Satellite Session **Conference on Complex Systems '15** ccs2015.org

The Industrial Age and Thermodynamics; the Information Age and … *What?*

Tempe Arizona, 30 September 2015
8:30 am – 5:00 pm

Visit http://csc.ucdavis.edu/InfoAge_CCS_2015.html

Talk Abstracts

Welcome and why we are here

Jim Crutchfield: ***Welcome to the new millennium of information***

Social change is intricately linked to technological progress, which is intricately linked to scientific understanding, which again influences how we interpret the world around us. The first steam locomotives were up and running two decades before Carnot published his thermodynamic "Reflections". After thermodynamics became a formal theory, its basic principles started to become a standard paradigm for interpretation. For example, the co-formulator of the theory of evolution, A. R. Wallace, proposed natural selection as a kind of feedback mechanism which "is exactly like that of the centrifugal governor of the steam engine". Concepts like equilibrium, transformation of work, flow of energies and resources, and a vast array of related mathematical concepts were used as guiding metaphors and formal building blocks in the creation of biological and social science theories. Currently, information and communication technologies transform our lives in a similar way. Once again, the underlying theories were discovered in parallel with the creation of those technologies, including innovations in telecommunication networks, cryptographic coding machines, computers and formal algorithms. And once again, the emerging theories have an important influence on the way we interpret the world around us. It is not surprising to hear laypeople and scientists alike suggesting that "evolution computes", "the economy processes information", "code is law", "ecosystems are communication networks", and "culture executes algorithms". Sometimes these analogies work better than other times. In order to obtain a deeper understanding, we have to go beyond mere metaphors.

This Session explores formal advancements in the application of information sciences to social and biological systems. If we live in an "information age", the related formal scientific theories must have something concrete to say about how to think about this. We call for papers that explore the explicit application of theories, concepts, and mathematical tools developed in fields like information theory and computer science. We welcome papers that explore the application of such concepts to all branches of ecological and social systems, including evolutionary ecology, economics, sociology, communication, political science, anthropology, and social psychology.

Martin Hilbert: ***The information age and its conceptual challenges***

Prediction and dynamic processes

Sarah Marzen: ***New tools for dimensionality reduction in prediction***

In order to survive, we must predict. Our best guide to the future, absent hard-wired "expert knowledge", is the past. But what about the past should we store when we lack the memory to store everything we would need to predict the future as well as possible? Predictive rate-distortion provides a set of answers to this question, but computing anything within this framework is surprisingly difficult. We discuss new techniques for calculating predictive rate-distortion functions and the corresponding optimal stochastic codebooks.

Cina Aghamohammadi: ***Beyond the typical set—fluctuations in intrinsic computation***

We show how to calculate the spectrum of statistical fluctuations in structured nonequilibrium steady states (SNESSs)—viz., memoryful, stationary processes generated by hidden Markov models—using their ε-machine presentations. We review basic fluctuation theory, drawing out parallels between statistical mechanics, information theory, and large deviations. To analyze the interaction between statistical fluctuations and process structure, we introduce the thermodynamic spectra of statistical complexity and excess entropy—structural properties that complement the oft-used spectrum of Renyi entropy rate that monitors fluctuations in information production. We show that Renyi entropy itself decomposes into two spectra that monitor rates of information loss and accumulation. In particular, we fully characterize the range of possible SNESS thermodynamic entropy-energy functions, giving new criteria for when a process's ground state has positive entropy rate. We explore fluctuations in SNESSs that are (i) maximum entropy rate, (ii) causally irreversible, (iii) nonergodic, or (iv) infinite memory. The result is a constructive and comprehensive picture of fluctuations in information processing and the balance of information generation and storage that a given stochastic process achieves.

Populations Dynamics, Games & Information Theory

Carl Bergstrom: ***Information transmission as the fundamental concept in biology***

A philosophically inclined talk about why information transmission is *the fundamental* concept in biology.

Marc Harper: ***Understanding finite population dynamics with information theory***

We will discuss recent advances in understanding finite population dynamics using information theory. After a quick review of the Moran process with mutation using evolutionary games, we will look at the stationary distributions of various example processes, the stationary extrema and the relationship to evolutionary stability using relative entropy, generalizing well-known results for the replicator dynamic. We will conclude with discussions of two further applications of information theory: equilibrium selection via entropy rates, and the study of the effects of the "evolutionary forces" of selection, mutation, and drift individually and simultaneously using constructions related to the detailed fluctuation theorem. This is joint work with Dashiell Fryer (Pomona and SJSU) and Matteo Smerlak (Perimeter Institute).

David Wolpert: ***The marginal value of information in noncooperative games***

In some games, additional information hurts a player, e.g., in games with first-mover advantage, the second-mover is hurt by seeing the first-mover's move. What properties of a game determine whether it has such negative "value of information" for a particular player? Can a game have negative value of information for all players? To answer such questions, we generalize the definition of marginal utility of a good to define the marginal utility of a parameter vector specifying a game. So rather than analyze the global structure of the relationship between a game's parameter vector and player behavior, as in previous work, we focus on the local structure of that relationship. This allows us to prove that generically, every game can have negative marginal value of information, unless one imposes a priori constraints on allowed changes to the game's parameter vector. We demonstrate these and related results numerically, and discuss their implications.

Demons & the physics of life

Dibyendu Mandal: ***Mawell's demon: Carnot's cycle for information engines?***

Heat engines were the drivers of industrial evolution, and Carnot's cycle was the basis to understand them. Similarly, we can think of information engines where information is utilized to do useful work. What would be the equivalent of Carnot's cycle for information engines? I shall argue that an ideal candidate is Maxwell's demon: the "neat fingered" intelligent being of James Clark Maxwell that can make measurements, store information, and with this information perform useful work. I shall introduce an autonomous version of the demon that can extract work out of a single heat reservoir by raising a mass against gravity, in defiance of the usual second law of thermodynamics, if it can write information on a memory device. By tuning the parameters, we shall also build an information eraser out of it, this time requiring external work according to the Landauer's principle.

Alec Boyd: ***Information engines: history and future prospects***

We are currently living in the information age, which is driven by transistor technology: microscopic machines that are used to do information processing. Our ability to develop faster and more efficient computing is contingent on the ability to make these information processing units operate at lower and lower energies. However, as we do this, we approach an energy scale where information has intrinsic energetic consequences which could stall our progress.

In the past century Landauer's principle was established, which set a firm lower bound on energy required to erase a bit of information. This hard bound may make the future of computing look bleak, but erasure is not an isolated event. It's the last part of an information processing cycle consisting of measurement, control, then erasure. By considering the information bearing degrees of freedom and the measured system on the same physical footing in this cycle, it's possible to bend Landauer's principle. Symmetrizing our physical models of information processing creates considerable flexibility in energetic bounds. We explore two different information processing physical systems, called information engines, where the information bearing degrees of freedom are accounted for explicitly.

Sara Walker: ***The information architecture of the cell***

In his celebrated book "What is Life?" Schrödinger proposed using the properties of living systems to constrain unknown features of life. Here we propose an inverse approach and suggest using biology as a means to constrain unknown physics. We focus on information and causation, as their widespread use in biology is the most problematic aspect of life from the perspective of fundamental physics. Our proposal is cast as a methodology for identifying potentially distinctive features of the informational architecture of biological systems, as compared to other classes of physical system. To illustrate our approach, we present a case study a Boolean network model for the cell cycle regulation of the single-celled fission yeast (Schizosaccharomyces Pombe) and compare its informational properties to two classes of null model that share commonalities in their causal structure. We report patterns in local information processing and storage that do indeed distinguish biological from random. Conversely, we find that integrated information, which serves as a measure of “emergent” information processing, does not differ from random for the case presented. We discuss implications for our understanding of the informational architecture of the fission yeast cell cycle network and for illuminating any distinctive physics operative in life.

New Horizons

Pierre-Andre Noel: *Mind the information flow: …on cycle-rich random graphs*

From opinion dynamics to power engineering, modern society faces numerous problems that can be understood as dynamical processes taking place on complex networks. Random graph ensembles help us understand how these processes' outcomes are affected by different network properties, and how to leverage this knowledge to control the issue. However, the traditional analytical apparatus mainly deals with tree-like random graphs, thus seriously restricting the spectrum of complex networks that can be investigated through them. For these reasons, processes fundamentally affected by the presence of cycles (e.g., cascades of failures on critical infrastructures and complex contagion on social networks) have not received the same level of attention as those for which tree-like structures suffice.

We recently introduced "wide motifs", a concept generalizing both ideas of network motifs and tree decomposition. Assemblages of wide motifs produce random graphs containing intricate combinations of cycles of any length, thus facilitating the analytical study of stochastic processes strongly affected by such structural properties. From an information theory perspective, our solution method is akin to belief propagation: we consider the different exchanges of information that may take place among neighboring vertices and thus decompose global correlations in terms of these local units. Our current method could probably be improved by achieving a better understanding of how information is generated by the vertices (entropy generation) and diffuses through the graph structure. Our work also motivates new empirical metrics that may better capture mechanistically-relevant information in the structure of complex networks.

Ryan James: *New horizons in information theory*

The science of the 21st century, as opposed to that of the 20th, is increasingly more data-centric and the questions being asked more nuanced. While Shannon's information theory has had many great successes tackling 20th century problems, it is beginning to show its weaknesses when confronted with demands of modern research. Here we highlight two primary, though not independent, domains in which traditional information theory fails, and review approaches currently being studied to overcome these failures. The first domain is quantifying redundant and synergistic effects among agents in a system. We will show that traditional multivariate measures fail to adequately distinguish between these notions, and examine a recently proposed framework, the partial information lattice, to tease apart these behaviors. The second domain is measuring information flow or transfer between agents (e.g. nodes in a network). The primary method of quantifying information transfer is the transfer entropy. Using the lens of the partial information lattice we will show that the transfer entropy does not quantify what it claims to, and suggest an alternative quantification.

Interactive Roundtable: *the Information Age and … What?*

Aghamohammadi, Bergstrom, Boyd, Harper, James, Mandal, Marzen, Noel, Walker, Wolpert.
Moderated by Crutchfield and Hilbert.