COMPLEXITY RISING: FROM HUMAN BEINGS TO HUMAN CIVILIZATION, A COMPLEXITY PROFILE

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Summary

It is generally recognized that life is becoming more complex. This article analyzes the human social environment using the "complexity profile," a mathematical tool for characterizing the collective behavior of a system. The analysis is used to justify the qualitative observation that complexity of existence has increased and is increasing. The increase in complexity is directly related to sweeping changes in the structure and dynamics of human civilization—the increasing interdependence of the global economic and social system, and the instabilities of dictatorships, communism and corporate hierarchies. Our complex social environment is consistent with identifying global human civilization as an organism capable of complex behavior that protects its components (us) and which should be capable of responding effectively to complex environmental demands.

1. Introduction

Philosophers and universalistic religions have often suggested the existence of unseen connections between human beings and an essential collective identity of humanity. Today, global connections are manifest in the economy, in transportation and communication systems, and in responses to political, social and environmental crises. Sometime during the past century a transition occurred first to global conflict, and then to global cooperation. Along the way the conditions of life changed, driven by technological, medical, communication, education and governmental changes, which themselves involved global cooperation and collective actions.

What is generally not recognized is that the relationship between collective global behavior and the internal structure of human civilization can be characterized through mathematical concepts that apply to all complex systems. An analysis based upon these mathematical concepts suggests that human civilization itself is an organism capable of behaviors that are of greater complexity than those of an individual human being. In order to understand the significance of this statement, one must recognize that collective behaviors are typically simpler than the behavior of components. Only when the components are connected in networks of specialized function can complex collective behaviors arise. The history of civilization can be characterized through the progressive (though non-monotonic) appearance of collective behaviors of larger groups of human beings of greater complexity. However, the transition to a collective behavior of complexity greater than an individual human being has become apparent from events occurring during the most recent decades.

Human civilization continues to face internal and environmental challenges. In this context it is important to recognize that the complexity of a system's behavior is fundamentally related to the complexity of challenges that it can effectively overcome. Historic changes in the structure of human organizations are self-consistently related to an increasing complexity of their social and economic contexts. Further, the collective complexity of human civilization is directly relevant to its ability to respond effectively to large-scale environmental challenges.

The language we use to discuss ourselves is not well suited to discuss these notions. Even a simple sentence expressing these concepts is difficult: We, each of us, are parts of a greater whole. Still, this relationship is shaping and will continue to shape much of our existence. It has implications for our lives as individuals and those of our children. For individuals this complexity is reflected in the diversity of professional and social environments. On a global scale, human civilization is a single organism capable of remarkable complex collective actions in response to environmental challenges.

2. Individual and Collective Behavior

Building a model of society based upon physical forces between atoms, or cellular physical and chemical interactions, would be quite difficult. Even constructing a model based upon social interactions is too difficult. To consider the collective behavior of human civilization, one must develop concepts that describe the relationship of individuals to collective behavior in a more general way. The goal of this article is to extend the tools we have for understanding collective or cooperative behavior so as to characterize such behavior in physical, biological and social systems. This extension enables us to consider properties of large and complex entities without representing their intricate details. Given such a method for study of collective behavior, the allure of applying it to human civilization is too strong to resist.

All macroscopic systems, whether their behavior is simple or complex, are formed out of a large number of parts. Nevertheless, some of them have simple behavior while others are complex. The following examples suggest insights into how and in what way simple or complex behaviors arise.

Inanimate objects often do not have complex behaviors. Notable exceptions include water flowing in a stream or boiling in a pot, and the atmospheric dynamics of weather. However, if water or air is not subject to external force or heat variations, their behavior is simple. This macroscopic behavior should be contrasted with their microscopic behavior. Microscopically, atoms move both rapidly and randomly. Indeed, atoms at room temperature in a gas, liquid or solid, move randomly at speeds of 1000 km/hr. This motion, called thermal motion, is the natural state of even simple materials. Why isn't this visible to us?

Thermodynamics and statistical mechanics explained this paradox at the end of the nineteenth century. The generally independent and random motion of atoms means that small regions of equal size contain essentially the same number of atoms. At any time the number of atoms leaving a region and the number of atoms entering it is also essentially the same. Thus, the water is uniform and unchanging to our eyes. The only evidence of the microscopic random motion is the temperature and pressure of the gas or liquid.

If we think about describing the specifics of atomic motion we find that describing the motion of all of the atoms in a cubic centimeter of water would require a volume of writing which is more than ten billion times the number of books in the Library of Congress. Though this would be a remarkably large amount of information, it is irrelevant to the macroscopic behavior of a cup of water.

The relationship between random motion of atoms and the simple behavior of materials suggests we consider other types of microscopic motion and how they relate to macroscopic behaviors. The opposite of random motion is completely coherent motion. If we were to take all the atoms of a liquid or gas and orient them to move in the same direction, we would surely see the motion, and the impact it would have when striking any object in its path. Similarly, the coherence of tiny atomic magnets that make up a bar magnet enables it to be observable to us. It is the collective coherent motion of all of the atoms in the object that enables them to have visible motion and impact on a large scale. Nevertheless, similar to the case of random atomic motion, this is a simple behavior despite the involvement of many atoms.

Thus, there are two paradigms for simple collective behavior. When the parts of a system have behaviors that are independent of each other, the collective behavior of the system is simple. Close observation reveals complex behavior of the parts, but this behavior is irrelevant to the collective behavior. On the other hand if all parts act in exactly the same way, then their collective behavior is simple even though it is visible on a very large scale.

How does visibly complex behavior arise? It is through the existence of many groups of coherently -- or correlated -- motions of atoms. The trick is to have some of the atoms move in a coherent way but independently of other groups of atoms that are moving in a coherent way. This is the pattern of behavior characteristic of complex motions of water flowing or boiling, or weather patterns of the air.

While biological organisms generally behave in a more complex way than inanimate objects, we can think about the three types of behavior: random, coherent, and complex. Similar to the random atoms, independent and randomly moving biological microorganisms also have simple collective behavior. The analog of a coherent set of microorganisms is an infection. On the other hand consider the cells that form a human being. The difference between the infection and the cells of the body is that the cells of the infection are all doing the same thing, while the cells of the human being are grouped together into tissues and organs with various degrees of coherence and independence of their behaviors.

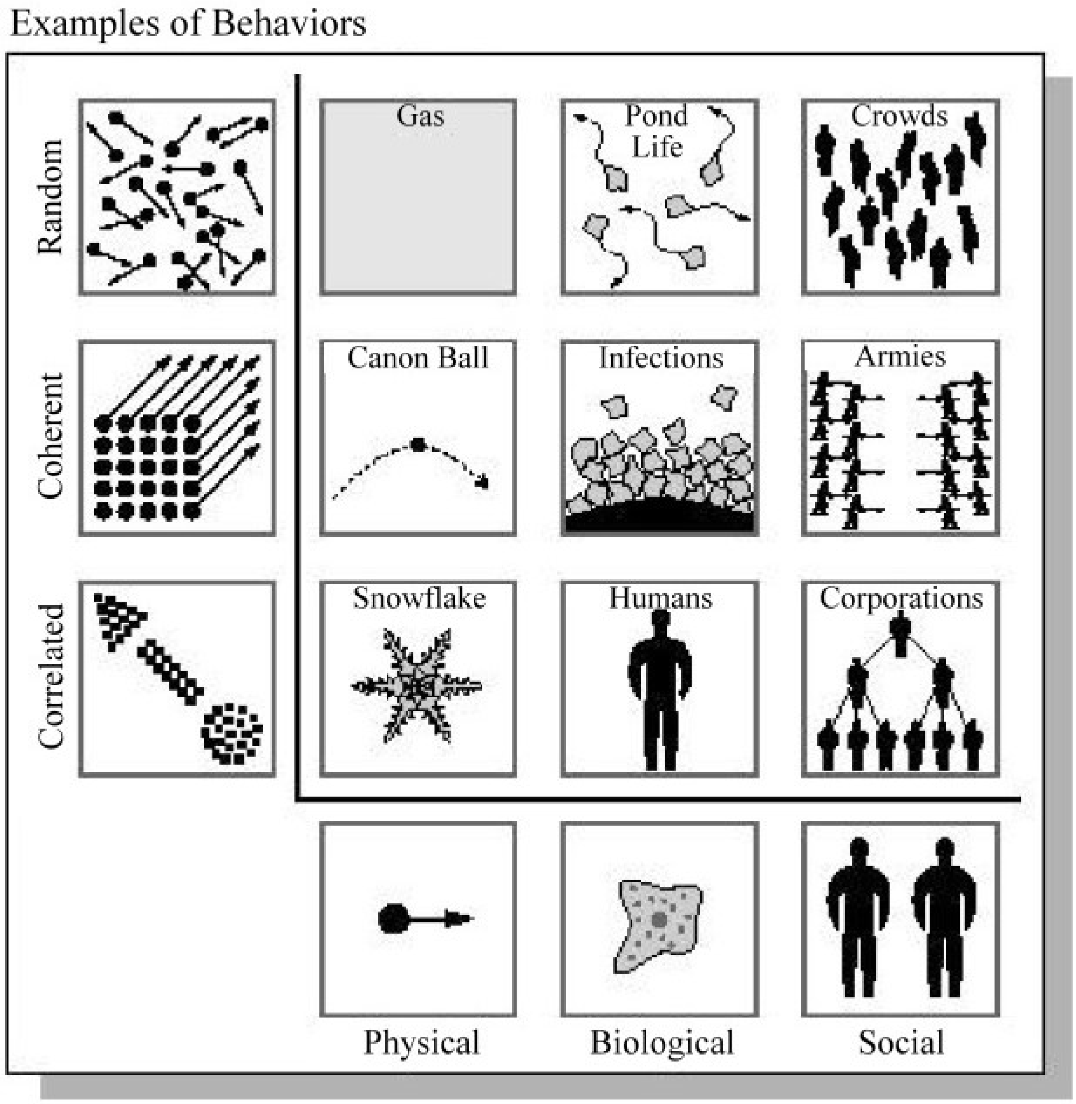

Figure 1: Examples of Behaviors

These examples of behavior can also be seen in social systems. Crowds consist of people moving randomly. Primitive tribal or agrarian cultures involved largely independent individuals or small groups. Ancient armies involved large coherent motions of many individuals performing similar and relatively simple actions. These coherent actions enabled impact at a scale much larger than the size of the military force itself. By contrast corporations involve diverse and specialized individual behaviors that are nevertheless coordinated. This specialization and coordination allow for highly complex collective behaviors. Thus the complex behavior of human organizations, like that of biological and physical ones, arises from the coordinated behavior of many individuals in various groupings.

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Biographical Sketch

Professor **Yaneer Bar-Yam** is founding president of the New England Complex Systems Institute. He received his Ph.D. from MIT in Physics in 1984. He was a Bantrell Postdoctoral Fellow, and a joint postdoctoral fellow at MIT and IBM. After a junior faculty appointment at the Weizmann Institute, he became an Associate Professor of Engineering at Boston University in 1991. He left Boston University in 1997 to become president of the New England Complex Systems Institute. He is also Associate of the Department of Molecular and Cellular Biology of Harvard University.

Prof. Bar-Yam studies the unified properties of complex systems as a systematic strategy for answering basic questions about the world. His research is focused both on formalizing complex systems concepts and on relating them to everyday problems. In particular, he studies the relationship between observations at different scales, formal properties of descriptions of systems, the relationship of structure and function, the representation of information as a physical quantity, and quantitative properties of the complexity of real systems. Applications have been to physical, biological and social systems.

Prof. Bar-Yam has made contributions to: the theory of the structural and electronic dynamics of materials; the theory of polymer dynamics and protein folding; the theory of neural networks and structure-function relationships; the theory of quantitative multiscale complexity; and the theory of evolution.

Prof. Bar-Yam is author of over a hundred scientific articles and the textbook *Dynamics of Complex Systems* (1997) addressing the entire field of complex systems. He is Chairman of the International Conference on Complex Systems and Managing Editor of *InterJournal* -- an on-line electronic journal. He has consulted and given courses for the World Bank, MITRE, and the US military and intelligence communities. He has taught about complex systems in Canada, China, Columbia, France, Italy, Japan, Korea, Portugal, Russia and many places in the U.S.