EXPLORATORY SIMULATION AND MODELING OF COMPLEX SOCIAL SYSTEMS

Chang-Hyeon Choi
Department of Public Administration, Kwandong University, Korea

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Summary

The idea of applying the natural scientific evolutionary, non-equilibrium, self-organizing, or chaos theory initiated by Prigogine and others to social systems at large is nowadays widely spreading. While research into chaos theory in such areas as chemical, physical, and biological sciences has made a significant progress during the last decade, scientific study of chaos is relatively new in the social sciences.

CAS shares many characteristics with chaos theory. Newtonian paradigm tends to focus on linear relationships, causal relationships, and equilibrium, or order and stability of the system, while chaos theory diverts attention to nonlinear relationships, feedback loops, and non-equilibrium, or chaos and instability of the system. It should be noted that a stable equilibrium state or an unstable chaotic state is just temporal states in the evolutionary system.

In this section, such characteristics of chaos theory as nonlinearity, feedback loop, sensitive dependency on initial conditions, and the resulting nonequilibrium chaotic

system is contrasted with Newtonian paradigm, and simulated using “Ithink”.

In this paper, a system dynamic approach using "Ithink" was used to simulate the chaotic behavior of Lotka-Volterra model. L-V model in population ecology theory was simulated in that it is a nonlinear model, and has feedback loops. The implications of using simulation in the analysis of chaotic behavior are presented.

1. Introduction

The idea of applying the natural scientific evolutionary, non-equilibrium, self-organizing, or chaos theory initiated by Prigogine and others to social systems at large is nowadays widely spreading. As Gleick noted, while research into chaos theory in such areas as chemical, physical, and biological sciences has made a significant progress during the last decade, scientific study of chaos is relatively new in the social sciences.

The apparently overwhelming success of Newtonian mechanical paradigm which views the world as simplistic and ordered based on the atomism and mechanism had been supported by Bacon's inductive method, but at the beginning of the 20th century it has been attacked. Hume insists that Newtonian physics postulate a universal causal law, but we cannot be confident of the fact that the same cause will cause the same effect in future. Hume's attack laid the basis of instrumentalism. Kuhn's criticism laid the foundation for appreciating new and emerging scientific paradigms. It was the establishment of chaos theory, relativity theory and quantum principles, however, that stimulated the grounds for the new scientific inquiry. Chaos theory abolished the illusion of Laplace that everything can be calculated by deterministic predictability. Relativity theory got rid of Newtonian illusion of absolute time and space. Quantum theory broke the dream that measurement process can be controlled.

Social scientists have attempted in vain to explain and predict the social phenomenon and particularly the behavior of the social system, with the unsatisfactory result that they were not so successful in terms of the accuracy of the prediction that they started to look into chaos theory. There might be several reasons why their predictions are not so accurate. Even if a social system such as individuals, groups, or organizations are faced with the same initial internal state and the same environment, and are governed by the same causal relations, the system has the potential to exhibit a totally different behaviors. This use of the word 'chaos' denotes something quite distinct from other causes of error in empirical studies, such as randomness, exogenous variables, and measurement error. Additionally, as used here, chaos does not imply antisocial or psychopathic meanings of the word. In chaos theory, chaos means a deterministic chaos.

Classical science emphasized stability and equilibrium; now we see instabilities, fluctuations and evolutionary trends in all areas of research ranging from atomic and molecular physics through fluid mechanics, chemistry and biology to large scale systems of relevance in environmental and economics sciences.

We come here to one of the basic problems which has been discussed since the dawn of rational thought in the Western world. If prediction is limited, laws of nature cannot be deterministic. This question was already discussed by the Greek pre-Socratic philosophers. In his book, *The Open Universe - An Argument for Indeterminism*, Karl Popper writes ",...common sense inclines...to assert that every event is caused by some preceding event, so that every event can be predicted. On the other hand, common sense attributes to... human persons...the ability to choose freely between alternative possibilities of action...

This is the "dilemma of determinism" as William James called it. After two and a half thousand years, the questions are still with us. However, recent developments in physics and mathematics associated with chaos have opened new roads of investigation. We begin to see these problems, which deal with the very position of humans in nature, in a new light. We can now avoid the contradictions of the past and elucidate the dilemma.

An essential new element entered this debate in the 18th century with the discovery of laws of nature. The foremost example is Newton's law relating force and acceleration. This law is both deterministic and, more importantly, time-reversible. Once we know the initial conditions, we can calculate all subsequent states as well as the preceding ones. Moreover, future and past play the same role as Newton's law is invariant in respect to the time inversion t to $-t$. This leads to Laplace demon: the demon imagined by Laplace capable of observing the present state of the universe and of predicting its evolution.

As is well-known, Newton's law has been superseded in the 20th century by quantum mechanics and relativity. Still the basic characteristics of Newton's law - determinism and time symmetry - have survived. The concept, of a passive nature submitted to deterministic and time reversible laws, is quite specific to the Western world. In Korea, China and Japan, nature means "what is by itself".

When we look at the trajectories themselves, we cannot predict their future. However, if we look at probabilities, we can predict what the probability will do. That is really a very interesting situation, because, in a sense, we can learn more from the probabilities than from the individual data points. The important result is that there are new solutions on the statistical level which are not applicable to individual trajectories. The behavior of populations cannot be reduced to that of the individuals which form the population.

The main conclusion is that, in general, laws of nature can no more be associated to certitudes but to possibilities. The future is not given; it is associated to a construction ever going on. The discovery that even in hard sciences a deterministic description was impossible has reduced the strong distinction between natural sciences and social sciences as super domains.

According to the Newtonian mechanical paradigm, the behavior of a system can be predicted by identifying its parts and the cause-effect relationships among them (and this is the very principle of atomism and mechanism). This crude assumption leads to a set of differential equations that rules the behavior of the system. However, real systems evolve, that is to say, they interact in the feedback loops over time, and deterministic model does not reflect this. Thus evolution must result from what has been removed in the reduction process. This might be inevitable if we stick to a methodological reductionism. In this paper, a system dynamic approach using "Ithink" was used to simulate the chaotic behavior of Lotka-Volterra model. L-V model in population ecology theory was simulated in that it is a nonlinear model, and has feedback loops. The implications of using simulation in the analysis of chaotic behavior are presented.

Why has chaos been neglected so far? There are several reasons for this.
1). Even though order is discovered within chaos, and again order is created out of chaos, our scientific inquiry based upon Newtonian paradigm has primarily put emphasis on stable or equilibrium state or at best near-to-equilibrium state, and has intentionally neglected far-from equilibrium state, so-called chaos, 2) Works on chaos theory appearing since 1980's, attention to chaos has been only recently paid, 3) computer simulation package such as Ithink used in this chapter was not available until relatively recently, 4) If researchers are not taught chaos theory, they will overlook chaotic patterns inherent in chaotic systems, since chaotic behaviors are so difficult to identify or work with.

Are there any reasons for studying chaos? 1) All evolutionary systems, whether they are natural or social, consists of four system states; that is, equilibrium state, near-to-equilibrium state, far-from-equilibrium state, and chaotic state. Equilibrium state or near-to-equilibrium state are just two possible system states in (usually a linear) system. But in a nonlinear dynamical system, the other two states might be inherent in a system. Thus, research into chaos extends our knowledge of the evolving systems. 2) The chaotic behavior of numerous models such as L-V model simulated in this paper or simple Lorenz equations indicates that mathematical models of social systems lack predictability, even when the initial conditions and causal relations are known.

Complex systems can be divided into two groupings. Complex deterministic ("nonadaptive") systems have constant parameters that, along with the functional form of the equations modeling the systems, define the behavior of the system. Chaos theory concentrates on examining these types of systems, which for the most part are physical systems consisting of inanimate components.

Complex adaptive systems, on the other hand, involve animate "agents" who, obviously engaging in "agency", interact, learn, modify their behavior, and evolve. Agents also interact with inanimate components (e.g., climate, geological phenomena, machines, artifacts). Complex adaptive systems thus share a number of characteristics that distinguish them from nonadaptive systems:

2. The Characteristics of a Complex Adaptive System (CAS)

CAS shares many characteristics with chaos theory. According to Prigogine, Stengers and Nicolis, Newtonian paradigm tends to focus on linear relationships, causal relationships, and equilibrium, or order and stability of the system, while chaos theory diverts attention to nonlinear relationships, feedback loops, and non-equilibrium, or chaos and Instability of the system. It should be noted that a stable equilibrium state or an unstable chaotic state is just temporal states in the evolutionary system.

In this section, such characteristics of chaos theory as nonlinearity, feedback loop, sensitive dependency on initial conditions, and the resulting nonequilibrium chaotic system are contrasted with Newtonian paradigm, and simulated using Ithink.

2.1. Nonlinear Dynamic System (NDS)

The best way to understand the dynamics of NDS is to compare the behavior of such systems with those of linear dynamic systems (LDS). In linear systems, the relationships among relevant variables remain stable over time, which means that the dynamics of the linear systems will typically show smooth and regular behavior. Linear systems respond to the changes in the parameters, or to external shocks, in a proportionate and consistent manner. On the other hand, NDS is typified by the dynamic relationships among variables. As these relationships change, the temporal behavior of the system might change from smooth and regular to unstable and irregular and even up to the point of seemingly random, referred to as chaotic state as noted by Kiel. As mentioned before, all evolutionary systems consist of 4 system states. Each of these states can be mathematically represented via a first-order nonlinear differential equation, commonly referred to as the logistic map. This quadratic map takes the form $Y_{t+1} = wY_t(1-Y_t)$. The initial condition is represented by the first value of Y. The value t represents time. The parameter is w. A transformation of Y is fed back, or iterated, into the previous outcome, generating a continuous time path of system behavior.

Let us consider a special form of chaos associated to maps. In the chaotic maps, like the famous Bernoulli map, you can multiply a number between zero and one by two, and if it exceeds one, you always bring it back to the interval between zero and one. You can show that if you take an arbitrary number, the arbitrary number is, generally speaking, an irrational number, and then in the series you get, the numbers fluctuate widely between zero and one. This is a characteristic of chaos. In other words, in chaos the trajectories defined by two series of such numbers which began with two very close starting values diverge.

The essence of a system is its complex, connective, interrelated web of structure, and its dynamical behavior. However, nonlinearity in NDS engenders analytical complications, and thus linear approximations are deemed desirable. While it is true that some balance should be struck between mathematical tractability and reality of the system, it must be recognized that the presence of nonlinearity is often the reason for the chaotic behavior of the system. If a system is in a state of equilibrium or in a state of near-to-equilibrium, linear approximation may well work, but if a system is in a state of far-from-equilibrium or in a state of chaos, employment of linear functions is inhibiting, and much interesting dynamical behaviors are no longer tenable. Therefore, traditional statistical methods based on a linear function might destroy much of the interesting behaviors inherent in the system.

2.2. Feedback Loops System

Theory-testing not only in natural sciences but also in social sciences is focused on one-way causality between predictor variables and predicted ones. Rare exception is the case of LISREL which tests reciprocal causality. Nevertheless LISREL still is unable to test feedback loops model.

Most of the managers got into trouble, because they don't think in circular ways. They are so obsessed with one-way causality that they strongly believe in the starting point and terminal. There are numerous examples of one-way causality way of thinking. Styles of leadership affect productivity, stimuli generate responses, and ends influence means, to name a few. These examples might be misleading in that the relationships can be in the opposite direction or they are reciprocal. This is true of most organizational events. It is necessary to think of change as feedback loops in which cases A causes B, and B causes A, rather than one-way process, where A causes B.

In the field of organization theory, only a few feedback models have been proposed; that is to say, the vicious cycles of bureaucracy, organizational decline, organizational life cycles, organizational power, double interact, and motivation model.

Cybernetics theorists, especially the second cyberneticians attempted to study how systems change. Numerous cyberneticians have attempted to develop methodologies studying this kind of mutual causality, and hence how systems engage in their own transformation.

One of the most notable methodologies is found in the work of Magorah Maruyama, who focuses on positive and negative feedback, where a change in a variable initiates changes in the opposite direction, is important in accounting for the stability of systems. Processes characterized by positive feedback, on the other hand, where more leads to more, and less to less, are important in accounting for system change. Together, these feedback mechanisms can explain why systems gain or preserve a given form, and how this form can be elaborated and transformed over time.

This discussion again not only emphasizes the difficulties associated with contextual analysis, but also reaffirms the power of this kind of thinking. Conceptions of simple causality are just inadequate for understanding the dynamics of complex systems. In complex systems there are always causes that cause causes to cause causes.

As Nicolis and Prigogine noted, by attempting to map systems relations and identifying their principal tendencies, it is possible to acquire "systemic wisdom" and to frame interventions that attempt to influence the pattern of relations defining a system, rater than attempting to manipulate artificial "effects").

Natural selection theories are dynamic. One explains the pattern of variations observable at one point in time through reference to a theory which considers the time path of some set of variables. The dynamic quality of natural selection theories focuses attention on the speed with which various processes occur and the lag structures which result.

Ecological studies abandoned the assumption of micro economic assumption of equilibrium, and this has methodological implications. Longitudinal data and dynamic models such as time-series model or rate model are required instead of cross-sectional data and static models. In this chapter competition theory of population ecology model is simulated by means of system dynamics methodology which is appropriate for dynamic models and longitudinal data.

2.3. Sensitive Dependency on Initial Conditions

In NDS, when nonlinearity is coupled with deviation-amplifying feedback loop, a trivial difference in the initial conditions can generate a chaotic behavior of the system. According to Stewart, this is so called a sensitive dependency on initial conditions. In atmospheric science, it's called Butterfly Effect. To fully understand the sensitive dependency on initial conditions, the famous equations of Lorenz would be helpful. Lorenz found that three simplified atmospheric nonlinear differential equations could reveal chaotic behaviors extremely sensitive to initial conditions. Lorenz equations are :

$$dx/dt = -10x + 10y,$$
$$dy/dt = -xz + 28x - y,$$
$$dz/dt = xy - 8/3z.$$

We would have to know the initial conditions with infinite precision to predict the trajectory as small differences in the initial conditions are exponentially amplified, as time goes by. This is called sensitivity to initial conditions and is characteristic of chaos.

But that puts into question the traditional goal of science, to reach certitude, to be able to predict the future. Whatever the precision of our experiments, we can only determine a finite region in which the initial conditions are located. As the result, long time predictability is lost.

Chaotic systems abound in nature. Foremost examples are found in physics, chemistry as well as meteorology, climatology or economics. In all situations, there are intrinsic limits to the prediction of the future.

Deterministic chaos is always associated with the presence of a basic instability that allows small random fluctuations (noise) to be amplified by the deviation-amplifying feedback loops and finally influences the overall behavior of the system. In system dynamics models, this instability is associated with the negative feedback.

The power of this kind of thinking was dramatically illustrated in the Club of Rome's project on the predicament of mankind. Their analysis demonstrated how systems of deviation-amplifying feedback loops that do not have deviation-counteracting feedback loops can result in system change that is highly sensitive on initial conditions.

2.4. Non-Equilibrium System

All evolutionary systems, whether they are natural or social, consists of four system states; that is, equilibrium state, near-to-equilibrium state, far-from-equilibrium state, and chaotic state. Equilibrium state or near-to-equilibrium state are just two possible system states in (usually a linear) system. But in a nonlinear dynamical system, the other two states might be inherent in a system.

Natural scientists have contributed to the development of non-equilibrium theory. One of the leading scholars in this area is Prigogine, who added new insights into the evolutionary process of the system. To understand Prigogine's concept of dissipative structure which is a far-from-thermodynamic equilibrium, it is worthwhile to briefly sketch the traditional laws of thermodynamics.

According to the second law of thermodynamics, entropy law, the evolution of all system is described by an increase in entropy, leading to decreasing complexity of the system, and eventually to a state of thermodynamic equilibrium, which ultimately ends in disorder, or death.

When nonlinear interactions coupled with feedback loops dominate, the system may extend beyond its stability boundary and pushed to the critical point of instability, referred to as the bifurcation point. Nicolis and Prigogine refer to systems in this far-from-equilibrium condition as dissipative structures.

2.5. Emergence

Complex adaptive systems consist of processes of mutual adjustment and self-regulation rather than of central direction. They could also be described as "distributed" or "decentralized", since the actions of autonomous agents combine in a "bottom-up" manner, instead of the system having a "top-down" centralized intelligence and control. The system is constantly rearranging itself as the effects of agents' actions ripple through it.

Out of the interactions of the independent agents in a system, an overall pattern, structure or organization emerges such that it "is not simply an aggregation of individual actions, but has unique properties not possessed by individuals alone"

2.6. Bifurcation

A complex system can display abrupt and dramatic qualitative changes in its overall behavior pattern. Gleick has written in his book that if this occurs as a result of small changes in the parameter values of the equations modeling a system, it is called bifurcation. It is analogous to a change in a system's attractor.

For complex adaptive systems, bifurcation due to parameter changes may be considered endogenous. Through constant adaptation, agents may in effect be continually modifying the equivalent of their system's parameters and even the functional form of the equations representing it. The system may thus have the ability to self-transform its overall pattern or attractor. This is another, complimentary way of viewing the concept of emergence.

In social systems, for example, many individual beliefs and behaviors are affected by group size, such as each agent's beliefs about how its actions influence the rest of the group. An agent may believe that its actions become less influential as the size of the group increases until, in a large crowd, the effect of its actions are completely diluted. If the individual behavior of agents is contingent on these beliefs, then the system may undergo significant changes (bifurcations) in its overall behavior pattern as the group size distribution varies.

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Biographical Sketch

Choi, Chang-Hyeon, Ph. D., Rockefeller College of Public Affairs & Policy, State University of New York at Albany, is assistant professor and chairman of the department of public administration at Kwandong University. He served as research fellow at Korean Telecommunications Development Institute. His publications include "Generalizations of the Lotka-Volterra Population Ecology Model:

Theory, Simulation, and Applications," Nonlinear Dynamics in Psychology, and Life Sciences (1997), "Hospital Outpatient Services and Medicaid Patients' Access to Care," Medical Care (1991); "Path Analytic Study of the Relationship of Organizational Structure, Attitudes towards Authoritarianism, and Job Satisfaction to Organizational Commitment: An Application of LISREL Model," Korean Public Administration Review (1991); "Styles of Organizational Adaptation to Environment: A Comparative Analysis of Structural Contingency, Resource Dependency, Population Ecology, and Institutional Theory," Korean Public Administration Review (1992); "Confirmatory Factor Analysis of Organization Structure," (1992). He has translated "Managing Chaos" by Ralph D. Stacey, and "Organization Theory for Public Administration" coauthored by Michael M. Harmon and Richard T. Mayer into Korean in 1992. Professor Choi presented a paper, "Outpatient Facilities and Medicaid Patients Access to Care," at 118th American Public Health Association Annual Meeting held in New York City, U.S in 1990 (co-authored with James Fossett), and a paper, "The Relationship of the Antecedents of Organizational Commitment to Organizational Commitment: An Application of LISREL Model," at the 3rd International Conference on Social Sciences Development held in Taipei, Taiwan in 1992. His research interest is in Organization Theory, Research Methodology, and Computer Applications in Public Administration.