Overview of **Network Science and Human Decision Making** Program

Presented by
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at

Bridging Psychology and Neurophysiology

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I propose to give a mile-high review of what has been accomplished by Professor Grigolini's research group within the program over the past year. The emphasis will be on the implications of the Principle of Complexity Management (PCM), which quantifies the limitations of information exchange between such complex dynamic networks as human brains, organizations and complex physical phenomena. I will briefly review the proof of CPM just published this past year and the reliance of that proof on a generalization of the linear response theory (LRT) from non-equilibrium statistical physics. The attenuation of simple signals by complex networks suggested to a number of scientists that LRT was dead, but we proved that this attenuation is only one of a number of possible responses of a complex network to perturbation. In fact this class of responses may well explain the physiological phenomena of habituation and why and how we forget, which I will briefly touch on in my remarks. It has also become apparent that the decision making model (DMM) used to study the phase transition properties of complex networks on a two-dimensional lattice has a parameter domain where its results overlap those of the Ising model. However the phase transition of DMM can be significantly broader and suggests mechanisms based on dynamics that are not accessible to the Ising model, to wit, temporal complexity such as non-stationary and non-ergodic fluctuations. I will close by mentioning that this is a general property of criticality and is entailed by the CPM.

Stephanie Hawkins
UNT Department of English

"Moving clouds of swarming atoms": William James and Psychophysics

American psychologist and philosopher William James devoted the entirety of his career to exploring the nature of volition, as expressed by such phenomena as will, attention, and belief. As part of that endeavor, James's unorthodox scientific pursuits, from his experiments with nitrous oxide and hallucinogenic drugs to his investigation of spiritualist mediums, represent his attempt to address the "hard problems" of consciousness for which his training in brain physiology and experimental psychology could not entirely account. As a student, James's reading in chemistry and physics had sparked his interest in the concepts of energy and force, terms that he later deployed in his writing about consciousness and in his arguments against philosophical monism and scientific materialism, as he developed his "radically empiricist" ideas privileging discontinuity and plurality. Despite James's long campaign against scientific materialism, he was, however, convinced of the existence of a naturalistic explanation for the more "wayward and fitful" aspects of mind, including transcendent experiences associated with hysteria, genius, and religious ecstasy. In this paper, I examine aspects of James's thought that are still important for contemporary debates in psychology and neuroscience: his "transmission theory" of consciousness, his ideas on the "knowing of things together," and, finally, the related concept of "the compounding of consciousness," which postulates the theoretical possibility for individual entities within a conscious system of thought to "know" the thoughts of others within the system. Taken together, these ideas suggest that James, in spite of, or perhaps because of, his forays into metaphysics, was working toward a naturalistic understanding of consciousness, what I will term a "distributive model," based on his understanding of consciousness as an "awareness" that interacts dynamically within, and in relation to, its environment.

Gerhard Werner
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Consciousness viewed in the framework of brain phase transitions and criticality

To set the stage for proposing a framework for viewing Consciousness in terms of brain phase space dynamics and criticality, I will at first review currently prominent theoretical conceptualizations and, where appropriate, identify ill-advised and flawed notions in Theoretical Neuroscience that may impede viewing Consciousness as a phenomenon in Physics. I will furthermore introduce relevant facts that tend not to receive adequate attention in much of the current Consciousness discourse. As a new approach to Consciousness, I will then propose considering it as a collective achievement of the brain's complex neural dynamics that is amenable to study in the framework of state space dynamics and criticality. In Physics, concepts of phase space transitions and the Renormalization Group are powerful tools for interpreting phenomena involving many scales of length and time in complex systems. The significance of these concepts lies in their accounting for the emergence of different levels of new collective behaviors in complex systems, each level with its distinct ontology, organization and laws, as a new pattern of reality. The presumption of this proposal is that the subjectivity of Consciousness is the epistemic interpretation of one of the levels of reality that originates in phase transitions of the brain-body-environment system.

Ken Norwich
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Neurophysiological Encoding of the Apprehension of Physical Events

How is the sensation of brightness of a light or loudness of a sound mediated neurally? The simplest postulate is that such perceptual features are encoded by the rate of transmission of action potentials, or electrical impulses, in afferent neurons (nerve fibers carrying information from sensory receptors toward the brain). We examine the results of experiments performed on human subjects in the 1960's and1980's designed to test this conjecture. Functional imaging using magnetic resonance, which is popular today, maps mental activity of various sorts onto characteristic regions of the brain; but do such studies increase our understanding of the neurophysiological basis of perception or comprehension? Neuroanatomical pathways from sensory receptors through the spinal cord, brain stem, midbrain to the cortex of the brain are well known for the senses of taste (tongue to cortex), hearing (cochlea to cortex) etc. However, these pathways are purely afferent in nature. Does the apprehension or perception of sensory signals also require efferent pathways (nerve fibers carrying information from the brain towards peripheral sensory receptors)? Termination of afferent pathways at the cerebral cortex seems incomplete. "Who is reading the sensory cortex?" Biological science seems to have reached its limit; further understanding must come from physics. Does collapse of the wave function depend on its extension to the cerebral cortex (Wigner's friend)? Statistical mechanical models of sensory function can be constructed, but can they be "mapped" onto known neurophysiological structures? A hypothetical quantum physical "sensory receptor" reproduces a known property of information transfer. If such physical models have validity, the process of "sensation" or apprehension of simple physical signals would be similar throughout the physical universe.

Dante R. Chialvo
Laboratory of Neurophysiology, Los Angeles

Critical brain dynamics allows optimal information flow

In this talk we will hammer over the idea that critical dynamics is the emergent collective property that allows for healthy brainfunction. Such conjecture, made more than a decade ago (Chialvo,Nature Physics, 2010), is now supported by a number of experimentalstudies which will reviewed here followed by most recent experiments and analysis. We will discuss results from fMRI resting brain data demonstratingthat critical dynamics endows the brain optimal information-transport across arbitrary distances, a property that is familiar to physicists related with divergence of correlations at the critical point. Indeed,we will demonstrate that correlations diverge with size of the brain regions sampled and consequently anomalous behavior of the variance of the fMRI mean signal. Finally, if time allows we will show how these results relate with avalanching dynamics. These uncovered properties,can not be explained outside criticality and expose optimal information-sharing properties across very diverse networks sizes, architectures and functions, something can be an important marker of healthy brain dynamics.

Dmitri Krioukov
Cooperative Association for Internet Data Analysis
University of California, San Diego

Percolation in self-similar networks

Brain circuits, gene regulation machinery, the Internet, and other real networks must be robust with respect to random structural and functional damage. This universal property has motivated an impressive flow of works studying percolation properties of complex networks. However, the progress in identifying percolation universality classes of networks has been limited as details seem to prevail. Here we focus on the implications that self- similarity or scale/conformal invariance have on network percolation. Self-similar networks are shown to have zero percolation threshold. The proof is amazingly simple, does not involve any tree-like approximations, and can be generalized to any processes on networks with critical parameters depending monotonously on the average degree in the network. The proof relies only on network self-similarity with an associated hierarchy of nested subgraphs whose average degree increases with the subgraph depth in the hierarchy. Therefore the proof applies equally well to equilibrium networks with or without strong clustering, or to growing networks -- in fact, to any networks that satisfy this property. We provide several examples of network models and real networks that do so. This finding suggests that self-similar networks must have well-defined percolation universality classes which depend only network rescaling properties. We also provide a geometric interpretation of network self-similarity, and relate it to network invariance with respect to scale or conformal transformations in the underlying hyperbolic metric space.

Stefan Boettcher
Physics Department, Emory University, Atlanta

Renormalization Group Classification of Critical Phenomena in Complex Networks

In the past 15 years, statistical physicist have increasingly applied the ideas of critical phenomena and scaling to problems outside of the immediate material realm, in newly emerging fields such as “Econophysics”, “Sociophysics”, “Psychophysics”, etc. The considered systems typically feature a large number of interacting agents sharing a finite set of intrinsic properties on account of which they interact. But unlike in a Euclidean defined arrangement of “actors” in a physical system, such as atoms in a material, these systems possess a more complex network of mutual interactions (which may even be directed). Thus, in many respects, the study of these phenomena is inseparable from the understanding of the geometry of networks. One major accomplishment of these investigations is the realization that many of the networks that are engineered by some natural or human activity themselves exhibit emergent complex properties, for instance, as found in the scale-free degree distribution of the internet. But while these networks, or dynamical systems on them, may behave critically, many of these phenomena were soon found to be non-universal, i.e. they are intimately tied to microscopic details of the specific system. In this sense, it would seem unlikely that any sweeping classification scheme could be devised to categorize this amorphous pile of particulars. Here, we will attempt a forray into such a scheme, albeit limited to those classical equilibrium phenomena, but on a large set of different networks. We suspect that our discussion might help to explain, for example, a number of similar observations of traditionally obscure critical behaviors, such as infinite-order transitions, in very different network models, in and out of equilibrium.

Maksim Kitsak
Cooperative Association for Internet Data Analysis
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Identification of Influential Spreaders in Complex Networks

Networks portray a multitude of interactions through which people meet, ideas are spread and infectious diseases propagate within a society. Identifying the most efficient 'spreaders' in a network is an important step towards optimizing the use of available resources and ensuring the more efficient spread of information. Here we show that, in contrast to common belief, there are plausible circumstances where the best spreaders do not correspond to the most highly connected or the most central people. Instead, we find that the most efficient spreaders are those located within the core of the network as identified by the k-shell decomposition analysis and that when multiple spreaders are considered simultaneously the distance between them becomes the crucial parameter that determines the extent of the spreading. Furthermore, we show that infections persist in the high-k shells of the network in the case where recovered individuals do not develop immunity. Our analysis should provide a route for an optimal design of efficient dissemination strategies.

Yuri Bakhtin
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Decision making and scaling limit for diffusion exit problem

Abstract: In this talk I will recall the theory of sequential decision making models based on diffusion along heteroclinic networks of dynamical systems, i.e., multiple saddle-type equilibrium points connected by heteroclinic orbits. I will interpret exit times for stochastic dynamics as decision making times and recall a result on their asymptotic behavior. I will report on extensive data on decision making in no a priori bias setting obtained in an experiment that we ran (together with Joshua Correll), and compare the data with our theoretical results. Addressing the last year's discussions, I will also report that the same kind of limiting distribution for exit times appears in neuronal computation model.

Ginestra Bianconi
Department of Physics, Northeastern University, Boston

The reinforcement dynamics modulates social interactions in humans and in simple animal

The reinforcement dynamics modulates social interactions in humans and in simple animal. We will present data on human social face-to-face and phone call interactions recorder by recent technology. These data is consistent with a non-poisson distribution of duration of contacts. A new temporal reinforcement dynamics describing a hebbian cognitive mechanism is the basic ingredient that is able to reproduce these features. We compare human behavior with group formation in leeches, where in a controlled setting we can study the neurological origin of the reinforcement dynamics. Similarities and differences from leech group behavior and human duration of contacts are highlighted.

Lazaros Gallos
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Global integration of self-similar modules in functional brain networks
(Collaboration with Hernan A. Makse and Mariano Sigman)

The human brain has been studied at multiple scales, from neurons, circuits, areas with well defined anatomical and functional boundaries, to large-scalefunctional networks which mediate coherent cognition. The hierarchical organization of the brain poses a conundrum: modules ought to be sufficiently independent to guarantee functional specialization and sufficiently connected to bind multiple processors for efficient information transfer. It is commonly accepted that small-world architecture may solve this problem. However, there is intrinsic tension between shortcuts generating small-world networks and the persistence of modules. Here we use network science tools to elaborate on this behavior.
We show that the functional brain network formed by percolation of strong links is highly modular. Modules are self-similar and therefore are far from being small-world. Incorporating the weak ties to the network converts it into a small-world preserving an underlying backbone of well-defined modules.
Weak ties are organized precisely as predicted by theory maximizing information transfer with minimal wiring costs. This trade-off architecture is reminiscent of the 'strength of weak ties' crucial concept of social networks and provides a natural solution to the puzzle of efficient information flow in the highly modular structure of the brain.

Gyorgy Korniss
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The Impact of Time Delays in Network Synchronization in a Noisy Environment

Coordinating, distributing, and balancing resources in networks is a complex task and it is very sensitive to time delays. To understand and manage the collective response in these coupled interacting systems, one must understand the interplay of stochastic effects, network connections, and time delays. In synchronization, coordination, and consensus problems in coupled interacting systems individual units attempt to adjust their local state variables (e.g., pace, load, orientation) in a decentralized fashion. They interact or communicate only with their local neighbors in the network, often with explicit or implicit intention to improve global performance. Applications of the corresponding models range from physics, biology, computer science to control theory.

I will discuss the effects of nonzero time delays in stochastic synchronization problems with linear couplings in an arbitrary network. Further, by constructing the scaling theory of the underlying fluctuations, we establish the absolute limit of synchronization efficiency in a noisy environment with uniform time delays, i.e., the minimum attainable value of the width of the synchronization landscape. These results have also strong implications for optimization and trade-offs in network synchronization with delays.

Paolo Grigolini
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From the transmission of chaos to the transmission of complexity

We review some models of cooperative interaction among units that in the absence of interaction would be driven by ordinary statistical physics. We show that all these models undergo a phase transition similar to that widely studied with the Ising model. However, this phase-transition behavior is more general and it is generated also by the model proposed by Viczek to explain the surprising coherence of a swarm of birds. We show that the at the phase transition long-range correlation links are established, thereby implying the emergence of a form of collective intelligence that is measured by means of a new definition of network efficiency called perception length. The condition of cooperation among the units of a regular two-dimensional lattice generates a scale-free network, with a fractal structure suggesting a possible connection between fractal dimensions and scale-free distribution of links.

We also illustrate a property that has been overlooked by the researchers in the field of Complexity. In addition to the spatial complexity generated by cooperation a temporal complexity emerges from the cooperative process. The global field lives in a quiescent state for a large time and from time to time it makes transitions from one to another quiescent state. It is remarkable that the time duration of quiescence has the same inverse power law structure as that generated by the adoption of the logarithmic time of Fechner. At the onset of phase transition the global field of the system fluctuates in time, and these fluctuations depart from the conditions of ordinary statistical physics. These fluctuations are not ergodic, implying that the organized system, either the brain or the flock of birds, or any other cooperative system, lives in a condition of perennial departure from thermodynamic equilibrium.

We review the recent work done to study the response of these fluctuations to an external stimulus. This theoretical research work proves that a new fluctuation-dissipation theorem holds true, and on the basis of that it leads to the surprising conclusion that a complex fluctuation is only sensitive to stimuli with the same complexity. A brain can only responds to the stimuli produced by another brain. This is a generalization of the phenomenon of chaos synchronization that can be interpreted as a form of complexity transmission from one network at criticality to another network at criticality. Is this the neuro-physiological counterpart of the James's transmission theory?