The Principles of Complexity: Life, Scale, and Civilization II
Santa Fe Institute August 1, 2013

Speaker Abstracts
August 1, 2013

GROUP I Universal Patterns in the Emergence of Complex Societies
Jerry Sabloff Team Leader, Laura Fortunato Assistant Team Leader

LAURA FORTUNATO and HANNAH DEROSE-WILSON
Santa Fe Institute
What is Social Complexity, Anyway?

Abstract: Across the social sciences, and in everyday discourse, there is a common perception that social complexity has increased over the course of human history: large-scale, industrialized societies are more "complex" than small-scale, subsistence societies. But are they? How is social complexity defined and measured? What attributes make a society complex?
It is easy enough to dismiss these questions --- after all, the prevailing perception is so intuitively obvious that it must be true. Indeed, scholars engaging in the debate have often been charged with pursuing political correctness at the expense of scientific accuracy. However, this is not the same as demonstrating that our intuition is scientifically founded.
We have reviewed literature from the social, biological, and physical sciences in an effort to probe the scientific foundation of the prevailing perception. We outline some of the difficulties and opportunities that arise in defining and measuring social complexity, in both human and non-human systems. In particular, we emphasize parallels with past and current debates in biology that can inform how we approach these issues in the study of human history.
Keywords: *social complexity | evolutionary trends | evolutionism | cultural evolution*

PAULA SABLOFF
Santa Fe Institute
Comparative Analysis of State Formation

Abstract: A team of interns and volunteers are building spreadsheets that will be used to compare archaic primary states (Egypt, Mesopotamia, the Indus Valley, China, Mesoamerica and the Andes) with each other, with secondary states (mainland Greece, Crete and Japan), and with complex societies that did not become states (Cahokia, Hawaii, the Southwest). The data extend from the Middle Paleolithic to state formation (often the Bronze or Iron Age). The immediate goal is to determine the necessary and perhaps sufficient attributes of state formation and what these artifacts mean. For example, does the transformation from crude, homemade to mass-produced pottery mean a change in status or role for women and men? What are the key technological

and structural changes that take place as societies scale up? We also plan to devise a formula to test whether or not the archaeological traditions follow the same order and time-to-state formation as other traditions. If so, what does this mean?

Comparative Analysis of State Hierarchies

Abstract: The second part of the project is to develop spreadsheets on the six primary archaic states that will allow us to analyze the political (government), economic, religious and pantheon statuses in the historic record. For example, do all "kings" derive authority from divine authority? Do political statuses and their concomitant roles replicate the religious hierarchy? In this way, we will learn whether or not archaic states share political, economic, religious, and pantheon hierarchies, i.e., similar organizations.
Keywords: *primary archaic states / scale / comparison / status and role*

SCOTT ORTMAN
Santa Fe Institute

Urban Scaling in the Ancient World: Evidence from Pre-Hispanic Central Mexico

Abstract: Cities are increasingly the fundamental socioeconomic units of human societies worldwide, but researchers still lack a unified characterization of urbanization that captures the kind of social organization realized by cities across time and space. Here, we analyze settlement data from the Pre-Hispanic Basin of Mexico to show that this urban system displays spatial scaling properties analogous to those observed in modern cities. Our data derive from over 1,400 settlements occupied over two millennia and spanning four major cultural periods, characterized by different levels of agricultural technology, political centralization and market development. We show that, for each period, total settlement area increases with population size according to a scale invariant relation, with an exponent in the range α= 2/3-5/6. These results are in agreement with theoretical expectations deriving from the interplay of social and infrastructural networks and suggest archaeological measures of settlement organization directly reflect socioeconomic properties of ancient societies. Our findings, from an urban system that evolved independently from its old-world counterparts, suggest that principles of urban organization are very general and may apply to the entire range of human history.
[In addition, see the essay by Scott on Imagining Complex Societies (*SFI Bulletin* 27(1):13-17) in which he notes that the complexity of the societies in which most humans live has increased dramatically in the past 10,000 years, and understanding how and why this has occurred is one of the central questions of anthropology. Recent comparative research on early civilizations suggests that a previously-overlooked constraint in the evolution of social complexity is shared beliefs that support social coordination at various scales. In this essay I discuss how abstract beliefs, which typically take the form of conceptual metaphors, interface with our brain and body to encourage coordinated behavior.]
Keywords: *archaeology / Mesoamerica / settlement area / urban development*

ERIC RUPLEY
Santa Fe Institute

Structural and Dynamic Foundations for the Initial Emergence of the State

Abstract: How did the differentiated yet integrated social and economic relationships characteristic of institutionally-ordinated political economies arise over the last 200 generations, after 5800 previous generations in which anatomically-modern humans participated in a predominately replicative economy, organized primarily by kinship relations?
In the last 30 years, our knowledge of individual instances of the emergence of the State has grown through extensive fieldwork across the planet. This flood of data has given rise to multiple particularist accounts of state formation, with less emphasis on the broader challenge of building comparative datasets and general models of cross-cultural scope. Our work at SFI is addressing this challenge, and I here present three aspects of this work:

- The role of spatial structure in state formation. How does the regional distribution of a population affect this transition? To what degree is agglomeration and modularity a precondition for state formation?
- Sources of variation in outcomes of agglomeration. It is clear that a number of cases of population aggregation were not followed by an episode of state emergence. What accounts for this variability?
- The question of irreversibility. State-level organization arose some 6,000 years ago. To what degree can these social and economic transitions be considered "irreversible"?

Keywords: *Evolution of complex societies | social and economic differentiation and integration | state emergence.*

PAUL HOOPER *(absent)*
Santa Fe Institute

Ecological Underpinnings of Human Political Hierarchies and States

Abstract: The emergence of formal political hierarchies in human societies has been associated with competition for concentrated and defensible resources. Hierarchies may arise as a function of differential control of resources within groups, or through the dynamics of between-group competition. This talk will present recent work modeling these processes, drawing on foundations in evolutionary and behavioral ecological theory. Particular attention is paid to the interactions between technology, demography, and the natural environment that may drive divergent evolutionary trajectories through historical time.
Keywords: *political hierarchy | resource competition | returns to scale | warfare | behavioral ecology*

GROUP II The Hidden Laws that Pervade Complex Biological and Social Phenomena

Geoffrey West Team Leader, Luis Bettencourt Co Team Leader

CLIO ANDRIS
Santa Fe Institute

Regularities and Patterns in the U.S. Inter-Urban Migration System 1980-2011

Abstract: We examine a 30-year range of city-to-city migration data in the United States. We are especially interested in flow dynamics and the persistence of flows from city to city. Our main questions are: How persistent are the point to point migration flows over time--does a city produce the same percentage of in-migrants and draw the same percentage of out-migrants with temporal consistency? We look at a city as a part of the larger system, and we characterize each city by its population and its residents' average income. Our larger questions are: to what extent are cities selective environments for migrants? How does a migration flow change the place of origin as well as the place of destination?
Keywords: *U.S. Migration | City Size | Zipf's Law*

YAOLI WANG
Santa Fe Institute

Spatializing Social Networks in an Urban Context

Abstract: This project will leverage data produced by mobile applications (such as *foursquare*, *Gowalla* and *Brightkite*) that allows users to "check-in", e.g. to publicly communicate their presence at a specific place at a given time. With a different point of view on what can be done with check-in datasets, we propose to leverage check-ins by uncovering whether social ties use the built environment in similar ways. More specifically, we analyze the nature of social ties and spatial movement in tandem, since users have a set of locations and a set of friends, who each have their associated sets of locations. We first find how a user (an “ego”) carves out his or her “activity space” in a city (from the individual check in locations), and the extent to which his or her personal contacts (“alters”) have similar activity spaces. We call the activity spaces of an ego and alter are called *linked activity spaces*- where the *link* is the social friendship. These results can be helpful for urban planners, geographers, civil engineers and transportation planners.
Keywords: *Social dynamics | social networks | volunteered geographic information | land use | spatio-temporal modeling*

MARCUS HAMILTON
Santa Fe Institute
Scaling the Size and Dynamics of Publicly-Traded Firms and Markets

Abstract: In this talk I review recent work from our group examining the size and dynamics of publicly-traded firms in the US. Using time series data of all 30,000 firms traded on US markets in the US from 1950-present, we show that despite fluctuations in the economy and a steady decline in the number of firms trading in recent years, the statistics of size and growth of companies are remarkably consistent over time. Moreover, the growth dynamics of companies over their lifespans are seemingly biological in many ways, initially exhibiting exponential growth but slowing as companies grow in size and age. I argue that firms compete in a very real, not metaphorical, ecology, where the lifespans of companies and the overall dynamics of markets are driven by the relative ability of companies to organize themselves, respond to external economic conditions, and compete with others for finite resources. However, this ecology displays many interesting properties not seen in the ecology of non-human biological systems.

MADELEINE DAEPP
Washington University – St Louis
The Lifespan of Publicly Traded Companies

Abstract: The firm is one of the most fundamental economic unit of human societies. Despite much research over the last decades, surprisingly little is known about the quantitative and statistical character of firms, especially concerning their lifespans and mortality. We examine a comprehensive database of more than 25,000 publicly-traded North American companies over the period 1950 - 2009 to derive the statistics of the lifespan of firms, using survival analysis to test the hypothesis that firm mortality rates are age-dependent. We determine that, in the aggregate, publicly-traded companies exhibit approximately constant hazard over long periods of observation, which suggests that mortality rates are independent of age. Our results shed new light on the dynamics of the births and deaths of publicly-traded companies and identify some of the general ingredients of a general statistical theory of firms.
Keywords: *Firm longevity | mergers and acquisitions | survival analysis | stock markets*

GROUP III Evolution of Complexity and Intelligence on Earth
David Krakauer Team Leader, Jessica Flack Co Team Leader

Center for Complexity and Collective Computation (C4) Talk Structure Themes
The C4 component of the SFI Templeton Complexity project has two major themes (1) extracting the natural scales of biological (to include social) systems and building empirically grounded models that map the microscopic dynamics to the functional macroscopic observables at these scales, and (2) quantifying the complexity of each scale and asking whether complexity and multiscale structure emerge as an inferential response to environmental regularities; in other words, we do expect increasing complexity to evolve? Jessica will introduce (1) and discuss C4's progress on these questions. David will introduce (2) and discuss C4's progress on these questions. There are several foundational issues that have motivated and grown out of our attempts to deal with the above themes. We list these below for discussion. The specific projects we will discuss at this meeting should be understood in the context of these questions.

PART 1
JESSICA FLACK
University of Wisconsin - Madison, The Center for Complexity & Collective Computation (C4)
Micro-Meso-Macro: Collective Computation and the Origins of Biological Space and Time
Introduction

EDDIE LEE
University of Wisconsin - Madison, (C4)
Regularities of Macroscopic Observables

Abstract: Natural phenomena exhibit simple patterns that hint at universal regularities. We explore two social systems as examples for how simple models describing stochastic coupling can elucidate important regularities of complex systems. We investigate conflict participation in a group of pigtailed macaques, finding that correlated groups of individuals coupled to strong individual noise capture important social regularities. We explore voting behavior in the US Supreme Court, finding strong order in voting tendencies and that pairwise statistics are sufficient to capture voting behavior. By proposing these models, we ground ourselves in the minimal statistics sufficient to capture observable properties.
Keywords: *simple models | minimality | maximum entropy | social data | conflict | strategy | macaques | political voting*

Eleanor Brush
University of Wisconsin - Madison, (C4)
Consensus Formation as a Mechanism for Producing New Temporal and Spatial Scales

Abstract: Animals in social groups can choose to use other members to learn about their environment. By choosing which of their peers to pay attention to, they construct networks of information flows. As the animals use each other to learn about the environment, they will tend to come to a consensus opinion. The robustness of that consensus opinion against noisy learning depends on the structure of the network and hence on the animals' strategies of choosing which peers to learn from. Robust consensus may be important for the group's ability to make collective decisions in the face of environmental stochasticity, or it may simply be a consequence of individuals' minimizing the noise with which they learn. We are interested in finding what the optimal strategies are if selection acts on the individuals' ability to learn about the environment, what the optimal strategies are if selection acts on the group's ability to come to a robust consensus, and when these strategies might actually be the same.
Keywords: *signaling | robustness | information flow | social network | multiscale*

Philip Poon
University of Wisconsin - Madison, (C4)
Niche Construction and Macroscopic Tuning via Adaptive Learning Rules

Abstract: Life is organized into hierarchical structures. In this project we consider the origins of both stable and periodically stable hierarchies. We analyze two multi-scale niche construction models in which competing strategies at the microscopic level construct, via adaptive learning rules, new institutions in the macroscopic levels in order to out-perform each other. These institutions provide slow, top-down feedback to the microscopic level. We demonstrate, under certain conditions, how the system can rapidly switch between probable to improbable microscopic states, with relatively long residence times between switches, without large changes at the institution level.
Keywords: *timescales | social evolution | niche construction | learning dynamics | multi-scale structure | micro-macro*

PART 2
DAVID KRAKAUER
University of Wisconsin - Madison, (C4)
Inferential Complexity
Introduction

Chris Ellison
University of Wisconsin - Madison, (C4)
Inferential Evolution and the Complexity of Life

Abstract: An intriguing and fundamentally unsolved problem in our understanding of life on Earth is to explain the existence of complex life. The difficulty stems, in part, from having no explicit relationship between evolutionary dynamics and complexity theory, and common metrics for environmental and organismal complexity. [This has resulted in a large body of work that
measures complexity in fairly simplistic ways, sometimes conflating diversity and entropy with complexity.] In this project, we recast evolution within a Bayesian framework in which organisms must update prior models of the environment into posterior models that incorporate information from the environment. Information-theoretic measures of complexity are then used to directly compare organismal complexities to environmental complexity. As organisms evolve, they learn about the environment and its regularities, and so, complex life can be seen as evolutionary consequence of organisms learning in complex environments.
Keywords: *evolutionary dynamics | evolution | Bayesian | complexity | information theory | life*

Bryan Daniels
University of Wisconsin - Madison, (C4)
Criticality and Information Flow in an Adaptive System

Abstract: In physical systems, boundaries in parameter space that separate different large-scale behavior correspond to phase transitions, where small changes in microscopic parameters lead to drastic changes in macroscopic observables. We use fine-grained data about conflict in a macaque society to ask whether this social system is located near a phase transition. We find using two
models (an equilibrium Ising model and a dynamic branching process model) that the system is near but below a transition, indicating that aggression dissipates quickly enough to avoid becoming typically widespread, but not so quickly that large fights are impossible. A relation between thermodynamics and information theory shows that being near the transition implies that it is easier for an observer of fight sizes to infer changes in individual proclivities to fight. More generally, this points to the possibility of quantifying a system's collective behavior-a possible indicator of its complexity-- by measuring the degree to which information can percolate among different spatial scales.
Keywords: *phase transitions | conflict | inference | information theory | thermodynamics | spatial and temporal scales*

Evandro Ferrada
Santa Fe Institute
The Simon Modularity Principle

Abstract: In order to explain the value and ubiquity of hierarchical, modular systems and their adaptive nature, Herbert Simon introduced the metaphor of a watchmaker. In this project, we first formulate this idea in the language of differential equations and explore its quantitative predictions. In addition, we explore the empirical generality of the model using the assemblage and evolutionary rate of macromolecular complexes experiencing different environmental selective pressures. Preliminary results suggest a range of parameters favoring modularity. Simulations, using RNA secondary structures, show that modular partitions of genotype space favor neutrality and therefore, may have intrinsic adaptive value.

GROUP IV Education Project: Complexity Explorer
Ginger Richardson Co-Team Leader, Melanie Mitchell Co-Team Leader

DAVID FELDMAN
College of the Atlantic
A Massive Open Online Course (MOOC) on Dynamics and Chaos

Abstract: I will describe my plans to offer a MOOC on Dynamical Systems and Chaos as part of SFI's Complexity Explorer project. The MOOC will run for eight weeks, Jan-Feb in 2014. The course will be structured around a handful of key themes that emerge from the study of chaotic dynamics and which are particularly relevant for complex systems. These themes include: bifurcations (sudden changes as a parameter is varied continuously); the butterfly effect (known more formally as sensitive dependence on initial conditions); the stability of non-periodic behavior, showing a way that order and disorder can coexist: and the realization that complex behavior can arise from simple rules.

A familiarity with high school algebra is the only requirement for the MOOC, although I do intend to have some more advanced optional lessons for those with a stronger preparation. I have taught a course at a similar level for almost 15 years at the College of the Atlantic, a small interdisciplinary college in Maine. I have recently published a textbook based on that course, Chaos and Fractals: An Elementary Introduction, Oxford University Press, 2012. I have found that chaos and dynamical systems are fun topics that engage a wide range of learners, and I look forward to bringing chaos to a larger audience via SFI's Complexity Explorer project.

JOHN DRISCOLL
Portland State University

Fractals, Biological Scaling and Urban Scaling

Abstract: This talk will cover Fractals, Biological Scaling and Urban Scaling which are sections of Complexity Explorer (CE) and the Massive Open Online Course (MOOC) Intro to Complexity. Each section includes simple, intermediate and advanced Netlogo models as well as manuals and additional materials relative to each subject. A wide range of topics will be covered with emphasis on pedagogy and curricula development. Biological Scaling (unit 9) of the MOOC will be discussed in terms of integrating research at SFI with online education and lessons learned from the Complexity Explorer project after 18 months of development. A variety of didactic models will be presented including L-systems, Zipf's law and power laws, box-counting dimension, biological scaling and urban scaling and various models created for this project. I will walk through the different aspects of these models and related tools we have developed for CE and how they integrate and reinforce the program at SFI as well as the CSSS and related outreach programs.