Physics of Complex Systems: Applications to Liquid State Physics, Econophysics and Failure Cascades in Interdependent Networks

H. Eugene Stanley [hes@bu.edu]
Departments of Physics, Chemistry & Biomedical Engineering
Boston University, Boston, MA 02215 USA

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After a brief introduction to complex systems, we will discuss three examples that are the subject of current student research in the BU physics and chemistry departments.

I. Liquid Water, the "Most Complex" Liquid:

We will introduce some of the 64 anomalies of the most complex of liquids, water—focusing on recent progress in understanding these anomalies. Specifically, we will interpret evidence from recent spectroscopy experiments designed to test the hypothesis that liquid water may possibly display "liquid polymorphism" in that it can exist in two different phases—and discuss recent spectroscopic work on nanoconfined water anomalies as well as the apparently related, and highly unusual, behavior of water in biological environments.

II. "What Can We Do before the Next Economic Crisis?"

Recent analysis of truly huge quantities of empirical data suggests that classic economic theories not only fail for a few outliers, but that there occur similar outliers of every possible size. In fact, if one analyzes only a small data set (say 10^4 data points), then outliers appear to occur as "rare events." However, when we analyze orders of magnitude more data (10^8 data points), we find orders of magnitude more outliers—so ignoring them is not a responsible option, and studying their properties becomes a realistic goal. We find that the statistical properties of these "outliers" are identical to the statistical properties of everyday fluctuations. For example, a histogram giving the number of fluctuations of a given magnitude x for fluctuations ranging in magnitude from everyday fluctuations to extremely rare fluctuations that occur with a probability of only 10^{-8} is a perfect straight line in a double-log plot.

We demonstrate the principles of scaling and universality by describing very recent work [2–4]. Financial market fluctuations are characterized by many abrupt switchings on very short time scales from increasing "microtrends" to decreasing "microtrends"—and vice versa. We ask whether these ubiquitous switching processes have quantifiable features analogous to those present in phase transitions, and find striking scale-free behavior of the time intervals between transactions both before and after the switching occurs. We interpret our findings as being consistent with time-dependent collective behavior of financial market participants.

III. The Fragility of Interdependency: Coupled Networks & Switching Phenomena

Recent disasters ranging from abrupt financial "flash crashes" and large-scale power outages to sudden death among the elderly dramatically exemplify the fact that the most dangerous vulnerability is hiding in the many interdependencies among different networks. In the past year, we have quantified failures in interconnected networks, and demonstrated the need to consider mutually dependent network properties in designing resilient systems.

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