Boundary and curvature effects in midpoint percolation

Seung Ki Baek 1, Petter Minnhagen 1, Beom Jun Kim 2

1. Department of Physics, Umeå University, Umeå, Sweden
2. Department of Physics, Sungkyunkwan University, Suwon, Korea

A lattice with a negative curvature has two percolation thresholds: an unbounded cluster first appears at the lower threshold, and a single cluster occupies a finite fraction of the volume at the upper threshold. We show that the double transitions can be well described by connections between the midpoint and boundaries. Such an explicit consideration on boundary effects can be also applied to ordinary $d$-dimensional lattices to detect critical properties as well as proliferation of percolating clusters above $d = 6$. It shows a qualitative correspondence between a negatively curved structure and a high dimensional one. We furthermore present analytic results by examining the enhanced binary tree, a prototype of negatively curved lattices, by the renormalization-group method and the layer-connectivity function.
The Hierarchical Random Energy Model

Michele Castellana ¹ ², Aurélien Decelle ², Silvio Franz ², Marc Mézard ², Giorgio Parisi ¹

1. Department of Physics, University La Sapienza, Rome, Italy
2. Laboratoire de Physique Théorique et Modèles Statystiques, University Paris Sud, Orsay, France

Both for spin glasses and for structural glasses, the mean field theory of disordered systems provides a suggestive picture of laboratory glassy phenomena. Unfortunately, the development of a first principles theory of glassy systems going beyond mean-field, has resisted decades of intense research. In this work, we introduce the Hierarchical Random Energy Model (HREM), a hierarchical version of the random energy model that qualifies as a non mean-field model.

The HREM can be defined as a system of $N = 2^k$ Ising spins with an energy function $H$ defined recursively. The recursion is started at the level of a single spin $k = 0$, with the definition of $H_0[S] = \epsilon_0(S)$. The single spin energies $\epsilon_0(S)$ are independent identically distributed (i.i.d.) random variables extracted from a distribution $\mu_0(\epsilon)$. At the level $k + 1$, we consider then two independent systems of $2^k$ spins $S_1$ and $S_2$ with Hamiltonians $H_{t_k}[S_1]$ and $H_{s_k}[S_2]$ respectively and put them in interaction to form a composite system of $2^{k+1}$ spins and Hamiltonian

$$H_{k+1}[S_1, S_2] = H_{t_k}[S_1] + H_{s_k}[S_2] + \epsilon_k[S_1, S_2],$$

where the $\epsilon_k$ are i.i.d. random variables extracted from a distribution $\mu_{k+1}(\epsilon)$, with variance $2^{2(k+1)(1-\sigma)}$. As for $0 < \sigma < 1$ the interaction strength scales sub-extensively with respect to the system’s volume $2^{k+1}$, the HREM qualifies as a non mean-field model.

We developed an analytical and a numerical solution method for the model. Both the methods provide the first evidence of a non-mean field spin-glass transition. Moreover, at variance with mean field, the high temperature branch of the free-energy is non-analytic at the transition point.
Brownian motors and glass-forming liquids, work production from out-of-equilibrium relaxation

Giacomo Gradenigo 1, Tomas Grigera 2, Andrea Puglisi 1, Alessandro Sarracino 1, Dario Villamaina 3

1. Centro Nazionale Ricerche - Istituto Sistemi Complessi (CNR-ISC), Physics Department - University "La Sapienza", Rome, Italy
2. Instituto de Investigaciones Fisicoquímicas Teóricas y Aplicadas (INIFTA) and Departamento de Física, La Plata, Argentina.
3. Physics Department - University "La Sapienza", Rome, Italy

No work can be extracted from an isolated system in equilibrium with a single thermostat. Nevertheless there are systems, e.g. glass-forming liquids, where relaxation to the thermostat temperature is so slow that two different temperatures can be defined within the same system: the temperature of the thermostat and the effective temperature associated to the violation of the equilibrium fluctuation-dissipation ratio. Here we present the first numerical study which shows how, by introducing a proper brownian motor, is possible to extract work from the out-of-equilibrium regime of a glass-forming liquid.
Using Monte Carlo simulations, topology and statistical mechanics to build scalable and stable quantum computers

Helmut G. Katzgraber,1,2 Ruben S. Andrist,1 Creighton K. Thomas,2 Hector Bombin,3 Miguel Angel Martin-Delgado,4

1. Theoretische Physik, ETH Zurich, CH-8093 Zurich, Switzerland
2. Physics & Astronomy Department, Texas A&M University, College Station, Texas 77843, USA
3. Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L2Y5, Canada
4. Departamento de Física Teórica I, Universidad Complutense, 28040 Madrid, Spain

Sensitivity to noise makes most of the current quantum computing schemes prone to error and nonscalable, allowing only for small proof-of-principle devices. Topologically-protected quantum computing aims at solving this problem by encoding quantum bits and gates in topological properties of the hardware medium that are immune to noise that does not impact the entire medium at once. There are different approaches to achieve topological stability or active error correction, ranging from quasiparticle braidings to spin models and topological color codes that use brane-net condensates in 3-colexes. The stability of these proposals against noise can be quantified by the error threshold. This figure of merit can be computed by mapping the problem onto complex statistical mechanical spin models with local disorder on nontrival lattices that can have many-body interactions or are described by lattice gauge theories. The error threshold then represents the point in the temperature-disorder phase diagram where a stable ferromagnetic phase vanishes. Using large-scale Monte Carlo simulations we show that topological color codes have similar error stability to the Kitaev toric code. Our results illustrate the generic robustness of topologically-protected quantum computing proposals, thus paving the road towards stable and scalable quantum computers.


Equilibrium vs. non-equilibrium in the 3D Ising spin-glass phase

V. Martin-Mayor\textsuperscript{1} for the Janus Collaboration

1. Universidad Complutense de Madrid, Spain

We compare the non-equilibrium dynamics of the $D=3$ Ising spin glass for finite times with the equilibrium properties of finite systems. The comparison is based on two massive simulations carried out on the special-purpose Janus supercomputer: one covers the non-equilibrium dynamics in the range from picoseconds to one tenth of a second [1] while our equilibrium parallel tempering simulation has thermalised lattices $L=32$ down to to $T=0.64 T_c$ [2]. The combination of these two studies offers a unique perspective on the nature of the spin-glass phase.

We demonstrate the relevance of equilibrium finite-size simulations to understand experimental non-equilibrium spin glasses in the thermodynamical limit by establishing a time-length dictionary. The unavoidable consequence is that our equilibrium simulations are probing the relevant length scale for experiments and that non-equilibrium experiments performed on a time scale of one hour can be matched with equilibrium results on $L=110$ lattices. A detailed investigation of the probability distribution functions of the spin and link overlap, as well as of their correlation functions, shows that Replica Symmetry Breaking is the appropriate theoretical framework for the physically relevant length scales.

The nature of the ordered phase of spin glasses

Mike Moore

School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

For over a quarter of a century a debate has raged as to the form of the order parameter of spin glasses. There are two rival pictures: one is derived from droplet scaling ideas, the other from the replica symmetry breaking approach of Parisi and co-workers. It is agreed by both camps that the debate can be clarified by studying the one-dimensional long-range Ising spin glass whose range exponent $\sigma$ can be tuned to mimic the properties of the spin glass with short-range interactions in any dimension $d$. Renormalization group calculations will be presented to elucidate the nature of the ordered state of this model as a function of $\sigma$. 
Relaxation dynamics of an elastic string in random media

Jae Dong Noh$^{1,2}$, Hyunggyu Park$^2$

1. Department of Physics, University of Seoul, Seoul, Korea
2. School of Physics, Korea Institute for Advanced Study, Seoul, Korea

We present the relaxation dynamics of an elastic string in two-dimensional random media. Starting from a flat configuration and measuring spatial fluctuations of its mean position, we find that the correlation length grows in time asymptotically as $\xi \sim (\ln t)^{1/\tilde{\chi}}$. This implies that the relaxation dynamics is driven by thermal activations over random energy barriers which scale as $E_B(\ell) \sim \ell^{\tilde{\chi}}$ with a length scale $\ell$. Numerical data strongly suggest that the energy barrier exponent $\tilde{\chi}$ is identical to the energy fluctuation exponent $\chi = 1/3$. We also find that there exists a long transient regime, where the correlation length follows a power-law dynamics as $\xi \sim t^{1/z}$ with a nonuniversal dynamic exponent $z$. The origin of the transient scaling behavior is discussed in the context of the relaxation dynamics on finite ramified clusters of disorder.
An exact analysis for dynamical properties of avalanche phenomena

Hiroki Ohta, Shin-ichi Sasa

Department of Pure and Applied Sciences, University of Tokyo, 3-8-1 Komaba Meguro-ku, Tokyo 153-8902, Japan

Avalanches are ubiquitous phenomena in nature. A rich variety of avalanches might be classified into some universality classes from the nature of cooperative slow dynamics. However, the determination of the universality class is generally difficult because such systems are rather complicated. Therefore, it is important to accumulate exactly analyzable examples, which help us understand the universality class. Here, we show an exact analysis for the dynamical properties of an avalanche phenomenon. Concretely, we study zero-temperature Glauber dynamics of a random-field Ising model on a Bethe lattice. With mapping the original system to another system, we can derive the evolution equation of a hidden order parameter. This leads to some critical exponents characterizing the universal class of an avalanche phenomenon.
Statistics of density fluctuations in supercooled viscous liquids

Ulf R. Pedersen, David Chandler

Department of Chemistry, University of California, Berkeley, California, USA

Small length scale density fluctuations in normal homogeneous liquids obey gaussian statistics over many orders of magnitude [1]. This dependence underlies successful theories of normal liquids [2]. Here, we examine the statistics of density fluctuations outside the realm of normal liquids, in particular for atomistic models of structural glass formers — both non-associated and networked. We use enhanced sampling methods to compute probability distributions of density fields, and we consider a range of length scales and amplitudes. We find that gaussian statistics persists to a remarkable extent, even in the supercooled regime. Implications will be discussed.

1. Hummer et al., PNAS 93, 8951 (1996); Crooks and Chandler, PRE 56, 4217 (1997)
2. Chandler, PRE 48, 2989 (1993)
Stochastically driven hysteretic systems

Günter Radons, Sven Schubert

Chemnitz University of Technology, Institute of Physics, Chemnitz, Germany

Many physical and technical systems are characterized by non-trivial hysteretic behavior. Topical examples are porous materials, shape memory alloys, and magnetic nanoparticles. The fact that external fields are often entirely erratic leads to the question how hysteretic systems respond to random processes. Hence we are interested in autocorrelation or spectral properties, respectively, of Preisach hysteresis models driven by stochastic input scenarios.

Starting from a known scenario, the case of uncorrelated input signals, where long-term correlations and 1/f-noise could emerge due to hysteresis [1], we investigate the role of long-term correlations in input signals for hysteretic systems using numerical simulations. For systematic investigations, firstly, we established a method to compute correlated input processes that allows us to determine the probability density and long-term autocorrelation decay of the input signal. Secondly, different hysteresis outputs are computed and, lastly, their correlation decay is analyzed. Our investigations indicate that correlations in the input signal and hysteretically induced correlations compete. As a result we observe two regimes: (1) long-time tails of input correlations survive in the output or (2) we observe long-time tails due to hysteresis, as if they were induced by delta-correlated input.

Ising Spin Glasses on the fixed connectivity hypercube

B. Seoane¹, L.A. Fernández, V. Martin-Mayor, G. Parisi

1. Universidad Complutense de Madrid, Spain

We introduce a mean field model for spin glasses with a natural notion of distance built in, namely, the Edwards-Anderson model on the diluted $D$-dimensional unit hypercube in the limit of large $D$. We show that finite $D$ effects are strongly dependent on the connectivity, being much smaller when the coordination number per spin is fixed than when it is random. We solve the non trivial problem of generating this kind of lattices. We use this model to investigate numerically the nonequilibrium dynamics of the mean-field spin glasses. Finite-Size effects in nonequilibrium dynamics come out smaller than in Erdos-Renyi lattices. Our three main findings are the following: (i) the dynamics takes place in an infinite number of time-sectors, (ii) the aging dynamics consists of the growth of coherent domains with a non vanishing surface-volume ratio, and (iii) the propagator in Fourier space follows the $p^4$ law. Finite $D$ effects in the nonequilibrium dynamics are studied, finding that a naive finite size scaling ansatz works surprisingly well.

This talk is based on arXiv:0911.4667, accepted for publication in Phys. Rev. B.
A spin glass perspective on martensitic shape-memory alloys

David Sherrington

Rudolf Peierls Centre for Theoretical Physics, University of Oxford, UK

Spin glasses are many-body systems with complex cooperative behaviour due to the combination of quenched randomness and frustration in their interactions and/or constraints. Their study has demonstrated unusual, often non-ergodic, behaviour and has led to many new concepts and techniques, as well as broad application of that knowledge in many areas. This presentation will consider structural effects in martensitic alloys by analogy with spin glass physics and show how such considerations both make predictions and provide explanations for properties of the martensitic materials and also indicate how these materials provide new laboratories for probing potentially interesting aspects of generalised spin glasses less accessible in conventional systems.
Micro-dynamics of quenched 2D dusty plasma liquids

Yen-Shuo Su ¹, Chong-Wai Io ¹, and Lin I ¹

1. Department of Physics, National Central University, Jhongli, Taiwan 320, R.O.C

Dusty plasma liquids can be formed by micro-meter sized dust particles which are negatively charged and suspended in low pressure gaseous discharge. The sub-mm inter-particle distance and a few seconds relaxation time scale make it a good system to investigate the dynamic of liquids at the discrete level. In this work, we use this system to investigate the spatio-temporal evolution of the micro-structure and motion of the quenched cold 2D dusty plasma liquid from the dusty plasma gas. It is found that dusts with high initial speed are quickly slowed down to form small ordered domains, which are then gradually merged to form larger domains with longer spatial correlation and slower structure reorganization time. The dynamical heterogeneity is presented and discussed.
Spatial extent of dynamic heterogeneity in a glassy hard sphere system

Grzegorz Szamel ¹, Elijah Flenner ¹

¹ Department of Chemistry, Colorado State University, Fort Collins, CO 80523, USA

We use large scale computer simulations to study the spatial extent of dynamic heterogeneity in a dense, glassy hard sphere system. To quantify the spatial extent of dynamic heterogeneity we evaluate a correlation function of mobility fluctuations, and use the small wavevector dependence of this correlation function to calculate a dynamic correlation length. Since we use a large number of particles, up to 80,000 particles, we are able to unambiguously determine the small wavevector dependence of the mobility correlation function and, thus, the correlation length. We investigate the dependence of the correlation length upon the $\alpha$ relaxation time. We also compare our results with those of earlier simulations that utilized smaller systems [R.S.L. Stein and H.C. Andersen, Phys. Rev. Lett. 101, 267802 (2008)] and with the theoretical analysis of Berthier et al. [J. Chem. Phys. 126, 184503 (2007)].
Quantum spin-glass phase transitions and Griffiths singularity at zero temperature

Kazutaka Takahashi, Yoshiki Matsuda

Department of Physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

We study the effects of random fluctuations on quantum phase transitions by the energy gap analysis. For the infinite-ranged spin-glass models with a transverse field, we find that a strong sample-to-sample fluctuation effect leads to broad distributions of the energy gap. As a result, the linear, spin-glass, and nonlinear susceptibilities behave differently from each other. The power-law tail of the distributions implies a purely quantum Griffiths-type singularity. We also discuss the mechanisms of the phase transition in terms of the energy gap by comparing the many-body interacting models, which demonstrate the difference between the quantum/classical and continuous/discontinuous phase transitions.
Effect of steepness of soft disks on dynamics near the glass transition

Yayoi Terada \(^1\), Michio Tokuyama \(^2\)

1. Institute of Fluid Science, Tohoku University, Sendai, 980-8577, Japan, terada@ifs.tohoku.ac.jp
2. WPI Research Center, Advanced Institute for Materials Research, Tohoku University, Sendai, 980-8577, Japan

The effect of steepness of the interparticle potentials on the area fraction dependence of the long-time self-diffusion of particles is discussed by performing extensive molecular-dynamics simulations of polydisperse soft disks. Soft disks are defined using inverse power potentials \(U(r) = \epsilon (\sigma / r)^n\), where the exponent \(n\) indicates the steepness of potentials, \(\epsilon\) and \(\sigma\) are set to be energy and length scales of interparticle potentials, and \(r\) is the distance between the disks. The long-time self-diffusion coefficient decreases more rapidly near the glass transition for large values of \(n\). Therefore the system shifts from strong-like glass to fragile-like glass and the singular point \(\phi_c\) decreases when \(n\) is increased. We also compare area fraction dependence of long-time self-diffusion coefficients with temperature dependence of those by changing steepness \(n\).
Connected spatial correlation functions and the order parameter of the 3D Ising spin glass

D. Yllanes\textsuperscript{1} for the Janus Collaboration

1. Universidad Complutense de Madrid, Spain

By means of a ground-breaking simulation of the three-dimensional Ising spin glass, carried out on the Janus supercomputer, we perform the first reliable determination of the spin-glass order parameter, $q_{EA}$, in the low-temperature phase of the $D = 3$ Edwards-Anderson model. Our approach focuses on the connected spatial correlation function, regarded as a function of the spin overlap $q$. We investigate by means of Finite Size Scaling the phase transition suffered by this correlation function precisely at $q = q_{EA}$.

Our computation is entirely based on the Fourier transform of the connected spatial correlation functions. These quantities, seldom considered in previous numerical investigations, hold considerable promise for the elucidation of the main features of the glassy phase. We investigate in depth these correlation functions, obtaining an exact scaling relation for the involved critical exponents. We compute the exponent that rules finite size effects, which turns out to be compatible with the replicon exponent.

This talk is based on arXiv:1003.2943.