

Santa Fe Institute Workshop

Summary Description

(Dated: December 1, 2010)

Title:

Randomness, Structure, and Causality:

Measures of complexity from theory to applications

Dates: 9-13 January 2011

Location: Santa Fe Institute, Santa Fe, New Mexico

Organizers:

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Description

In 1989, SFI hosted a workshop—*Complexity, Entropy, and the Physics of Information*—on fundamental definitions of complexity. This workshop and the proceedings that resulted [1] stimulated a great deal of thinking about how to define complexity. In many ways—some direct, many indirect—the foundational theme colored much of SFI’s research planning and, more generally, the evolution of complex system science since then. Complex systems science has considerably matured as a field in the intervening decades and we believe it is now time to revisit fundamental aspects of the field in a workshop format at SFI. Partly, this is to take stock; but it is also to ask what innovations are needed for the coming decades, as complex systems continues to extend its influence in the sciences, engineering, and humanities.

The goal of the workshop is to bring together workers from a variety of fields to discuss structural and dynamical measures of complexity appropriate for their field and the commonality between these measures. Some of the questions that we will address in the workshop are:

1. Are there fundamental measures of complexity that can be applied across disciplines or are measures of complexity necessarily tied to particular domains?

2. How is a system's causal organization, reflected in models of its dynamics, related to its complexity?
3. Are there universal mechanisms at work that lead to increases in complexity or does complexity arise for qualitatively different reasons in different settings?
4. Can we reach agreement on general properties that all measures of complexity must have?
5. How would the scientific community benefit from a consensus on the properties that measures of complexity should possess?

It's a four-day workshop with about 20 or so participants. We will have a stimulating and highly interdisciplinary group with representation from physics, biology, computer science, social science, and mathematics. An important goal is to understand the successes and difficulties in deploying complexity measures in practice. And so, participants come from both theory and experiment, with a particular emphasis on those who can constructively bridge the two.

Since the 1989 SFI workshop, a number of distinct strands have developed in the effort to measure complexity. Several of the well-developed strands are based on

- Predictive information and excess entropy [2–7],
- Statistical complexity and causal structure [8–10],
- Logical depth and computational complexity [11–15], and
- Effective complexity [16, 17].

While these measures are broadly based on information theory or the theory of computation, the full set of connections and contrasts between them is not well developed. Some have sought to clarify the relationship among these measures [7, 17–20] and so another goal of the workshop is to foster this kind of comparative work by bringing together researchers developing various measures.

A second motivation for the workshop is to bring together workers interested in foundational questions—who are mainly from the physics, mathematics, and computer science communities—with complex systems scientists in experimental, data-driven fields who have developed quantitative measures of complexity, organization, and emergence that are useful in their fields. The range of data-driven fields using complexity measures is impressively broad: ranging from molecular excitation dynamics [21] and spectroscopic observations of the conformational dynamics of single molecules [22] through modeling subgrid structure in turbulent fluid flows [23] and new visualization methods for emergent flow patterns [24] to monitoring market efficiency [25] and the organization of animal social structure [26]. The intention is to find relations between the practically motivated measures and the more general and fundamentally motivated measures. Can the

practically motivated measures be improved by an appreciation of fundamental principles? Can fundamental definitions be sharpened by consideration of how they interact with real-world data?

Overall, the workshop's intention is to re-ignite the efforts that began with *Complexity, Entropy, and the Physics of Information* workshop. A new level of rigor, in concepts and in analysis, is now apparent in how statistical mechanics, nonlinear dynamics, information theory, and computation theory can be applied to complex systems. The meteoric rise of both computer power and machine learning has led to new algorithms that address many of the original computational difficulties in managing data from complex systems and in estimating various complexity measures. Given progress on all these fronts, the time is ripe to develop a much closer connection between fundamental theory and applications in many areas of complex systems science.

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