamics modeling of liquid-metal droplets with electrochemical oxidation

Eutectic Gallium-Indium (EGaIn) is a room-temperature liquid metal with tunable surface tension and complex interfacial dynamics under applied electric fields. Due to its high electrical conductivity, fluidity, and low toxicity, EGaIn has gained significant interest for applications in robotics, electronics, and

biomedical devices. In this work, we consider the dynamics of an EGaIn droplet immersed in a NaOH electrolyte on a flat substrate. A one-dimensional lubrication model is developed for the film thickness of the liquid metal and the oxide concentration at the EGaIn/NaOH interface. This model incorporates Marangoni effects, bulk surface tension, modified intermolecular forces, and an electrochemical oxidation flux determined by a two-dimensional multiphase electric field model. Using the coupled model, we numerically study the spatiotemporal evolution of the droplet shape and the surface oxide concentration under various electric potential boundary conditions. We demonstrate fundamental droplet behaviors such as wetting, dewetting, and directional transport. Furthermore, the simulations reveal that complex dynamics, including droplet coalescence and splitting, can be achieved by altering boundary voltages over time, offering a potential framework for programmable liquid metal manipulation.

Patrick Martin II- Torsion in Graph Magnitude Homology

Magnitude homology is a bigraded homology theory for finite graphs introduced by Hepworth and Willerton, serving as a categorification of the power series invariant known as magnitude, originally defined by Leinster. Building on the results of Kanata-Yoshinaga, Sazdanovic-Summers, and Asao-Izumihara, we show that for your favorite finitely generated abelian group A , we can embed it almost anywhere in the theory of graph magnitude homology.

Paul Spears- Numerical Computation and Identification of Electromagnetic Vortex Knots

Topological vortex knots propagated by electromagnetic beams have been modeled theoretically using the paraxial wave equation. They have also been observed experimentally, but their identification in the received field required human intervention. This project uses a combination of analytical and computational methods to fully automate vortex knot identification, accompanied by numerical simulations to assess its robustness. The results can be used for estimating the capacity of communication channels where the transmitted and received knots serve as alphabet symbols in information theory.

Matthew Nuyten- Provable avoidance of barren plateaus for the Quantum Approximation Algorithm with Grover mixers

We analyze the dynamical Lie algebras (DLAs) associated with the Grover-mixer variant of the Quantum Approximate Optimization Algorithm (GM-QAOA).

When the initial state is the uniform superposition of computational basis states, we show that the corresponding DLA is isomorphic to

$$\mathbb{C}^{\frac{su}{d}} \oplus \mathbb{C}^{\frac{u}{1}} \oplus \mathbb{C}^{\frac{u}{1}},$$

where d denotes the number of distinct values of the objective function.

We also establish an analogous classification for other choices of initial states and Grover-type mixers. Furthermore, we prove that the DLA of GM-QAOA has the largest possible commutant among all QAOA variants initialized with the same state, corresponding physically to the maximal set of conserved quantities.

We derive an explicit formula for the variance of the GM-QAOA loss function in terms of the objective function values, and we show that for a broad class of optimization problems, GM-QAOA with sufficiently many layers avoids barren plateaus.

Nakul Haridas- Failure Cases of t-SNE

Showing that the dimension reduction algorithm has infinite local minima.

Pat Haughey- Statistical Validation of Transionospheric SAR Autofocus Using Large-Scale Synthetic Simulations

We investigate transionospheric SAR autofocus through large-scale synthetic simulations and global optimization. Local, multi-start, and swarm-based gradient methods are compared under varying ionospheric phase distortions and clutter modeled via Rayleigh statistics. While global schemes reduce cost function values, improvements in image quality metrics (NCC, ISLR, PD) depend strongly on clutter and initialization. In low-clutter environments, our autofocus cost function is well tuned to recover high-fidelity images closely matching the true scene, demonstrating robust phase error correction and efficient convergence across thousands of randomized scenarios.

Xiao Shen- Random growth and the KPZ universality class

TBD

Ala' Alalabi- Well-posedness and Optimal Control in Poroelasticity

Fluid flows through deformable, porous media arise in numerous applications, ranging from geophysics to biomedicine. Such processes are described using poroelastic models which couple parabolic-elliptic partial differential equations (PDEs), describing the interaction between fluid transport and mechanical deformation. Mathematically, these coupled systems belong to the class of implicit, degenerate evolution equations. While the existence and regularity theory for such systems is well established, optimal control problems constrained by poroelastic dynamics, especially relevant in biomedical applications, have only recently been considered. These control problems are challenging due to the degeneracy of the equations, the implicit nature of the coupling, and the structure of the control-to-state map. In this work, we analyze the system using radiality theory - a generalization of the classical Hille-Yosida framework for non-explicit evolution equations. This abstract formulation yields new insights into well-posedness theory and enables a unified treatment of linear control problems constrained by degenerate evolution dynamics.

Jiajia Yu- TBD

TBD

Chuxiangbo Wang- Independent Component Analysis in Wasserstein Space

This project develops and analyzes the independent component analysis (ICA) framework in Wasserstein space. The motivation arises from data analysis scenarios where each observation is naturally represented as a probability measure or point-cloud, such as in gene expression studies. Traditional ICA methods effectively identify independent components in Euclidean spaces, but may lose important structural information when applied to point-cloud data. To address this gap, we propose extending ICA into Wasserstein space. We demonstrate how spectral ICA methods, utilizing the Wasserstein distance, can identify independent components from probability measures or point-cloud data.

Ian Stevenson- Collective Dynamics of Walking Droplets: Towards a Hydrodynamic Analog of Quantum Condensates

Millimetric droplets may "walk" along the surface of a vibrating fluid bath, self-propelled through a resonant interaction with the waves they generate upon each bounce. Here, we investigate the collective dynamics of many such "walkers" confined within a circular corral. We demonstrate that wave-mediated interactions drive a transition from an uncoupled, gas-like state to a coherent, global wave state in a manner reminiscent of quantum condensates approaching absolute zero. We systematically sweep the parameter space to characterize this collective transition in terms of corral size, particle packing and inertia, path memory, and pilot-wave extent. Notably, we also observe a resonance between corral size and this global wave state, which reappears periodically with increasing corral radius. Special attention is given to elucidating the mechanisms underlying both the emergence of the global wave state and its resonance with corral size. As the bath's vertical forcing increases, the effective size of the wave packet produced by each walker grows, eventually saturating the domain and coupling the dynamics of all walkers through a system-wide mean wave potential. The associated corral-size resonance arises from the interference pattern generated by local wave contributions over a disc. We conclude by discussing the experimental realization of such wave-mediated collective dynamics, which has thus far been hindered by droplet-droplet coalescence and desynchronization of their vertical bouncing phases. This collective walker framework opens new avenues for exploring wave-mediated active matter and developing hydrodynamic analogs of quantum many-body phenomena, including quantum condensates, many-body localization, and Hall phases.

Siu Wun "Tony" Cheung- TBD

TBD

Kaitlyn Hohmeier- Application of Gromov-Wasserstein Optimal Transport to Graph Classification Problems

Gromov-Wasserstein (GW) optimal transport provides a framework with which to compare metric measure spaces, regardless of their underlying structure or geometry. For network-based data, this framework enables direct comparisons of graphs with different numbers of nodes, without an embedding or other abstraction. Furthermore, through a variant of GW known as fused GW (fGW), it is also possible to incorporate node features, in addition to graph structure. Due to this geometry-invariance, we are interested in using GW optimal transport and its variants to build computationally efficient and accurate classification algorithms for graph datasets. In particular, we present a proof-of-concept involving GW and fGW barycenters in nearest centroid classification (NCC) and implement the GW, generalized linear GW (gLGW), and fGW distances in k-nearest neighbors (kNN) classification. While classification results for NCC are mixed, GW-kNN and fGW-kNN consistently performed well across multiple datasets, suggesting that metric classifiers such as kNN work well in the GW framework. We further prove the universal consistency of the GW-kNN classifier on the space of equivalence classes of metric measure spaces with finite support and uniform probability measure. By viewing graphs as finitely-supported metric measure spaces equipped with the pairwise distance metric and equipped with uniform probability measure on the nodes, we have universal consistency of GW-kNN for the space of graphs.

Amartya Banerjee- Adaptive Multimodal Protein Plug-and-Play with Diffusion-Based Priors

In an inverse problem, the goal is to recover an unknown parameter (e.g., an image) that has typically undergone some lossy or noisy transformation during measurement. Recently, deep generative models, particularly diffusion models, have emerged as powerful priors for protein structure generation. However, integrating noisy experimental data from multiple sources to guide these models remains a significant challenge. Existing methods often require precise knowledge of experimental noise levels and manually tuned weights for each data modality. In this work, we introduce Adam-PnP, a Plug-and-Play framework that guides a pre-trained protein diffusion model using gradients from multiple, heterogeneous experimental sources. Our framework features an adaptive noise estimation scheme and a dynamic modality weighting mechanism integrated into the diffusion process, which reduce the need for manual hyperparameter tuning. Experiments on complex reconstruction tasks demonstrate significantly improved accuracy using Adam-PnP.

Yi Gong- A Plug-and-Play Framework for Volumetric Light-Sheet Image Reconstruction

Cardiac contraction is a rapid, coordinated process that unfolds across three-dimensional tissue on millisecond timescales. Traditional optical imaging is often inadequate for capturing dynamic cellular structure in the beating heart because of a fundamental trade-off between spatial and temporal resolution. To overcome these limitations, we propose a high-performance computational imaging framework that integrates Compressive Sensing (CS) with Light-Sheet Microscopy (LSM) for efficient, low-phototoxic cardiac imaging. The system performs compressed acquisition of fluorescence signals via random binary mask coding using a Digital Micromirror Device (DMD). We propose a Plug-and-Play (PnP) framework, solved using the alternating direction method of multipliers (ADMM), which flexibly incorporates advanced denoisers, including Tikhonov, Total Variation (TV), and BM3D. To preserve structural continuity in dynamic imaging, we further introduce temporal regularization enforcing smoothness between adjacent z-slices. Experimental results on zebrafish heart imaging under high compression ratios demonstrate that the proposed method successfully reconstructs cellular structures with excellent denoising performance and image clarity, validating the effectiveness and robustness of our algorithm in real-world high-speed, low-light biological imaging scenarios.

David Hernandez- Strong and Weak Solutions for a Multiscale Interface Coupling of Poroelasticity and Lumped Hydraulic Systems

We consider a heterogeneous system which consists of a (locally accurate) 3D descriptive model of fluid flowing through deformable porous media equations, coupled with a systemic 0D lumped model of the remainder of the circulation, where the fluid flow through a vascular network is described via its analogy with a current flowing through an electric circuit. In this talk, we present new results on wellposedness of strong and weak solutions for this multiscale interface coupling.

Aric Wheeler- Behavior of small-amplitude waves in thin films with surfactants

We study a coupled system of nonlinear PDE derived from a lubrication model of a thin film with an insoluble surfactant flowing down an inclined plane. Motivated by understanding the stability of viscous shocks in this model, we first use Fourier analytic techniques to understand the stability of uniform states. We find that the gravity-driven nature of the problem yields fast- and slow-wave modes. This physically motivated system is unusual because in some parameter regimes it has a lack of dissipation.

For the fast mode, we find the long-time behavior approaches similarity solutions of a certain Burgers' equation. For the slow mode, we observe that the form of the solution is sensitive to the form of regularization present in the system and can yield diffusive or dispersive waves in different regimes. Finally, our linear analysis yields predictions of the diffusion and dispersion coefficients for reduced models for the long-time behavior.

Jiaqi Zhang- Discrete Superconvergence Analysis for Quantum Magnus Algorithms of Unbounded Hamiltonian Simulation

Motivated by various applications, unbounded Hamiltonian simulation has recently garnered great attention. Quantum Magnus algorithms, designed to achieve commutator scaling for time-dependent Hamiltonian simulation, have been found to be particularly efficient for such applications. When applied to unbounded Hamiltonian simulation in the interaction picture, they exhibit an unexpected superconvergence phenomenon. However, existing proofs are limited to the spatially continuous setting and do not extend to discrete spatial discretizations.

In this work, we provide the first superconvergence estimate in the fully discrete setting with a finite number of spatial discretization points N , and show that it holds with an error constant uniform in N . The proof is based on the two-parameter symbol class, which, to our knowledge, is applied for the first time in algorithm analysis. The key idea is to establish a semiclassical framework by identifying two parameters through the discretization number and the time step size rescaled by the operator norm, such that the semiclassical uniformity guarantees the uniformity of both. This approach may have broader applications in numerical analysis beyond the specific context of this work.

Ling Zhou- Persistent Cup-Length: A New Invariant for Topological Structure Detection

Persistent cohomology enhances persistent homology by incorporating the cup product, introducing a graded ring structure that encodes higher-order topological information. We define the persistent cup-length, an invariant that tracks the evolution of nontrivial cup products across a filtration. This captures interactions between cohomology classes, offering insights beyond what homology alone can provide. We present a polynomial-time algorithm for computing this invariant from representative cocycles and prove its stability under interleaving-type distances. We also provide the first practical implementation, optimized through integration with Ripser and landmark subsampling. Applied to neural population data, our method successfully detects toroidal structure in neural manifolds, which persistent homology alone fails to reliably identify.

Lorenzo Micalizzi- Algorithms of very high space-time orders of accuracy for hyperbolic equations in the semidiscrete WENO-DeC framework

In recent years, there has been a growing interest within the scientific community in high order numerical methods. Compared with low order ones, such schemes can achieve, for smooth problems, smaller errors on coarser meshes within shorter computational times, offering significant computational benefits. Despite this fundamental advantage, high order methods introduce additional challenges: their implementation is considerably more complex than that of low order ones, and they are more susceptible to nonphysical oscillations that may even cause simulation breakdowns. Consequently, these methods remain largely confined to academic research, and even in this setting, problems involving discontinuities rarely employ orders higher than five.

In this presentation, we explore very high order realizations of a general framework for solving hyperbolic PDEs numerically, based on a Finite Volume semidiscretization with WENO spatial reconstruction and Deferred Correction time integration.

The method is examined up to 13-th order on a broad set of test cases, including smooth flows, strong discontinuities, and long-time evolutions.

We discuss both the advantages and the limitations of employing extremely high order space-time discretizations, analyze the influence of the numerical flux in this setting, and highlight the accuracy degradation that occurs when pairing a high order spatial reconstruction with a lower order temporal scheme.

Yuliang Wang- TBD

TBD

Chenxi (Thea) Wang- Effect of Local Topological Changes on Resistance in Tunably-Disordered Networks

Disordered materials arise in nature and also offer a larger design space than ordered or crystalline structures. Here, we investigate a two-dimensional disordered network metamaterial created from a Delaunay triangulation of an underlying point pattern.

Small perturbations in the point pattern cause topological changes to the network that, in turn, can create sizable jumps in the effective resistance measured diagonally across the network. We show numerically that effective resistance exhibits a spatially heterogeneous response to local topological changes:

Delaunay edge flips near the neighborhood of the source or sink of current cause the largest change in effective resistance. This is further explained analytically through a derivation of the effect of a single edge flip on the effective resistance. The derivation shows that edges with a large voltage difference produce larger changes in the effective resistance. In particular, these edges are found near the source or sink nodes. Localized topological effects are of interest for finite-sized physical samples and experimentally measurable properties such as electrical transport, yet they have a limited global effect. Specifically, we show that the global measurement of total effective resistance has much smaller jumps than the effective resistance, and increasing the network size decreases the effect of localized topological changes on the effective resistance. Together, this work highlights how global characterizations of the network or disorder may be insufficient for predicting experimentally realizable transport properties of such disordered network metamaterials, as well as the importance of specific localized regions in the design of such materials. Work mentored under Dr. Katie Newhall.

Kangning Cui (Jason)- Efficient Localization and Spatial Distribution Modeling of Canopy Palms Using UAV Imagery

Understanding the spatial distribution of palms in tropical forests is essential for ecological monitoring, conservation strategies, and the sustainable integration of natural forest products into local and global supply chains. However, the analysis of remotely sensed data is challenged by overlapping palm and tree crowns, uneven shading across the canopy surface, and the heterogeneous nature of the forest landscapes, which often affect the performance of palm detection and segmentation algorithms. To overcome these issues, we introduce PalmDSNet, a deep learning framework for efficient detection, segmentation, and counting of canopy palms. To model spatial patterns, we introduce a bimodal reproduction algorithm that simulates palm propagation based on PalmDSNet outputs. We used

UAV-captured imagery to create orthomosaics from 21 sites across western Ecuadorian tropical forests, covering a gradient from the everwet Chocó forests near Colombia to the drier forests of southwestern Ecuador. By integrating detection and spatial modeling, we effectively simulate the spatial distribution of palms in diverse and dense tropical environments, validating its utility for advanced applications in tropical forest monitoring and remote sensing analysis.

Shenghan Mei- TBD

TBD

Connor Magoon- Differentiation Through Black-Box Quadratic Programming Solvers

Differentiable optimization has attracted significant research interest, particularly for quadratic programming (QP). Existing approaches for differentiating the solution of a QP with respect to its defining parameters often rely on specific integrated solvers. This integration limits their applicability, including their use in neural network architectures and bi-level optimization tasks, restricting users to a narrow selection of solver choices. To address this limitation, we introduce dQP, a modular and solver-agnostic framework for plug-and-play differentiation of virtually any QP solver. Our key theoretical insight is that the solution and its derivative can each be expressed in terms of closely-related and simple linear systems by using the active set at the solution. This insight enables efficient decoupling of the QP's solution, obtained by any solver, from its differentiation. Our open-source, minimal-overhead implementation will be made publicly available and seamlessly integrates with more than 15 state-of-the-art solvers. Comprehensive benchmark experiments demonstrate dQP's robustness and scalability, particularly highlighting its advantages in large-scale sparse problems.

Frane Ljubetic- Memory-enhanced diffusivity in stochastically forced walking droplets

The motion of particles subject to random perturbations is a ubiquitous problem across fields, including fluid mechanics, active matter, and statistical physics. Whether arising from temporal fluctuations or spatial heterogeneities, such stochastic forces typically lead to diffusive behavior in the long-time limit. A notable exception is Anderson localization, in which diffusion is suppressed due to the interplay between spatial disorder and the wavelike nature of quantum particles. A recent hydrodynamic analog of this phenomenon, observed in walking droplets – which exhibit dual wave-particle behaviors by virtue of their guiding wave field – raises fundamental questions about how path memory governs the emergent transport in wave-dressed active particles. Replacing spatial disorder with temporal fluctuations, here, we demonstrate that walking droplets exhibit an increased orientational persistence and, consequently, an amplified diffusion coefficient compared to inertial active particles lacking wave memory. By analyzing the nonlocal wave forces generated during sharp turns, we identify a wave-mediated restoring force that tends to drive the droplet back toward its previous direction of motion, thereby rationalizing the observed enhancement in diffusivity. Our results arise from generic wave interference effects and may thus extend to other wave-dressed active particle systems, suggesting new strategies for controlling transport via wave-mediated memory.

Xinyun Liu- Emergent Dynamics in Vibrating Active Foams

Foams are complex materials composed of numerous bubbles that intricately adapt their shapes to large-scale geometric constraints, yet are prone to coalescence. Existing stabilization techniques with additives often obscure the foam's intrinsic physics while keeping the system largely passive. Here, we demonstrate that vertical vibration can not only stabilize a densely packed assembly of bubbles but also transform it into an active foam that exhibits rich collective dynamics. In our experiments, a layer of capillary-sized bubbles is held by buoyancy against the top wall of a vertically vibrating fluid chamber. Owing to parametric forcing, each bubble undergoes shape oscillations and, in some regimes, exhibits self-propulsion. Within the assembly, bubbles dynamically deform and rearrange in response to interactions with neighbors. A sweep of bubble size and driving parameters reveals a variety of collective behaviors, including labyrinthine pattern formation, unjamming transitions, and active turbulence. We rationalize the onset of collective motion in terms of the excitation of two oscillation modes: a lateral breathing-like mode that opens gaps, and quadrupolar elongations that promote neighbor exchange. More broadly, our active foam offers a controllable platform to study collective behavior of soft, shape-shifting agents, enabling comparison with biological systems such as cells to reveal universal principles across inert and living deformable active systems.

John Albright- Error Function Regularization: A New Approach to Sparse Logistic Regression

We apply the recently introduced ERF regularization to sparse logistic regression. ERF is a smooth approximating function for the L0 norm that avoids bias from the L1 norm while requiring fewer hyperparameters to tune than other non-convex regularizations such as MCP and SCAD. We adapt an iteratively reweighted L1 scheme to solve the nonconvex optimization problem with guaranteed convergence and demonstrate empirical competitiveness on synthetic and real-world data.

Vasishta Tumuluri- Multifidelity Sensor Placement in Bayesian State Estimation Problems

We consider optimal sensor placement for Bayesian state estimation problems with sensors of varying cost and fidelity. In this special case of the optimal experimental design problem, we quantify optimality using the D-optimality criterion and approach the problem using previously established connections between sensor placement and the Column Subset Selection Problem from numerical linear algebra. We implement a greedy approach for this problem, whose computational efficiency we improve using rank-one updates via the Sherman-Morrison formula. We additionally present an algorithm that, for each feasible allocation of sensors, greedily optimizes over each sensor fidelity subject to previous sensor choices, repeating this process until a termination criterion is satisfied. These are novel approaches in the context of cost-constrained multifidelity sensor placement. We evaluate our methods on several benchmark state estimation problems, including reconstructions of sea surface temperature and flow around a cylinder, and empirically demonstrate improved performance over random designs.

Thuy Le- Expert-guided Causal Bayesian Optimization

Causal Bayesian Optimization (CBO) has emerged as a powerful paradigm for decisionmaking under uncertainty, effectively leveraging causal structures to guide interventions. However, existing CBO methods do not adequately integrate domain-specific expertise, potentially leading to inefficient exploration and suboptimal outcomes in realworld applications involving complex human

decision-making and economic considerations. To bridge this gap, we propose Expert-guided Causal Bayesian Optimization (ECBO), a framework that integrates human expert knowledge into the CBO process. We introduce an expert weighting mechanism that adaptively modulates the Expected Improvement (EI) acquisition function, reflecting expert endorsements or exclusions of candidate solutions. By embedding these expert-derived preferences, our model proactively balances exploration and exploitation. Additionally, we implement a robust harmfree mechanism to guard against potentially detrimental expert interventions, alongside an adaptive trust parameter that dynamically adjusts expert influence based on observed discrepancies. Our experimental results underscore the practical value of effectively incorporating expert knowledge in complex causal environments.

Avery Zapata- A Study of Model Parameters on the Clustering Dynamics of Chromatin

One mechanism leading to chromatin organization is the interplay between stochastic binding dynamics and thermal fluctuations, producing dynamic clustering while permitting gene expression. Central to understanding this process is how molecular crosslinkers such as condensin regulate the spatial and temporal stability of chromatin structures. Building on the framework of Coletti et al. (Phys. Rev. E 111, 044407 (2024)), this work investigates a bead-spring model for chromatin that incorporates Brownian motion, wormlike chain elasticity, and excluded volume interactions within a confined domain. We aim to parameterize a minimal three-bead system to investigate how condensin-like binding and unbinding kinetics, together with other model parameters, influence cluster size, configuration, and lifetime. Ongoing work seeks to extend this framework to longer polymers and varying crosslink densities, providing a foundation for exploring how physical interactions and kinetic processes jointly govern chromatin organization.

Alexander Richardson- Statistically Principled Distance Metrics for Topological Data Analysis

TBD

Bryan Castillo- McKean--Vlasov limits of scaling-critical reaction-diffusion equations with random initial data

We study a large class of scaling-critical reaction-diffusion equations in two spatial dimensions, where the initial data is white noise mollified at scale ε^2 and the reaction term is attenuated by a factor of $(\log \varepsilon^{-1})^{-1}$. We show that as $\varepsilon \rightarrow 0$, the solution converges to the solution of a McKean--Vlasov equation, which is Gaussian with standard deviation given by the solution to an ODE. Our result covers the case of the reaction term $f(u)=u^3$, and thus gives a new proof of the limiting behavior for the Allen--Cahn equation discovered in the recent work of Gabriel, Rosati, and Zygouras (Probab. Theory Related Fields 192: 1373--1446, 2025).

Nabiha Choudhury- Image Denoising Using Transformed L1 (TL1) Regularization via ADMM

We investigate image denoising using the Transformed ℓ_1 (TL1) regularizer within the Alternating Direction Method of Multipliers (ADMM) framework. The TL1 penalty, being non-convex, offers enhanced sparsity in gradient magnitudes while preserving important image edges. We detail the optimization

formulation, ADMM iterations, and experimental results demonstrating the effectiveness of TL1 in Gaussian noise removal.

Philip Warrick- Automated Interpretation of Intrapartum Fetal Monitoring

Labour and delivery is routinely monitored electronically with sensors that measure and record maternal uterine activity (UA) and fetal heart rate (FHR), a procedure referred to as cardiotocography (CTG). The objective of this monitoring is two-fold: to detect the fetus at substantial risk of hypoxic injury so that intervention can prevent its occurrence; to assess the mother's progress in labor, usually observed by cervical dilation. To provide clinicians with more objective and consistent CTG interpretation, research efforts have been ongoing to automate this analysis. The two main objectives here are 1) the detection of the key CTG patterns that correspond to clinical guidelines; and 2) the assessment of the maternal/fetal state from the CTG patterns. CTG analysis is challenged by signal non-stationarity and noise in the form of signal discontinuities and maternal heart rate interference. Machine learning approaches are emerging as promising tools for analyzing these signals and providing accurate and timely diagnostic decision support.

Klaas van de Groep- Rocking Rollers – Spontaneous Self-Propulsion of Vertically Vibrating Spheres Partially-Filled with Liquid

Self-propulsion technology is at the forefront of biomedical engineering, driving advances in microsurgery, targeted drug delivery, and fluid transport. We report the discovery of an exciting spontaneous rolling motion of partially fluid-filled spheres subject to vertical oscillation. Normally, sloshing inside a sphere causes periodically symmetric rocking. However, by inducing a harmonic instability, an asymmetric rocking occurs, resulting in a net motion that propels the sphere laterally across the platform, perpendicular to its vertical driving. In our study, we identify the instability responsible for propulsion, measure the onset threshold across a range of parameters (radius and fluid viscosity), and reconstruct the resulting trajectories and velocities.

Justin Hager- Understanding Correlated Noise in Stochastic Gradient Systems

Stochastic Partial Differential Equations (SPDE's) are continuum models of spatially-extended noisy physical systems. In practice, such models are often explored numerically through problem-specific discretizations. At a critical correlation length scale, the assumption of independent (white) noise fails, and a spatial correlation must be considered. Under certain assumptions, correlated systems obey the same invariant measure as their independent counterparts; however, spatial correlations affect the dynamic behavior and the exploration of the energy landscape. Of particular interest are energy landscapes with multiple minima that exhibit metastability. We therefore study the mean time to transition between local energy minimums, and the expected path between these states. We begin with a two-dimensional correlated system amenable to mathematical analysis, verifying results through numerical simulations.

Ford Khoudary- Polygonal Patterns in Parametrically Driven Active Matter

We investigate the emergence of polygonal patterns arising from the collective dynamics of active particles whose preferred speed is parametrically modulated within a harmonic potential. Using both a discrete active-particle model and a mean-field hydrodynamic model, we analyze the collective behavior under weak forcing, determine the critical threshold for the onset of polygonal modes, and characterize

the emerging dynamics once the patterns are fully developed. Our results are summarized in phase maps parameterized by forcing frequency and driving amplitude, revealing the spectrum of vibration modes and their corresponding stability tongues. Furthermore, by comparing these findings with analogous patterns in Bose–Einstein condensates and Faraday waves, we uncover universal principles of parametric pattern formation and identify a new class of polygonal states exhibiting intrinsic chirality.

Madhusudan Madhavan- A control-oriented approach to optimal sensor placement

We propose a control-oriented optimal experimental design (cOED) approach for linear PDE-constrained Bayesian inverse problems. In particular, we consider optimal control problems with uncertain parameters that need to be estimated by solving an inverse problem, which in turn requires measurement data. We consider the case where data is collected at a set of sensors. While classical Bayesian OED techniques provide experimental designs (sensor placements) that minimize the posterior uncertainty in the inversion parameter, these designs are not tailored to the demands of the optimal control problem. In the present control-oriented setting, we prioritize the designs that minimize the uncertainty in the state variable being controlled or the control objective. We propose a mathematical framework for uncertainty quantification and cOED for parameterized PDE-constrained optimal control problems with linear dependence to the control variable and the inversion parameter. We also present scalable computational methods for computing control-oriented sensor placements and for quantifying the uncertainty in the control objective. Additionally, we present illustrative numerical results in the context of a model problem motivated by heat transfer applications.

Perry Beamer- Multi-Scale Analysis of Spatial Clustering Methods for Tissue Domains with Persistent Homology

Spatial gene-expression data can be clustered to segment a tissue into distinct spatial domains representing tissue structure. Though clustering algorithms are limited to a single fixed scale (by choice of a resolution hyperparameter k), we develop new methods from topological data analysis to analyze patterns in clusters across multiple scales. Zero-dimensional persistent homology analyzes the connectivity of data by tracking changes in homology groups across a filtered simplicial complex. We build a new filtration scheme to analyze similarity between clusters generated from multiple choices of scale parameter k , where persistent components represent clusters which exist across scales. We apply these results to select optimal scale parameters for spatial gene-expression clustering. These results have potential clinical application in tumor identification, where the size and scale of cancerous domains within healthy tissue is not known a priori.

Aaron Jacobson- Collateral Damage in Machine Unlearning

The best-performing machine learning models are often trained on large, internet-sourced datasets, some of which contain billions of samples. For many reasons, including compromise of security or privacy, copyright infringement, unjust bias, or adversarial poisoning, some of this data may have undesirable effects on model training. However, identification of harmful samples can be difficult, and retraining models from scratch is cost-prohibitive. The field of machine unlearning seeks to provide cost- and time-efficient update methods to remove the effects of undesirable data without causing collateral damage to related, non-problematic data. To understand the effects of machine unlearning methods, we investigate the internal representations of data in diffusion-based generative models. We observe that the unlearning process induces changes in latent-space representations of data; importantly, the local

intrinsic dimension of data manifolds is increased when the corresponding classes of data are unlearned. Using this insight, we propose a method to identify data which may be subject to collateral damage from unlearning and measure the degree to which it was affected. Our method consists of two tasks: (1) Brainstorming: the process of identifying classes of data which are at-risk for collateral damage, and (2) Evaluation: the process of quantifying the damage done to these classes.

Avery Paulsen- TBD

TBD

Joseph Clampett- Experimental Investigation of Freely Interacting Walking Droplets

Droplets may walk along the surface of a vertically vibrating fluid bath through resonant interaction with their self-excited wavefield. This macroscopic system, which exhibits dual wave-particle behaviors, has given rise to a range of Hydrodynamic Quantum Analogs that push the boundaries of classical mechanics. However, the experimental exploration of quantum many-body analogs has been hindered by droplet coalescence upon collision. Here, we demonstrate that freely interacting walking droplets can be sustained experimentally by increasing ambient pressure, which widens the range of Weber numbers over which coalescence is prevented. Moreover, because walking droplets bounce subharmonically relative to the bath oscillations, they may chaotically switch out of phase with one another, leading to fundamentally distinct collective phenomena due to wave interference. For experiments requiring vertical phase synchronization, we thus draw from previous ‘superwalker’ studies to show that a second driving frequency may synchronize all droplets’ vertical phase. More broadly, our experimental platform opens new avenues for exploring hydrodynamic analogs of quantum many-body systems, as well as collective phenomena in wave-dressed active matter.

Minji Kim- TBD

TBD

Chuying Huo- Liberata - Novel Academic Metrics for a Share Based Accreditation System of Publishing

The academic publishing system today has three major problems that render it increasingly untenable for modern academic research. First, the metric problem: the lack of accurate metrics on scientific contributions causes nepotistic citations and marginalization of certain demographics from career advancement opportunities. Second, the curation problem: the lack of well-designed incentives for peer review leads to poor quality peer review, which reinforces academia’s dependency on proxy signals of quality like journal prestige. Third, the replication crisis: the lack of any incentives for replicating a study causes most scientific findings to have only a single study backing them.

As a result, retraction rates have been steadily on the rise. This leads to mistrust of scientific literature by academia and the general public. Creative solutions are needed in order to improve fairness, equity and trustworthiness in the academic publishing system. Liberata aims to simultaneously solve these three issues using game-theory-designed incentive structures inspired by the most successful financial instruments and marketplaces devised in human history.

We introduce three key innovations. The first is a shares-based contribution system that allocates proportional ownership of a paper to all contributors. The second is a three-role structure—author, peer reviewer, and replicator—each recognized through shares. The third is a weighted citation system that

normalizes citation value by the total number of references in the citing work. Together, these components generate the References Graph, Shares Graph, and Academic Capital Graph, which enable quantitative insights into scholarly contribution, influence, and integrity.

Meghan Kwon- A Stochastic and Spatial Model of Microtubule Polarity in Neuronal Dendrites

Neurons are specialized cells which transmit signals and move biological material across their axons and dendrites. The fundamental organization of neurons relies on microtubules (MTs) which are elongated protein polymers with a plus and minus end in the cell. These MTs form tracks on which cargo can be transported within the cell. It is well known that dendritic MTs are extremely dynamic, reorganize rapidly, and have mixed polarity where plus ends may point in opposing directions. Despite this, the long arrays formed by MTs are highly stable structures. Our group has developed a stochastic and spatial model which tracks individual MTs throughout time in a linear region of a dendrite and predicts the overall behaviors. Results using a baseline set of parameters (determined using experimental measurements in *Drosophila* fruit fly neurons) provided a framework to understand the mechanisms behind the formation of biased polarity of MTs in the trunk of sensory neurons of dendrites. This work aims to investigate how different model parameters may affect the status of biased polarity. Namely, we vary the distance between nucleation sites, the characteristic length of MTs, and the total number of MTs in the domain. We also have preliminary results which extend our 1D model to one including dendritic branches and thus incorporating the contribution of additional biological mechanisms.

Ryan Rinaudo- Parameter Threshold Effect in Push-Pull Cropping Models

TBD