

123rd STATISTICAL MECHANICS CONFERENCE

SHORT TALK SCHEDULE

SESSION A

A1: Michael Gullans, University of Maryland/NIST

Title: Error Mitigation Thresholds in Random Circuits

Coauthors: Pradeep Niroula and Sarang Gopalakrishnan

Abstract: Noise in quantum devices can be corrected with quantum error correction or it can be mitigated via classical post-processing. The latter can be done without overhead in the spacetime volume of the circuit, but eventually incurs exponential overhead in sampling complexity. Such error mitigation techniques require accurate noise tomography and one might wonder if they are robust to imperfections in the learned noise model. We show that noisy random quantum circuit models with imperfectly characterized noise can exhibit a disorder-driven error mitigation threshold at a finite rate of disorder. Based on Imry-Ma arguments, we conjecture that this transition is in the same universality class as the classical random field Ising model in $D+1$ dimension for $D>1$ spatial dimensions of the qubits. Our results are based on a replica analysis of statistical mechanics models for random circuits, as well as numerical simulations of error mitigated random quantum circuits. We discuss the implications for quantum algorithms in near-term devices.

A2: Matthew Marko, Marko Motors LLC

Title: Experimental observations of the effects of intermolecular Van der Waals force on entropy

Abstract: An experimental effort was conducted to measure the change in internal energy of non-ideal carbon dioxide as its volume rapidly expanded with the sudden opening of a valve from one to two compressed gas cylinders. This was achieved by measuring the mass heat capacity of the gas cylinders and the manifold-valve, and measuring the change in temperature from the sudden doubling of volume of the non-ideal carbon dioxide. It was determined that an empirical equation for the change in internal energy of a non-ideal fluid was more accurate than previous methods used for estimating the change in internal energy by estimating the change in entropy. With this empirical equation, a theoretical ideal Stirling cycle heat engine that exceeds the Carnot efficiency was realized by utilizing non-ideal carbon dioxide as a working fluid.

<https://www.nature.com/articles/s41598-022-11093-z>

A3: Ronald Fisch

Title: Improved Model for the Magnetic Behavior of $\text{Cu}_{(1-x)}\text{Mn}_x$ FCC Alloys

Coauthors: Sean Ridout, Andrea Liu

A4: Daniel Swartz, MIT

Title: Competition in Expanding Populations

Coauthors: Daniel Swartz*, Hyunseok Lee, Kirill Korolev, Mehran Kardar

Abstract: In growing populations, the fate of mutations depends on their competitive ability against the ancestor and their ability to colonize the new territory. Here we present a theory that integrates both aspects of mutant fitness by coupling the classic description of one-dimensional competition to a minimal model of front shape. We solved these equations and found three regimes, which are controlled solely by the expansion rates, solely by the competitive abilities, or by both. Collectively, our results provide a simple framework to study spatial competition.

A5: Satyam Anand, New York University

Title: E. coli through obstacles: fluxes, entropy production and extractable work in active matter

Coauthors: Xiaolei Ma, Shuo Guo, Stefano Martiniani, and Xiang Cheng

Short Talk Abstract: Relating entropy production to underlying thermodynamic fluxes and extractable work for systems arbitrarily far from equilibrium remains a challenging problem. For systems in a non-equilibrium steady state, entropy production rate (EPR) has been studied based on the statistical irreversibility between time-forward and time-reversed trajectories of observed degrees of freedom (DOFs), both globally and, more recently, locally. Here, we explore the relation between local EPR, fluxes and extractable work for an active matter system consisting of swimming *E. coli* rectified by funnel-shaped obstacles using theory, simulations and experiments. We propose a minimal mechanical model to quantitatively capture experimentally measured local fluxes at funnel tips. We then measure irreversibility in different DOFs such as position and momentum, and show how they are related to the corresponding fluxes. Finally, we measure the local work extracted by an optically trapped colloid at a funnel tip that is weakly coupled to bacterial motion and characterize its relation to fluxes and EPR. Our work sheds light onto the intrinsic relation between fluxes, irreversibility and work in active systems far away from equilibrium.

A6: Dan Pirjol, Stevens Institute of Technology

Title: Kac-Helfand lattice gas with arbitrary interaction range

Abstract: We study the thermodynamical limit of the Kac and Helfand (1963) one-dimensional lattice gas with n sites and exponential attractive interactions $e(i,j) = -\gamma \exp(-\gamma |i-j|)$. They showed that taking $n \rightarrow \infty$ followed by $\gamma \rightarrow 0$, the system is described by the van der Waals theory and has a phase transition at temperatures below the critical temperature $\beta_{cr}=2$. We consider the case when the thermodynamical limit is taken at fixed ratio $\gamma n = a = O(1)$, and obtain two results: i) upper and lower bounds on the thermodynamical pressure, which differ by less than 3% over the entire range of a ; ii) an exact solution for the thermodynamical pressure at finite a , which is used to demonstrate the existence of a phase transition for sufficiently small temperature. The equation of state reduces to the van der Waals equation in the limit $a \gg 1$.

A7: Shivang Rawat, New York University

Title: Coherence influences the dimensionality of communication subspaces

Coauthors: David J. Heeger, Stefano Martiniani

Abstract: The brain relies on communication between specialized cortical areas to accomplish complex cognitive tasks. To understand this ability of the brain, we need a deeper understanding of information transfer across cortical areas. There are two leading hypotheses for communication between cortical areas: 1) The communication through coherence (CTC) hypothesis posits that coherent oscillations between source and target populations of neurons are required for information propagation. 2) The information transmission via communication subspace (CS) hypothesis, recently introduced by Semedo et al., advances the idea that low-dimensional subspaces of population activity are responsible for communication across cortical areas. There is a clear divide between these two mechanisms and the CTC hypothesis, in particular, has been surrounded by considerable skepticism, with many authors reducing oscillations in the cortex to an epiphenomenon (viz., a by-product with no functional role). Here, we reconcile these two mechanisms of communication through a spectral decomposition of communication subspaces. In our main result, we predict that coherence influences the dimensionality of the CS: Dimensionality is lowest, and the prediction performance is highest, at frequencies that exhibit a peak in coherence between a source and target population (e.g., V1 to V2). We arrive at these results by developing an analytical theory of communication for circuits described by stochastic dynamical systems exhibiting fixed-point solutions. We compute directly (i.e., by a simulation-free method) the predictive performance for the mean-subtracted activity of a target population from that of a source population, and show that our predictions are in agreement with the experimental results by Semedo et al. Then via a band-pass filtered version of the covariance matrix, we arrive at our main result. Hence, our theory makes experimentally-testable predictions of how oscillations influence interareal communication while advancing a new hypothesis for the functional role of oscillatory activity in the brain.

A8: Rhine Samajdar, Princeton University

Title: On the triangular-lattice quantum dimer model with variable dimer density

Coauthors: Zheng Yan, Yan-Cheng Wang, Subir Sachdev, Zi Yang Meng

Abstract: Based on recent large-scale quantum Monte Carlo simulation results, we discuss an extension of the triangular lattice quantum dimer model with terms in the Hamiltonian annihilating and creating single dimers. We find distinct odd and even spin liquids, along with several phases with no topological order: a staggered crystal, a nematic phase, and a trivial symmetric phase with no obvious broken symmetry. We note implications for experiments on Rydberg atoms trapped in arrays of optical tweezers.

A9: Murray Skolnick, Princeton University

Title: Simulated Diffusion Spreadability for Characterizing the Structure and Transport Properties of Materials

Coauthors: Salvatore Torquato

Abstract: In multiphase heterogeneous media, time-dependent diffusion processes between phases are widespread in physical, chemical, and biological systems. Examples of such media include composites, porous media, and complex fluids. The recently developed diffusion spreadability, $\{\text{cal S}\}(t)$, provides a direct link between time-dependent interphase diffusive transport and the microstructure of two-phase media across length scales [1]; thus making $\{\text{cal S}\}(t)$ a powerful tool for classifying the (non)hyperuniformity of microstructures. In this work, we develop a computationally efficient algorithm for ascertaining $\{\text{cal S}\}(t)$ and its associated entropy production rate directly from digitized representations of microstructures via simulated random walks. We apply our algorithm to a variety of two- and three-dimensional (non)hyperuniform microstructures to assess their non-equilibrium transport properties. Overall, our algorithm has practical use in the discovery and design of materials with desirable time-dependent diffusion properties. [1] Torquato, S., Phys. Rev. E., 104 054102 (2021) Research was sponsored by the Army Research Office and was accomplished under Cooperative Agreement Number W911NF-22-2-0103, as well as the Air Force Office of Scientific Research Program under award No. FA9550-18-1-0514.

A10: Stefan Boettcher, Emory University

Title: Density fluctuations in granular piles traversing the glass transition: A grain-scale characterization via the internal energy

Coauthors: Paula A. Gago

Abstract: We explored the transition into a glassy state of the ensemble of static, mechanically stable configurations of a tapped granular pile we described in <https://www.pnas.org/doi/10.1073/pnas.2012757117> using extensive molecular dynamics simulations with 60000 particles. We find that different horizontal layers along the height of the pile traverse this transition in a similar manner but at distinct tap intensities. We supplement the conventional approach based purely on properties of the static configurations with investigations of the grain-scale dynamics by which the tap energy is transmitted throughout the pile. In <https://www.science.org/doi/10.1126/sciadv.abl6304>, we show that the effective energy that particles dissipate during the tap is a function of the height of their layer and, moreover, that its value plays a distinctive role in the transformation between configurations. This internal energy provides a “temperature-like” parameter that allows us to align the transition into the glassy state for all layers, as well as different annealing schedules, at a critical value.

A11: Robert Ziff, University of Michigan

Title: Percolation in a two-species antagonistic random sequential adsorption model

Abstract: We consider two-species random sequential adsorption (RSA) in which species A and B adsorb randomly on a lattice with the restriction that opposite species cannot occupy nearest-neighbor sites. When the probability x_A of choosing an A particle for an adsorption trial reaches a critical value 0.626441(1), the A species percolates and/or the blocked sites X (those with at least one A and one B nearest neighbor) percolate.

Analysis of the size-distribution exponent τ , the wrapping probabilities, and the excess cluster number shows that the percolation transition is consistent with that of ordinary percolation. We obtain an exact result for the low $x_B = 1 - x_A$. For the one-dimensional case a three-site approximation appears to provide exact results for the coverages, which are also found by an exact calculation.

A12: Sidney Redner, Santa Fe Institute

Title: Birds on a wire

Coauthors: Paul Krapivsky

Abstract: We investigate the occupancy statistics of birds on a wire and on higher-dimensional substrates. In one dimension, birds land one-by-one on a wire and rest where they land. Whenever a newly arriving bird lands within a fixed distance of already resting birds, these resting birds immediately fly away. We determine the steady-state occupancy of the wire and the distribution of gaps between neighboring birds.

SESSION B

B1 : Mohamed Bahri, Princeton University

Coauthors : Siddhartha Sarkar, Daniel A. Matoz-Fernandez, Andrej Košmrlj

Short Talk Abstract : D-dimensional thermally equilibrated fluctuating elastic membranes embedded in d-dimensions have been understood using Euclidean field theory and are predicted to have a bending rigidity that diverges with an anomalous exponent, ν , whereas the Young's modulus converges to zero with a exponent $\nu_u = 2 - 2\nu$, related via a Ward Identity derived from symmetries that preserve the form of the strain tensor in an elastic Hamiltonian. This scaling behavior is associated with a non-Gaussian fixed point known as the Aronovitz-Lubensky fixed point. However, less results are known when non-equilibrium effects are introduced. In recent years, for 2-dimensional elastic systems, odd elasticity has been developed and introduces two novel elastic constants, A, K (under the simultaneous constraint of isotropy), that break conservation of energy and angular momentum. We present a set of new results utilizing the perturbative renormalization group in order to comprehend the effect of introducing such non-Hamiltonian-derived forces into fluctuating elastic membranes. To investigate this requires the use of over-damped Langevin equations and the MSRJD formalism, assuming a Gaussian noise and that the membrane obeys Rouse dynamics (thus being completely permeable and not slave to solvent interactions). In particular we find that such a theoretical approach need not necessarily respect the symmetries that preserve the form of the strain tensor. In our analysis, we therefore find that fluctuation-dissipation need not generally hold and is spontaneously unstable in principle. If we restrict ourselves to the manifold where fluctuation-dissipation holds and perform a stability analysis of the Aronovitz-Lubensky fixed point, to draw the closest comparison to previously results known in the equilibrium theory, we find that K (which only breaks conservation of energy) is field-theoretically irrelevant whereas A (which breaks conservation of angular moment and energy), is a marginal perturbation. Our simulations match with the theory we have provided.

B2: Michael D'Eom, Brandeis University

Title: Fractonic Coulomb Gas

Abstract : There is a rich history of the study of the Coulomb Gas in the context of defect-driven phases and phase-transitions. The recently developed theory of "fractons" (Phys. Rev. B 98, 115134 (2018)) has found applications in classical systems via a mapping of defects in 2D crystals to scalar fractonic charges (Phys. Rev. Lett. 120, 195301 (2018)) and a mapping of forces in an amorphous solids to vector fractonic charges (arXiv:2204.11811). The latter mapping leads to the possibility of using a vector-charge Coulomb gas theory to study the behavior of forces embedded in an amorphous solid. For example, molecular motors in tissues or hydrodynamics forces on the particles of a dense suspension close to jamming. These questions have led us to investigate the statistical mechanics of a Coulomb gas of vector charges, which have to obey both charge

conservation, and charge-angular momentum conservation. It is the second conservation law that leads to the sub dimensional propagation of fractions and distinguishes them from vector charges representing dislocations in crystals. We will present our recent results of the collective behavior of such fractonic vector charges.

B3: Kanaya Malakar, Brandeis University

Title: Role of elasticity in cell organization inside tissues

Coauthors: Mike D'Eon, Max Bi, Bulbul Chakraborty

Abstract: Dense tissues show randomness in the positions and shape of the individual component cells. Yet there appears to be an overall organization in the arrangement of cells in such dense tissues. The origin of this collective behavior, especially of the cell shapes is not well understood. In this project we address this question by modeling the cells as contractile force dipoles interacting via the tissue which is an elastic medium. We use a recently developed theory of the elasticity of non-thermal amorphous solids to express the dipole interactions in terms of the Poisson ratio characterizing the tissue. We compare our results to observations in experiments and numerical simulations.

B4: Andriy Goychuk, Massachusetts Institute of Technology

Title: Conformational dynamics of active polymers

Coauthors: Deepti Kannan, Arup K. Chakraborty, Mehran Kardar

Abstract: Polymers in living systems are frequently driven out of equilibrium by active processes involving molecular motors and energy-consuming reactions. With a view to chromatin as a possible model system, we explore the effects of inhomogeneous active processes on the conformational statistics, folding, and the dynamics of polymers. Using a minimal active Gaussian chain model, we find that active and passive mechanisms can lead to equivalent folding patterns, thus leaving only dynamics to differentiate between these models.

B5: Haina Wang, Princeton University

Title: Realizability of Iso- ρ Processes via Effective Pair Interactions

Coauthors: Frank H. Stillinger, Salvatore Torquato

Abstract: An outstanding problem in statistical mechanics is the determination of whether prescribed functional forms of the pair correlation function $\rho_2(r)$ [or equivalently, structure factor $S(k)$] at some number density ρ can be achieved by d -dimensional many-body systems. The Zhang-Torquato conjecture states that any realizable set of pair statistics, whether from a nonequilibrium or equilibrium system, can be achieved by equilibrium systems involving up to two-body interactions. In light of this conjecture, we study the realizability problem of the nonequilibrium iso- ρ process, i.e., the determination of density-dependent effective potentials that yield equilibrium states in which ρ_2 remains invariant for a positive range of densities. Using a precise inverse methodology that determines effective potentials that match hypothesized functional forms of $\rho_2(r)$ for all r and $S(k)$ for all k , we show that the unit-step function ρ_2 , which is the zero-density limit of the hard-sphere potential, is remarkably numerically realizable up to the packing fraction $\phi=0.49$ for $d=1$. For $d=2$ and 3, it is realizable up to the maximum "terminal" packing fraction $\phi_c=1/2^d$, at which the systems are hyperuniform, implying that the explicitly known necessary conditions for realizability are sufficient up through ϕ_c . For ϕ near but below ϕ_c , the large- r behaviors of the effective potentials are given exactly by the functional forms $\exp[-\kappa(\phi)r]$ for $d=1$, $r^{-1/2}\exp[-\kappa(\phi)r]$ for $d=2$, and $r^{-1}\exp[-\kappa(\phi)r]$ (Yukawa form) for $d=3$, where $\kappa^{-1}(\phi)$ is a screening length, and for $\phi=\phi_c$, the potentials at large r are given by the pure Coulomb forms in the respective dimensions, as predicted by Torquato and Stillinger [Phys. Rev. E, 68, 041113 1-25 (2003)]. We also find that the effective potential for the pair statistics of the 3D "ghost" random sequential addition at the saturation density $\phi_c=1/8$ is much shorter-ranged than that for the 3D unit-step-function ρ_2 at ϕ_c , and thus does not constrain the realizability of the unit-step-function ρ_2 . Our inverse methodology yields effective

potentials for realizable targets, and as expected, it does not reach convergence for a target that is known to be non-realizable, despite the fact that it satisfies all known explicit necessary conditions. Our findings demonstrate that exploring the iso- ϕ process via our inverse methodology is an effective and robust means to tackle the realizability problem and is expected to facilitate the design of novel nanoparticle systems with density-dependent effective potentials, including exotic hyperuniform states of matter.

B6: Charles Maher, Princeton University

Title: Disordered Bimodal Sphere Packings Achieve Higher Packing Fractions Than Their Binary and Monomodal Counterparts

Coauthors: Adam B. Hopkins, Salvatore Torquato

Abstract: Studies of dense, disordered, polydisperse sphere packings are typically limited to discrete or monomodal particle size distributions (PSD) or bimodal size distributions with a very limited range of polydispersity, which is the ratio of the mean and standard deviation of the PSD. Here, we use the Torquato-Jiao linear-programming packing algorithm [Torquato and Jiao, Phys. Rev. E 82, 061302 (2011)] to produce strictly jammed isostatic disordered sphere packings with radius distributions given by the combination of two truncated Gaussian distributions with mean ratios between 0.45 and 0.125 and individual-mode polydispersity up to 0.7. We show that such bimodal packings have packing fractions up to ~ 0.03 larger than their binary counterparts because their broader size distribution allows for more efficient filling of space. In addition, bimodal packings have packing fractions up to 0.15 greater than an equivalently polydisperse monomodal packing because in monomodal packings the presence of intermediate-sized spheres diminishes the ability of the small spheres to fit in interparticle voids. Any putatively monodisperse set of particles will, in practice, exhibit a positive polydispersity, even if small. Thus, these findings more accurately describe the packing fraction for practical binary (i.e., bimodal) packings and can aid in the choice of particle size parameters for tuning the density of polydisperse packings such as additive manufacturing particle beds or understanding the jamming transitions in glassy colloidal systems. Moreover, given a mean radius ratio, one can use these results to find which values of the polydispersity and relative small sphere number fraction yield packing fractions identical to those of an idealized binary packing with the same size ratio.

B7: Gerald Goldin, Rutgers University

Abstract: The unitary representations of a single infinite-dimensional group characterize the kinematics of all known quantum systems, and have predicted some exotic possibilities. I will mention the relationship of this approach to Heisenberg quantization.

B8: Giacomo Gori, University of Heidelberg

Title: Critical correlations are metric

Coauthors: A. Trombettoni, A. Galvani

Short Talk Abstract: Critical correlations in a bounded system with ordered boundary are argued to be function of a suitably chosen metric g . This isotropic metric rules the order parameter profile according to general scaling arguments. A natural candidate for g is the solution of a differential geometry problem known as Yamabe problem i.e. find a local rescaling of a metric making curvature constant. The correct Yamabe problem to be considered entails a fractional (anomalous in physics) generalization of the Ricci scalar curvature.

B9: Istvan Kovacs, Northwestern University

Title: Cluster tomography

Coauthors: Sam Frank

Abstract: In cluster tomography, we consider the N number of clusters intersected by a line across a finite percolation sample in two and three dimensions. As expected, in leading order, N scales linearly with the L

length of the cross-section as aL , where a depends on the microscopic details. However, at criticality, there is an additional nonlinearity in the form of $b \ln(L)$. By performing large scale Monte Carlo simulations in both 2d and 3d, we find that b is universal and depends only on the angles at which the line intersects the surface of the sample. In comparison, we overview and extend the known results for line segments that do not cross the entire system, corresponding to partial tomography. Being broadly applicable, cluster tomography can be a useful tool to detect phase transitions and characterize the universality class in any classical or quantum system with a relevant cluster structure, both in- and out-of-equilibrium.

B10: Alexei Tsvelic, Brookhaven National Laboratory

Title: Solvable 3D Kondo lattice model exhibiting order fractionalization

Coauthors: P. Coleman, A. Panigrahi

Abstract: The Kondo lattice model plays a key role in our understanding of quantum materials, but a lack of small parameters has posed a long-standing problem. We present a 3 dimensional $S=1/2$ Kondo lattice model describing a spin liquid within an electron sea. Strong correlations in the spin liquid are treated exactly, enabling a controlled analytical approach. Like a Peierls or BCS phase, a logarithmically divergent susceptibility leads to an instability into a new phase at arbitrarily small Kondo coupling. Our solution captures a plethora of emergent phenomena, including odd-frequency pairing, pair density wave formation and order fractionalization. The ground-state state is a pair density wave with a fractionalized charge S_e , $S=1/2$ order parameter, formed between electrons and Majorana fermions.

B11: Michael Widom, Carnegie Mellon University

Abstract: Title: Configurational entropy of high entropy alloys High entropy alloys are multicomponent solid solutions in which several chemical species randomly occupy sites of a crystal lattice. Many high entropy alloys form as single phases at high temperature, stabilized by their entropy. While an equiatomic alloy of N species has ideal mixing entropy $S_{\text{Ideal}} = k_B \ln(N)$ per site, chemical bonding preferences among the elements correlate the occupations of nearby sites and thereby reduce the entropy. Improved estimates of the entropy are provided by $S = S_{\text{Ideal}} - k_B \text{Info}$, where Info is the Shannon information content of the correlation functions. this approach utilizes a variant of Kikuchi's Cluster Variation Method.

B12: Vadim Oganesyan, CUNY

Title: Phase diagram of 2D Ising models in the complex temperature plane and non-unitary circuits

Coauthors: Sankhya Basu, Daniel P. Arovas, Sarang Gopalakrishnan, Chris A. Hooley, and Vadim Oganesyan

Abstract : Complex-temperature equilibrium phases of the exactly solvable square-lattice anisotropic Ising model are richer than those of the isotropic one, as initially discussed by Michael Fisher in his generalization of Yang-Lee zeroes. We find two new incommensurately ordered phases with smoothly varying periods. These can be mapped to time-crystal and spin-density wave phases of a 1+1 dimensional quantum circuit with measurements and postselection.

<https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.4.013018>