# The Principles of Complexity: Life, Scale, and Civilization II

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**Krakauer/Flack Group**

1. How do space and time scales evolve or develop in living systems, and how are these scales exploited to ensure stability or adaptability?

2. When do we expect complexity to increase, assuming that we can measure it, and when do we expect complexity to decrease or to saturate? A natural extension of these questions is the intimate relationship between energy and information.

3. Where do mechanical models of complexity end and purely statistical models begin? In other words, will a purely parsimonious statistical model of complexity satisfy our curiosity and what are the limits to our comprehension of complex models for phenomena?

4. To what degree is it important to capture heterogeneity to explain real-world adaptive systems? At coarse-grained scales we find fundamental (emergent) regularities, but are these important for a system (e.g. allow the components to make robust predictions about the future) or are they merely expedient for the human brain? A useful analogy would be the success of renormalization as a motivation for simple models in physical systems.

5. What are the dynamical features of complex systems to include criticality and robustness? Do we expect life to trend on the average towards responsive fragility?

6. Can we measure how 'collective' the collective behavior is, and how might measures of 'collectiveness' relate to complexity measures? If there is a correspondence, or we can also measure the complexity of collective behavior, how important is the complexity of the collective behavior to producing functional, tunable macroscopic properties? What do we gain from thinking about this process as a collective computation?

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**Sabloff Group**

1. What are the key technological and structural changes that take place as societies scale up?

2. For a particular archaeological sequence, how can the extent of the development of political hierarchy be formally operationalized, for the purpose of comparing such a measure to the predictions produced from theoretical models?

3. How can we understand how ideas of economic growth may apply to ancient non-monetized economies where the agricultural sector was predominant.

4. A key theoretical challenge we face is integrating agency-based theories of state formation, which focus on the actions of individuals as they create novel political organizations (political networks) & the evolution of "agency-amplifying" or "event-amplifying" social and economic structures (as well as counterbalances to these effects).

5. At what point does a state become robust, i.e., able to last a long time? What is a long time in archaeological terms?

6. Concurrently, what makes a state resilient to outside changes (human or ecological -- or not?

7. How do we know when a society has achieved statehood?

8. What is a complex society? How is social complexity defined and measured?

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## West/Bettencourt Group

1. A major challenge in developing a general theory of complexity, if such exists, is the need to integrate energetics ("metabolism") with information ("genomics"), thermodynamics with information theory, and infrastructure with the social, etc, etc. In the kinds of systems you study how are these quantified and what are their relative roles? Do you presume, or do you find, that one of these dominates the dynamics and evolution of the system? How do such considerations feed into formulating a theory or model of the system and how does that feed back onto developing a general theory of complex adaptive systems?

2. In conventional physical systems "extremization" (that is, maximizing or minimizing some universal quantity such as the so-called "action") plays a fundamental role in determining the dynamical equations governing the system whether string theory, the motion of the planets, or the collective behavior of a nucleus. What, if anything, is being "optimized" in the complex systems you study? Does optimization play any role? Are adaptation and evolution, though apparently random, optimizing in some large-dimensional space of possibilities? Can you imagine that concepts like maximum entropy can be used as a fundamental point of departure for constructing realistic theories for your system?

3. Since canonical power-law scaling appears to be ubiquitous across diverse biological and social systems, is there a "universal" mechanism underlying the coarse-grained behavior of all of these systems? If, however, underlying mechanisms are unique to systems, or classes of systems, why do they exhibit such similar statistical behavior and how do "universals" evolve/emerge?

4. Are there general principles of human ecology and evolution that suggest how and why our species evolved such complex social systems as cities and the global economy from a fundamental foraging lifestyle? Cultural diversity is a new axis of intraspecific variation unique to the human species. How did this new axis of variation evolve from underlying general biological and physical processes? Was the emergence of complex human systems inevitable?

5. Do different forms of human systems (cities, nations, languages, firms, religions, etc.) have characteristic behaviors (i.e., growth rates, longevities etc.), and if so, what mechanisms set the constraints?

6. Migration is a major factor in socio-economic life history. Given that cities have very different properties of size, density, economics and culture, why do we see so many regularities in their roles in the urban migration system? Why, for instance, are migration rates independent of city size? What is the role of a city's average income in drawing or sending migrants? Do migrants from a city with a low average income go to the same places where people from a city with a high average income go? Do patterns emerge that could help us better understand the social mechanisms behind migration, such as chain migration, information feedback loops, etc.

7. In studying publicly traded firms we found that mortality is independent of age, much like organisms. "Birth" refers to the first selling of shares, and not to the actual creation of the firm. Can this difference be expected to affect this result? What factors should we expect to see affecting a firm's lifespan? Can we understand extreme outliers like Japan's Kongo Gumi, which "lived" for 1400 years? Since publicly traded companies are such a new innovation, is Kongo Gumi relevant to our data? Are similar dynamics at work for cities?

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## Mitchell/Richardson Group

1. What do the other teams want to communicate to the greater public about their research?

2. How should we structure a multi-course curriculum in complex systems science at the undergraduate and/or graduate level?

3. How can we integrate the Complexity Explorer project into SFI's research efforts?