Award Abstract #1207431

Structures and Dynamics in Disordered Systems

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ABSTRACT

TECHNICAL SUMMARY

This award supports theoretical and computational research and aging on hierarchically structured systems and aging in glasses. Hierarchical structures are pervasive in many environments, such as biological networks, and social and economical organizations. Custom-made materials that exhibit hierarchical properties may lead to complex yet well-controlled functionalities not found in ordinary matter. Their recursive design lends itself to rigorous analysis as well as to efficient engineering. Applying venerable tools from condensed matter physics, such as the renormalization group, deep new insight can be gained for transport and critical phenomena on such structures, benefiting applications such as the design of tunable phase transitions or of quantum computing devices.

In the spirit of the powerful concept of universality arising from renormalization group, as applied to systems on conventional lattices, the PI is formulating a renormalization group-classification scheme for critical phenomena on hierarchical networks. Hierarchical networks exhibit a number of uncommon critical phenomena that are rare to find in real materials, such as inverted Kosterlitz-Thouless transitions, infinite-order or discontinuous transitions, and non-universal transitions with tunable critical exponents. Understanding and controlling such transitions ultimately provides the possibility to engineer materials and nanostructures with custom properties not available in ordinary materials. These notions will be developed for a broad range of condensed matter systems. In the process,

the PI will investigate and advance the application of RG methods to handle global constraint, and novel RG schemes will be devised for non-equilibrium and quantum transport phenomena on networks. For example, the PI will investigate problems in quantum computing in recursive lattices to analyze with rigorous methods how quantum interference affects Grover's algorithm for quantum search in higher-dimensional structures to suggest efficient realizations of memory in a quantum computer.

The central hypothesis of the second project on glassy relaxation is that aging generally is connected with record fluctuations, implying that intermittent events or "quakes" drive the dynamics in many glassy materials, with quenched or structural disorder, irrespective of specific microscopic details. Specifically, this project aims to study a new real-space model that provides the relevant phenomenology for record dynamics. Extensive simulations of this model will be conducted to reveal its consistency with known aging phenomena, including the reproduction of various thermodynamic measures. New measures will be explored and tested for their experimental efficacy. Theoretical descriptions in terms of record dynamics will be devised and matched to recent experimental results.

While there are theories that capture various features of aging behavior in glassy materials, there are few unifying concepts among them. Mode-coupling theory does not apply below the glass transition, kinetically constrained models rarely have a transition, and effective temperature concepts from mean field theories lack fluctuations to capture the full non-equilibrium nature of the aging phenomenon. In general, thermodynamic descriptions provide useful indicators, yet, blur the true sub-extensive character of activated dynamics. The PI will examine the significance of the importance of intermittent, extremal fluctuations as a controlling impetus for the relaxation process by devising and analyzing a model based on record dynamics and by providing quantitative insights into a broad spectrum of aging phenomena. In the long run, a more unified description of complex relaxation may emerge, enhancing control in the use and design of disordered materials. Implications for the understanding of complex energy-landscapes, useful in materials design as well as for biological evolution and combinatorial optimization, will be explored.

NON-TECHNICAL SUMMARY

This award supports theoretical and computational research and aging on hierarchically structured systems and aging in glassy materials. The study of complex networks has revolutionized our understanding of many man-made and natural structures in the last decade. Hierarchical structures, in particular, have become a central issue in the design of complex materials as well as in the study of biological networks, social and economical organizations. The PI's research on the dynamics of transport processes within hierarchical networks and modeling the flow of granular materials or electrons, reveals entirely new patterns, very distinct from the typical behaviors observed in ordinary materials. One goal of this project is to understand and classify these novel properties using the tools of traditional condensed matter physics, appropriately adapted to these structures. Such insight can be exploited to engineer meta-materials with custom-made and controllable features.

Another system exhibiting complex dynamics is provided by colloidal and similarly disordered materials. At high density and/or low temperature these amorphous materials attain a glassy state characterized by extremely slow relaxation dynamics, which itself depends on the history of the process. Slow relaxation in disordered systems arises at many levels, for better or for worse: We desire to "unpack" traffic jams faster, to transport grains through hoppers more quickly, or to pack objects more densely, but we also hope that actual glass - in principle a fluid material - retains it shape for long times. A unifying phenomenology referred to as "aging" has been used to describe manifestations of this relaxation dynamics over a wide class of otherwise unrelated materials. Yet, a generic mechanism needed to justify such a sweeping generalization has been elusive. In this second project, the PI will investigate in depth a promising mechanism theoretically and numerically, and in close connection with the experimental evidence.

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