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■ *Research Paper*

Exploring Dynamics of Emergence

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The British emergentists have their pros and cons in the discussion of emergence. They succeeded in expressing the basic characteristics of emergence, but failed to explain how and why a property became emergence. So, the main subject of studying emergence is to explore the dynamics at present. This article redescribes the concept of emergence and proposes the concept of dynamics of emergence to explain how emergence comes into being. The dynamics of emergence can be divided into two parts: micro-dynamics and macro-dynamics. The former deals with the emergence coming from the interaction of pre-existing components of a system through their local interaction, bifurcation and iterative effect going to global pattern, while the latter discusses what the macro conditions and environments of emergence are, how systems adapt to the environment and how the environment selects systems at the edge of chaos. This article also points out that the dynamics of emergence has important implication in the research of organizations. Copyright © 2007 John Wiley & Sons, Ltd.

Keywords emergence; micro-dynamics; macro-dynamics; edge of chaos; China's reform

INTRODUCTION

'Emergence' has become one of the central concept in the studies of complexity sciences. The workshop of Santa Fe Institute (SFI) points out that 'complexity is the science about emergence substantially. The challenge that we are faced with is how to discover the basic laws of emergence' (Waldrop, 1992, p. 115). Another institute, New England Complex Systems Institute (NECS), takes emergence and complexity equally as the two basic concepts of complex systems (Bar-Yam, 1997, pp. 9–10). The editors of an international journal of complexity *Emergence: Issues of Complexity in Organizations and Management* says that the reason why they name the journal *Emergence* lies in that the idea of emergence is used to indicate the appearance of patterns, structures, or properties that cannot be adequately explained by referring only to the system's pre-existing components and their interactions. Emergence has become more and more important in the process of self-organization in complex systems (Goldstein, 1999, p. 1). Thus scientists of Systems Science have rediscovered the concept of EMERGENCE which has long been existing in philosophy and has nearly faded out of people's memory, and

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have enriched it with new contents and forms. This paper is to study emergence from the dynamic perspective from a cross disciplinary approach.

BASIC FEATURES OF EMERGENCE IN SYSTEMS

The term 'emergence' covers emergent things, patterns, configurations, behaviour, properties or orders. The emergence of a system is a problem of how to differentiate between the whole and its parts at first, and then of finding out the characteristics of the whole which is more than the sum of its parts. But the problem caused a long-term controversy in philosophy and science and no agreement is reached up to now. In our opinions, there are five features about emergence:

1. *Wholeness*: Wholeness means that the whole produces some entities, properties, structures, functions and special laws which do not exist in and even mean nothing to its pre-existing components. For example, the chemical molecular components of organisms or cells, such as amino acids and nucleotides, have no life at all, but organisms or living cells composed of those components exhibit the whole characteristics of life such as metabolism, heredity and variation, self-sustaining, self-repairing and self-reproducing.
2. *Novelty*: Since the wholeness not existing in its components at the micro-level of systems, the new properties arise continuously in the process of evolution and aggregation of the elements and systems. It can be explained as so-called combinational exploding from simplicity to complexity. According to modern physics, there are only 108 kinds of chemical elements at the atom level, which includes even unstable atoms or elements. But there are nearly 7000 000 kinds of molecules at the next higher level, which are produced from the interaction of these different atoms. As to the next higher level of living organisms, there are about several hundred millions kinds of biological species on the earth through the interaction of four kinds of nucleotides and 20 kinds of amino acids, which do not include the possible species in the possible space that have not yet been realized. From the point of view of mathematics, if the number of elements of a system increases in arithmetic series, the possible relationships among elements will increase in geometric series and the number of states of the system composed of those elements will still increase in exponent series, with the number of the states of element as the bottom and the number of elements as the power. That is why the diversity and novelty of emergence at higher levels are more than those at lower levels. As we all know, only 26 letters compose all the English words, and the words compose all the English literary writings. These are the novel things of emergence.
3. *Downward causality*: Once the wholeness of a system comes into being, it will execute some kinds of causal reaction called downward causality on its components. This is because once the special pattern, configuration and organizational structure come into being, they will execute some constraints on its components by changing their behaviours and functions to force them to follow the laws of higher levels. These are the functions of regulation, control, figuration and selection of the whole and the environment over its components. The distinct example is the influence of the social institutions, social ethos, education of the school and the family on the behaviours and personality of individuals. Another example is the emergent path-formation of ants which influences the movement of the ants because they follow the pheromones.

The above-mentioned three characteristics of emergence belong to scientific ontological analysis in essence. To some extent, we have many views about emergence in common with the British emergentists. In his *Emergent Evolution*, Morgan says that 'Under what I here call emergent evolution stress is laid on this incoming of the new. Salient examples are afforded in the advent of life, in the advent of mind and in the advent of reflective thought. But in the physical world emergence is no less exemplified in the advent of each new kind of

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atom, and of each new kind of molecule. It is beyond the wit of man to number the instances of emergence. But if nothing new emerges—if there be only regrouping of pre-existing events and nothing more—then there is no emergent evolution' (Morgan, 1923 pp. 1–2). When talking about downward causation, Morgan says: 'Now what emerges at any given level affords an instance of what I speak of as a new kind of relatedness of which there are no instances at lower levels. The world has been successively enriched through the advent of vital and of conscious relations. . . .. . But when some new kind of relatedness is supervenient (say at the level of life), the way in which the physical events which are involved run their course is different in virtue of its presence—different from what it would have been if life had been absent . . .. . How, then, shall we give expression to it? I shall say that this new manner in which lower events happen, depends on the new kind of relatedness which is expressed in that which Mr Alexander speak of as an emergent quality' (Morgan, 1923 pp. 15–16).

There are another two characteristics of system emergence which belong to epistemology mainly. They are unpredictability from its components and irreducibility to its lower level systems.

4. *Unpredictability*: Unpredictability of emergence means that the wholeness and patterns of emergence cannot be deduced from the system's pre-existing components and their local interaction before the emergent properties arise. This is because the premise of this deduction is insufficient. 'Before the emergent properties arise' means that the emergent properties have never been substantiated in our background knowledge up to then. As a result, we will have no knowledge of the configuration of emergence from the low level elements, thus having no knowledge of the initial condition and boundary condition of emergence, which means that it is impossible for us to deduce them completely. What's more, the appearance of these initial conditions and boundary conditions of emergence is largely indeterministic, occasional and nonessential from a lower level point of views, therefore, it is impossible to predict emergence from the behaviours of the pre-existing components of lower levels.

   Suppose we live in the first few minutes after the Big Bang. All the elementary particles were already there by then, and the cosmic constant had been defined, but who could deduce all the events after that? Who could predict the emergence of the earth and life, and human mind?
5. *Irreducibility*: Irreducibility of system emergence to its components means that emergence is not only unpredictable from the components before emergent properties arise, but also not deducible completely to its components as well after the properties arise. This is because there are different properties, different natural kinds, different laws and different behaviours between different levels, thus it is impossible to get the whole information to do those cross-hierarchy deduction from lower levels. Although with the complete knowledge of amino acids and nucleotides in the chemical level, we are unable to have any idea about the concepts or the configurations of the so called 'hereditary codes', 'genotype' or 'phenotype', which requires independent research for a long time in the biological level. How can we deduce the laws and theories of genetics from chemistry? So, reductive explanation of the emergence is necessary to a certain extent, but not sufficient to understand them. Explaining emergence reductively is not to explain it away, which is the main idea of irreducibility of emergence.

Through the comparison of the whole with its parts, higher level with lower level, we get the five characteristics of emergence in this section. They have been principally recognized by the British emergentists in the early 20th century (Alexander, 1920; Morgan, 1923; Broad, 1925). However, these features are closely connected into an indivisible whole with following relations:

1. The five features of emergence exhibit the differences between the whole and its parts

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adequately. When the differences become large enough, so much so that they differ in basic properties, laws, entities and natural kinds, the primary levels as physical-chemical level, life level, psychological level and social level and sub-levels as cells, organisms, species, biological communities and ecosystems in life level and individuals, families, groups, organizations, countries, societies, international communities in the social level, will come into being ontologically, which constitutes the ontology and world view of emergence and levels of complex systems.
2. The first feature, wholeness, is first advanced by Aristotle, who expresses it as 'the whole is not the same as the sum of its parts' (Aristotle, 350 B.C.), and almost all schools of philosophy agree with it. But Aristotle's expression can be extended to indicate the whole is not the sum of its components and their local interactions in complexity sciences. The third feature, downward causality, and the fifth one, irreducibility, are also closely related, to show irreducibility of emergence not only in causal ontology but also in epistemology, namely that the causal reaction and their epistemological features of entities at the higher level cannot be deleted or replaced by that of the lower one. The second feature is closely related to the fourth one, because if an emergence can be predicted, it is not novel at all.

The main problem of the British emergentists is that they rest on the static analysis of emergence. As a result, they cannot settle the following problems: why are there emergences in nature? How and why can a property become emergent? Why are there five features about emergence? To these problems they fall into the situation of nail-biting and stand at paradox: if emergence can be deduced from its pre-existing components, it will be able to be predicted and consequently will not be emergence at all; conversely, if deduction is impossible, how can we know why there exists emergence in nature? That paradoxical tendency is exhibited in the works of the British emergentists. Alexander says: 'The higher level quality emerges from the lower levels of existence and has its roots therein; however, once it emerges from there, it will not belong to that level, but constitute a new order of existence with its own special laws. The existence of emergent qualities thus described is something to be noted, as some would say, under the compulsion of brute empirical fact, or, as I prefer to say in less harsh terms, to be accepted with the ''natural piety'' of the investigator. It admits no explanation' (Alexander, 1920 pp. 46–47). Morgan cites the phrase of 'natural piety' again and again, which seems that emergence is a black box; we can only see the input of lower level entities here and the output of emergence there. But at the end of the 20th century, with the development of complex science, computer science and the technology of high-speed computer, we can open the black box of emergence nowadays. By using multi-agent simulation, we can explore the detailed process of emergence, its mechanism and structure and consequently turn the black box of emergence to a translucent box.

MICRO-DYNAMICS OF EMERGENCE

In this paper, we propose a transition from the traditional static approach to a dynamic approach. Instead of only comparing the wholeness with its parts statically, this dynamic approach focuses on how and why new properties become emergent, as well as how and why emergent wholes or emergent patterns arise. We call this approach the dynamics of emergence. It can be divided into two parts. The first part discusses the micro-dynamics of emergence, focusing on the question of self-organization. In this part, we will examine mechanisms of lower-level components from which emergence of systems arises, including micro–micro (action-formational) mechanisms and micro–macro (action-transformational) mechanisms. The second part discusses the macro-dynamics or environment dynamics of emergence, focusing on questions of adaptation and selective evolution. In this part, we will examine mechanisms of the environment from which emergence arises, including macro–micro (downward) mechanisms and macro–macro mechanisms. Here, we

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understand mechanisms as processes within a system or between the system and its environment that exhibit how the system works or how the system operates to make it what it is. As a result, mechanisms of a system are dynamic and the dynamics of systems studies mechanisms of systems.

Self-organization can be defined as spontaneous creation (no central control or any intervention from the outside) to form globally coherent pattern, structure and function out of local interactions of the pre-existing components of systems. Prigogine and Haken studied those problems from specific natural sciences, and cellular automata give a multi-agent-based simulation to those self-organizational processes from mathematics and computer science. The former does not extend to the general principles of complex systems, whereas the latter can give some hints to those principles but does not offer complete description. Our method is to combine them together and make some generalizations to work out some general principles of self-organizational mechanism of emergence. Our main idea is that the macro-emergent properties are formed by the local interaction of micro-elements through bifurcation and iteration length by length.

Emergence as a Global Order Through Local Interactions

The classic example of studying self-organizational emergence is Benard rolls: some liquid is heated evenly from below in an open plane container, while cooling down evenly at its surface. The liquid forming some of troposphere which tends to self-organize into a pattern of hexagonal cells, or a series of parallel rolls when temperature increases at the critical point (see Figures 1 and 2).

Another classic example is material magnetization. In the process of magnetization of a piece of iron which consists of atomic magnets called spins, the temperature is high at the beginning, it causes random movement of spins which will point to different directions, so that their magnetic fields cancel each other and become disorder in the whole, and as a result, the macro-iron bar has no magnetism at all. However, when the temperature decreases, the heat disturbance of spins decreases and the spins will tend to align themselves. Every spin begins to influence its near neighbours to form the local areas with their local interactions that cause their spins to point to the same direction. But in those areas, the regular tendency will be distorted by the heat disturbance. So, the main feature of local interaction is that all the local areas are independent basically, and do not influence each other. Knowing the configuration of components in one area of the system would give you no information about the others.

However, essential changes will take place when self-organization transits to global inter-

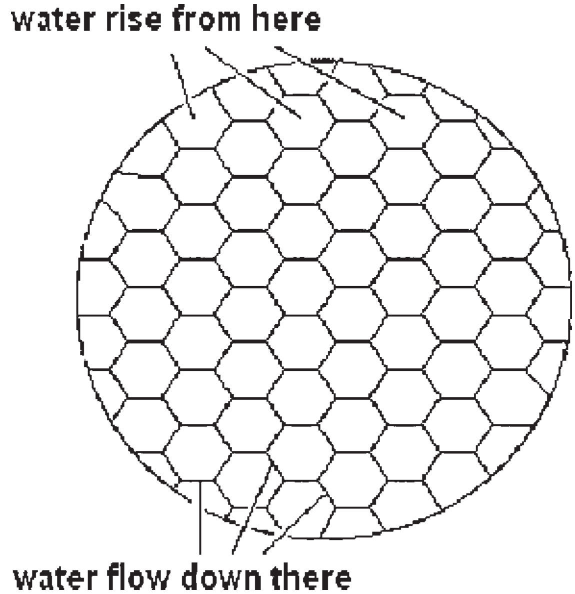

Figure 1. Hexagonal cells of Benard rolls

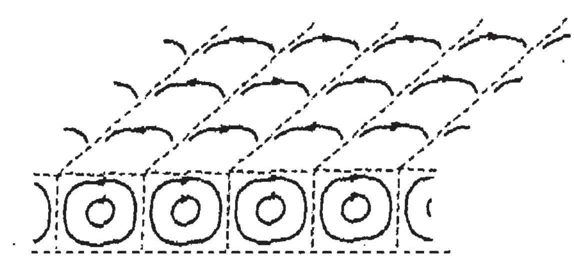
Figure 2. Benard parallel rollers

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action of the components from local interaction in the system. All the components and their local interaction areas of the system are closely correlated. For example, in the magnetized state, all the spins in the iron bar point to the same direction uniformly. If you explore the direction of one part of the spins in the magnetized bar, you can predict the south-north poles of the whole bar, because some macro-laws have come into being. The same situation also exists in the Benard rolls. If you know one of the roll moving in clockwise, you can predict the next roll moving in anticlockwise and so on. The macro-laws have been formed in the emergent process, so we can use them to predict some of the macro-phenomena.

It seems that in the process of emergence there exists an anacoluthia of continuous process during the transition from local interaction of its components to global interaction. This so-called anacoluthon is called the critical point in natural sciences, beyond which fluctuation and bifurcation will be free to form the global patterns, global orders, global structures and functions which cannot be defined in the description of local interactions. This explains why emergence is irreducible.

Emergence as a New Attractor Through Fluctuation and Bifurcation

The theories of self-organization of complex systems indicate that the transition from local interaction of elements to their global interaction should be through bifurcation in order to arrive at macro stable configuration or new attractor. However, there are several potential stable structures, none of which enjoys any preference or pre-selection when the self-organizational process passes through the critical point. Which possible state will be reached is determined by chance called fluctuation. In the situation of Benard's rolls, whether the liquid flowing out of the centre of hexagonal cells goes up or down is determined by random. Another example is the magnetization of the iron bar. When the process of magnetization of iron bar passes through the critical point, the spins of the whole bar will arrange in order which is certain and predictable. But which direction the spins will point to is undetermined and unpredictable, and chance fluctuation will have the final say (Prigogine, 1984, § 5.6). This is one of the reasons for the unpredictability of emergence.

Emergence as a Macro-Pattern Through Iterative Effect of Simple Rules

As is discussed above, after 1980s, there appeared an upsurge of the research of cellular automata and artificial life with the development of multi-agent-based simulation of computer science. The 'life game' of John Conway, the 'Boids' of Craig Reynolds and the virtual ants of C. G. Langton, to list a few, all show us a large number of examples about how the agents following simple rules produce plentiful complex patterns of colonies through iteration in time and aggregation in space in virtual experiments. Take Conway's two-dimensional cellular automata for example. The automata are like a boundless checkerboard, and each square formed by crossed lines is like a checker with two possible states: 'living' or 'dead', 'creating' or 'vanishing', '1' or '0', which is determined by the states of their eight neighbouring squares. The rules for the next step of life are quite simple:

(1) If a living cell has less than two neighbours, then it dies (the lonely ones die).
(2) If a living cell has more than three neighbours, then it dies (die by overcrowding).
(3) If an empty cell has three live neighbours, then it comes to life (reproduction).
(4) If a cell has two live neighbours, then it stays as it is (stasis).

Conway's game of life and its behavioural rules are very simple, but if those rules are designed adequately, such simple behaviours will simulate all the patterns and configurations of the possible and real forms of life, including metabolism, growth, propagation and evolution and so on, through the interaction of cells in space and iterative operation in time. For example, if we begin to play from a very simple

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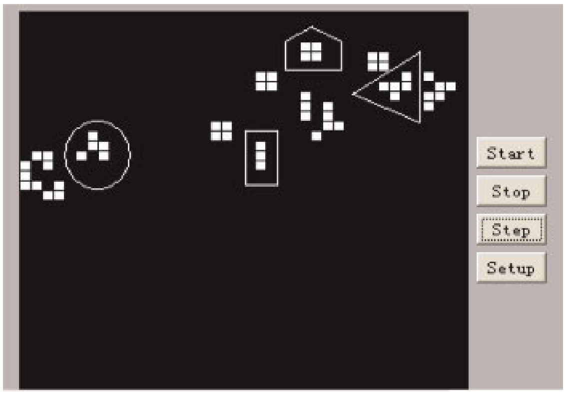

Figure 3. Pentomino

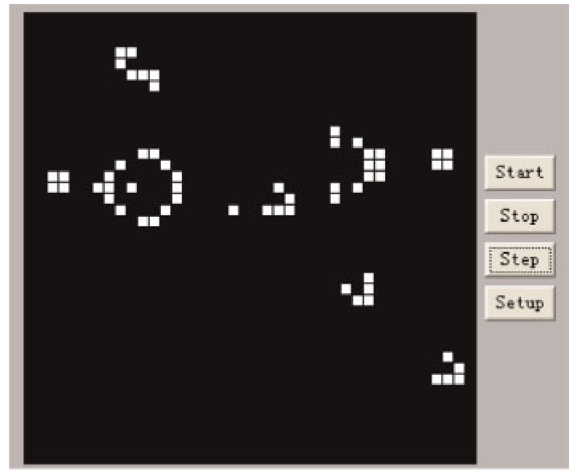

Figure 5. 'Glider gun'

initial configuration 'r' Pentomino (see Figure 3, in the triangle) alone, through 70 time steps, we can see a lot of configurations of 'Life' in the grid, such as 'stable blocks' (see Figure 3, in the pentagon), 'blinkers' (see Figure 3, in the rectangle), 'gliders' (see Figure 3, in the ellipse) and so on. More attention should be paid to the phenomenon of the glider, whose renewal takes place in a period of four time steps (see Figure 4), and whose moves follow the diagonal of the space of grid with the velocity C/4 (here C means the velocity of its jump from one square to the next square). These are their macro rules that are formed in the interaction of the cells. If you have enough time, you will be surprised to find that some of complex patterns, such as 'glider guns' (Figure 5) or 'spaceships' (Figure 6), can emerge spontaneously from the interaction of its cells in a random initial condition or in the artificial way of Conway's game of life. Finally, we can use glider guns to design a universal computer (Turing Machine) to realize all the functions of computing. Cells, gliders, glider guns and the pattern that can realize some logic functions of universal computing can be understood as emergent forms at different levels of the pattern of cellular automata.

In the above discussion, there are three key words in the micro-dynamics of emergence: global coherence, bifurcation and iteration effect. The iteration effect means using simple rules in the process of systems to produce complex patterns. If we want to get a complete understanding of the problem, we ought to turn to macro-dynamics of emergence.

Implications to Organization Research

An organization or community is the network of interaction among individuals in society. When individual actions cannot arrive at his or her purpose or satisfy his or her demands independently, the communicative relation arises. The

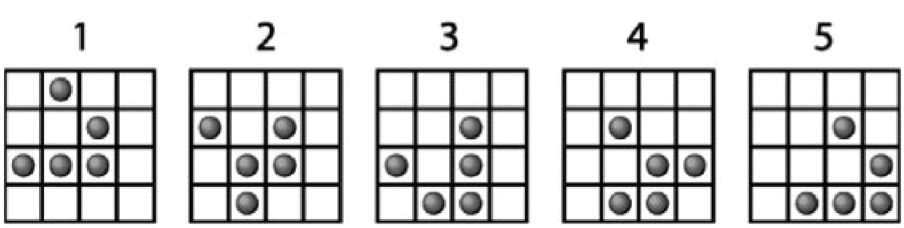

Figure 4. Glide

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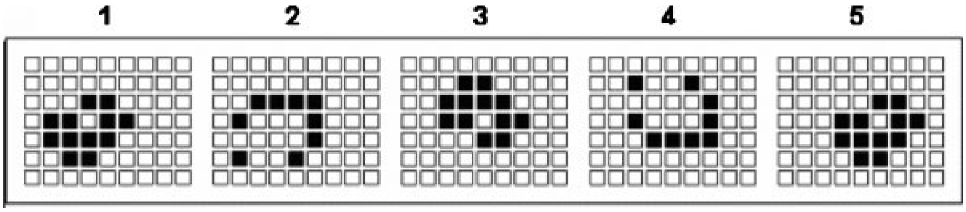

Figure 6. 'Spaceship'

agreement and combined action will be reached, through iterative negotiation, competition and cooperation of one another. In these games, each gives up some of his rights and interests, under the condition that the others give up some of theirs equally, in order to get larger interests for all. In this way, the social patterns, social organizations and social phenomena will emerge. So social organizations are usually the result of the self-organization of individuals. Organizations compelled to stand from the outside power usually cannot exist for long. Take command economy and collective farm for instance, they no longer exist now. The mechanism of social emergence is the transition from local interaction of individuals to the global patterns through bifurcation and iteration just like that in natural phenomena and mathematic simulation. The term 'local' here means the range which the interactions of individual agents can reach. Beyond the range, the effect of the interactions will be weakened and then neglected if no enlarging mechanism acts on it in society. But when the local process goes beyond the critical point, one of the local interrelations of human being will be enlarged to produce many kinds of emergent social patterns. In the economic field, when independent producers have residual goods, they will do the labour exchange with each other. Every one will give up some goods which are more valuable to others, and persuade others to give up theirs as well, to realize the exchange. When the region of exchange extends from local to global ranges, many economic patterns will emerge, such as money and credit, stock company, bank and even international bank, etc. When the local market extends to the whole country, many surprised political economic phenomena will emerge: money worship, power-money exchange, anti-feudal revolution, the rise of capitalist nations and so on. Those micro-mechanics of macro social emergence can only be realized under the macro conditions of the development of productivity and transformation of social ideology.

MACRO-DYNAMICS OF EMERGENCE

Macro-dynamics of emergence of complex systems mainly studies the environment and the macro conditions of emergence, namely the conditions in which the process will be constrained and selected to generate emergent patterns.

Emergence at the Edge of Chaos

This is the basic condition of the abundance of complexity, life and other emergent patterns. Chaos is a state of a system, the movement and change of which are irregular, unrepeatable and thus unpredictable, but those irregularity does not come from randomness and chance of the environment. Chaos can be understood as internal randomness, because the equation of chaos is determined causally and does not include any random items. That is to say, even though we have known all the previous states of systems and their causal rules, we still cannot predict the future states. The next characteristic of chaos is their sensibility to initial condition, which is called 'butterfly effect' by Lorenz (Gleick, 1988, chapter 2). Evidently, life, complexity and emergent patterns will not appear, or rather, all of them will collapse, in the extremely irregular states; neither of them will appear in the extremely static states, where the system is stagnant. In order to figure out the conditions of complexity and emergent patterns, let's talk a

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little about logistic iterated equation, the typical equation about chaos theory: $x_{n+1} = gx_n(1 - x_n)$, here $x \in [0, 1], g \in [0, 4]$. As the control parameter g increases, the behaviours of the system display four different states: (1) when $0 \le g < 1$, the system is stable and orderly; no matter what x_0 is, the state of system converges to 0, (2) when $1 \le g \le 3$, the system is still stable at the fixed point: $q = g - 1/g$, (3) when $3 < g \le 1 + \sqrt{6}$, to any x_0, $n \to \infty$, iterate serial approximates to ε_1, ε_2, ε_1, ε_2, ..., that is, period 2; when $1 + \sqrt{6} < g < g_\infty$, as g increases, there appears a double period bifurcation solution in the system; (4) when $g = g_\infty = 3.56994$ ......, the system enters the region of chaos. The research shows that the abundant and relatively stable configurations of emergence can neither exist in state (1) and (2), which are stagnant and orderly excessively, nor in the extremely unstable chaotic state (3). It typically exists in state (4), which is neither too far from equilibrium states so that organizations could come into being, nor too close to the equilibrium states in which diversity and activation are lost. This is the region or critical point of self-organization called 'the edge of chaos' (Langton, 1991, p. 1). That is a very important general law of complex systems, which is also confirmed in many other disciplines and research areas such as cellular automata, Boolian nets, number theory and so on (see Table 1). But in different systems, even in one system, there are many dimensions of 'edges' and control parameters. When one dimension or one parameter goes to the 'edge', the others may not be. There does not exist a general complexity constant, but the values of those parameters indicate a situation where the flow of kinetic energy and information is neither too high nor too low, the number of connections of components neither too large nor too small, the diversity of system patterns and configurations neither too many nor too few, the states of the system neither too stable nor too unstable. Those soft criteria can also be applied to social phenomena. For example, in the Spring-Autumn and Warring States period of China (770–221 B.C.), there were many seigneurs contended for hegemony, pushing the whole society to a state of crises and consequently China was at the edge of chaos. But during this period,

Table 1. Conditions for the appearance of complexity and emergence in different fields

Discipline	Personage	Criteria	Appearance of complexity and emergence		
History of science	W. Waver	Development in time	Simplicity	Organized complexity	Disorganized complexity
Dissipative structures	I. Prigogine	Parameter of control	Disorder	Non-equilibrium order	Chaos
Chaotic dynamics	M.J. Feigenbaum	Parameter g	Fixed point and double period	High double period	Chaos
Cellular automata	Stephen Wolfram	Evolved behaviour	Class I and II	Class IV	Class III
Cellular automata	Chris Langton	Lambda parameter	Order $\lambda < 1/3$	Complexity $\lambda \approx 1/2$	Chaos $\lambda > 2/3$
Boolean nets	Stuart Kauffman,	Variable K	Order $K = 1$	Edge of chaos $K = 2$	Chaos $2 < K \le N$
Sandpile experiment	Per Bak	Shape of sandpile	Flat and stable	Critical	Tall and unstable
Number theory	Alan Turing	Set of number	Computability	Partial computability	Uncomputability
Organization and management	R. Stacey	Flows of energy and information	Predictability	Partial predictability	Unpredictability
Economics	J.M. Keynes	Commutative relations	Planned economy	Market economy with macro-control	Libertarian market economy
Politics	Aristotle	Tradition of politics and culture	Oligarchy	Democracy	Anarchism

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because of the pressure of the survival environment and social motivator, there appeared a complexion of 'hundred flowers blossom in arts and hundred schools of though contending in academics', resulting in the most rapid development in science, technology, philosophy, social thoughts and other areas of culture developed in the history of China. Another example is the global society during World War II. All the major countries during this period experienced serious political, military and economic crises. They faced a choice of being survival or perish, and they were at the edge of chaos. But at the same time many impotent discoveries in science and inventions in technology, such as penicillin, missile, radar, electron computer, atom bomb, cybernetics, systems engineering and so on, emerged to satisfy the special needs under the pressure of the war. To emergence and creation, the edge of chaos is a macro–micro mechanism that shows the downward acting of the environment to the systems and their components.

The reason why we consider the edge of chaos and its control parameter as macro properties is that the self-organization of elements needs proper macro conditions which are usually controlled by so-called control parameters in real experiments or ideal experiments. Nevertheless, researchers usually ignore that the situation of the edge of chaos and its control parameters belong to macro conditions. For example, in the experiment of dissipative structure, the formational condition and control parameter of Benard rolls is temperature, which is a macro variable. In Bak's (1996) sand-pile experiment, the control parameter is the number of gross sand grain and its shape, which is a macro variable too. As to the Boolean nets, in order to decide how to produce complexity and abundant emergence, we ought to decide what is moderate connecting of nods of the nets, which is also a macro condition (see Table 1).

Natural Selection and Adaptation

Although there are many macro patterns and configurations from the fluctuation, bifurcation and self-organization at the edge of chaos, not all of them can survive. A process of selection by the environment and a process of adaptation of systems to the environment will have the final say. Embedded in a selective process of the environment to the systems is a macro–macro mechanism, where the systems such as organisms or species are macro objects and the environment of the systems is a higher-level macro object. Embedded in an adaptive process of systems to the environment is a macro–micro mechanism, where the environment can change the 'gene pool and genetic structure' of the systems. The theories of natural selection and survival of the fittest were developed first by Darwin to resolve the problem of the origin of species. The modern complex adaptive systems theory and other evolutional systems theories extend Darwin's ideas to explain the phenomena of emergence, including the emergence of the levels of matter structure, giant molecules of life, organs and functions of organisms, ecological systems, the cultural system and other social systems. There are two basic principles about the mechanisms of these general evolutionary theories:

The first is the principle of spontaneous and self-organizational variation. Here, the term of 'variation' indicates the diversity of natural kinds of macro-patterns or macro-configurations, and the diversity of structures, functions, characteristics and behaviours of one kind of configuration. The more emergent patterns a system creates, the more possible patterns to adapt to the environment will exist, and consequently, the larger the potential probabilities of the evolution of a system will be. A classic example is the danger of mono-culture with a single kind of plants which is very easy to get some kinds of diseases or parasites and consequently destroy all crops. It is easy to adapt to the environment, on the other hand, if there is a mixed farming. The immunity of human being can fight against the invasion of many kinds of bacteria and viruses just because the lymphocytes of human body have enough varieties and aberrances for the immune system to choose from and clone to fight against any specific bacterium and virus.

The second is the principle of selective retention of systems. Different patterns or

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configurations of emergence have different adaptabilities. Here adaptability means the probability of survival, and selection means the process of the diminishment of diversity of emergent patterns under the pressure of the environment. This process will eliminate the emergent patterns, potential alternatives which cannot adapt to the environment. This is the principle of survival of the fittest and elimination of the unfit, or the principle of selective retention of systems.

The emergence evolution of complex systems needs a mechanism of retention and propagation of emergent properties or substances. This mechanism is heredity in the species, replication in life giant molecular, 'memes' or cultural genes in social systems. Languages, books, education, cultural traditions, scientific paradigms and so on all play a part of heredity mechanism to induce people to repeat those patterns. 'Blind Variation and Selective Retention' by Campbell is always used to describe the evolutionary mechanism of Complex Adaptive Systems. But Campbell only applied it to the evolution of knowledge, and we here apply it in the most general context. On the other hand, the term 'Blind Variation' is not fit for complex adaptive systems, so we would like to change it into a more exact phrase 'spontaneous and self-organized Variation and Selective Retention' to express the general evolution theory of complex systems.

Emergence From Modelling and Learning Process

A complex adaptive system can be understood as a self-organized system which consists of agents and has modelling and learning functions, and can adapt itself to the environment outside the system. This system produces emergent properties, which can evolve autonomously. Natural selection pushes complex systems to the edge of chaos and chooses the fittest one. But not all of the behaviours and actions of selected systems are fittest. As the environment of the system changes in time, some of the behaviours of the systems become unfit to their environments. The direct solution to this problem is to let the environment decide which behaviours are fittest and which are not, and eliminate the unfit ones together with their carriers. But it will need a very long time to undergo the evolutional process. In this context, some of the complex systems will develop a modelling function to obtain information from their environments and set up the internal model or schema, then use them to direct their actions and get the information about the results of the actions, and finally test and revise the models and schemas according the feedbacks. Then, those schemas or models can be used in turn to judge the suitability and adaptability of potential or possible actions. As a result, these models or schemas become a 'vicarious selector' of the environment (Campbell, 1974. p. 421), or as K. Popper put it, the alteration of the internal models means collapse or destruction of the organizations. Gell-mann and Holland made a detailed research on the modelling function of adaptive agents and adaptive systems with the mathematic method and computer simulation. Holland points out that the model of agents consists of a lot of possible rules composed of some kinds of signal clusters. The possible rules are abundant enough to be arranged and combined to form possible patterns. He uses bucket brigade algorithm created by himself and genetic algorithm to simulate the internal patterning mechanisms and learning mechanisms of agents. This explains why there are so many novel and unexpected emergences. In this situation, we can see how macro mechanisms and micro mechanisms interrelate and interact with each other.

Implications to Research of Organizational Dynamics

The research of emergence in organization is certainly an important issue in the field of management, and the research of the macro-dynamics in general will provide those researches with some heuristic rules in methodology:

First, abundant emergences will appear in and among organizations in a certain situation, among which many abnormal organizational emergences, such as the appearance of families,

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villages, communities, bazaars, money economy, supermarkets, towns and cities, provide human beings with enormous creative power and appropriateness. When appearing for the first time, they are appearing spontaneously with neither planning or design nor any blue print. Contrarily, some organizations, which had been decided by human being in detail, ended up with collapses. Therefore, how to deal with emergent organizations and emergences in organizations, especially the abnormal ones, is an important issue in organizational dynamics.

Second, we are not puppet before the emergent organizations and organizational emergences. We can handle them and control them as if we are vicarious selector. We can use the social power to push the organizations concerned to the edge of chaos in certain dimensions in order to get abundant emergences. It is especially important at the stage of social transformations. In 1980s, the Chinese government boldly pushed the economic units in the countryside and towns to the edge of chaos, thus a lot of economic patterns of market economy appeared, such as 'obligation institution contract with families', 'making a production contract with each household', 'southern Jiangsu model' (collective economy in dominating position), 'Wenzhou model' (private economy in dominating position), 'Special Economic Zone Model' (introduction of foreign capital), 'reform of property right', 'institution change of country-corporations', 'stock market' and so on, which caused China's GNP to increase rapidly. 'Do not be afraid of the disorder in some dimensions and let self-organizations undergoing by the people, to the people and for the people' may be a better approach to China's political reform. On the other hand, not all the emergent patterns of organizations are fit to the circumstances of environment. For example, so called 'chain debts', 'economic crime', 'officer-businessman collusion' and so on, must be eliminated though they are also emergent things from socialist market economy. According to the dynamics of emergence, when new economic or social organizations appear from the pre-existing components of complex systems, they will undergo an adaptive and learning process. If the emergent organizations are desirable, we ought to offer appropriate macro conditions to them.

CONCLUSION

Modern Complex Systems Science rediscovers the concept of emergence in the field of philosophy, and takes it as its main subject, by endowing it with new import and wider application. We turn to the dynamic approach to study and understand it. We put forth six principles for the emergent dynamics: emergence through global coherence from local interaction among components, emergence through fluctuation and bifurcation, complex emergent patterns from the iteration and folded aggregation of simplicity, emergence at the edge of chaos, spontaneous and self-organized variation and selective retention, adaptation to the environment through internal modelling and learning. The first three principles are about micro-dynamics of emergence. The 4th and 5th principles are about macro-dynamics of emergence, which are frequently neglected. The last principle is about the relationships between micro- and macro-dynamics. The research will be partial and incomplete in understanding emergence if the adaptability of the systems and the selection by the environment are not taken into account. The application of emergence dynamics to organization and management involves emphasis on the autonomy of individual agents in the self-organization of society as well as the macro conditions and macro regulations about these emergences of those organizations. Organizational emergences and emergent organizations are neither completely predictable and controllable, nor are they completely unpredictable or uncontrollable. They happen between the two extremes.

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