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ANCIENT AND CURRENT CHAOS THEORIES

Güngör Gündüz

Department of Chemical Engineering, Middle East Technical University
Ankara, Turkey

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SUMMARY

Chaos theories developed in the last three decades have made very important contributions to our understanding of dynamical systems and natural phenomena. The meaning of chaos in the current theories and in the past is somewhat different from each other. In this work, the properties of dynamical systems and the evolution of chaotic systems were discussed in terms of the views of ancient philosophers. The meaning of chaos in Anaximenes' philosophy and its role in the Ancient natural philosophy has been discussed in relation to other natural philosophers such as of Anaximander, Parmenides, Heraclitus, Empedocles, Leucippus (i.e. atomists) and Aristotle. In addition, the fundamental concepts of statistical mechanics and the current chaos theories were discussed in relation to the views in Ancient natural philosophy. The roots of the scientific concepts such as randomness, autocatalysis, nonlinear growth, information, pattern, etc. in the Ancient natural philosophy were investigated.

KEY WORDS

chaos, randomness, dynamical systems, natural philosophy, ancient philosophy, information, biological evolution, nonlinearity

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*Corresponding author, η: ggunduz@metu.edu; (90) 312 210 26 16;
Kimya Mühendisliği Bölümü, Orta Doğu Teknik Üniversitesi, Ankara 06531, Turkey

INTRODUCTION

In the last three decades, the chaos theories have born, grown, matured, and revolutionized our understanding of natural phenomena. Classical physics, statistical physics, electromagnetism, quantum theory, and relativity also had great revolutionary impacts in explaining natural phenomena, but none of these had so rapid influence on the fields other than basic physics. In the past, it usually took some decades for the application of physical laws in applied sciences and engineering after their discovery. However, chaos theories soon found applications in almost all branches of technical, medical, and social fields, and also in arts.

The term chaos is first seen in the Sumerian epic of Gilgamesh which is the oldest script strongly touching the fundamentals of human psychology and human's understanding of the earthly and heavenly events. In one of the paragraphs of the epic, the Earth God complains to other Gods about humans, and says 'humans have gotten so overcrowded, and they have run into dearth, starvation, and chaos, and they do not respect me; something has to be done'. Gods then decided to send water flood to extinct them. The flood of Noah in religious scripts is based on this story. In terms of chaos current theories, it is true that anything that multiplies can cause overcrowding and thus chaos, then the components becomes pretty much free from the general rules (the rules of the system or of Gods) [1]. It is possible to control the chaos, and to get out from it by external intervention of physical forces, i.e. Gods' intervention in Gilgamesh epic.

The chaos concept has been a fundamental metaphor for both natural and social events, and cosmogony in ancient societies. According to a Mesopotamian cosmogony, the conjunction of male Apsu which represents freshwater and of female Tiamat which represents seawater gives birth to Goddess Mummu who represents the chaotic fog and clouds. Mummu then gave birth to primitive ocean and water. First Gods came out from the primitive water, and one of them then became a creative God and created earth, stars, and all living things [2]. The Sumerians used to believe that the earth and stars were floating soil on water [3]. Similarly, the Egyptians also used to believe in that the universe was essentially water, and all stars were surrounded by water. There is also a phrase in Cor'an stating that the essence of all things is water.

The Egyptians attributed a kind of philosophical meaning to the word chaos and thought that it is the primordial state before genesis, and it is the medium for the coexistence of form and structure. It is in fact a kind of reservoir in which all kinds of field forces and forms dissolve in infinitesimal time. In Genesis, it is understood as a coarse but homogeneous structure with feasibility [4]. In Hesiod's Theogony, chaos meant an empty space or matter not yet formed. It was believed that order (i.e. cosmos) came out from chaos, which was also the beginning of time.

RATIONAL THINKING

The predominating elements of Middle East cosmology before rational thinking were: (i) unlimited and infinity, (ii) the basic element of all things, and (iii) chaos and order. In this respect, water was believed to represent all the properties described as such; and the first natural philosopher, Thales of Miletus, considered water as the element of everything [5]. He also thought that the earth rests on water as in the Sumerian cosmogony. Thales considered water to be an element, and also as something that all other things can be reduced into [6]. He used to visualize water together with a force that revives or moves it. In other words, the mover and the moving are not separated and they coexist in the same object [7].

Water as the sole material principle, has been objected by Anaximander, the second philosopher of Miletus. He introduced the concept of 'apeiron, the unlimited or infinity' and proposed that it is both a principle (arche) and an element. Apeiron is a kind of reservoir where all varieties are not yet differentiated; they are entangled in the form of a composite state. Apeiron is like a tank of all qualities, and it serves to conserve all beings.

He rejected the idea of a single element (like water) to be the founding principle of all existing. He claimed that the single element wouldn't allow the appearance of others. According to him, any 'elemental stuff' can change into one or more of the other elemental stuffs, and every 'coming into being' is due to the change of a pre-existent. He, in fact, is the founder of a dynamic universe model by claiming the continuous generation of new things.

Anaximander thought that the contradictions like earth (dry), water (wet), fire (hot), and air (cold) pre-existed before apeiron, and they were at fight (i.e. competition) with each other. He thus pointed the importance of four-stuff long before Empedocles.

Anaximander also thought that the need for earth's stability like water bears in some problems, and one needs something stronger than an analogy and deeper than a cushion of water [5]. He in fact thought the earth to be at rest at mid-space. He also claimed a kind of primitive biological evolution theory.

The third philosopher of Miletus, Anaximenes, did not respect much the uncertainty in the apeiron concept, and he returned to more concrete basic elements. He was also disturbed with the idea that the earth suspends in space without any support. He thought that something light and mobile, and thus readily available everywhere should surrender it. Anaximenes considered air to be the essential material of everything. The Anaximander's principle of unlimited was indeterminate and metaphysical, and Anaximenes considered air to be the 'unlimited'. The word 'gas' was derived from the word 'chaos' that meant 'air'. The Anaximenes' chaos does not only represent a material, but it also represents a principle.

The carrying medium for all stuff in the universe was later changed into something celestial and indestructible by Aristotle, and he called it 'aither', which may correspond to his 'primeval matter' [4]. Aither was assumed to be the carrying medium needed for the propagation of electromagnetic waves by Maxwell in 19th century. Einstein discarded it by his special theory of relativity. However, the developments in quantum electromagnetism and in quantum field theories introduce a kind of space which is not absolute empty but owns something, and it interacts with material medium, i.e. particles. In fact, Dirac proposed a vacuum full with oscillators.

In Anaximenes' cosmology, some sort of motion produces variations in the density of 'air', and hence, the basic stuffs of the universe are generated. This view has some parallelism with the production of mass from quantum fluctuations. In quantum electrodynamics vacuum fluctuations result in pair production of virtual electrons and positrons, which immediately annihilate; however, the interaction of a real electron with the virtual particles (i.e. vacuum fluctuations) increases its mass at small but measurable quantity. Anaximenes' primordial state and our quantum vacuum are both full, they both have some kind of contents, and they are not empty.

According to Anaximenes, the motion (i.e. force) that causes the changes in the density of air is also in air. He also thinks as Thales that the moving and the mover coexist in the same object. This monism realizes the universe as an animate object of which deriving force is inside the body. For nonliving objects the force needed for motion is supplied from outside. In fact in most physical theories, classical and quantum mechanics, electromagnetism, and relativity, an external force is needed to move the object. However, in general relativity and in Bohm's quantum world the action and the potential coexist in a unified form as in Anaximenes's state of chaos. In Aristotle's philosophy a change happens in the chronological order 'from potentiality to actuality'. In Bohm's world the potentiality and actuality form a composite state and the things interact through 'implicate order'. The relationship between the potential and the actual is the relationship between implicate and explicate order. The general relativity equations inherit a dynamic property that implies a dynamic and expanding universe. Einstein had introduced a cosmological constant for a static universe, but, he then removed it after Hubble's discovery of expanding universe.

As mentioned above, any supporting medium for the universe needs itself also another supporting medium according to Anaximander. Anaximenes overcame this difficulty by air (or chaos) hypothesis; it is so light that it does not need anything else and it is self-sufficient. That is, 'the cause and the source of chaos is itself'. This philosophy has made important influence on the proceeding philosophers, especially on Aristotle. His aither concept based on the ultra light property of Anaximenes' air, and he removed its materialistic properties and attributed metaphysical properties to it. Aristotle attributed 'to be self sufficient and to be the cause of itself' only to the 'first mover'. Science and religion both used this postulate; the former said that the universe is self-sufficient while the latter said God is self-sufficient. This postulate could not be yet changed or improved further throughout the history of philosophy.

Anaximenes considers the chaos (or gas) as the most disordered state. We do not know if disorder (i.e. randomness) prevails in quantum vacuum, but it prevails in the world of chemical atoms. The exchange of properties takes place only through the principles of conservation of momentum and energy. Boltzmann called this random exchange dynamics as 'molecular chaos', and the word chaos has been a scientific term since then [8].

In a system where there are no attractions between the components (i.e. molecules) the changes could be described only by kinetic terms. In fact, Anaximenes explained the changes in nature in terms of 'hot and cold', and 'densification and rarefaction' mechanisms. In modern sciences especially in statistical physics, 'hot and cold' refers to the change of kinetic energy of molecules. In Maxwellian distribution of speeds, the shift of the speed distribution to the right or to left makes the system hotter or colder. It is not clear if Anaximenes supposed that the change in density is sufficient to produce all the existing stuff. In fact, what is meant by density is somehow blurred. It may mean the number density or the mass density per unit volume. However both can be correlated with each other. If the mass density is of nuclear origin then the mass density mostly changes with the number of protons of which changes go by number. The change of the number of neutrons and the binding mass are also functions of the number of protons in the nucleus. Therefore 'densification and rarefaction' essentially corresponds to changes in number, which in turn changes the chemical potential. It seems that in Anaximenes' view 'densification and rarefaction' corresponds to change in number. In this respect, 'the continuous creation and destruction' principle of Aristotle differs from the 'densification and rarefaction' principle of Anaximenes.

Although the change in nature through chemical changes is implicitly seen in Anaximenes, it is well established by Aristotle by his 'continuous generation and destruction' principle. His thoughts are based on the philosophy of atomists though Aristotle stood against them.

The isomeric changes in organic molecules keep the number constant but change the chemical potential, which is associated with the shape or 'form' besides the atomic mass content. In modern sciences, 'densification and rarefaction' can imply both the kinetic changes due translational energies and also the structural changes due to 'vibration & rotation & electronic excitation' modes of the atomic motion. These modes of motion are bound to the shape of the object, but it was too early for the philosophers of the Miletus to talk about the evolution of a preferred shape in natural events. As believed, they probably could explain the wood stuff but not trees and plants. In this sense, it is not clear how evolutionary processes take place in Anaximenes' universe. Neither quantum fluctuations nor the axioms of most physical theories say anything about the evolutionary processes. The evolution is inherently associated with irreversibility, and it can be tackled with the entropy concept of thermodynamics.

Parmenides pinned down an important corner stone in ancient natural philosophy. His philosophy emphasizes on 'being', and he rejects the dynamical 'change'. According to him 'all' in the universe is unified and the change is an illusion. Parmenides' philosophy can be summarized as,

(i) Nothing perishes; nothing comes from nothing.

(ii) 'Change' is the loss of one quality and the gain of another.

(iii) 'Quality' and 'object' are indistinguishable.

These assertions make to explain the 'change' in nature impossible. Both 'ii' and 'iii' fall in contradiction with 'i' [6]. The first assertion has stood as the keystone of all natural philosophies throughout the history. The attempt to change the second assertion led Anaxagoras to develop his 'information' (or 'sperma') concept, and led Aristotle to develop his 'potential' concept, which was actually first introduced by Platon.

The attempt to change the third argument yielded two new developments introduced by Empedocles and by atomists. Empedocles being a member of the Parmenides School emphasized on four-stuff view (i.e. earth (solid), water (liquid), air (gas), and fire (energy)), and claimed that all changes in nature can be interpreted in terms of four-stuff, which, cannot change into other things; and so, their number is fixed. Four-stuff are elements and unlimited. Historically, the four-stuff developed from water of Thales, gas of Anaximenes, earth of Xenophanes and Parmenides, and fire of Heraclitus. All changes occur by the combination of four-stuff at different ratios. In order to account for the continuous combination and dissociation in nature Empedocles introduced 'love' and 'strife'. This was a revolutionary concept in natural philosophy, and today we know in the world of science that attraction (e.g. love) and repulsion (e.g. strife) are the two fundamental classifications of all forces in nature.

The indivisible particle (or 'a-tomos') concept introduced by atomist philosophers was a kind of antithesis to the philosophy of the Parmenides School (i.e. Eleatic School). According to atomists (i.e. Leucippus, Democritus, Epicurus, and Lucretius) the infinite numbers of atoms each with its own identity (i.e. chemical potential) collide and react freely and randomly, and the change of any quality (or property) depends on the types of atoms reacted. In the views of atomists 'atoms are infinite in number each having a different shape, they randomly collide with each other until they find the best fit of shape, and then they combine'.

The principles proposed by atomists essentially form the fundamental bases of the dynamics of chemical atoms in our age. Chemical atoms randomly collide, and exchange momentum and energy. The random collisions may be elastic or reactive, the latter yields molecules. The elastic collisions redistribute the momentum and energy carried by each atom, and a system when kept isolated for sufficiently long time goes to equilibrium where all observable properties remain constant in time. The approach to equilibrium is one-directional, or irreversible. However, this fact bears some problems. The total mass and total energy are both invariable in an isolated system; but all other observable properties are apt to undergo deviations from thermostatic equilibrium values. In other words, they undergo 'fluctuations' around equilibrium values. These fluctuations are usually neglected since the relative frequency of the occurrence (or the probability) of a fluctuation decreases very sharply with its size and duration. Large deviations from equilibrium are exceedingly rare, and small fluctuations occur more frequently. The observable fluctuations manifest themselves only under very favorable conditions, such as the Brownian movement of suspended particles in a liquid, or the opalescence of liquids near the critical point. About a hundred years ago Einstein, Smoluchowski, and other physicists demonstrated that these phenomena can be explained by the idea of fluctuations. So fluctuation is also a physical fact as well as a philosophical concept [9, 10].

RANDOMNESS

When the collisions are elastic, the speed distribution of molecules is given by the Maxwellian distribution [8]. Randomness has been objected by many thinkers who claim that the universe must work as a perfect clock, and not by a mechanism relying on chance. However, randomness must be interpreted as ‘nonpreference’. That is, the objects collide with each other without any preference. This implies that there is no divine preference and intervention in natural processes. In this respect, the Milesian School of philosophy (i.e. Thales, Axaximander, and Anaximenes) did a pioneering work by setting up the most fundamental grounds for scientific thinking. The physics of stochastic processes relies on Anaximenes’ nature.

Boltzmann showed that the equilibrium solution of his transport equation yields the Maxwellian distribution. That means, if the restrictions are removed from a system, its components obey the Maxwellian distribution, otherwise they obey a non-Maxwellian distribution. In other words, all distributions in nature tend to be Maxwellian in time, which, somehow stands like a background distribution.

If the total energy (i.e. temperature) of a system increases, the distribution curve shifts to the right and gets broadened. In other words, the differences between the components increase under the effect of increased energy. In ancient natural philosophy ‘being’ is realized by ‘fire’; in other words, the things come into ‘being’ under the effect of fire. Energy increases the possibilities, that is, it creates new states that the components of the system can get into. As the energy is decreased the Maxwellian curve becomes steeper and shifts to the left; it finally becomes a pulse function or an arrow on the y-axis (e.g. number or population axis) when the temperature was decreased to zero degrees Kelvin. At this temperature all components are at perfect order and they all have same zero energy. The perfect equality could be achieved only at complete nothing, i.e. at zero degrees Kelvin.

Whenever the system is given little energy, every member of the system gains different amounts of energies and become different from each other. All changes become possible with the exchange of fire as proposed by Heraclitus. Although Heraclitus’ fire is not identical to energy of our time, fire serves as energy in some respects. The addition of fire increases differentiation and hence the differences between the properties of different components. In other words, energy increases the driving force (or the contradiction) between the components of a system. It is no wonder that Heraclitus introduced both ‘fire’ and ‘contradictions (duality or dialectics)’ as the fundamental entities of nature.

The interaction of molecules or species in a random system takes place entirely through probabilistic interactions. According to Popper it is difficult to have a satisfactory theory of probability free from contradictions, and numerical probability denotes how frequent an event takes place [11]. Probability theory serves as the best tool to make predictions about random (or Maxwellian) systems. In order to predict how much something happens depends entirely on the energy distribution of species. So energy (or fire) does not only provide the needed threshold, but also arranges how many are involved and what happens. In fact, in Heraclitus’ world, things are not ‘made of’, but ‘made from’ fire.

The shift of the Maxwellian curve to the right with temperature is due to the increase of ‘complexions’ according to Boltzmann. The randomness can increase both in the coordinate and the velocity spaces so-called the phase space of a system. A peculiar property of Maxwellian distribution is that, it is an asymmetric curve and starts from zero and goes to infinity; that is, there is no upper limit, and the number of complexions can go to infinity. The increase of the energy of a system creates new possibilities or states that the system can go. Boltzmann showed by his famous H-theorem that once the molecules left their places, it becomes difficult for them to go back to their original positions. The increase in complexions is an increase in new possibilities for a system, so the number of choices, and thus the degrees of freedom or randomness increases. Boltzmann identified this property with the increase of entropy. In classical thermodynamics entropy is defined as the less availability of energy, while Boltzmann defined entropy as the increase of randomness. On the same line, Shannon showed in early 1950s that entropy is the decrease of information of the system available to us. In fact both the Boltzmann's entropy equation and the Shannon's information equations have the same mathematical structure with opposite signs.

The right hand side of the Maxwellian distribution represents the superior property and those having these properties are always low in number. However, it is this part of the system that provides larger possibility for a change in nature. As an example, let this part to represent the number of fast runners (needed for Darwinian natural selection in animals), or very beautiful species (needed for Darwinian sexual selection), or very clever or rich people (needed for economic development), or very honest people (needed for social stability and cooperation), etc. They are low in number but have large capability to affect others. Although the distributions of these properties do not perfectly fit the Maxwellian distribution we can use the Maxwellian (or non-Maxwellian) distribution as a tool to make interpretations. These properties are transmitted to others through different means; economic wealth is transmitted through the exchange of goods, while genetic properties are transmitted through cross breeding. The superior properties, which are 'actuality' at present, make the 'potentiality' of future in the words of Aristotle. In terms of genetic science, a property of grand parents may not show up in sons or daughters who carry them as potential values, but may appear in grandchildren.

The Maxwellian distribution does not tell us why biological evolution takes place, but it tells us the simple mechanism of natural selection. As an example let the speed distribution at a lower temperature represent the speed distribution of predators and that at high temperature represent that of the preys. That is, the speed distribution of preys is shifted beyond the velocity distribution of predators. It is clear that the low speed preys have no chance to survive, nor the low speed predators. Only the preys and the predators on the right part of the curves (i.e. high speed species) can survive. Natural selection pushes the species in this example in such a direction that the offspring have the potentiality to be fast runners. Depending on the ecological conditions the biological species are always pushed to gain new properties (i.e. higher speed, better vision, better hearing, higher intelligence, higher birth rate, etc.). The 'change at present' is an attempt to have 'future equilibrium'. The equilibrium is always transient and it is apt to change always causing irreversible changes in the biological structures of living organisms.

If everything is exchanged randomly, how can the objects, the patterns, and order come out from randomness? The view of Anaximenes that everything comes from air cannot easily explain the reason and the mechanism of generation of order (or cosmos). Because a perfectly disordered system cannot go to an ordered state; this is also what Boltzmann says. One thing we can think of is that the disordered system may have tiny order at the very micro level so that each tiny ordered form can behave as the 'sperma' of Anaxagoras; they grow and form the objects. Recently Hong questioned microscopic irreversibility, that is, a possibility of the generation of form in an irreversible way in relation to biosystems [12]. The existence of sperma in completely disordered state is usually difficult to accept. Anaxagoras criticized the second assertion of Parmenides for accepting 'change' as the loss of one quality and the loss of another. He said there is no smallest part of anything, and the things can be infinitely divisible.

Everything was mixed at the beginning and it is so now. According to Anaxagoras the change that we observe in the objects is due to change in the proportions of infinitely small constituents of the objects. According to atomists any object can be a collection of different atoms but only some specific atoms can make up an object. Anaxagoras' philosophy bases on the existence of everything in a single object, and some of them are dominant in their proportions. In this respect Anaxagoras' philosophy forms a kind of foreground for the 'potential' concept of Aristotle. What Anaxagoras emphasized is that the smallest constituents can persistently stay together making a 'seed' (or sperma) which behaves like the nucleus of objects. Anaxagoras' sperma probably corresponds for instance to unit cell in crystals, DNA in biological cells, etc. Sperma owns specific information that tells to the system how or in what way to grow. The sperma regulates the proportions of the constituents in a growing object. In the atomists' philosophy each atom has a specific property; they may be round, cornered, sharp, etc. All these, in fact, correspond to chemical potential in atoms. In Pythagorean philosophy the abstract geometric shapes with proportioned edges are the constituents of matter.

The interpretation of entropy in terms of information by Shannon has much deeper philosophical importance than 'degradation of energy'. The increase of entropy denoting the increase of randomness and thus the loss of information about the system can also be used not only for quantitative changes, but also for qualitative changes. The loss of beauty of a flower in time, or the decrease of the moral attitudes of a society due to poor economy and corruption all can be treated as an increase in entropy in the corresponding parameter state. The Boltzmann entropy equation and Shannon's information equation thus serve as mathematical relations at the interface of physical and nonphysical worlds, because, both the physical and the nonphysical phenomena have their own appropriate 'configuration'. For instance, an ordinary speech can be made either more or less effective by rewording it without changing the number of words in it. Its influence on people can be in a way either to improve the ties between people or to worsen it. The entropy decreases in the former while it increases in the second.

According to Boltzmann, the Maxwellian distribution represents the maximum entropy (i.e. disordered) state and order does not come out from it. In maximum entropy state the system has fluctuations at micro level but they do not cause creation of any sperma, because whatever created is subsequently destructed. This is due to the principle of 'microscopic reversibility', that is, any molecular process and its reverse takes place with the same frequency.

AUTOCATALYSIS

The current chaos theories started after the pioneering work of Lorenz [13]. The nonlinear thermodynamics provided an important ground for chaos theories and also for the theories on pattern formation. The creation of pattern in chemically reacting systems was first handled by Turing [14] by using a set of differential eqautions, and then studied in detail by Prigogine [15]. The work of Turing is of utmost importance to understand the pattern formation that he called it 'morphogenesis'. The Lotka-Volterra problem, the Belousov-Zhabotinsky reactions, and the Bruselator problem of Prigogine were the model problems of nonlinear thermodynamics, and they were all autocatalytic (i.e. self-multiplying) reactions. That is, in all these problems the product catalyzes itself and changes other things (i.e. reactants) into product. The Lotka-Volterra problem discusses the change of populations in wild life. It is a simple but powerful model for ecological systems. As an example we may consider the relation between grass (G), rabbit (R), and fox (F). The reaction between them can be given by,

$$G + R \rightarrow R + R$$

$$R + F \rightarrow F + F$$

$$F \rightarrow E$$

Overall:

$$G \rightarrow E \tag{1}$$

Rabbit feeds on the grass (e.g. $G + R$), and after a while, it gives birth and thus multiplies in number (e.g. $R + R$). Fox eats the rabbit (e.g. $R + F$), and it also multiplies (e.g. $F + F$). Foxes then die and go extinct (e.g. E). The dead fox decays, on which grass grows, and it multiplies, too.

The competition between species and the conversion of others into a specific species or state has grounds in the philosophy of Empedocles. The four-stuff philosophy of Empedocles was a way out from the very static philosophy of Parmenides to explain the change in nature [6]. According to him the four-stuff (i.e. earth, water, air, and fire) cannot be converted completely into each other, because each of the four-stuff is an element, and there is always an eternal 'competition' between them. In this respect he opened a door to atomists who said each atom is unique by itself and cannot be changed into anything else. The philosophers defending four-stuff attributed autocatalytic property to each of the four-stuff. They said the universe cannot be made from one single element (i.e. entity); otherwise everything would finally be converted into it.

The change in nature takes place by mutual interaction of four-stuff, and each tries to increase its amount. Ice immersed into water cools it and tries to freeze it, but water warms up ice and tries to convert it into water. In this sense, all natural phenomena are autocatalytic, and each 'being' tries to convert others into itself, as rabbit converts grass into rabbit, fox converts rabbit into fox, etc.

The events are also somehow autocatalytic in Bohm's world. According to Bohm the events are constantly generated by the whole and swollen back by it. Bohm's 'whole' resembles Anaximender's apeiron, and it is also somehow autocatalytic, because each event reproduces another event that looks like itself. Each whole aims to reproduce its subwholes [16].

If we consider grass, rabbit, or fox with their unique configurations (or structure) each tries to convert the other into itself. In biological world natural selection appears to be a competition phenomenon between configurations (i.e. species). Since each configuration (i.e. species) owns specific information, natural selection results in reshaping of a specific configuration by selecting those of which some zones of its DNA is more (or less) expressed over others. The species, which have the chance to survive for sufficiently long time, have appropriate sets of biological reactions driven by their DNA to stabilize themselves against their environments. In single cells, the natural mutations cause the change of configurations in the offspring. Therefore the ensemble partition function of translation, vibration, rotation, and excitation energies of DNA becomes the determining basis for natural or spontaneous mutations. The chemical environment and the mutagens accelerate mutations. However, the spontaneous mutations do not seem to be sufficient in more complex species. The high rank species have opposite sexes, which tremendously accelerate the reconfiguration of DNA creating the birth of quite different new offspring (or configurations, differently structured DNA s, information, Anaxagoras spermas, or whatever).

Atomists substituted four-stuff by atoms and they assigned different shape or a kind of hook to each atom as mentioned earlier [17]. Different tiny shape or hook corresponds to the chemical potential of an atom in today's language. Every chemical potential is a result of the distribution of electrons on the shells of atoms. Atomists were not well understood in Antiquity, and most other philosophers defended four-stuff theory.

Schlögl did an interesting work enlightening the relation between phase change (i.e. change of four-stuff) and chemical kinetics (i.e. atomic reactions) [18]. He considered autocatalytic reactions similar to (1).

One of his systems is,

$$A + 2X \rightleftharpoons 3X,$$
$$B + X \rightleftharpoons C,$$

Overall:

$$A + 2X \rightleftharpoons C. \tag{2}$$

Here two X molecules are involved in an autocatalytic reaction and they change A into another X. One of X then combines with B and gives C. The rate equations for all steps can be written and solved for the change of the concentrations of the reactants. The simple chemical kinetics approach to express C in terms of X at steady state conditions yields an equation, which is, mathematically identical to the equations of phase change (i.e. Van der Waals and virial) of classical thermodynamics [18]. In fact the changes of earth, water, and air into each other is nothing but the changes of states in thermodynamics. The four-stuff philosophers in fact visualized the changes in nature to take place through phase changes. These state changes are called first order phase transition. We also have second order and λ-phase transitions, and they deal with order-disorder transitions.

Another system studied by Schlögl is,

$$A + X \rightleftharpoons 2X$$
$$B + X \rightleftharpoons C$$

Overall:

$$A + B \rightleftharpoons C. \tag{3}$$

At steady state the relation between C and X yields a mathematical equation, which is of the form of second order phase transition. In second order phase transition the appearance of the object does not change, but the inner order or structure changes. A magnet has an ordered pattern at atomic level, but it is destroyed above a critical temperature, and it becomes demagnetized.

The very striking discovery of Schlögl was that the explanation of change in nature based on four-stuff could be explained by atomic dynamics (i.e. chemical reactions). It is interesting that in this explanation the molecules have to be autocatalytic, that is, they compete for themselves as each of the four-stuff.

The autocatalytic or self-multiplying systems were shown to exhibit so-called sigmoid growth in time. It was first observed by Verlhurst for the growth of microbial organisms; it is interesting that some empires also display same growth pattern [19]. The rate of such growths can be mathematically described by a parabolic equation so-called logistic equation. Its iteration gives an idea about how a self-multiplying system goes into chaos. The original parabolic shape becomes two overlapping parabola in the second iteration, and it gives more complex structures on further iterations. In the sixth iteration a complex structure with different hyper symmetries is obtained with no resemblance to the original parabola [19]. Figures 3.1 – 3.10 in [19] give beautiful description of the iterations of logistic map. Four important observations can be made on the chaotic route of the system:

(i) in every step of iteration the original parabolic shape repeats itself in decreasing sizes and with some deformations of the parabolic shape. However its number increases in the overall domain but spread out to varying positions on the curve (self-similarity and memory),

(ii) the decrease of the dimensions of the parabolic shape in the proceeding iterations obeys some mathematical proportioning (fractal dimension and patterns),

(iii) the curved structure is lost in the final shape and it changes very abruptly with the loss of differentiability (unpredictability),

(iv) new geometrical structures and higher symmetries formed indicate higher complexities (evolution of order and complexity).

SELF SIMILARITY AND MEMORY

The first of the above indicates that in chaotic growth fragmentation takes place, and one or more of the parameters grow in number and/or in magnitude, but the system tends to loose its original shape. Every fragment carries some of the properties of its precursors, and also gains new structures (or information sites). The system reproduces new pattern of its kind at smaller sizes. The self-similarity is a unique property of chaotic systems, and it can be clearly seen especially if the function studied has complex terms as in Mandelbrot transformations, which also yield Julia sets [20 – 22]. Chaotic growth inherits self-similarity [20 – 30]. Whatever descends from the precursor serves as memory to the new system. As chaos increases, the total sizes of memory regions decrease and the system runs into difficulty in memorizing its past. Every chaotic or nonlinearly growing process has its own history. Some of the original information is lost in each step of change while new information (or structural changes) is gained at the expense of loss of former information. The system has a kind of mechanism which weakens the memory due to the continuous generation-destruction mechanism of Aristotle; the more number of steps of new generations the more difficult to get the original shape on going backward. The living organisms also show the same behavior. They have both common and different genes on DNA. In the developmental stages (i.e. iteration steps) some are expressed and some not. For instance, tail-forming genes are expressed in the fetus of baboon, but they are not expressed in chimpanzee. Tail information centre is lost in chimpanzee. The system gains new information in the course of evolution. The new information can result from two sources, one is due to the new additions of atoms or species, and the second is due to the change of the overall shape of the object. The second one is due to the configurational change of the system. A system may have different configurational structures without changing its material content but changing only the order of the alignment of its atoms or molecules. The difference between two same-material structures can be characterized by their configurational entropies. The Anaxagoras' sperma depends not only on atoms but also on their alignment in space. The sperma unlike the atoms undergoes changes in evolutionary processes. Non-evolving sperma may function as atoms, which stay unchanged according to Ancient atomists. Anaxagoras' sperma is unlimited in number and present in primordial mass. Aristotle's interpretation of unlimited sperma is unlimited principles. In our scientific world they should be interpreted as information centres whatever the structure of the object is. The information can be piecewise as atoms or structurewise as ensembles or configurations. In chaotic or nonlinear dynamic growth new information is created in the form of micro structures, and they all depend on the chemical potentials of atoms (shapes or hooks), energy (fire), and the way of organization (i.e. principles).

In chaos, the sperma may correspond to microstructures formed in the system, or in the chaotic attractor. However, Anaxagoras proposed his sperma theory to find a way out from the Parmenides philosophy that rejects change. Anaxagoras thought that everything contains tiny bits of everything, and the cluster of some similar bits can dominate and thus form a sperma, which then informs the system about what shape or property to undergo. Anaxagoras' sperma resembles micro structures in chaos or strange attractor. In this respect strange attractor is full of information, and can yield different outcomes depending on which microstates dominate inside. Anaximander had proposed a historically important biological evolution theory which bases on the combination of best fitting parts. It also represents a kind of change from chaos to order.

FRACTAL DIMENSION AND PATTERNS

Chaos theories introduced a revolutionary concept to explain the shapes of objects or patterns in nature. The change from one phase into another becomes possible under the effect of fire that exists at different proportions according to Heraclitus. In chaotic growth the energy supplied does not only affect the dynamics, it also changes the geometric dimensions at every step of iteration. The proportionality (or scaling) occurring in the change of shapes or structures can be mathematically expressed by a power law. The scaling power for the nonlinear growth was called ‘fractal dimension’ by Mandelbrot [20]. Most objects in nature own a scaling dimension [20 – 24, 31 – 35].

The change of dimensions at certain proportions results in generation and destruction of similar geometric objects at varying dimensions. In fact, the solution of the mathematical equations of Bénard cells, which occur in viscous liquids heated from the bottom shows that some geometries are repeatedly produced in the system. Nonlinearly growing systems draw our attention to geometric shapes which are the elements of the Pythagorian School. In fact, as mentioned earlier, Aristotle claimed that atoms correspond to the geometric entities of the Pythagorian School.

Not all energy given to a system causes immediate change. The system absorbs the energy given for a while, and after reaching a critical amount it becomes unstable and splits itself into two, that is, it bifurcates. Every bifurcation can be viewed as a kind of phase change operation. A chaotic state can be arrived after a series of subsequent bifurcations. This introduces a kind of history to the final pattern accomplished. Therefore every final pattern generated in chaotic growth represents a ‘happening’ not only a ‘being’ or ‘event’ [36]. In the history of natural philosophy only Aristotle had a sound proposal about the importance of the shapes of objects. He considered shape (i.e. form) as a priori entity which when filled by matter makes an object. It cannot be separated from matter; it exists when matter exists.

In biological world, pattern forms as a result of information supplied by DNA. In nonlinearly growing objects every step changes the total information content of the former step, and the evolution of a form (shape, or morph) comes out from the evolving information content of the system. Therefore it is time dependent and bases only on finally achieved material (i.e. atomic) content, and also the way of combination of atoms.

Chaotic systems are in continuous exchange with the environment meanwhile they maintain their self-similarity, and this establishes a new framework to guide research in many fields [37]. As the similarity is concerned Popper points out that ‘something repeats itself’ is based on the judgment of similarity. Similarity concept heavily depends on our experience so we can never demonstrate that the world of phenomena is inherently repetitious [11]. In nonlinear growth dynamics the repetitions are not static repetitions as in the growth of a crystal where the information obtained from the unit cell always remains same; rather, the units change their shape and their inner contents resulting in a change also in their information content. That is, the present structure is not sustainable in the next step, and finally complex systems evolve spontaneously from simple precursors interacting haphazardly or weakly. The self-organization involves self-similarity, and according to Mandelbrot’s fractal principle it extends everywhere in the universe [38]. The fractal dimension is not the property of points, but of how they are arranged with respect to each other; therefore it is inherently nonlocal [39]. So it influences every point around.

Unlike the patterns like shores, leaves etc. the chaotic attractors are true fractals [40]. In phase space the trajectories exponentially diverge from each other, and they wrap on each other imparting fractal geometry to the attractor as time goes to infinity. As a result, fine structures form at all scales, and complexity is created [23 – 35, 37, 41]. The Lyapunov exponents give the divergence of trajectories; and the system goes into chaos if we can assign a Lyapunov exponent to the system. The chaotic attractor represents the coherent coexistence of diverging points [42]. The border of the attractor is the most dynamic region where, the turbulence takes place. The system either forms patterns or goes into randomness, or perhaps extinction as in Mandelbrot pattern [21, 38]. No matter how turbulent the system is, it remains chaotic if a correlation exists between the components of the system. When the Hamiltonian is non-separable due to nonlinear terms, the system is apt to chaos [41, 43].

Chaos theories introduced an important concept into the physics world. In all physical theories there was no place for numbers; in fact, number theory had never been a concern of physicists. Since the chaotic attractor involves too many cycles, it is of concern to find out how all these varying oscillations can coexist in the system. It was found out by Lorenz that some frequency ratios expressed in terms of prime or semi prime numbers have higher durability [13]. In fact, in circle map, mode locking occurs when the ratio of two fundamental frequencies of toroidal motion is rational [29]. It corresponds to a relatively more stable state. When the system parameters are expressed by irrational numbers, then, the system is directed to chaos. In fact the fractal dimension is also an irrational number. In other words, chaotic dynamics uses numbers, and especially prime numbers. The prime numbers can be considered to be the atoms of ordinary numbers. According to Pythagorean School the truth can be tracked only by mathematical reasoning, and numbers can express the attributes of all things. The fractal dimension is an irrational number and never ends, it is a kind of unlimited in the sense of Pythagorian School; and it is a property of our nature.

Another interesting outcome of the role of numbers in chaotic dynamics is in understanding of aesthetics. The stability achieved through mode locking introduces a hierarchy of rational numbers, which are established according to Farey tree construction [44]. Farey tree can be constructed by using continued fractions. The irrational numbers can be also expressed in terms on continued fractions, which end at infinity. The least convergent continued fraction can be constructed by using ‘1’. This continued fraction leads to what is known as ‘golden ratio’, which has been used in numerous artifacts, architecture, sculptures, pictures, etc. throughout the human civilization. Golden ratio has been a kind of measure of aesthetics [43 – 49]. The chaos theories imply that the philosophy of aesthetics should be based on the importance of numbers in the dynamics of nonlinearly growing systems. The conservative and the stretching forces balance each other to generate such patterns, which create the feeling of aesthetics in our minds. Among all those patterns the one, which is the least stable and apt to easiest change (i.e. golden ratio configuration), is perceived as the most aesthetic configuration. It is interesting that the golden ratio shows up also in the growth of empires, which are also dynamical systems where stability during growth should be of primary issue [19].

UNPREDICTABILITY

A chaotic system loses its continuity with abrupt changes, and it cannot be described by smooth functions. Therefore integrability is lost, and one cannot predict the future of the system. Classical chaotic systems are deterministic but not predictable. Therefore one cannot easily go backward in coordinate space to obtain the initial pattern from the last pattern. Renormalizability techniques are useful but one cannot get the full recovery [50]. The recovery can be improved by defining several points around the starting origin [39]. Therefore, determinism is lost at this point. In fact an infinitesimal change in the initial conditions may amplify some growing parameters and take the system into chaos, a property so-called ‘sensitive dependence on initial conditions’. In addition, if the initial conditions are expressed by irrational numbers such as π and $2^{1/2}$ there is no way to measure it exactly. Therefore predictability is lost in chaotic systems. According to chaos theories most nonlinear dynamical systems cannot be reduced to the superpositions of elementary functions [51]. So the analysis of the system for forecasting usually becomes impossible.

In Laplacian thought the determinism and the predictability are the same thing; they are image of each other. Thus there exists a parallelism between the Laplacian thought and the religious destiny or fate. There can be no real possibilities in such a world; because every happening has to be necessarily so. The truths, which are necessary, do not have to be logically necessary [52].

The separation of determinism and predictability from each other can be on the grounds that determinism is an ontological concept while predictability is an epistemic concept [53]. This separation has made important contribution to the concept of free will. It is believed that unpredictability can be a source of human cognitive powers [54]. There is a conflict between free will and determinism. Heisenberg's uncertainty principle shed a light on free will, however Schrödinger claimed that free will is an illusion. There is almost no place for free will also in Bohm's quantum world. However, some philosophers talk in favour of indeterminism [55].

COMPLEXITY

The generation of new patterns, higher order symmetries, or cosmos in terms of ancient philosophy is a unique property of chaotic dynamics. Chaos can be viewed as the science of pattern formation. The critical question here is why chaos can lead to order. According to Landsberg the disorder of a system can be defined as the entropy divided by the system's maximal entropy. If the rate of increase in the number of micro states due to increase of entropy is less than the rate of increase of maximal entropy, then the disorder decreases [56, 57]. The basin of strange attractor is full of microstates, which behave like the sperma of Anaxagoras. In other words the strange attractor is full of information, which can lead to different new formations. The variety of information increases with the extent of chaos, that is, the more chaotic the system is the more variety of micro states; and thus the higher chance for new patterns. The number of existing microstates determines the pathways of new evolving systems from chaos. The complexity of pathways increases the diversity of new formations; however, the rate of evolution decreases as it has higher degree of branching. The decrease in the number of microstates and thus the decrease in the complexity of pathways can accelerate the evolution of certain species. For instance, small mammals first showed up by the end of third geological period. The sharp change by the end of third period and the extinction of almost 95 % of all species including dinosaurs accelerated the evolution of mammals in the fourth geological period.

The genetic information of a living species denotes the maximum information content, but not its organizational information. Only some of them are used in the structural and metabolic organizations. The loss of some of the current information can lead to the increase of the accumulating potential information, which then leads to mutations for new species. The increase in the maximal information content provides a ground for the increase of the potential information, and thus the possibilities for new species. The amphibians like frog have much longer DNA compared to most other species. Such huge potential information was actually needed to have special organization to adopt a new life on earth rather than in water. It helped also to have a variety of new species in the course of evolution such as reptiles, birds, etc.

The structural and metabolic organization in a living species is all controlled by active sites of DNA. The active sites can be considered as active microstructures of DNA. Anaximander had proposed a primitive evolution theory 2500 years ago, and claimed life originated in the seas. He said new parts form under solar radiation from cracking of shells of forms, which in turn join to give the living species. Only best fitting parts can join and give the species. This primitive theory more or less shows a parallelism with the current evolution theory assuming the active sites of DNA refer to the parts of Anaximander.

In chaotic systems hyper symmetries are generated while fragmentation takes place (see Figs. 3.7 and 3.10 in [19]). In other words the increase of complexity is a natural consequence of nonlinearly growing systems. Forster considers a possibility of a kind of conservation law that says simplicity achieved at the higher level is at the expense of complexity at the lower level [58]. This approach is interesting in the sense that it somehow inspires a kind of metaphysical conservation law. This thought may have roots in Parmenides' philosophy.

The understanding of complexity will help also to understand the living organisms [59]. The property of the whole cannot be reduced to the properties of components but related to the interaction between them as Aristotle said. In the complexity theory, the self-organizing systems get involved in new interactions and form new connections between the components.

The rate of the change of entropy of a system that nonlinearly grows is a measure of how it undergoes complexity [41]. In fact the rate of change of Shannon entropy gives Kolmogorov entropy. The Kolmogorov entropy is zero for steady systems, and positive for chaotic systems. So the Kolmogorov entropy can be used as to understand how complexity develops. The high Kolmogorov entropy means high rate of change of the internal structure, and of the information content; therefore, the faster development of complexity. According to Gatlin the Shannon entropy denotes capacity to carry the real 'potential information' [60]. Therefore the Kolmogorov entropy is a measure of the gain of new information and thus of complexity. In other words, it indicates the rate of Aristotelian change 'from potentiality to actuality'.

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ANCIENT AND CURRENT CHAOS THEORIES

Güngör Gündüz

Odsjek kemijskog inženjerstva, Bliskoistočno tehničko sveučilište
Ankara, Turska

SAŽETAK

Teorija kaosa razvijena u zadnja tri desetljeća znatno je doprinijela našem razumijevanju dinamičkih sustava i pojava u prirodi. Suvremeno i prošlo značenje kaosa međusobno se u određenoj mjeri razlikuju. U ovom radu svojstva dinamičkih sustava i evolucije kaotičnih sustava razmatraju se sa stajališta filozofa antike. Značenje kaosa u filozofiji Anaksimena i njegova uloga u antičkoj filozofiji prirode razmatrani su obzirom na druge filozofe prirode poput Anaksimandara, Parmenida, Heraklita, Empedokla, Leukipa (tj. atomiste) i Aristotela. Dodatno, temeljne postavke statističke mehanike i suvremene teorije kaosa su razmatrane obzirom na antičku filozofiju prirode. Korijeni znanstvenih koncepata, poput nasumičnosti, autokatalize, nelinearnog rasta, informacije, strukture i sl., u antičkoj filozofiji su razmotreni.

KLJUČNE RIJEČI

kaos, nasumičnost, dinamički sustavi, filozofija prirode, drevna filozofija, informacija, biološka evolucija, nelinearnost