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Fundamental Characteristics of a Complex System

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ABSTRACT

In this review basic concepts are presented, as well as the fundamental characteristics related to Complexity and some examples of their applications in organizations. It is an interdisciplinary area that is becoming increasingly important in the relentless pursuit of science to expand the limits of our knowledge and the laws governing the phenomena of nature. The main argument of this paper is that the understanding and consequent application of such approaches in the organizational process, provides an improvement in the decision making.

KEYWORDS: *Randomness; Complexity; nonlinearity*

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INTRODUCTION

ALVES MONTEIRO(1) points out that research on complex systems is becoming increasingly important in the natural and social sciences, however, there is no concise definition of a complex system, much less a definition on which all scientists agree. We have analyzed several attempts to characterize a complex system and consider a central set of features broadly associated with complex systems in the literature and by those in the field. However, some features are neither necessary nor sufficient for complexity, and others are too vague or confusing for any analytical use. In order to bring mathematical rigors to the question, it can be said that the notion of the order produced by complex systems is that of Statistical Complexity. The idea of complexity(1) is sometimes considered part of a new unifying framework for science and a revolution in our understanding of systems whose behavior has proved difficult to predict, such as the world economy. However, it is important to ask whether a unique natural phenomenon called complexity, which is found in a variety of physical systems, can be the subject of a single scientific theory. But are the different examples of complex systems complex in ways that sometimes have nothing in common? So the basic question of this theme is to answer what is complexity?

MENDES (2) states that there is a list of conditions necessary to establish complexity. These conditions are qualitative and may not be sufficient together for complexity. We can hardly think of any important scientific concepts that allow for analysis under necessary and sufficient conditions, but which should not dissuade us from introducing such clarity and precision as we can.

COMPLEX SYSTEM CHARACTERISTICS

In a way we can say that mentioning that there is a complexity means that we have structure with variations. In a preliminary assessment, a complex system(2) is one whose evolution is very sensitive to initial conditions or small disturbances, one in which the number of interactive independent components is large, or one in which there are multiple paths by which the system can evolve. For ALVES MONTEIRO (1) analytical descriptions of such systems usually require nonlinear differential equations. A second characterization is more informal; that is, the system is "complicated" by some subjective judgment and cannot be accurately described, analytical or otherwise. In a general sense, the complex adjective "describes a system or component that, by design or function, or both, is difficult to understand and verify. Complexity is determined by factors such as the number of components and the complexity of the process. Interfaces between they, the number and complexity of conditional branches, the degree of nesting, and the types of data structures.

As mentioned by EDMONDS (3), complexity theory indicates that large unit populations can self-organize into aggregations that generate patterns, store information, and participate in collective decisions. Complexity in natural patterns is a manifestation of two main characteristics:

A. Natural patterns are formed from nonlinear processes, those that modify the properties of the environment in which they operate or are tightly coupled.
B. Natural patterns in systems that are open, driven by equilibrium by the exchange of energy, momentum, material or information across their boundaries.

In recent years, the scientific community has coined (3) the rubric "complex system" to describe phenomena, structure, aggregates, organisms, or problems that share a common theme. These systems are inherently complicated or complex, are rarely deterministic, involve mathematical models of the system are generally complex, and include nonlinear or chaotic behaviors. Moreover, systems are predisposed to unexpected results, the so-called emergent behavior, and complexity begins when causality ends.

Based on the culture of complexity science expressed by a wide range of popular and academic sources, such as LUZZI and VASCONCELLOS(6), as well as NICOLIS, and PRIGOGINE(7), we come to the following list of properties associated with the idea of a complex system:

1. NONLINEARITY

PIQUEIRA (8) mentions that nonlinearity is generally considered essential for complexity. Apply any solution by any factor and get another. Nonlinearity means that the principle of superposition does not apply, that is, the sum of two equations that are solutions of the problem does not imply a new answer to the given question. The interesting consequences (8) of nonlinearity are often when the divergence of the system from the superposition principle is particularly extreme with respect to properties other than those specified by a given microstate. Nonlinearity in the equations of motion may have the consequence that slight differences in the values of the initial conditions may result in radically different macro states. Nonlinearity should be considered an important part of complexity theory, because a huge number of complex systems are also nonlinear systems.

For CHAPMAN (9) complexity is often linked to chaos; and as noted above, can be connected with it. There are systems that exhibit complexity because they are chaotic. On the other hand, we can say that the relationship between macro states and microstates is key to complex sciences, because often what is interesting about the system is the way a stable causal structure arises.

2. FEEDBACK

Feedback is an important necessary condition for complex dynamic systems. A part of a system receives feedback when the way its neighbors interact with it later depends on how it interacts with them at an earlier time. STACEY(16), approaching the notion of change, from the perspective of complexity theory, states that in the stable zone feedback is negative, the current state is maintained and learning is simple. But it is in the transition phase between stability and instability, that is, when feedback is positive, that behavioral patterns change and learning becomes double-loop. The presence of feedback in a system is not sufficient for complexity because individuals need to be part of a group large enough to display complexity, and because of how feedback needs to give rise to some kind of higher-level order.

For example, the behavior of ants that are capable of performing complex tasks, even though no individual ant has any idea what they are doing, since when left alone, it exhibits much simpler behavior. Ants behave the way they interact with each other. Another example is the flight of a group of birds. Each member of the group takes a course that depends on the proximity and size of the birds around them, but when the leader adjusts his course, all of his neighbors, in response, change in part to their trajectory. So when it comes to the case where the leader will plan his next move, his neighbors' states now partly reflect their own past behavior.

Control theory is related to complexity theory because another central idea associated with complex systems is that of order, organization, and control that is locally distributed and generated, as occurs in ant behavior. Many researchers say that chaos cannot be defined, but unlike chaos, complexity can be readily defined as systems that exhibit so-called strong mixing. Note that in chaos theory, it is always considered a deterministic chaos (LEJARRAGA, T. and GONZALEZ (10)).

3. SPONTANEOUS ORDER OR SELF-ORGANIZATION

Given the above, it is clear that a fundamental idea(6) in the research of complex systems is that of order in the behavior of a system that arises from the aggregation of a large number of uncoordinated interactions between elements. However, it is not easy to say what the order is. Related notions include symmetry, organization, periodicity, determinism, and pattern. One of the most confusing questions is how order in complex systems relates to state information content and dynamics constructed as information processing. The problem is that the interpretation of states and processes as involving information can be argued as being of purely heuristic value and based on notions concerning the observer of information being projected into the physical world. We note that the notion of order can mean so many things that it must be carefully qualified to be of some analytical use in a theory of complex systems, but we also note that such a notion is central because pure randomness is sufficient for no complexity.

On the other hand, total order is also incompatible with complexity. The facts that complex systems are not random, but not completely ordered, are of central importance in what follows. However, it is a necessary condition for a complex system that exhibits some kind of spontaneous order (LUZZI and VASCONCELLOS (6)).

4. ROBUSTNESS AND LACK OF CENTRAL CONTROL

This text on robustness can be referenced by the article by GRIBBLE (11) and begins with the statement that order in complex systems is robust because, being distributed and not centrally produced; it is stable under system disturbances. For example, the order observed in the way a flock of birds stay together, despite the individual and erratic movements of their limbs, is stable in that the launching of the system by wind or the random elimination of some of the group members does not destroy the establishment. On the other hand, a centrally controlled system is vulnerable to malfunctions of some key components. Clearly, while lack of central control is always a feature of complex systems, it is not sufficient for complexity, since non-complex systems may have no control or order. A system can maintain its order in part by using an error correction mechanism.

Robustness seems to be necessary but not sufficient for complexity (11), because a random system can be considered robust in the trivial sense that perturbations do not affect its order because it has none. A good example of robustness is the climate structure of Earth's climate where rough but relatively stable regularities and periodicities in the basic phenomena of wind speed, temperature, pressure, and humidity arise from an underlying nonlinear dynamics.

Such properties exist and allow us to massively reduce the number of degrees of freedom. Note that robustness can be formulated in computational language as the ability of a system to correct errors in its structure. In communication theory, error correction is achieved by introducing some form of redundancy, which need not be explicit. It may be more subtle, for example, to exploit parity checking, which is more computationally intensive but also more efficient than simple duplication. Charles Bennett specifically mentions that irreversibility seems to facilitate complex behavior, giving chaotic systems diminishing the generic ability to correct errors.

The situation can be seen like this: a living cell is undoubtedly a complex paradigmatic object and, in fact, has the ability to repair itself (correct errors), for example, a defective component can be broken and released into the surrounding environment. In contrast to a non-complex object such as a gas in a box, a small disturbance of that gas is quickly dispersed without limitation to the many billions of degrees of freedom within the gas. The cell, on the other hand, has a unidirectional direction for this dispersion, errors within the cell are carried out, and errors outside the cell are kept out assuming that the errors are small enough (GRIBBLE (11)).

5. EMERGENCY

ALLEN, P.M. & STRATHERN (12) refer to Emergence as a notoriously obscure notion with a long history in the philosophy of science, usually associated with the limitations of reductionism. The notion of emergence is linked to the fact that emergent objects, properties, or processes exhibit something called "downward causation." Upward causation is uncontroversial in the following sense: a subatomic decay event can produce radiation that induces a mutation in a cell that in turn causes the death of an organism. The biological, chemical, economic and social worlds are not causally closed to physics: economic effects can have physical causes.

On the other hand (12), many people believe that the physical world is causally closed, in the sense that all physical effects have physical causes. This immediately raises the question of how complexity relates to physicalism, and whether it is understood in terms of causal completeness or merely in terms of some kind of weak and asymmetrical supervenience of everything in the physical. There is a sense in which approximately elliptical orbits arise to over time from the gravitational interaction between the sun and the planets. This is not the notion of emergency in question here.

In a way we can say that we are concerned about the kind of emergence exemplified by crystal formation, the organization of ant colonies; and, in general, how levels of organization in nature emerge from fundamental physics and physical parts of more complex systems. There is much controversy about how this happens and its implications. Again, we conclude (13) that the notion of emergence would need to be characterized very precisely to avoid simply increasing our confusion about the nature of complex systems.

NIAZI & HUSSAIN (13) prefer to define emergence in terms of increasing complexity and, therefore, it is better not to use the concept in the definition of complexity itself, as both concepts appear to be at a similar level of generality. The emergence is either purely epistemological, in which case it may be strong or weak depending on whether the lack of reduction is in principle or simply in practice; or is it ontological. In its last form, there is no consensus on how to understand it; although it is misleading to say that there is a very important sense in which the physical interaction of atoms and molecules with light and electricity and magnetism and all other physical entities led to the emergence of the immensely complex and structured life system on earth, including the human brain and the complexity of human culture and social life.

Certainly, we must say that emergence (13) in all epistemological senses is necessary for complex systems. If a system does not display a higher level order as discussed above, then it is not complex. However, emergence is not enough because, for example, an ideal gas exhibits an emergent order, but it is not a complex system.

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The best example of such a system is an ecosystem or the entire life system on earth. Other systems that exhibit this organization include individual organisms, the brain, the cells of complex organisms, and so on. A nonliving example of such an organization is the cosmos itself, with its complex structure of atoms, molecules, gases, liquids, chemical types, and geological types, and finally stars and galaxies, and clusters and super clusters.

6. NUMEROSITY

Philip Anderson, in his article on complexity “More is Different”, argues against reductionism and also emphasizes the importance of considering hierarchies of structure and organization to understand complex systems. Its title alludes to the fact that much more than a few individual elements must interact to generate complex systems. The kind of hierarchical organization that emerges and gives rise to all of the features we discussed above only exists if the system consists of a large number of parts, and usually only if they are involved in many interactions. It is a large-scale system whose behaviors can change, evolve or adapt. The physical and complex systems we find in nature are made up of an extremely large number of components, such as particles, atoms, molecules, cells, and it is often possible to deduce the macroscopic properties of systems from the microscopic properties of their constituents. The fact that a system has one or a very large number of components does not mean that the system is necessarily complex, so the fundamental question is what is the minimum number of components in a complex system. Numbering of components is a necessary but not sufficient condition of complexity. This basically means that you will need to consider several other properties, such as nonlinearity, hierarchy, emergence, among others, to characterize a system as complex. In general, increasing the numerity of an event independently would in principle not cause an increase in the average effect, which means that there would be an upper limit to an increase in numerosity. Future research may consider the analysis of the limits of this effect (PELHAM (18) et al.)

7. INTERCONNECTION AND INTERDEPENDENCE

MORIN (4) states that complex systems cannot be understood in isolation because they are essentially systemic and therefore naturally interconnected and interdependent. This state of interconnectedness and interdependence is inherent in physical, psychological, biological, social and cultural phenomena. In this case, it understands systems as integrated wholes with properties not reducible to smaller units. Since when the system is fragmented into isolated elements, the systemic properties disappear. Connectivity and interdependence are factors that increase complexity. Traditional risk management and decision making models are not sufficient to deal with the number of variables in these interconnected contexts. It is not possible to predict the results of isolated actions because they are part of a complex system. The interconnected and interdependent nature makes it difficult to predict the outcome of business decisions in complex. Connectivity and interdependence (4) involve nonlinear interactions and unpredictable outcomes hinder our ability to act directly on systems through traditional risk mitigation models. In complex environments, we do not directly know the outcome of our actions given the interconnected and interdependent nature of factors. This means that one variable implies the existence of the other, but also influences its value. Connectivity and interdependence are factors that increase complexity. Traditional risk management and decision-making models are not sufficient to deal with the number of variables in these interconnected contexts. It is not possible to predict the results of isolated actions because they are part of a complex system.

ORGANIZATIONS AS COMPLEX SYSTEMS

Complex Systems Theory is useful in the organizational analysis of open and unpredictable systems resulting from the interaction of agents that form complex patterns of behavior and adapt to the contingencies of the environment. The theory of complexity applied to organizational management, starts from the idea that organizations have a dominant scheme called ordinary or formal management; this system makes up the structure, hierarchy, rules and administrative processes. WOOD (15) et al, says that in the turbulent environment of contemporary organizations, change movements cannot be analyzed from the perspective of simple causation and Cartesian determinism. They require a complex look, compatible with the tangle of cultural, power, formal, and informal relationships that exist in these systems. An organization, while representing a unit is a multiplicity because it is composed of several units. One of its fundamental characteristics is to be both more and less than the sum of the capacities of its constituent units. If, on the one hand, the organization is able to bring out qualities arising from the interaction between its parts, at the same time each unit suffers constraints and constraints that prevent its capabilities from being fully expressed. Biological or social organizations have yet another level of complexity because they are simultaneously concentric (function anarchically through spontaneous interactions), polycentric (have many control centers or organizations), and centric (at the same time have a decision center). Biological or social organizations have another level of complexity because they function anarchically through spontaneous interactions, have many control centers, and at the same time have a decision center. In DOOLEY's (16) view the real state of the organization is essentially hidden in its complexity as a whole from anyone's view alone, exceeding human intellectual, analytical and perceptive capacities. The perceived organizational state is a mixture of images, stories, thoughts, beliefs and feelings. The difference between perceived and desired organizational state creates a state gap, a perception that the organization is not functioning as it should be, which motivates organizational change to occur.

FINAL CONSIDERATIONS

Throughout this work it was found that Complexity Theory can be applied to organizations as a way of explaining their behavior towards their environment. This is because, according to STACEY (17), the basis of study of the theory is human beings, since understanding the essentially human aspects has the understanding of organizations. Thus, from Complexity Theory we can have a simpler organizational management to execute, since the changes can be somewhat planned and the goals can be achieved more easily. In general, organizations, such as open and complex systems, seek organizational effectiveness. From the text so far, it is clear that the definition of complexity and complex systems is not straightforward and philosophically interesting.

The notions of order and organization presented above and the idea of feedback are suggestive of a theoretical approach to information complexity, since complex systems can be useful for interpreting their hierarchical order and organization by exchanging information between their parts. Several researchers mention that it is helpful to think of complex systems characterized by the way they process information, as well as the theoretical information properties of the data we obtain by sampling. This system collects, processes, stores, analyzes and disseminates information for a specific purpose. On the other hand, the indiscriminate use of the term information without appropriate concepts has resulted in its trivialization in the social and scientific context.

In an attempt to define information, theorists of all times, dedicate themselves to investigate it, aiming at the delimitation of the object that guides the practical and scientific activities of the area. Information is presented as a complex term, with multiple meanings and full of abstractions. Scholars such as Weiner, Kolmogorov, Shannon, and Mandelbrot have speculated, and also researched mathematically on concepts such as feedback, complexity, and information. Therefore, in an upcoming article we will explain the foundations of information theory to address a mathematical theory of complexity, a subject that can be found in many texts, such as in JIIRGEN KURTHS(14) et al.

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