Abstracts of Invited Talks

Michael Aizenman Princeton University

Ruminations on Matrix Convexity and the Strong Subadditivity of Quantum Entropy

The familiar second derivative test for convexity is shown to yield a useful tool also in the context of matrix-valued functions. We demonstrate its applicability on a number of theorems in this field. These include convexity principles which play an essential role in the Lieb-Ruskai proof of the strong subadditivity of quantum entropy. (Joint work with Giorgio Cipolloni.)

Natan Andrei Rutgers University

Kondo Effect in 1-D superconductors

The study of a Kondo impurity in a BCS superconductors stretches back several decades. It has been found by several authors that the impurity is screened by a local bound state – the Yu-Shiba-Rusinov (YSR) intra-gap states. Here we study a system that consists of a one-dimensional charge conserving spin-singlet superconductor coupled to a magnetic impurity at the boundary. In such system quantum fluctuations are enhanced and we show that they lead to the destruction of Yu-Shiba-Rusinov (YSR) intra-gap bound-states in all but a narrow region of the phase diagram, as opposed to a Kondo impurity in a BCS superconductor where the Shiba state occurs over the whole phase. We find that for large enough impurity spin exchange interaction a renormalized Kondo-screened regime is established. In this regime, not found for BCS superconductors, there are no YSR states and a renormalized Kondo scale is generated. Another regime, not present in BCS superconductors is the moment regime that occurs for weak coupling.

Louis-Pierre Arguin CUNY, Baruch College

A statistical mechanics perspective on the large values of the Riemann zeta function

I will give an account of the recent progress in probability and in number theory to understand the large values of the zeta function on the critical line, especially in short intervals. The problems have interesting connections to statistical mechanics of disordered systems, both in their interpretations and in the techniques of proofs. Though this is not directly related to the work of Chuck Newman on the zeta function, this is another evidence of the relevance (and power) of statistical mechanics in understanding the function.

This is based on joint works with E. Bailey and with P. Bourgade and M. Radziwill.

Gérard Ben Arous NYU

High-dimensional limit theorems for SGD: Effective dynamics and critical scaling

We study the scaling limits of stochastic gradient descent (SGD) with constant step-size in the high-dimensional regime. We prove limit theorems for the trajectories of summary statistics (i.e., finite-dimensional functions) of SGD as the dimension goes to infinity. Our approach allows one to choose the summary statistics that are tracked, the initialization, and the step-size. It yields both ballistic (ODE) and diffusive (SDE) limits, with the limit depending dramatically on the former choices. Interestingly, we find a critical scaling regime for the step-size below which the effective ballistic dynamics matches gradient flow for the population loss, but at which, a new correction term appears which changes the phase diagram. About the fixed points of this effective dynamics, the corresponding diffusive limits can be quite complex and even degenerate.

We demonstrate our approach on popular examples including estimation for spiked matrix and tensor models and classification via two-layer networks for binary and XOR-type Gaussian mixture models.

These examples exhibit surprising phenomena including multimodal timescales to convergence as well as convergence to sub-optimal solutions with probability bounded away from zero from random (e.g.,Gaussian) initializations. The full version of this paper is accessible on Arxiv (2206.04030). A short version is published at NeurIPS 2022, and received an outstanding paper award.
This is a joint work with Reza Gheissari (Northwestern) and Aukosh Jagannath (Waterloo).

Federico Bonetto Georgia Institute of Technology

Autonomous evolution for the speed of 2 electrons in a thermostated system

We study a system of two particles moving in 1 dimension under the influence of an electric field E and a deterministic thermostat that keeps the total kinetic energy constant. The particles undergo random elastic collisions with "virtual" obstacles at a rate proportional to their speed. We show that in the small E/large time limit the evolution of the particles speed is described by a SDE uniformly in time up to the steady state. This is a joint work with Livia Corsi.

Federico Camia NYU

Conformal Statistical Mechanics

The last two decades have seen the fast development of a research area concerned with random fractal structures characterized by a certain invariance under conformal transformations. Structures of this type arise from the continuum scaling limit of two-dimensional models of statistical mechanics at (or near) criticality. The study of such structures has generated tremendous progress in probability theory, complex analysis, statistical mechanics and conformal field theory. In this talk, I will give a personal perspective on some aspects of this research area.

Bulbul Chakraborty Brandeis University

The collective behavior of particles with “noisy” interactions

Diversity in the natural world emerges from the collective behavior of large numbers of interacting objects. Statistical physics provides the framework relating microscopic to macroscopic properties. A fundamental assumption underlying this approach is that we have complete knowledge of the interactions between the microscopic entities. But what if that, even though possible in principle, becomes impossible in practice? Can we still construct a framework for describing their collective behavior? Dense suspensions and granular materials are two often quoted examples where we face this challenge. These are systems where because of the complicated surface properties of particles there is extreme sensitivity of the interactions to particle positions. In this talk, I will present a perspective based on notions of constraint satisfaction that provides a way forward. I will focus on our recent work on the emergence of elasticity in the absence of any broken symmetry, and sketch out other problems that can be addressed using this perspective.

Ovidiu Costin Ohio State University

Noise Effects on Padé Approximants and Conformal Maps

We analyze the properties of Padé and conformal map approximants for functions with branch points, in the situation where the expansion coefficients are only known with finite precision or are subject to noise. We prove that there is a universal scaling relation between the strength of the noise and the expansion order at which Padé or the conformal map breaks down. We illustrate this behavior with some physically relevant model test functions and with two non-trivial physical examples where the relevant Riemann surface has complicated structure.
Work in collaboration with Gerald V. Dunne and Max Meynig, U Connecticut

Rodica Costin Ohio State University

Non-perturbative Solution of the 1d Schrodinger Equation Describing Photoemission from a Sommerfeld model Metal by an Oscillating Field

We analyze non-perturbatively the one-dimensional Schrodinger equation describing the emission of electrons from a model metal surface by a classical oscillating electric field. The amplitude of the external electric field and the frequency are arbitrary.

We prove existence and uniqueness of classical solutions of the Schrodinger equation for general initial conditions. When the initial condition is in L2 the evolution is unitary and the wave function goes to zero for any fixed x as t becomes large.To show this we prove a RAGE type theorem and show that the discrete spectrum of the quasienergy operator is empty. To obtain positive electron current we consider non-L2 initial conditions containing an incoming beam from the left. The beam is partially reflected and partially transmitted for all t > 0. For these initial conditions we show that the solution approaches in the large t limit a periodic state that satisfies an infinite set of equations formally derived, under the assumption that the solution is periodic, by Faisal, et. al [Phys. Rev. A 72, 023412 (2005)]. Due to a number of pathological features of the Hamiltonian (among which unboundedness in the physical as well as the spatial Fourier domain) the existing methods to prove such results do not apply, and we introduce new, more general ones. The actual solution exhibits a very complex behavior, as seen both analytically and numerically. It shows a steep increase in the current as the frequency passes a threshold value (which depends on the strength of the electric field. For small electric field, this represents the threshold in the classical photoelectric effect, as described by Einstein's theory.Work in collaboration with Ovidiu Costin, Ian Jauslin and Joel L Lebowitz.

Michael Damron Georgia Institute of Technology

First-Passage Percolation in the Critical Regime

In 2d first-passage percolation (FPP), we place nonnegative i.i.d. weights (t_e) on the edges of Z^2 and study the induced weighted graph pseudometric T = T(x,y). If we denote by p = P(t_e = 0), then there is a transition in the large-scale behavior of the model as p varies from 0 to 1. When p < 1/2, T(0,x) grows linearly in x, and when p > 1/2, it is stochastically bounded. The critical case, where p = 1/2, is more subtle, and the sublinear growth of T(0,x) depends on the behavior of the distribution function of t_e near zero. I will discuss my work over the past few years that (a) determines the exact rate of growth of T(0,x) and (b) determines the "time constant" for the site-FPP model on the triangular lattice. If time permits, I will mention recent work that (c) estimates the growth of T(0,x) in a dynamical version of the model, where weights are resampled according to independent exponential clocks. These are joint works with J. Hanson, D. Harper, W.-K. Lam, P. Tang, and X. Wang.

Daniel Fisher Stanford University

A Hitchhiker's Guide to Spin Glasses

Reza Gheissari Northwestern University

Low-temperature Ising dynamics from ground state initializations

Ilya Gruzberg Ohio State University

Conformal invariance and Anderson transitions

Anderson transitions (ATs) share many features with conventional second-order phase transitions in statistical mechanics, and it is natural to expect that conformal invariance should appear at the fixed points of ATs, giving us tools of conformal field theories to employ. However, ATs also exhibit unusual features, such as the absence of a natural order parameter, no upper critical dimension, and continuous families of critical exponents characterizing multifractal critical wave functions. In this talk I will review connections of these unusual features to the questions of conformal invariance at ATs, some history and examples highlighting these issues, and the growing evidence that many ATs do not exhibit conformal invariance, against expectations.

Nina Holden NYU

Regularity of the Schramm-Loewner evolution: Up-to-constant variation and modulus of continuity

We find optimal (up to constant) bounds for the following measures for the regularity of the Schramm-Loewner evolution (SLE): variation regularity, modulus of continuity, and law of the iterated logarithm. For the latter two we consider the SLE with its natural parametrization.
More precisely, denoting by $d\in(0,2]$ the dimension of the curve, we show the following.
1. The optimal ψ-variation is $\psi(x)=x^d(\log\log x^{-1})^{-(d-1)}$ in the sense that η is of finite ψ-variation for this ψ and not for any function decaying more slowly as $x \downarrow 0$.
2. The optimal modulus of continuity is $\omega(s) = c\,s^{1/d}(\log s^{-1})^{1-1/d}$, i.e.\@ $|\eta(t)-\eta(s)| \le \omega(t-s)$ for this ω, and not for any function decaying faster as $s \downarrow 0$.
3. $\limsup_{t\downarrow 0} |\eta(t)|\,(t^{1/d}(\log\log t^{-1})^{1-1/d})^{-1}$ is a deterministic constant in $(0,\infty)$.
Based on a joint work with Yizheng Yuan.

David Huse Princeton University

Transitions to many-body quantum chaos and thermalization

Quantum many-body systems can show phase transitions in their dynamics between thermalizing chaotic dynamics and non-thermalizing dynamics. Examples of the latter include near-integrability and many-body localization. Periodically driven Floquet systems can also show transitions between heating and not heating with both phases chaotic. These transitions are in the dynamics and not in the thermodynamics, so the large-system limit that makes these transitions sharply defined need not be the same as the thermodynamic limit, and in most cases it is not. Time permitting, I will focus on the case of integrability-breaking.
"Onset of many-body quantum chaos due to breaking integrability", (V. B. Bulchandani, D. A. Huse and S. Gopalakrishnan), Phys. Rev. B 105, 214308 (2022).
"Universality classes of thermalization for mesoscopic Floquet systems", (A. Morningstar, D. A. Huse and V. Khemani), arXiv:2210.13444.

Charles Kane University of Pennsylvania

Quantum Brownian Motion 35 years later

In 1985, Matthew Fisher and Wilhelm Zwerger introduced a simple model of quantum Brownian motion in a periodic potential that foreshadowed many important developments in quantum condensed matter physics. It formed the foundation for my own collaborations with Matthew in the 1990's on the theory of Luttinger liquids. It posed a problem in boundary conformal field theory that remains unsolved today and shows up in seemingly unrelated problems of current interest. I will describe applications to the theory of a point contact in a quantum spin-Hall insulator, and to topological superconductor-normal metal junctions.

Vedika Khemani Stanford University

Operator relaxation and the optimal depth of classical shadows

Werner Krauth Ecole normale supérieure

Lifted non-reversible Markov chains: From solvable models to real-life applications

Markov-chain Monte Carlo is an outstanding computational tool in science. Since its origins, in 1953, it has relied on the detailed-balance condition (that defines equilibrium) to map general computational problems onto equilibrium-statistical-physics systems. In contrast, non-reversible Markov chains violate the detailed-balance condition. They are, by definition, out-of-equilibrium, but their steady state is unchanged. I discuss a number of solvable models (single-particle diffusion, one-dimensional hard-sphere models related to the TASEP), and point out possible applications of non-reversible Markov chains in statistical mechanics and physical chemistry.

Ravi Krishnamurthi Suny New Paltz

Convergence of discrete dynamical web to dynamical Brownian web

We prove the path-wise convergence of Discrete dynamical web to the dynamical Brownian web. Major part of work is in proving tightness. Results from Marking construction of Brownian net and dynamical Brownian web are used to obtain the result. Joint with Kumarjit Saha

Dmitry Krotov IBM Research

Modern Hopfield Networks in AI and Neurobiology

Modern Hopfield Networks or Dense Associative Memories are recurrent neural networks with fixed point attractor states that are described by an energy function. In contrast to conventional Hopfield Networks, their modern versions have a very large memory storage capacity, which makes them appealing tools for many problems in machine learning and cognitive and neuro-sciences. In this talk I will introduce an intuition and a mathematical formulation of this class of models, and will give examples of problems in AI that can be tackled using these new ideas. I will also explain how different individual models of this class (e.g. hierarchical memories, attention mechanism in transformers, etc.) arise from their general mathematical formulation with the Lagrangian functions.

Eyal Lubetzky NYU

On the level lines of the Solid-On-Solid model above a wall

We will review the picture for the level lines of the SOS model above a wall, outlining the properties rigorously confirmed in the discrete model and recent progress in understanding its continuous approximations.

Jon Machta University of Massachusetts

Optimal Paths for Annealing Algorithms: Insights from Non-equilibrium Statistical Physics

Population Annealing is a useful computational method for problems ranging from sampling equilibrium states of spin glasses to solving optimization problems in industry. Like simulated annealing, population uses a Markov chain Monte Carlo method with slowly varying control parameter(s) to transform an easy to simulate initial distribution to a hard-simulate target distribution. The efficiency and accuracy of both simulated annealing and population annealing depends on the "annealing" path in the space of control parameters (e.g. temperature and magnetic field). In this talk I will introduce population annealing (simulated annealing is a special case) and then obtain a criterion for optimal annealing paths. Optimal annealing paths are shown to be closely related to non-equilibrium thermodynamic paths of minimum excess work discussed by Sivak and Crooks [PRL 108, 190602 (2012)].

Stefano Martiniani NYU

Play. Pause. Rewind. Model-free measurement of local entropy production and extractable work in active matter

Time-reversal symmetry breaking and entropy production are universal features of nonequilibrium phenomena. Despite its importance in the physics of active and living systems, the entropy production of systems with many degrees of freedom has remained of little practical significance because the high-dimensionality of their state space makes it difficult to measure. Here we introduce a local measure of entropy production and a numerical protocol to estimate it. We establish a connection between the entropy production and extractability of work in a given region of the system and show how this quantity depends crucially on the degrees of freedom being tracked. We validate our approach in theory, simulation, and experiments by considering systems of active Brownian particles undergoing motility induced phase separation, as well as active Brownian particles and E. Coli in a rectifying device in which the time-reversal asymmetry of the particle dynamics couples to spatial asymmetry to reveal its effects on a macroscopic scale.

Roger Melko University of Waterloo/Perimeter

Autoregressive models for quantum simulation

One of the most promising neural network architectures to emerge from the field of machine learning is the autoregressive model. These generative models, employed widely in applications such as natural language processing, are highly expressive, have good training heuristics, and produce tractable likelihoods. In this talk, I will discuss how autoregressive models such as recurrent neural networks (RNN) have been repurposed as ansatze for quantum states, which can be trained either via projective measurement data, or variationally with a Hamiltonian. As an example, I will show results for Rydberg atom quantum computers, where RNNs can learn a groundstate from measurement data, from variational training, or a combination of both.

Jed Pixley Rutgers University

Universality classes of observer driven phase transitions

We will discuss the universal nature of the measurement and control induced phase transitions in random quantum circuits. First, the properties of the underlying conformal field theory at the measurement induced transition are studied allowing us to identify 3 distinct universality classes, depending on the quantum nature of the gates. Second, we show how static disorder drives this transition to flow to an infinite randomness fixed point. Last, using post selection and feedback we identify a control induced phase transition that is concomitant with an entanglement transition but that is diffusive.

Leo Radzihovsky University of Colorado

Lifshitz dualities

I will discuss phases and transitions in a variety of physical systems (crystals, smectics, nematics, "fractonic" bosons,...) through the lens of the m-Lifshitz model and its gauge duals.

Nick Read Yale University

Short-range spin glasses: single-replica equivalence and indecomposable metastates

I will review recent progress on rigorous results about short-range spin glasses and other disordered spin systems. A key concept when analyzing this problem is that of a metastate, a probability distribution on equilibrium (or Gibbs) states, introduced by Aizenman, Wehr, Newman, and Stein. Recent work with Newman and Stein shows that, for a given Gibbs state drawn from the metastate, if the Gibbs state is a mixture of pure states, then those pure states are macroscopically indistinguishable, a result that has various consequences. A further concept is that of an indecomposable metastate. For the latter, all pure states in all Gibbs states drawn from it are macroscopically indistinguishable, and the Gibbs states also possess further natural properties, compatible with replica symmetry breaking.

Lily Reeves Cornell University

Chemical distance for 2d critical percolation

Percolation clusters induce an intrinsic graph distance called the chemical distance. Besides its mathematical appeal, the chemical distance is connected to the study of random walks on critical percolation clusters. In this talk, I will begin with a brief survey on the chemical distance. Then, I will zoom in to the progress and challenges in the 2d critical regime. A portion of this talk is based on joint work with Philippe Sosoe

Eric Siggia Rockefeller University

Geometry and Genetics

The application of quantitative methods to biological problems faces the choice of how much detail to include and the generality of the conclusions. Both routine data analysis and airy pronouncements that have almost nothing to say about almost everything are to be avoided. The middle ground entails some use phenomenology, a well-regarded approach in physics. The phenomenon of canalization is a license to develop models that are quantitative and dynamic yet do not begin from an enumeration of the relevant genes. Modern dynamical systems theory has many similarities to experimental embryology and allows the enumeration of categories of dynamical behaviors. Applications to stem cell differentiation will be given as illustrations. Theory can also use computational evolution, in analogy to a screen, to suggest dynamical systems that generate the desired pattern from plausible boundary conditions. Phenomenology of the sort envisioned is essential to bridge the scales from the cell, to tissue to embryo, by breaking the system into blocks that can be separately parameterized.

Daniel Stein NYU

Ground State Stability and the Nature of the Spin Glass Phase

I will present a new approach toward understanding the spin glass phase at zero and low temperature by studying the stability of a spin glass ground state against perturbations of a single coupling. Four proposed scenarios for the low-temperature spin glass phase --- replica symmetry breaking, scaling-droplet, TNT and chaotic pairs --- will be analyzed through the lens of the predictions of each scenario for the lowest energy large-lengthscale excitations above the ground state.
Using a new concept called σ-criticality, which quantifies the sensitivity of ground states to single-bond coupling variations, each of these four pictures can be identified with different critical droplet geometries and energies. If time permits, I will also present necessary and sufficient conditions for the existence of multiple incongruent ground states. (This work was done in collaboration with Chuck Newman.)

Senthil Todadri Massachusetts Institute of Technology

The dipolar Bose Hubbard model

I will describe a simple model of interacting bosons on a d-dimensional cubic lattice whose dynamics conserves both total boson number and total boson dipole moment. This model provides a simple framework in which several remarkable consequences of dipole conservation can be explored. As a function of chemical potential and hopping strength, the model can be tuned between gapped Mott insulating phases and various types of gapless condensates. The condensed phase realized at moderately large hopping strengths (in $d > 1$), which we dub a Bose-Einstein insulator, is particularly interesting: despite having a Bose condensate, it is insulating, and despite being an insulator, it is compressible. Time permitting, I will also describe the special phase diagram of the $d = 1$ model.

Misha Tsodyks Institute for Advanced Study

Human Memory: Theory vs Experiments

Human memory is a multi-stage process that is notorious for its unpredictability and hence difficult to study quantitatively. However we recently discovered that under carefully controlled experimental conditions some reproducible results are obtained, in particular when memory recall and recognition are studied with random lists of words and sentences. We developed a phenomenological theory of both processes that can be mathematically solved and results in analytical predictions for performance that were confirmed by experiments with surprising precision.

Romain Vasseur University of Massachusetts Amherst

Learning global charges from local measurements

Monitored random quantum circuits (MRCs) exhibit a measurement-induced phase transition between area-law and volume-law entanglement scaling. In this talk, I will argue that MRCs with a conserved charge additionally exhibit two distinct volume-law entangled phases that cannot be characterized by equilibrium notions of symmetry-breaking or topological order, but rather by the non-equilibrium dynamics and steady-state distribution of charge fluctuations. These include a charge-fuzzy phase in which charge information is rapidly scrambled leading to slowly decaying spatial fluctuations of charge in the steady state, and a charge-sharp phase in which measurements collapse quantum fluctuations of charge without destroying the volume-law entanglement of neutral degrees of freedom. I will present some statistical mechanics and effective field theory approaches to such charge-sharpening transitions, and relate them to the efficiency of classical decoders to “learn” the global charge of quantum systems from local measurements.

Sagar Vijay UC Santa Barbara

Monitored Quantum Dynamics and Beyond

The evolution of a quantum many-body system under repeated, local measurements by an external observer (“monitored quantum dynamics”) has been the subject of much recent study. Pioneering works by Matthew Fisher and collaborators have shown that frequent, local measurements can give rise to different universality classes of quantum many-body dynamics, even in the presence of little additional structure in the evolution. Phases of monitored quantum systems are distinguished by the universal behavior of quantities such as the entanglement entropy of the evolving, observed states, which can exhibit a scale-invariant structure at a phase transition point. In this talk, I will review recent progress, in collaboration with Matthew Fisher, to relate the universal entanglement properties of monitored quantum systems to an effective classical statistical mechanics, which reveals ways in which the observer can use the measurement outcomes to extract universal properties of these phases and their phase transitions. I will conclude with some future prospects for this field.

Smitha Vishveshwara University of Illinois

Fractional Quasiparticles: A Collective Quest

One of the most spectacular manifestations of collective behavior in strongly correlated systems is the emergence of quasiparticles exhibiting fractional quantum statistics. Recently, two landmark experiments in quantum Hall systems reported observations of such anyons. In this talk, I trace a few key ideas from a quarter century back, starting with proposals to measure the fractional charge of these quasiparticles, to two-particle correlation measurements, initially proposed in the astronomical realm, that form the basis of these experiments. I also describe how the quantum Hall bulk offers a rich playground for quasiparticles to exhibit parallels with quantum optics and even black hole dynamics.

Wei Wu NYU Shanghai

“Massless phases for the Villain model in d>=3”

The XY and the Villain models are models which exhibit the celebrated Kosterlitz-Thouless phase transitions in two dimensions. The spin wave conjecture, originally proposed by Dyson and by Mermin and Wagner, predicts that at low temperature, spin correlations of these models are closely related to Gaussian free fields. I will review the historical background and discuss some recent progress on this conjecture in d>=3. Based on the joint work with Paul Dario (CNRS).

Lai-Sang Young NYU
Growth and depletion in some stochastic reaction networks
This talk is about the dynamics of inter-conversion among a finite number of substances through reactions that consume some of the substances and produce others. The models are continuous-time Markov jump processes, intended as idealizations of a broad class of biological networks. Reaction rates depend linearly on “enzymes", which are among the substances produced; a reaction can proceed only when all of its upstream materials are available. The following two scenarios are considered under the assumption of exponential network growth: (i) all substances experience sustained growth, and (ii) one of the substances depletes. I will give a complete description of the large-time behavior in the case of (i). When a depletion occurs, network dynamics undergo a bifurcation (or "phase transition").
I will present a mean-field approximation of post-depletion dynamics viewing it as a slow-fast dynamical system.