TOWARDS COMPLEXITY OF SCIENCE

Sidik Permana A.M
Bandung Fe Institute

sidikpam@yahoo.com

Abstract
In the development of science, since antiquity, it's been developed with the main purpose to study regularities. This has meant that insofar as complexity is viewed as the absence of regularities, it has tended to be ignored or avoided. But the frustration occurred among scientists because of specialization and isolation of scientific discipline. For centuries, Newtonian ideology has made many natural phenomena remain unsolved. Since the development of complexity, there are many changes in science, instead in its paradigm. The study of complexity, or complex system, or non-linear dynamic system, has been increasing in the last three decades. It has become plausible that the study of *self-organizing, self-producing* system is, in some sense, have similar problems, though the details differ considerably. Henceforth, the theory that explains and predict of "emergent phenomena" across discipline is very important to this science.

Keywords: complexity, complex system, self-organizing, self-producing, emergent, simplicity.

1. Introduction

When Newton pursued his mechanical theory for the very first time in 17th century, there emerged huge hope among scientists. They believed then that men could solve mostly problems of things motions, from stones, vehicles till planets. But as time went by, they found out that there were a lot of problems still remain unsolved, particularly when they had to solve mechanical problems involving more than two bodies. In gas particles motions for example, which involving huge numbers of particles, there seemed to be hopeless to solve using Newton's theorem. Even in 1890 King Oscar II of Sweden offered a prize for person who could use Newton's theorem for more than two bodies. Henri Poincare then found formula to solve three things problems, but still there were no solution for n-bodies problems.

A lot of people in East Asia suffered as economic crisis blew the region in mid 1997. The Asian miracle has fall down, said the analyst. Their currencies made a free-fall, the number of poor people and unemployment surprisingly increased, the national political turmoil became headline on world newspaper, demonstrations and riots happened all over the countries. The oppositions used the crisis as lethal weapon to step down the government, as there were so many leaders in the region had to resign or forced to step down concerning the attack of their own people and oppositions. In those circumstances, many people and also the analyst could only say, "If we only knew!"

Concerning the prognosis and the application of science in helping men facing their daily problems and future, we need strong tools in making such things. As Newtonian philosophy has been used since four centuries ago, there have been so many giant steps in human civilization. The growth of science and technology has increased in the rate that never happened before. But at the other side, the specialization and isolation of scientific discipline has made frustration among the scientists because there are many problems unsolved with the prevailed method. Instead specialization in science has obviously made great advances, there are a fundamental ignorance remains about the workings of the world, especially in the realm of living system [Mitchell, 1992]. We can't make satisfying and comprehensive study in e.g. behavior of a society, monetary system, the growth of cells in human body, etc.

Three decades ago, the scientists found out that in many cases, instead of social problems have been mentioned, including biological configurations, chemical reactions, physical structure, had certain similarities. The underlying behavior of such systems can be shown somehow to have complexity, and this complexity has chaotic behavior (in mathematical sense) and in some cases exhibits patterns of emergent order [Wilson, 1999].

2. What is Complexity?

The study of complexity, or complex system, or non-linear dynamic system, has been increasing in the last three decades. It is plausible that the study of *self-organizing, self-producing* system is, in some sense, have similar problems, though the details differ considerably. These days, the term *complexity* or *complex system* has been used in many areas, occasionally beyond its original area [Edmonds, 1999]. People usually use the term when describing a complicated condition, e.g. behavior of a society, monetary system, the growth of cells in human body, etc. In the beginning of its appearance, people used the term "complexity" as antonym of "simplicity", where "simplicity" *means that property that guides the rational choice between competing theories that are equally supported by evidence* [Edmonds, 1999].

There is no standard definition of complexity; instead there are certain different conceptions of complexity depending on the base language chosen, the type of difficulty focused on and the type of formulation desired with that language. Bruce Edmonds [Edmonds, 1999] underlie some important aspects of this approach:

- It applies to models rather than natural systems
- Complexity is distinguished from ignorance
- It is relative to the modeling language it is expressed in
- It relative to the identification of components and overall behavior
- Complexity is a global characteristics of a model
- You will get different kind of complexities from different type of difficulties
- Complexity represents the gap between components knowledge and knowledge of global (or emergent) behavior

According to Bruce Edmonds, in complexity approach, we always model the system in two sort ways. Fist, *object model* that consists of parts of the system and the rules prevailed among those parts. Second, overall model which shows the resultant behavior of object model. Complexity is the difficulty in finding an overall model for the resultant of the object model. I will here show the example taken from Bruce Edmonds':

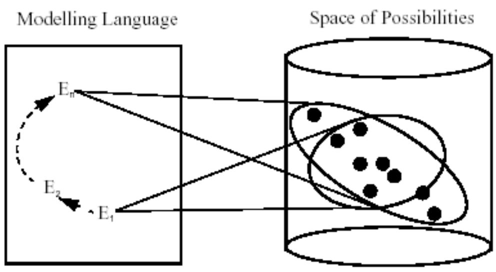

Figure 1. Finding a description to cover a data model

The next step is mapping this model to numeric structure so that we can match the data model of the phenomenon under consideration and process the data computationally. This condition shows in figure 2:

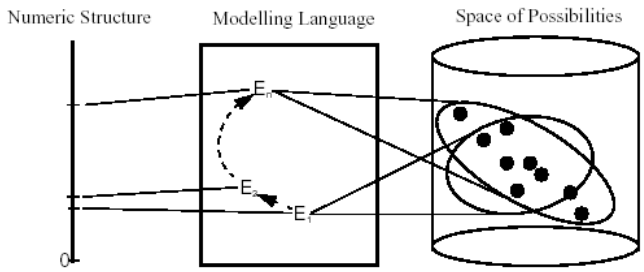

Figure 2. Measuring the difficulty of finding a model description

The example given above is a very simple one. In reality, mostly the model is very complicated, and contains many aspects of complexity i.e. [Edmonds, 1999]:

- the complexity of data
- the complexity of the informal (mental) model
- the complexity of using the formal model to predict aspect of the system under study given some conditions;
- the complexity of using the formal model to explain aspects of the system under study given some conditions.

The use of term "complexity" usually refers to some conditions, such as size, variety, difficulty, order and disorder. In the past, people intuitively said that the bigger the size of a system, the more complex the system would be. We always said that amoeba is a simple system of living body and human as a complex one. But as science getting forward, one may say that in some cases, amoeba is more complex than human body. People also occasionally assumed that complexity of a system would increase as we doubled the size of the system. In fact, this assumption is mostly wrong, and only in a few cases such in the symmetrical systems the assumption was right.

Complexity is also often associated with variety. Consider the dynamics of population in monoculture country, it is quite simple and easy to predict rather than those in a multicultural country. Henceforth, the increase of variety of a problem usually gives more complexity to the system.

Other problem occurs in study of complexity is the difficulty. There're certain kinds of difficulty that will arise while using complexity approach upon a system. The first difficulty arises concerning the size of the system; therefore one needs enough memory to solve it. This kind of difficulty is not fundamental and with the advance of technology e.g. computer with enough memory one can overcome this problem quite easily. The most difficult problem to comprehend is in reducing a big problem to ones involving more fundamentals units [Edmonds, 1999].

Another difficulty to study complex systems is when we still use traditional causal relationships (i.e. A causes B), because it is very common to have circular causality in complex system (e.g. A causes B, B causes C, C causes A). In such systems we need to study global properties and individual interactions in order to understand the system. We cannot reduce the study of the system only of its element, because we would lose the sight of the properties, which emerge from the interactions among elements [Gershenson, 2002].

Complexity is sometimes said to be the midpoint between order and disorder. The disorder condition means condition with no rule i.e. random. In the following figure it is shown the presumed graph of disorder against complexity:

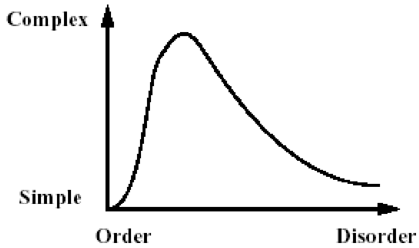

Figure 3. Presumed Graph of Disorder against Complexity

The unique characteristic of such approach, which differs from the classical approach, is the role of initial condition and the changes prevailed in the system. In the classical approach, men always assumed that little changes in a system would produce small outcomes. And initial condition assumed to have little matter to the whole system.

But in *chaotic* approach, initial condition has very significant influence to the whole system. So are the changes in the system, as shown by "Butterfly Effect", in which the visualization of butterfly's flapping wings changing weather all around the world. In the following I will show you how big is the role of initial condition and small changes in a system. I use logistic equation to show you this phenomenon.

$$x_{n+1} = s\, x_n(1-x_n)$$

For first condition, we use growth rate (s) 4 and initial population 0.001, then for the second one we use same growth rate (s) 4 but with initial condition 0.0012. After 8 iterations, as shown in the following table, it is shown that a little change in initial condition produce very big different outcomes.

x0	0.00479424	0.0012
x1	0.019085021	0.00479424
x2	0.074883132	0.019085021
x3	0.277102594	0.074883132
x4	0.801266986	0.277102594
x5	0.636952812	0.801266986
x6	0.92497571	0.636952812
x7	0.277582585	0.92497571
x8	0.802121974	0.277582585

x0	0.003996	0.001
x1	0.015920128	0.003996
x2	0.06266671	0.015920128
x3	0.234958373	0.06266671
x4	0.719011744	0.234958373
x5	0.808135423	0.719011744
x6	0.620210244	0.808135423
x7	0.942197989	0.620210244
x8	0.217843755	0.942197989

Table 1. The comparison between two logistic equations with
the same growth rate but different initial condition

Now we need a measure to determine how complex the system is. A measure that is widely used and corresponds much better to what is usually meant by complexity refers not to the length of the most concise descriptions of an entity, but to the length of concise descriptions of a set of the entity's regularities. In some cases, it may be very difficult to find the regularities of an entity. But classes of regularities can be identified. One can do this by choose the most important set of a system, each of which functions precisely by identifying certain regularities in the data stream reaching it, compressing the regularities into a concise package of information. The data streams contain information about the system, its behavior, its environment and the interaction between the system with its environment.

It can be said that the complexity of a system scales with the number of elements it has, the number of interactions among them, the complexity of its part, and the complexity of their interactions. As the number of elements and interactions of a system is increased, we can observe an "emergent complexity". But it is often hard to tell whether something that is apparently complex really possesses effective complexity or reflects instead underlying simplicity combined with certain amount of logical depth or "emergent simplicity" (Gershenson, 2002). So in natural phenomenon for example, we should be able to distinguish between effective complexity and logical depth or emergent simplicity.

An interesting method to study this kind of system was pursued by Goertzel [Goertzel, 1994] and Gerhenson [Gerhenson, 2002]. They consider that it is somehow very difficult to solve complexity problem, and they suggested not predicting the complexity on the level of detail because it's very possible that we would get nothing. It will be very interesting to predict on the level of structure [Goertzel, 1994] or Abstraction level [Gerhenson, 2002].

Abstraction levels [Gerhenson, 2002] represents simplicities and regularities in nature. We can have clear concept of phenomenon when they are represented in simple ways. An element of an abstraction level has a simple behavior, and therefore can be easily observed and described.

3. Complexity and Its Implications

Since the development of complexity, especially when the computer technology make great advance, which make it becomes much more easier for one to make sophisticated computations, there are many changes in science, instead in its paradigm. In the development of science, since antiquity, it's been developed with the main purpose to study regularities. This has meant that insofar as complexity is viewed as the absence of regularities, it has tended to be ignored or avoided. Nowadays, those kinds of things (complex system) tend to be something very interesting to solve. Here some examples of development of sciences regarding the development of complexity.

<u>Natural Science Implications</u>

When in 1600s physics had made great success and also there were another new discoveries led to the idea that that it is possible to explain the operation of natural systems in essentially mechanical terms. For example, Rene Descartes said in 1637 that someday man would be able to explain the operation of a tree just like that of a clock. In 1700s and 1800s, mathematical method was used in solving economics and populations' problems. Charles Darwin in 1859 used statistical approach to explain the phenomenon of evolution. By 1800s, in chemistry there was new discovery that the components in biological system have similarity with that in physical ones. Most of the physicist in early 1900s avoided complexity by concentrating on properties and systems simple enough to be solved using current mathematical formula. But by 1940s, many physicists consider that the study of complexity is important concerning the fluid turbulence and features of nonlinear differential equation. In 1970s, questions about pattern formation, particularly in biology and in relation to thermodynamics, led to a sequence of reaction-diffusion equations, which then emerged the term like *self-organization, synergetic* and *dissipative structures.*

<u>Philosophical Implication</u>

There are so many implications caused by the development of complexity. Most important things are probably those in epistemology. In the past, we always thought that when we have an adequate model of the world in our mind, then we could simply know about whatever we want the world to do. But now, we find out that even a given model it may be difficult to work out its consequences. In the past, the behavior of a system simply deduced by operations regarding the basic laws, and it was always trivial. But now, we know that it's not that simple. Indeed, we discover that there are series of questions that are worth investigating in science. In ontology, complexity provide explanation that special components are less necessary that might ever been thought. It is due to the fact that many sorts of sophisticated characteristics can emerge from the same kinds of simple components.

Economics Implication

It has been known that there are a lot of naïve things in *neo-classic* economic theory. It is said that price is a reflection of value. And the value of an asset is equal to the total of future earnings, which will be obtained from it, discounted for the interest that will be lost from having to wait to get those earnings. From this point of view, it is hard to understand why there occasionally emerge significant fluctuations in prices. Henceforth, many believe that we just can estimate the price of goods rather than determine it exactly. And the problem then occur when we make such estimations, because in fact the estimations can only be determined by considering all things, conditions in the world and in many times those things and conditions beyond the economics problem.

Technology Implications

As shown in previous section, the use of complexity in many fields of science needs great capabilities of computation. Henceforth, one of the most important product of technology that is fully useful in complexity is computer. And as there are vast ranges of very different kinds of rules that all lead to exactly the same computational capabilities - and so can all in principle be used as a basis for making computers.
Men intuitively suggested that to process such sophisticated computation it is needed a system with complicated underlying rules. But according to Wolfram [841], this is not the case, and that in fact even systems with extremely simple rules can often be universal, and thus be capable doing computations as sophisticated as any other systems. This fact makes it quite plausible that the component of that kind of computer can be produced by simple chemistry reactions, thus this means that computations would then translate almost directly into building actual physical out of atoms.

Sociology Implications

Since there are obviously shown that systems will behave in different ways regarding their initial conditions and changes emerge in those systems, what about the future of meta-narrative of social science? Can we say generally that in any kind of society - the Adam Smith theorem about *invisible hand* for example -carry out? If we do agree that each society has its characteristic, then it is obvious that we can't treat every society in the same way. Or, in other words, the social theory should be spatio-temporal.

Another aspect that emerges because of complexity theory is that using this approach, sociology, will not only see society as emerging from interactions among individuals. The society is not the individuals and their interactions. The society is the individuals and their interactions, but at a different abstraction levels [Gerhenson, 2002]. This becomes very important thing because it is necessary for understanding social behavior.

Psychology Implications

Even the term chaos psychology has been widely known; there are still only a few people use complexity approach in psychology. Goertzel [1994] said that even though a strange attractor may govern the dynamics of the mind/brain, the structure of this strange attractor need not be as coarse as that of the Lorentz attractor, or the attractor of logistic map. And it's not an easy work for one to describe the structure of brain, which contains billion of neuron that each has connections with others. Goertzel then said regarding to those all conditions, it is necessary to shift up from the level of physical parameter, and take a "process perspective" in which the mind and brain are viewed as networks of interacting, inter-creating processes.

4. The Future of Complexity

As many phenomenon of complexity we see in our world, it become obvious that there's no other way, e.g. not as the Newtonian did, to comprehend the phenomena emerge in our world unless using the complexity approach. But one thing that must me remembered that this kind of science is relatively new. Even now we don't have a grand unified theory of complexity yet, or may be we don't need any (and this is still a hot topics for scientists in complexity to talk about).

But as said by Mitchell (Mitchell, 1995), we think we will not have any kind of theory, but the theory that explain and predict of "emergent phenomena" across discipline is very important to this science.

And the science of complexity is about to begin.

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