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EDITORIAL

Dear readers, in this issue of the journal INDECS, there are articles with interdisciplinary perspective which combine description of classes of dynamic systems with elements of humanities and medical sciences.

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In the article by V. Silobrčić et al. the preliminary insight into scientific output of Croatian Universities is given. That article in the form of accepted manuscript, available since some time at web page of the Journal, raised comments, which resulted in the need for changing a part of its content. Owing to the fact that questioned data was repeated in the article, the conventional form of their change, e.g. *errata*, was not considered sufficiently appropriate. Because of that, the version of the manuscript published in the printed and CD-ROM editions of the Journal is the final version integrating the accepted manuscript and *erratum*. In order to enable the interested readers to get insight into the commented parts, and the accepted manuscript version of the article, in the online edition all versions and all comments are available.

In the fifth article, M. Sedighi Anaraki et al. formulated, and applied onto realistic cases, an interesting improvement of the method of complex networks.

In this issue, the results for INDECSA for the year 2005 should be presented. Somewhat unexpectedly, INDECSA 2005 will not be awarded, as there were more than three articles published in Volume 3 of INDECS which obtained equal number of votes of eligible voters. In accordance with the previously stated propositions for conducting the contest for INDECSA, in that case there is no awarded article.

With publishing of this issue, in which four of the published articles are eligible for INDECSA, the INDECSA 2006 has been started.

Zagreb, 3 July 2006 — Josip Stepanić

LIST OF REFEREES

The following scholars, listed in alphabetic order, refereed manuscripts for INDECS in year 2005:

Stanislaw Sieniutycz	Urban Kordeš
Karl Heinz Hoffmann	Karin Šerman
Franz-Markus Peschl	Maja Žumer
Žiga Knap	Rafael Ball
Branko Lesjak	Katalin Martinas
Sergej A. Amelkin	Marek Frankowicz

Their contribution to the quality of the Journal's content is acknowledged.

Zagreb, 3 July 2006

Josip Stepanić

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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

CLASSIFICATION

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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

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PHYSICAL DESCRIPTION AND DETERMINANTS OF EVOLUTION OF STRUCTURES. AN ATTEMPT TO ANALYSE THEIR IMPLICATIONS FOR OPTIMISING ARCHITECTURAL AND URBAN SPACE PLANNING

Jerzy Z. Hubert

Department of Structural Research – IFJ, Polish Academy of Sciences
Kraków, Poland

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SUMMARY

Physical conditions for spontaneous growth and development of complex structures are discussed: using the concept of {free energy (thermodynamic negentropy)} $\rightarrow$ {structural information (Shanonnian) negentropy} transformation. The phenomena of structure ageing and decay are analysed. Degree of complexity of a structure, direction of its evolution is related to the number of elementary configurations (of constructing of its elements) that could be used to construct its identity. Practical conclusions which are drawn refer to the proposition of the optimum architectural design and city planning. As a criterion in this optimisation the best conditions for human well being, development and assuring the best conditions for flourishing of their creativity. Important for non mathematical scientists: presentation is written in simple language using only simple mathematical formulas. It is illustrated by examples in house construction.

KEY WORDS

negentropy, social synergetics, architecture, city planning

CLASSIFICATION

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*Corresponding author, η: jerzy.hubert@ifj.edu.pl; +48 12 662 8267, +48 12 662 88093;
IFJ – Polish Academy of Sciences, Radzikowskiego 152, 31-342 Kraków, Poland

INTRODUCTION

FORM AND MATTER

Any piece of matter we can think of has to have some form[1], matter moulds itself into forms, it cannot express itself but through forms. Forms are not static. Any form can engender another form. Can anything change into anything? No. Observation teaches us that some forms have no self-inherent power to change into other forms. Or rather that they can change only in one direction. A house may dilapidate; walls will crack and fall apart. But not the other way round. A heap of rubble will not change spontaneously, by itself into walls and ceilings. There is an intrinsic irreversibility in the transformation of forms which exist in the inanimate world. This irreversibility suggests that these forms are differing from each other by some essential quality which is, so to say, correlated with the flow of time: direction of its changes is parallel to time's arrow. From past , through the presence, to future.

In the inanimate world forms that succeed each other in the course of time become, so to speak, hazier, less ordered, less distinct. Could this degree of haziness, or of distinctness, be somehow teoretically distilled from forms themselves and defined in a universal manner, applicable for discussion of any forms whatsoever? Could a quantitative, physical description of forms account for this phenomenon of irreversibility of transformations in the inanimate world and at the same time of reversibility in the living world? The answer to these questions is a positive one. How can this be done?

First we have to consider forms as complex entities consisting of some elements connected together by some links. We may think for example about atoms or molecules when studying the structure of a crystal. When studying the form of a house separate bricks or perhaps even some grosser architectural elements (like windows, walls etc.) could be chosen as the appropriate elements.

A priori the elements can be interrelated and interconnected in many different ways. A particular form is realized by a particular mode of interconnecting the elements. If a given form is not very sophisticated there are many ways in which these elements can be interrelated without changing identity[2] of this form. On the other hand, if the form is very refined then almost any changes of interconnections will change it into another form. This basic observation is quantitatively generalized and expressed by the concept of entropy. To talk about it, to define it first we have to introduce the concept of elementary configuration.

NUMBER OF ELEMENTARY CONFIGURATIONS - A MEASURE OF UNIQUENESS AND COMPLEXITY OF FORM

What is elementary configuration? To introduce this concept we shall use an example. Let us consider a heap of bricks. Using a mathematical language we would say: a set of elements called „bricks" assuming the form called „heap". An elementary configuration (of bricks within the heap) is defined if to any brick (element) there is ascribed an exact position in space (and eventually in time). A change of position of any brick corresponds then to a change of elementary configuration. Now, within a heap positions of bricks can be interchanged in whatever manner we like and heap will always remain heap. It does not matter what exact place within a heap occupies a given brick. This particular form is also insensitive to the angular orientation (of bricks).

The situation is different when the bricks assume a more complicated form, for example that of a house. The position of any brick within the space occupied by the house is not so indifferent as within that occupied by a heap. They must be placed within the volume occupied by walls in an orderly manner, i.e., parallel or perpendicularly to the symmetry axes. But again, it is not important whether the brick number one is on the top of the wall and the brick number two at the bottom or vice versa – at least as long as the bricks are identical. Respective positions of bricks (elements) within the wall have no importance. Any repartition of identical bricks within the wall will make the same wall so that the form called „house" corresponds also to a number of elementary configurations (of bricks). It could be shown, however, that this number is much smaller than the number of elementary configurations corresponding to the form „heap".

There are, however, examples of forms which correspond to very few elementary configurations. Consider for example a system in which elements are electronic parts like transistors, capacitors, mini-circuits, resistors etc. making the form called „computer". It is obvious that almost any change of places between the elements will change the form „computer" into the form „assembly of electronic parts". There is perhaps only one or very few configurations of these elements which make this particular form. All other configurations make another form.

We could perhaps announce the following general statement: some forms are more sensitive to changes of interrelations among the elements which make them than other forms; the sensitivity of a form is inversely proportional to the number of elementary configurations of which it could be constituted.

Also „the degree of order" or „complexity" could be defined as entities inversely proportional to the number of elementary configurations (very complex forms are, generally speaking, very intolerant to the arbitrary changes of interrelations of elements which make them up).

ENTROPY

We are now prepared to define a quantity which may classify and characterize all forms irrespective of the particular nature of elements and their interrelations. This quantity is called entropy and it depends only on the number of elementary configurations of which a particular form or pattern could be constituted. This dependence is so defined as to increase it with this number. When the occurrence of any of the elementary configurations is equally probable then entropy is defined as a quantity proportional to the logarithm of that number.

FROM BEING TO BECOMING: NEGENTROPY

We humans are interested in creation of forms, in expressing ourselves in ever more complicated and efficient actions, in becoming. Existing forms and states are our starting points, which we then transform or transcend is our daily plight. So we should be more interested in changes of entropy than in its absolute value.

A „heap", a quantity of material, a set of loosely packed elements are characterized by the greater value of entropy than a more sophisticated form into which they may be transformed. The becoming expressed by creation of forms, by a passage into finer states, by emerging of order is characterized therefore by the decrease of entropy. The decrease of entropy mathematically can also be expressed as increase -of negentropy. These are different ways of speaking about the same thing. The word „negentropy"[3] has been coined from the expression „negative entropy" – meaning something opposite to entropy which, taken tout court, is a symbol of chaos disorder. The opposite of disorder is order. Development of forms, appearing of order, becoming of finer states, may therefore be, very summarily and very generally, described as: production of negentropy

To express the above said in formulas we can write:

$$N = -\Delta H, \tag{1}$$

where N is negentropy and H entropy (the notation appearing in many texts $N = -H$ is wrong. Negentropy appears or disappears only when there is a change of entropy. Curiously enough this fact has been noticed and discussed in depth not by a physicist but by a sociologist K. Bailey [1].

When we are primarily concerned with human situations, by activities in most cases implying a more or less conscious effort, then perhaps we are even more entitled to use the term „production of negentropy". Especially when we are more interested in kindling and sustaining a dynamic process itself (i.e., in producing negentropy) than in achieving this or that goal of action and/or producing this or that material object. It does not mean that achieving of some chosen goals of action or producing some material objects is not important. In many cases it is just indispensable (as for example when building houses or producing food) for sustaining this process of negentropy production for a length of time.

ORIGIN OF IRREVERSIBILITY: WHY THINGS SPONTANEOUSLY GET OLD?

Let us again come to the concept of irreversibility mentioned already in the first section.

Consider two structures (forms): one which can be realized by many elementary configurations (let us say by one million of them), the other only by one unique configuration. Let us label this one unique configuration with the letter C.

No complete and everlasting isolation of a system is possible. Sooner or later there appear various external forces and influences acting on it and changing its elementary configurations (even if it were possible to isolate a system completely and „forever" there is always a possibility of internal fluctuations, caused for example by inevitable thermal agitation of molecules). Now, if the first system (or, stated more precisely, some of its specific form) can exist in this million of elementary configurations, it is very unlikely that any external forces (or internal fluctuations) will cause the loss of its identity. There are very high chances that any practically realized change of elementary configurations will remain in that million of elementary configurations (permissible for subsistence of the system's identity).

Clearly it is just the other way round with the other system – that which can be expressed only by one configuration C. Now the situation is very unstable: any change of elementary configuration will result in the loss of the system's identity.

In normal conditions a spontaneous change of this system into a system of the former type is much, much more probable than the other way round. That is the phenomenon of irreversibility. That makes the new change into old, dead bodies and trees into soil, etc.

REVERSIBLE PHENOMENA

But there were these small words „in normal conditions", „if unattended", etc. People have known for a long time – and Ilya Prigogine and his co-workers have developed this empirical knowledge into a new and exciting science of „far from equilibrium irreversible thermodynamics" – that under special conditions, even in the physical, unanimated systems, macroscopic structures can spontaneously develop (like Benard's cells, Lisegang spirals, pearlitic structures, etc.).

The whole world of living beings is also the world of reversible phenomena. To this we should also include human, society and the (artificial) world.

In this paper we are interested by this last world especially that created by architecture and city planning. We shall look into its interaction with the dynamics of the human world of the human creativity and well being. Is it friendly to it, when it will assure the best conditions for our development on all planes of existence ?

What are these conditions? How to formalise them physically?

In the following we shall discuss these questions in more detail for a specific kind of structures, structures of spatial-temporal character (with emphasis on the second part of this word): those created in the human world, by human (purposeful) activities and evolve from haziness into distinctness, from high into low entropy, from a more probable form to a less probable one, from the virtual space of the possible into some material reality.

DYNAMIC STRUCTURES (PATTERNS) IN THE HUMAN WORLD

THE SPACE OF POSSIBILITIES

Humans, both as individuals and as groups, live in the open world; which opens for each individual into the space of a priori physically possible courses of actions or modes of behaviour, and which is is (more or less) opened for each group of people as a space of possibilities comprising all possible interpersonal relations and structures.

When an individual has more possibilities of action, this space is „greater" or encompasses more possible courses or paths, or, as formulated above, there are more „elementary configurations" which are a priori accessible. This situation – as in the case of purely spatial structures - may be also described by entropy defined in the spatial-temporal space. The more possibilities there are, the greater is this entropy - called an a priori entropy of action. The number of a priori possible courses of action depends on the characteristics of an individual and of the environment in which he/she is acting.

CHOICE, DECISION AND ACTION: COLLAPSE OF ENTROPY VALUE

Entropy of a system after a choice has been made and some course of action adopted, called an a posteriori entropy, decreases considerably. If the state that has been chosen is defined very sharply in a very fine manner, it may be even said to assume the zero value. In this last case the change of entropy caused by a decision and action process is numerically equal to the a priori entropy value. For non-random choices and activities this change is always negative: we have a negative increment of entropy (i.e., its decrease), or stated otherwise, there appears negentropy. Any process of selection (choosing) and decision-making, and of its implementation, is a process accompanied by appearance of negentropy. Thus we might look at any such process as a means to produce negentropy.

Note: Let not the reader be mislead to think that assuming the zero a posteriori entropy value means that no more negentropy can be produced. The dynamics of the system comes to a standstill.

Why is it so? To see the best would be to make use of simple formulas for the (information) negentropy *NI*:

$$NI = H_1 - H_2 \tag{2}$$

where H_1 is an a posteriori value of entropy and H_2 is an a priori one.

Let the system in question pursue two goals of action first the goal A then the goal B. Then according to the Shanonian definition of entropy (used also by Brillouin) we shall have:

$$H_1(\mathrm{A}) = p_1(\mathrm{A})\cdot \ln p_1(\mathrm{A}) + \ldots + p_n(\mathrm{A})\cdot \ln p_n(\mathrm{A}) \tag{3}$$

$$H_1(\mathrm{B}) = p_1(\mathrm{B})\cdot \ln p_1(\mathrm{B}) + \ldots + p_k(\mathrm{B})\cdot \ln p_k(\mathrm{B}) \tag{4}$$

Where p_n(A) is an a priori probability for the system to settle spontaneously in n-th state (form) related to the goal A of action. Similarly, p_n(B) is that probability for the goal B.

Now we can think – independently for the goal A and for the goal B – about the moment of choice and decision (collapse of the entropy value).

The system chooses only one of the terms of the sum (2) or (3). Then as its probability becomes one we have:

$$H_2(\mathrm{A}) = H_2(\mathrm{B}) = 0$$

The production of negentropy involved in the action A is:

$$NI(\mathrm{A}) = H_1(\mathrm{A})$$

and in the action B:

$$NI(\mathrm{B}) = H_1(\mathrm{B})$$

Assumption of zero a posteriori value – related to some given goal of action – does not mean then that the overall dynamics of the system is finished.

A PRIORI PROBABILITY SPECTRUM

A priori probabilities of various options - determining the value of negentropy production in a decision process – depend on very many factors. These factors predetermine, so to say, the choice of options that are most likely to be taken up by the subject. This possibility spectrum may naturally vary from individual to individual. Options quite natural for some people are practically impossible for others. The idea of this spectrum is a similar concept to the so called „attitude vector" proposed in social physics (synergetics) by W. Weidlich [2 – 4] (social synergetics is a special application of general synergetics developed by H. Haken [5]).

AVAILABLE (FREE) ENERGY AND NEGENTROPY

It is evident that any human activity is intrinsically connected with its material basis – and therefore also with the energy sources. The decrease of entropy must be paid for by dissipation of some portion of energy that is available to the human organism[4]. The relation between these two quantities is not always simple and linear. This means that decisions involving more negentropy do not necessarily imply dissipation of more energy. The dissipation depends not only on the value of produced negentropy but above all on efficiency of the transformation process:

$$\{\text{available (free) energy}\} \rightarrow \{\text{negentropy}\}$$

It seems that one of the most important potentially available sources of this free energy (for transformation purposes) lies in the possibility of a synergetic reinforcement which may exist among people [6]. The question is how to obtain this reinforcement in a long term and on a mass scale – possibly of the planetary radius?

There are two major requirements for obtaining a powerful (laser like) reinforcement. First, there is a need for a certain synchronicity, simultaneity (in time and in space) of a choice of options (of Weidlich's attitudes). (For example, two people living under the same roof – if they want to reinforce each other, they should share at least some interests, not have conflicting life styles, etc.). Second, the common options should be so chosen as to positively catalyze the negentropy transformation power of all, or at least of the majority, of individuals in a group. The second requirement can be more easily satisfied in small groups.

The fulfillment of synergistic reinforcement is especially important for groups involved in any creative process, which requires high disposability of free energy sources. Or, stated differently, it may be achieved only in moments characterised by high transformation intensity rates. This problem has been discussed in detail in many places by the author [7 – 9].

Attaining a certain degree of synchronicity for large population, however, or at least avoiding negative interference or mutual cancellation of efforts, is a very difficult problem (it becomes especially difficult when we it comes to spiritual and moral reinforcement). This one of the most difficult challenges for our civilisation.

THE SPACE OF POSSIBILITIES AND THE ARCHITECTURAL SPACE – INTERPRETATIONS FOUNDED IN INFORMATION THERMODYNAMICS

How the architectural space created by city planners, architects, interior decorators and structure designers should be in the best manner designed to keep the human creativity space wide open – to assure for every one the best conditions for the negentropy transformation process?

The modern living conditions in cities, the modern means of fast communication, liberalization and permissiveness on all levels of social life, expansion of all kinds of information media, dramatically increase the volume and density of information signals imposing themselves on everyone. For every individual only few of these signals carry a positive semantic content – may positively catalyse the negentropy transformation processes. Most of them are at least redundant if not dangerously disturbing these processes. A necessary filtering and selection in this ever increasing bulk of deluging information noise imposes – according to the Brillouin Principle of Information- increasing negentropy costs, increasing dissipation of available, free energy. A possibility of a bad choice, of an error of judgment – of a choice not leading to the increase of negentropy production – becomes in such conditions ever more difficult to avoid. The best design of architectural space should aim at reducing to minimum these negative effects of social density, of ubiquity of redundant information, of information menacing psychological homeostasis and social stability.

The aim could be realised (among others) by creation of, as many as possible, and wherever possible

(i) empty spaces,

(ii) isolated (small) spatial enclaves.

Realisation of these postulates would considerably ameliorate the quality of life of city dwellers.

Empty spaces

- where the natural conditions allow such empty spaces - in form of common grounds - should be created within the city landscape (in Krakow there is a good example of such a space, a grassy area, an empty field about 1,5 km in length and not far from the city center, used as a recreation ground),
- city landscape should be free of advertising of unnecessary lights etc. (advertising should not impose on people; it should be localized in restricted areas in form of commercial information for those who wish to use it at a given moment).

  Billboards should be absolutely forbidden. They do not only violate the above mentioned laws of development and creativity but also violate the civil rights : freedom of choice. You can close eyes when TV shows adds but you cannot when you are driving or walking. They create conditions of hazardous driving : in the crowd of multitude of information, imposing on the nervous system at every minute and in any place and direction, road signs and regulations can be easily omitted.
- in interior decoration: use of few ornamental and decorative details, preference of semi-empty walls and interiors (Japanese style) etc. In planning of apartments their considerable area

should be consecrated to hide away places for things that are not presently used in the living area (as are in the Japanese houses).

The spiritual goal for the use of empty spaces: the spatial emptiness is friendly to create the state of deep relaxation of the nervous system , the state sometimes described as the state of „mental emptiness" of the brain. The momentary emptiness – freedom from bothering thoughts and emotions – the perfect homeostasis of the brain. This phenomenon is well known in Zen philosophy and taught by its masters and also, in general, well known and recognised for its value in eastern philosophy and spirituality.

Design of isolated spatial enclaves

- creation of secluded, semi-isolated (by verdure, architectural forms and other means) enclaves in parks, on city squares, in railway station halls and in other open, public places wherever possible,
- isolation of pedestrian lanes and pavements from the motor traffic by verdure (ex. in form of thick tall hedges) and other means,
- it is deplored that in the current style of tree grooming in city parks and green patches reigns the style once used in the Victorian parks in England (and reigned in royal gardens in Paris).

Tree branches are cut up to the height of few meters. Thus parks and other green places are exposed to the city traffic. Also some beautiful churches and castles become hidden by tree foliage of trees which deprived of leaves near to the ground develop huge tree crowns above (alas that's the case of Krakow where instead of seeing the Wawel royal castle a park pedestrian is exposed to car traffic).

The application of these postulates, as possible devices in attainment of the general goal – of reducing to minimum the negative effects of social density – would considerably ameliorate the quality of life of city dwellers.

NOTES

[1]We take that word in its broadest annotation sense, i.e., a shapeless, hazy, „diffused" body also has a form: a shapeless, hazy, „diffused" one.

[2]We are not going to discuss here when a given form looses its identity, when it becomes another form. This problem is pertinent rather to the research on pattern recognition. We are rather concerned with the entropic description and the physical conditions which must be fulfilled before a form can appear. A region between one identity of a form and another one succeeding it, might be a „mushy", hazy region. (There is that famous example with Plekhanov's beard: one hair does not make a beard, neither two, three, ..., ten, ..., fifty, etc. make a beard. But where in that point in this sequence when adding one hair changes a collection of hairs into a beard?). But nevertheless, in whatever way we delineate this region, decrease or increase of the number of elementary configurations and its connection with irreversibility is a fairly clear concept.

[3]Some people are strongly opposing „this horrible word negentropy". In one aspect they are right: negentropy stands for something very positive so the prefix „neg" might be misleading. On the other hand, life phenomena - in the words of von Neuman - „are lone islands bravely facing the ever growing tide of the average entropy increase". This counteraction is our „no", or defying, our „neg"ation of decay and annihilation. „NO" to increase of entropy! – in short: „NEGENTROPY". It must be remembered at the same time that – as explained in the text above – that negentropy is not simply „minus entropy" (but rather its decrement).

[4]In fact, any living system absorbs from environment exactly the same amount of energy as it gives back to it. However, it degrades it: it has less power to be changed into work, movement, etc. As degradation of energy is connected with thermodynamic entropy value, we can – with more precision – express the transformation principle only in terms of negentropy:

$$\{\text{thermodynamic negentropy}\} \rightarrow \{\text{structural negentropy}\}.$$

This equation is a generalization of the well known Brillouin's Principle of Information Gain. (Brillouin has discovered that no information gain can be obtained without degradation (dissipation) of some portion of energy (see [9]). This, in turn, is an extension of the Second Law of Thermodynamics into information yielding and structure building processes.

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FIZIKALNI OPIS I ODREDNICE EVOLUCIJE STRUKTURA. POKUŠAJ ANALIZIRANJA NJIHOVIH POSLJEDICA NA OPTIMIRANJE ARHITEKTONSKOG PLANIRANJA I PLANIRANJA GRADA

J.Z. Hubert

Odjel za strukturna istraživanja – Institut za nuklearnu fiziku, Poljska akademija znanosti
Krakov, Poljska

SAŽETAK

Razmatrani su fizikalni uvjeti za spontani rast i razvoj kompleksnih struktura primjenom koncepta pretvorbe {slobodna energija (termodinamička negentropija)} → {strukturna informacija (Shanonnova) negentropija}. Analizirane su pojave strukturnog starenja i raspada. Stupanj kompleksnosti strukture i smjer njene evolucije su povezani s brojem elementarnih konfiguracija (povezivanja njenih elemenata) pomoću kojih je moguću konstruirati identitet strukture. Izvedeni zaključci primijenjeni su na prijedlog optimalnog arhitektonskog dizajna i planiranja grada. Kao kriterij optimirianja odabrani su optimalni uvjeti za ljude te osiguranje optimalnih uvjeta za razvoj njihove kreativnosti. Izložene cjeline potkrijepljene su jednostavnom matematikom razumljivom nestručnjacima. Izloženu materiju ilustriraju primjeri konstrukcije kuća

KLJUČNE RIJEČI

negentropija, socijalna sinergetika, arhitektura, planiranje grada

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SCIENCE AND TEAM DEVELOPMENT

Ralitsa B. Akins[1, *] and Bryan R. Cole[2]

[1]Department of Paediatrics, Texas Tech University Health Sciences Center
El Paso, Texas, United States of America

[2]Department of Educational Administration and Human Resource Development
Texas A&M University
College Station, Texas, United States of America

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SUMMARY

This paper explores a new idea about the future development of science and teams, and predicts its possible applications in science, education, workforce development and research. The inter-relatedness of science and teamwork developments suggests a growing importance of team facilitators' quality, as well as the criticality of detailed studies of teamwork processes and team consortiums to address the increasing complexity of exponential knowledge growth and work interdependency.

In the future, it will become much easier to produce a highly specialised workforce, such as brain surgeons or genome engineers, than to identify, educate and develop individuals capable of the delicate and complex work of multi-team facilitation. Such individuals will become the new scientists of the millennium, having extraordinary knowledge in variety of scientific fields, unusual mix of abilities, possessing highly developed interpersonal and teamwork skills, and visionary ideas in illuminating bold strategies for new scientific discoveries. The new scientists of the millennium, through team consortium facilitation, will be able to build bridges between the multitude of diverse and extremely specialised knowledge and interdependent functions to improve systems for the further benefit of mankind.

KEY WORDS

teamwork development, knowledge development, science development, concept development, inter-relatedness of knowledge and science and teamwork

CLASSIFICATION

JEL: Z

*Corresponding author, η: ralitsa_akins@yahoo.com; +1 915 545 6785;
Pediatrics-El Paso, School of Medicine, 4800 Alberta Avenue, El Paso, TX 79905, USA

PURPOSE AND INTENT

The purpose of this paper is to explore a new idea about the development of science and teams, to pictorially present what the science teams of the future might look like, and to predict the possible applications in science, education, workforce development and research.

REVIEW OF KNOWLEDGE ABOUT SCIENCE DEVELOPMENT

Despite the multitude and variety of scientific publications, few address the development of science itself. Among the scientific society, there seems to be no unequivocally accepted theory about emerging knowledge and predicting the direction of new developments.

Two theories have direct implications on our understanding about scientific development. One of them, the theory of scientific revolutions, was developed by Kuhn in the middle of the 20th century. It implies that the scientific society has a very strong commitment to already accepted scientific knowledge, and allows new developments only within the paradigms that rule the scientific disciplines at any given point of time.

The other theory with implications in science development is the Chaos theory. In the early 1960's, Lorentz, a meteorologist, published his observations about the effect of tiny changes in the initial conditions of the system on the end result. His work later became to be known as the Chaos theory.

The development of knowledge and science can be related to the chaos theory, suggesting that scientific development is dependent on the initial state and the dynamics of the system in every scientific field. At any given point of time, the dynamic system of knowledge creation and expansion is trying to become orderly. Although the system's movement from chaos to order, back to chaos and achieving order again seems to be overwhelming, the developments in the system of knowledge at a macro level seem to follow the general rules of any smaller dynamic system with better defined initial conditions. The chaos theory implies that the development in any scientific discipline is defined by the state of other knowledge areas.

These two theories, Kuhn's theory of the nature of scientific revolutions and the chaos theory, are discussed more in depth in the following text. Although addressing science development from a different point of view, each of these theories shows that the development of the body of knowledge in any individual scientific field is dependent on the interactions with other scientific disciplines.

After the discussion of these two theories, the impact of knowledge growth on specialities and sub-specialities development is explored from a historical aspect, as well as in the light of applications of the internal similarities in scientific development and the roles of contemporary scientific paradigms.

KUHN'S THEORY OF SCIENTIFIC REVOLUTIONS

A landmark in intellectual history, Kuhn's book, The structure of scientific revolutions, offered an elegant, clear and in-depth explanation of the process of discovery [1]. Kuhn defined the "normal science" as research based on previous scientific achievements, and intricately grounded in the prevailing scientific paradigms, which defined the accepted models for solving scientific problems.

The scientific community has the vested power to choose between paradigms. The reigning scientific paradigms in any given field of discovery govern the methods of research and ultimately shape the nature of the "legitimate" problems to be studied and resolved by contemporary science. To become part of the scientific community, researchers strive to fit nature processes into the known and shared paradigms, committing to the same rules and standards of scientific discovery.

When an observed event violates the expectation of the ruling paradigm, that area of anomaly attracts researchers' attention; thus, paradigms trace the road for the next discoveries by preparing researchers to recognise and study scientific anomalies. Eloquent and insightful, graciously presenting scientific aphorisms and depicting researchers' mindsets, Kuhn's theory of scientific revolutions suggests that the motor behind scientific discovery lies in the power of scientific paradigms and the bravery and curiosity of individual researchers studying the observed scientific anomalies. Developments in one scientific field open the doors for using the new knowledge in other science disciplines. The nature of scientific development postulates that development of individual scientific fields is dependent on the dynamic interactions with other scientific disciplines.

THE CHAOS THEORY

The field of science is seemingly orderly to the scientific observer. There are scientific disciplines, which study the order (or, rather, strive to provide an acceptable nomenclature) in the development of mankind's knowledge. However, the system of human knowledge is extremely dynamic, with rapid progression and developments, possibly in a state of chaos, and, as other dynamic systems, is struggling to achieve order.

The *Chaos theory* explains the order in seemingly random behaviours in dynamic systems, where the movement never repeats itself but stays within a loop, called the Lorentz attractor [2]. The Lorentz attractor is fractal and displays attributes of self-similarity; however, it is not periodic. The sensitivity of dynamic systems to their initial conditions causes slight differences in the initial parameters to change the state of dynamics, leading to diverging and bifurcating. Therefore, a slight change in the initial system's conditions would yield a different result in time. The chaos theory is also discussed in light of the possible effect of the movement of a butterfly's wings to the weather conditions in time in a different part of the world, an effect known as "the butterfly effect."

Robert May, a biologist experimenting with population growth, discovered that a dynamic system in growth bifurcated soon after the population growth rate passed 3. Instead of settling down to one single population number, the number of the population jumped between 2 different values for each observation period. This bifurcation of the population numbers is reminiscent of the Lorentz attractor [2]. In the May's population growth experiment, the higher the growth rate, the quicker the bifurcations occurred; the population lines bifurcated faster and faster until suddenly, chaos appeared.

Even when a system is in a perfect chaos, there are "windows of order" within that dynamic system, where bifurcations may temporarily occur before that part of the system enters state of chaos again. Feigenbaum determined that the bifurcations in dynamic systems came at a constant rate, calculated as 4,669; thus, discovering the rate of bifurcations' self-similarity [2].

Mathematician B. Mandelbrot was studying the stock prices over time and discovered that the prices did not fit the normal distribution, but the curves for daily and monthly changes matched perfectly over a period of 60 years. Many real-world systems are self-similar, such as the growth of tree leafs, bronchioles in human lungs, blood vessels in mammals, or the stock-market values over time [2]. The development of human knowledge and science follows self-similarity, expanding in any given field under the influence of other scientific fields, and bifurcating (entering new areas of knowledge) when the growth rate of knowledge expands.

HISTORY OF SCIENCE GROWTH

Early science development

In the inception of human discovery, scientists had a holistic approach, studying all fields of the available knowledge, being mathematicians, philosophers, astronomers and people of the arts. The Sophists' practical arts of rhetoric, history, music and mathematics opened opportunities for public careers and success in society. Socrates argued that the purpose of "philosophy" is not the discovery of cosmos, rather finding out how man's life should best be lived. In those first scientific schools, the individual scientist – philosopher, artist and mathematician – was at the centre of scientific development [3].

Gradually, new and more distinct sciences emerged; biology, physics, ethics, politics and other sciences joined the core of logic and mathematics. In the first and second centuries AD, the first known "research centre" was functioning at Alexandria on the Egyptian coast. The body of scientific knowledge had grown significantly and scientists were specialising in astronomy, anatomy, medicine, geography, poetry, grammar, mathematics, natural history, philology, and other disciplines. The Roman emperor Julian in the fourth century AD established specific regulations for the candidates for professorship, requiring the candidates to teach to be approved by the municipal senate. Later, the Cathedral church schools endorsed the mastery of the Seven Liberal Arts (grammar, rhetoric, dialectic, arithmetic, music, geometry and astronomy), claiming that a scholar should be knowledgeable in everything and no knowledge is superfluous [3].

Speciality and sub-speciality development

The abundance of knowledge in each separate scientific field led to further branching of each discipline into sub-disciplines. For example, medicine branched into paediatrics, surgery, internal medicine, pathology, and so on. With the accumulation of new knowledge, each new speciality continued to branch into even more narrowly specialised sub-specialities (e.g., surgery branched into colon and rectal surgery, neurological surgery, orthopedic surgery, plastic surgery, and thoracic surgery). Currently, in the United States there are 24 member boards to the American Board of Medical Specialties (ABMS) [4].

Table 1 presents an excerpt from the US approved specialities and sub-specialities, as available through the ABMS. It is interesting to note that the majority of the medical specialities, while continuing to divide into sub-specialities and further branch, remain within known parameters, defined by the available other specialities.

As shown in Table 1, *paediatrics* has a sub-speciality of *emergency medicine,* which is otherwise a separate speciality. Some of the sub-specialities in paediatrics appear to be common for other specialities. For example, *medical toxicology* is also a sub-speciality in *emergency medicine*, and *clinical and laboratory immunology* is also a sub-speciality in *allergy and immunology*. Likewise, the speciality of *emergency medicine* has *paediatric emergency medicine* as a sub-speciality. Three of these internal relations (loops) between different medical specialities and their sub-specialities are demonstrated on Table 1. Of course, many more exist.

LINKING TOGETHER KUHN'S THEORY AND THE CHAOS THEORY

As demonstrated in Table 1, between-specialities relations form knowledge "internal loops." These "internal loops" of knowledge show self-similarity, as suggested by the *Chaos theory.* The knowledge in one medical discipline expands in interaction with other medical disciplines; thus, knowledge from other areas pertinent to one particular medical field forms a

Table 1. Contemporary medical specialities and sub-specialities in the US (excerpt).

Speciality	Sub-specialities
Allergy and Immunology	Clinical & Laboratory Immunology
Anaesthesiology	Critical Care Medicine Pain Medicine
Emergency Medicine	Medical Toxicology Paediatric Emergency Medicine Sports Medicine Undersea & Hyperbaric Medicine
Family Practice	Adolescent Medicine Geriatric Medicine Sports Medicine
Internal Medicine	Adolescent Medicine Gastroenterology Cardiovascular Disease Hematology Clinical Cardiac Electrophysiology Geriatric Medicine Clinical & Laboratory Immunology Infectious Disease Critical Care Medicine Medical Oncology Interventional Cardiology Nephrology Pulmonary Disease Rheumatology Sleep Medicine Sports Medicine Transplant Hepatology Endocrinology, Diabetes & Metabolism
Paediatrics	Adolescent Medicine Paediatric Endocrinology Clinical & Laboratory Immunology Paediatric Gastroenterology Developmental-Behavioral Pediatrics Paediatric Hematology-Oncology Medical Toxicology Paediatric Infectious Diseases Neonatal-Perinatal Medicine Paediatric Nephrology Neurodevelopmental Disabilities Paediatric Pulmonology Paediatric Cardiology Paediatric Rheumatology Paediatric Critical Care Medicine Paediatric Transplant Hepatology Paediatric Emergency Medicine Sleep Medicine Sports Medicine

sub-speciality for that field. For example, the advancements in understanding of human immunology helped develop a new sub-speciality in paediatrics.

Such "internal loops"/self-similarities in the development of knowledge are also present in other scientific fields (e.g. engineering). Furthermore, such similarities exist in the development of scientific fields in different countries, while some minor differences in the specific science-field branching could be observed.

It is logical to suggest that the development of internal science-field-related similarity sets is dependent on the specific initial set of parameters, influenced by political, educational, economical and other societal rules that possibly interfered with the growth of knowledge and development of science. This all comes at a time when a systems perspective of problem solving is more critical than ever. While disciplines are increasingly sub-specialising, problems are increasingly becoming more complex, and require a multi-disciplinary/cross-functional perspective for effectively addressing them.

The internal similarity in knowledge development is consistent with the *Chaos theory*. Seemingly random developments in diverse scientific fields are interrelated from the perspective of the human knowledge macro-system. Discoveries in one field prompt discoveries in another. For example, the discovery of the X-rays led to the development of new medical diagnostic techniques, better understanding of many diseases, and eventually a new medical speciality, radiology. The development of radiology as a speciality, however, was only possible because of the recognition of the scientific paradigm behind this novelty by the scientific society (consistent with Kuhn's theory of scientific revolutions). Therefore, Kuhn's theory of scientific revolutions, coupled with the *Chaos theory* could possibly explain the overall development of new scientific fields and disciplines.

REVIEW OF CURRENT KNOWLEDGE OF TEAM DEVELOPMENT

Although contemporary science is more likely developed in teams rather than by an individual (e.g. research projects in any given field of medical science), studies of teams and team development are somewhat lagging in understanding of the modern teamwork and the philosophy behind it. Despite the abundance of publications on teamwork, there is a staggering gap in our knowledge about the development of teams and teamwork as a concept. Different types of teams and environments are described and studied but the links between the emerging and development of teams and the evolution of teamwork remain unexplored. In general, scarcity of funding for research on the development and functions of different kinds of teams has been noted [5]. A brief review of the current understanding of teams and teamwork is presented below.

TEAM DEVELOPMENT STAGES

Historically, teams have been viewed as temporary units, which create, function and disintegrate over time. Human teams go through a set of stages in their development (L – defining values, A – acquiring resources, I – assuming roles and G – leadership coordination); however, there is no typical sequence, nor does every team go through every stage. The team development stages are also known as forming, storming, norming, and performing. At the end of the team's life, the group usually deals with matters of termination [6, 7].

ROLE OF THE TEAMWORK ENVIRONMENT

A team's ability to form, function and sustain itself is interrelated to its communication and cooperation with other individuals and groups within the organisation and/or external parties. With the increasing complexity of team make-up or performance tasks, the importance of coordinating, keeping records and tracking progress increases [8].

It has been argued that the multidimensionality of group effectiveness could be determined by 3 criteria: (1) team's productivity, (2) social, intellectual or material rewards to the team members, and (3) sustainability of the team as a social unit over time [9]. More often than not, when performing complex tasks and drawing from different expertise, the team's productivity, gained by the division of labour is decreased by the added lines of communication and the need for coordination [10]. For example, in healthcare, the interdisciplinary health care teamwork is highly dependent not only on diagnosis and management, but also on interpersonal communications. In order to cut costs, a lesser trained workforce is expected to assume greater responsibilities, meaning that interpersonal and team skills may be less developed, thus contributing to fragmented care and opportunities for mistakes [5].

TRANSACTIVE MEMORY IN KNOWLEDGE SHARING

Team members can have different knowledge areas and use one another as external knowledge "storage." By dividing the responsibility for different knowledge expertise, the team members can share knowledge more effectively. When knowledge in a particular area is needed, the team members can communicate (or, have "transactions") with their colleagues and retrieve the needed information. This "transactive memory" is used in team knowledge sharing and improved performance [11 – 13]. Since complex teams have members with diverse background and area of expertise, this collective memory is critical for successful task completion [14]. From an organizational perspective, organizational transactive memory can be technology-supported, assigning knowledge responsibilities within specialized departments and supporting knowledge transfer between individuals from different organizational divisions [15].

FACILITATED COMMUNICATIONS

The role of facilitated communications proves to be an important area of research in light of teamwork. Both human-to-human and human-technology interactions shape the outcome of teamwork. Additionally, facilitator influence in teamwork has proved to be a well-demonstrated phenomenon [16].

Facilitator characteristics

It has been argued that facilitators could, at least in part, determine the outcome in the context of facilitated communications, dependent on their characteristics, attitudes and beliefs. The variability in facilitator influence on the outcomes is due to contextual and attitude factors [16]. Facilitator characteristics, including gender, education, age, years of experience, special training, etc. are usually reported. Specific attributes, such as commanding respect from others, being good communicators, being proactive in making things happen, willing to challenge and having the potential to develop beyond their current role, have been considered as key elements of successful facilitators [17].

Skills in human relations and communications have been consistently reported as crucial in facilitated interactions. McFadzean described five areas of general competencies for facilitators (planning, group dynamics, problem-solving and decision-making, communication, and personal growth and development), and five levels of specific competencies (attention to task, attention to meeting process, attention to team structure, attention to team dynamics, and attention to team trust) [18].

However, there is no consistent body of knowledge about the implications of variable facilitator characteristics. One study [19] reported that facilitators with higher education, training and experience, and facilitators who are older, are less likely to influence the outcome of facilitated communications. Another study [20] noted positive correlation between the amount of facilitator training and (1) learning about group's characteristics and goals, (2) identifying areas of conflict and (3) discussing the use of technology.

Complex teams often need to work across boundaries: departmental, organizational, cultural, language, time or distance. Such boundary-crossing issues could affect teamwork and relationship-building. Awareness about the existence of boundary-crossing issues is essential for complex team facilitators. Boundary-crossing facilitation would require different relationship-building expectations, strategies and selection of communication channels [21]. Therefore, more research on team facilitator characteristics, including training, education and experience, and their influence is needed.

Intellectual teamwork

To understand the intellectual teamwork, which utilises information technology to augment performance, we would need technical expertise and knowledge about the social and behavioural processes that the technology is designed to support [20, 22]. Individuals in intellectual teams are not always together to produce a material outcome; rather, to exchange and manipulate available knowledge and information. Intellectual teams function in a variety of environments and tasks. Utilising communication and cooperation, intellectual teams perform interdisciplinary research, formulate multi-site corporate strategies and decide on medical diagnosis [22]. The intellectual teams have laid the basis for the emergence of "virtual" teams, in which members may or may not have person-to-person contacts and are heavily relying on information technology connectivity and communicability [23].

Collaboration between human and digital facilitators

The information communication technology is rapidly evolving. Embedded intelligent systems can assist in problem recognition and pattern identification, while providing real-time response, information and expertise [24]. While the globalizations and accessibility of electronic communication tools create new opportunities, they also create information overload and additional work in information management [25].

The ability to communicate across the globe has become a requirement for success. Boundary-crossing teams are strongly dependent on electronic channels of communication. Use of telephone, email, videoconferencing and web conferencing allow crossing time and distance barriers. More often than not, team facilitators select the technology they are most familiar with and trust, and which is readily accessible. Issues with digital facilitators include management of the information overload and difficulty in managing cultural perspectives of the teamwork relationships [26]. Cultural differences may determine misinterpretation of electronic communications; therefore, awareness and sensitivity to local cultures are key factors in appropriate relationship building [21].

NEW IDEA ABOUT SCIENCE AND TEAM DEVELOPMENT

The incredible expansion of human knowledge and the increasing complexity of scientific problems demand working in teams and coordination between the timing and tasks each team member accomplishes. Therefore, the developments of science and teamwork can no longer be viewed or studied separately. A new concept about the interrelatedness of science and team development emerges and defining the parameters of a scientific (or, knowledge) unit becomes necessary.

THE IDEA OF SCIENCE UNIT CONTAINMENT IN TEAMWORK DEVELOPMENT

Defining the "science unit"

Centuries ago all or most of the knowledge could be contained by one individual (e.g., ancient philosophers), and the individual was in a sense a self-sufficient "science unit." With the development of science, this became impossible.

Next, all the knowledge in one discipline (e.g., medicine) could be contained by one individual, presenting another type, but still individually self-sufficient "science unit." With the growth of knowledge, this became impossible and specialities developed. For example, in medicine, one individual treated adults and children, performed surgeries and autopsies, and did not send any of his patients to consultations with specialists, simply because specialists did not exist. With the growth of knowledge, specialities and further sub-specialities developed, and the perimeter of activity of the doctor-generalist (e.g. family medicine doctor) started to decrease. The necessity for interactions between and among individual "science units" in order to solve problems and complete tasks started to increase.

The broader, more specialised and in-depth the knowledge of human diseases became, the more restricted the knowledge and types of activities the generalists could perform appeared. Furthermore, with the development of human civilisation, new diseases occurred: diseases which were not previously identified due to knowledge insufficiencies, diseases spread by the growth of travel and migration, or provoked by changes in environment, industries or lifestyles. This interdependence might be another example of an “internal loop” or, could represent a true Mandelbrot similarity set.

Shared knowledge and teamwork

With the globalisation of business, communication and research, the importance of teamwork becomes enormous. Human knowledge development occurs simultaneously in many parts of the world and is shared very quickly by means of information technology. The access to monster-size databases, the possibility for computer simulation modelling, and continued technological advancements give a rapid boost to human knowledge development by allowing exploration of paradigms and anomalies never seen before. Thus, working in teams (face-to-face, intellectual or virtual) becomes inevitable; teamwork has become the science standard rather than the exception. The knowledge is now contained within the team, meaning that the team has become the new “science unit.”

The team as the new “science unit” also evolves with the development of knowledge. In the beginning of science branching and sub-speciality development, team interactions were within a science field (e.g. team of doctors in one department). The new knowledge and understanding of human diseases has pushed the boundaries of teams across disciplines with new team members representing different levels of care giving, diverse knowledge fields, varied technology, and dispersed physical locations.

Roles of the team facilitators

The pressure to co-ordinate between intellectual teams requires team facilitators to be knowledgeable in the subject matter, the technology, and the interpersonal dynamics, and to have well-developed communication skills and consensus-building abilities, as well as a systems perspective, which recognises the interdependence between and among team members’ specialities. It is possible that over time, due to developing communication and knowledge constraints, the team’s “central person” (in terms of communication and co-ordination) would tend to specialise and secondary “central persons” would emerge – leaders that facilitate the contact not between team members, but between the individual teams’ facilitators. These communication facilitators would represent the third level of “science units,” having overview knowledge of diverse scientific fields and being able to recognise links and interactions not exploited before.

INTERRELATEDNESS OF SCIENCE AND TEAM DEVELOPMENT

The schematic representation of the evolution of the science units and the role of teams and team facilitators are presented in Figure 1. In the future, communication and knowledge would not be contained within one team; rather, they will be co-ordinated between a team of teams, a ***consortium*** of teams, where the team members are other, more narrowly specialised teams, representing a variety of organisations and industries. The facilitator between these multiple teams (A in Figure 1) would be self-similar to the ancient philosopher, just at a higher level of knowledge, coordination and interaction. In order to effectively co-ordinate tasks with ever increasing complexity, that individual would have to be knowledgeable in a number of different teams’ scientific areas, be able to imagine the links between different

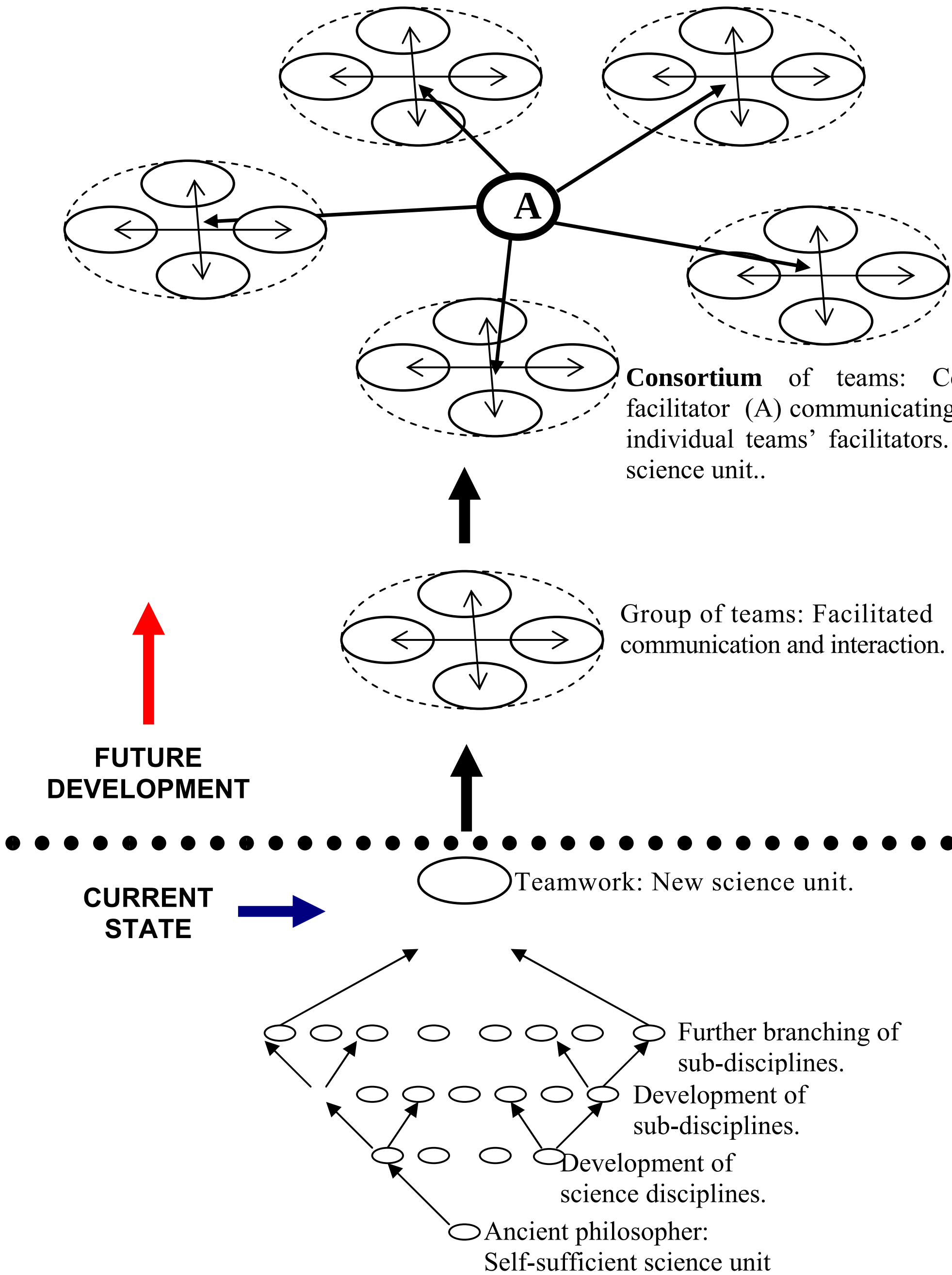

Figure 1. Schematic of the new concept of science and team development.

kinds of knowledge, and recruit, construct and utilise all existing pertinent knowledge into maximally effective work design and outcomes.

APPLICATION OF THE NEW CONCEPT OF SCIENCE AND TEAM DEVELOPMENT

This innovative idea about the interaction in the development of science and teams might have important implications in a variety of aspects:

1. **development of science**: Scientists are no longer working autonomously; teams of scientists from different fields perform interdisciplinary research to augment the positive potential of their studies of the anomalies. Interdisciplinary work and teams including members with various skills are not the rare exclusion, but the scientific standard,
2. **development of education**: Changes in the way students are being prepared to advance in their studies and conduct research would become necessary. Collaborative work and team-skills would be absolutely critical in preparation for the work place. The concept of continuous learning would be the central paradigm for students, professors and researchers,
3. **workforce development**: The need for new work-style and interpersonal skills with attention to interdisciplinary approaches would spread over the entire workforce. Implementation of research into practice would speed these requirements for changes in workforce development,
4. **interdependence of science and teamwork**: Science and teamwork are interrelated and interdependent. The process of mass globalisation of education, business and research would promote teamwork as the standard of scientific development. Therefore, more knowledge about the processes within a team and between and among consortium teams would need to be developed. Without proper development of teams, the boost of new scientific discovery might be delayed,
5. **new research toolbox**: New research toolbox needs to be created in order to study the dynamic changes in knowledge, science and team development, multi-level and multi-team interactions, consortium partners' interrelatedness, and in order to predict the future developments of science and teams.

RESEARCH APPROACHES IN STUDYING SCIENCE AND TEAMS

Although separately studied, the fields of knowledge, science and team development have not been studied from the viewpoint of their interrelatedness and interactions. Therefore, a new "research toolbox" should be developed to allow emphasis on their interrelatedness and dynamics. Overall, the availability of various research approaches in other scientific disciplines is perceived as an advantage in studying the connection between the two concepts of teamwork and science development, and in defining a new method in research in science, based on the interrelatedness with teamwork constructs.

Use of computer modelling would be useful in validating the suggested new idea about the interrelatedness of science and team development, and in studying of the predicted interactions and dynamics in team consortiums. As the next step in research, input of historic data about known scientific developmental milestones, known parameters from the Chaos and other theories, as well as team parameters and mapping models, would allow building of a computer model to further study the possible implications of science and teamwork interrelatedness.

Borrowing approaches from other scientific fields will help to define and adapt research methods to organize and implement a specific array of research methods to best suite the study of the interrelatedness of science and team development. In the light of this, to make the research more animated, the following research agenda is suggested for future studies:

1. mapping of teamwork dynamics in complex teams in relation to various facilitator characteristics,
2. use of computer models with known and suggested data to study science and team interrelatedness,

3. in-depth study of models of facilitator-to-facilitator and facilitator-to-team interactions in complex teams and team consortiums to determine needs for facilitator training and education,
4. continued study of facilitator characteristics with focus on applications to team consortium interaction models,
5. studies of modes of operation in complex teams and teamwork evolution, especially in the context of dynamically evolving environments,
6. study of the changes in interactions between intelligent systems and human facilitators with emphasis on development of new approaches to solving multidimensional problems,
7. continued study of the reliability of intelligent systems' advice, guidance, information and expertise as compared to human intelligence and expertise under different conditions of task complexity and stress levels,
8. comparative studies of human resource workload changes and success in task completion by teams under varied conditions of facilitated communications,
9. study of the development of team culture in complex teams and team consortiums, and its impact on new scientific developments,
10. defining and studying the implications of the science and team development interrelatedness to the notion of "area of specialization" as pertinent to facilitated communications. There is a need to define the skill set and possible training lines for complex team facilitators and facilitators in team consortiums.

This new idea about the interrelatedness of knowledge, science and research needs to be studied and validated by known, adapted or newly created scientific approaches. Even with the utilization of advanced technology, building of interpersonal relationships and informal communication systems is expected to remain pivotal in teamwork and problem solving. Therefore, attention to the emotional component of interpersonal relationships will remain to be of critical importance in team development and future studies of science and teamwork development.

Talent management, as the way to create excellence, is already capturing the focus of business and research [27]. Identifying, selecting and developing institutional talent is related to allocation of resources and expectations for individual's contributions. Successful businesses start implementing human resource management systems to enhance performance-oriented culture, low turnover of employees, high levels of employee satisfaction, timely obtaining of qualified talent replacements, investment in employee development, and performance evaluation [28]. Applications of talent management in regard to facilitated communications is an area yet to be explored.

IMPORTANCE OF THE NEW IDEA

This new idea about the inter-relatedness of the development of science and teamwork is important because it suggests a very likely future direction for scientific improvement. It shows the necessity of studying the teamwork processes and the possible development of team consortiums, consisting of large numbers of specialised teams with narrowly defined knowledge areas.

The facilitators of the teams of the future would be extremely important in science development. It will become much easier to produce highly specialised engineers, surgeons or genome engineers, than to discover, educate, and develop those individuals capable of the delicate and complex work of multi-team (team consortium) facilitation. Such individuals would emerge as the new scientists of the millenium, with extraordinary knowledge in a variety of fields, unusual mix of abilities, highly developed teamwork and interpersonal skills, and visionary ideas in illuminating bold strategies for new scientific discoveries.

The new scientists of the millennium, through team consortium facilitation, will be able to build bridges between and among the multitude of disperse and extremely specialised knowledge for the further benefit of mankind. Simultaneously, this approach to cross-disciplinary teams provides the opportunity to explore issues at a deeper level by highly-specialised scientists and to understand the relationships between and among key specialisations in addressing issues systemically; thus, increasing the probability that root causes would be addressed, rather than symptoms, which is more likely from an individual, isolated discipline approach. The increasing complexity of exponential knowledge growth and work interdependency calls for changes in the scientific way of thinking and functioning, and for even deeper changes in our educational systems and workforce development strategies.

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ZNANOST I RAZVOJ GRUPA

R.B Akins i B.R. Cole

[1]Odjel pedijatrije, Centar za zdravstvene znanosti Sveučilišta *Teksas Teh*
El Paso, Sjedinjene Američke Države
[2]Odjel za administraciju obrazovanja i razvoj ljudskih resursa, Sveučilište A&M u Teksasu
College Station, Sjedinjene Američke Države

SAŽETAK

U radu se istražuje nova zamisao o budućem razvoju znanosti i grupa te predviđaju posljedice takvog razvoja u znanosti, obrazovanju i razvoju i istraživanju radne snage. Međusobna povezanost razvoja znanosti i grupnog rada upućuje na rastući značaj kvalitete vođe grupe, kao i na značenje detaljnih studija procesa u grupama i konzorcijima grupa na rastuću kompleksnost eksponencijalnog rasta znanja i međuovisnosti poslova.

U budućnosti će biti jednostavnije osposobiti specijalizirano osoblje, npr. neurokirurge i inženjere genoma, nego izdvojiti, obrazovati i razviti pojedince sposobne za osjetljiv i kompleksan posao vođenja konzorcija grupa. Takvi pojedinci će postati novi znanstvenici tisućljeća, izuzetnog znanja u nizu znanstvenih polja, neuobičajene kombinacije sposobnosti, visoko razvijenih vještina grupnog rada i vizionarskih pristupa širenja odvažnih strategija za nova znanstvena dostignuća. Novi znanstvenici tisućljeća, putem vođenja konzorcija grupa, bit će sposobni izgraditi mostove između mnoštva različtih i izuzetno usmjerenih znanja i povezanih funkcija, radi poboljšavanja sustava i daljnjeg doprinosa čovječanstvu.

KLJUČNE RIJEČI

razvoj timskog rada, razvoj znanosti, razvoj koncepta, međusobna povezanost znanosti i timskog rada

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RESEARCH OUTPUT OF CROATIAN UNIVERSITIES FROM 1996 TO 2004, REGISTERED BY THE SCIENCE CITATION INDEX-EXPANDED

M. Jokić[1], J. Stepanić[2], B. Kamenar[3] and V. Silobrčić[4]

[1]National and University Library
Zagreb, Croatia

[2]Faculty of Mechanical Engineering & Naval Architecture – University of Zagreb
Zagreb, Croatia

[3]Faculty of Science – University of Zagreb
Zagreb, Croatia

[4]Zagreb, Croatia

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SUMMARY

The paper aims at assessing the research output of scientists working in "hard sciences" at six Croatian Univeristies (Dubrovnik, Osijek, Rijeka, Split, Zadar and Zagreb). The data obtained may serve as the starting point for further follow-up and in-depth studies of research performance at Croatian universities. This can be particularly relevant for implementation of the Bologna Process in Croatia. The methodology of the Academic Ranking of World Universities (2004) was applied (http://ed.sjtu.edu.cn/rank/2004/Methodology.htm). The number of papers published from 1996 to 2004, registered in the WoS-Science Citation Index-Expanded, authored by scientists from the six Croatian universities, was enumerated. Also, highly cited authors, authors of articles published in Nature and Science, Nobel Prize and Fields Medal winners were sought among these scientists. It was found that scientists at the Croatian universities produced 7527 of the total of 11068 articles authored by Croatian scientists. Of the six universities, the University of Zagreb was more productive than the remaining five. There were no highly cited authors, Nobel Laureates or Fields Medal winners from Croatia. One of 14 authors of an article in Science was from a Croatian university. Also, a letter on science policy, appearing in Nature, had one of two authors from Croatia. It can be concluded that scientists performing research in "hard sciences" at six universities in Croatia contributed about 68 % of all the articles published by Croatian scientists. University of Zagreb was the most productive.

KEY WORDS

universities, ranking, Croatian universities, scientific productivity, bibliometric study

CLASSIFICATION

JEL: O, Z

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*Corresponding author, η: vlatko.silobrcic1@zg.t-com.hr; +385 1 461 4323, +385 91 461 4323;
Tomašićeva 11, HR – 10 000 Zagreb, Croatia

INTRODUCTION

The first bibliometrically based evaluations of research institutions were carried out by Martin and Irvine in 1983, in the UK [1]. Since then numerous analyses of scientific productivity and institutional research output were published. The rankings, based on these analyses, were intended to identify excellence in these institutions and among researchers [2].

The academic ranking of world's universities was published in 2004 [3]. The ranking was based on four criteria: 1) Quality of education (alumni winning Nobel Prizes and Fields Medals); 2) Quality of faculty (staff winning Nobel Prizes and Fields Medals, and highly cited researchers); 3) Research output (articles in Science Citation Index – Expanded, Social Science Citation Index, and in Nature and Science); 4) Size of institution (academic performance related to size). The criteria under 2 and 3 carried 80 % of the weight.

Among the 500 most prestigious universities listed in the above ranking there were no universities from Croatia. Obviously, based on the above mentioned criteria, Croatian universities did not earn enough points to be included in the list. This induced us to examine the present standing of the Croatian universities, using the same criteria (see ref. [3]). We intended to collect data for an initial standing of the universities. These could be subsequently used to assess the development at the universities in the follow-up, as well as to gain certain deeper insights into the standing of each of the six Croatian universities and disciplines within them. The data thus obtained can be particularly relevant in relation to the implementation of the Bologna process in Croatia.

The overall productivity of Croatian scientists since Croatia's independence (year 1991) has been analysed in a few studies. They were based on both the national database [4, 5] and ISI databases [6, 7]. These studies indicated that general productivity and number of citations of Croatian scientists were below the average productivity of scientists in the world. Also, the internationally registered productivity of Croatian scientists in "hard sciences" was several times higher than the productivity of their colleagues in "soft sciences". Therefore, to begin with, we decided to concentrate on research performance of scientists conducting research in "hard sciences" at the Croatian universities.

UNIVERSITIES AND METHODS

UNIVERSITIES

There are six universities in Croatia: University of Dubrovnik, University of Osijek, University of Rijeka, University of Split, University of Zadar and University of Zagreb. The oldest among them is the University of Zagreb [8], founded in 1669 (modern university in 1874), whereas the youngest one is the University of Dubrovnik, founded in 2003 [9]. The Universities of Dubrovnik and Zadar started functioning independently in the year 2000, while formerly they had been part of the University of Split [10], founded in 1974. The University of Rijeka [11] was founded in 1973, and that of Osijek in 1975 [12].

The University of Zagreb has 29 faculties and academies, 20 of which belong to the category of "hard sciences" [8]. The University of Rijeka includes 10 faculties, 4 dealing with hard sciences [11]. Nine faculties constitute the University of Split, 6 offering programs in "hard sciences" [10]. Of the 10 faculties at the University of Osijek 7 are in "hard sciences" [12]. The University of Zadar has only one faculty (Faculty of Arts), whereas the University of Dubrovnik offers 6 study programs, 4 of which are in "hard sciences".

DATABASE

We have used the WoS (Web of Science) version of the Science Citation Index-Expanded (Thomson-ISI, see [13] and [14]) to find author(s) with addresses in Croatia and at Croatian universities. The search was performed during January 2005 The search was performed during January 2005, using the WoS at Institute Rudjer Boskovic, http://wos.irb.hr. Names of authors were associated to their universities; a paper published by authors from more than one university was ascribed as one paper to each university. Articles published by Croatian universities' scientists in two prestigious science journals Nature and Science were counted separately. The research covered papers published in the period between 1996 and 2004. The year 1996 was chosen as the initial year since at that time one year passed after the Homeland War in Croatia had ended (August 1995).

In addition, we have searched the Thomson-ISI Highly cited researchers [15] to find out whether there were any highly cited scientists from Croatian universities. Furthermore, the lists of Nobel Prize [16] and Fields Medal [17] winners were checked (see Discussion).

RESULTS

From 1996 to 2004, scientists with Croatian addresess published a total of 11 068 articles indexed in the SCI-expanded database. Among them 7527 papers have at least one author with the universities' address. Research output from Croatian universities related to the total output of Croatian scientists, working in "hard sciences", is depicted in Figure 1.

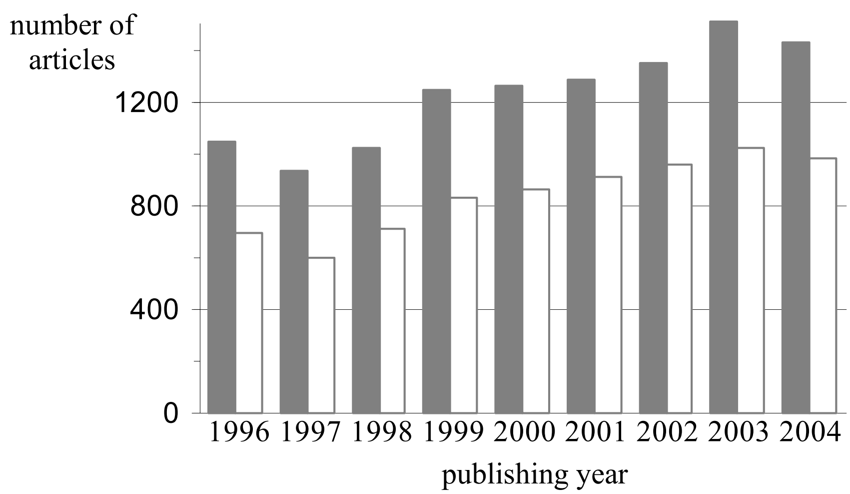

Figure 1. Total number of articles by author(s) from Croatia (grey boxes) and from Croatian Universities (white boxes), published between 1996 and 2004, registered in SCI-Expanded.

Clearly, the productivity of Croatian scientists in "hard sciences", during the whole period covered, depended heavily on contributions of scientists working at Croatian universities. The calculated average percentage (and standard error) during the period was 0,68 ± 0,02, indicating that about 68 % (range 67 to 73 %) of the total published papers came from authors working at the universities.

Next, we counted number of articles published by scientists from individual universities in the observed nine years. Besides the total number of articles produced by a given university, we also counted the number of articles for which the corresponding author was from the respective university. These data are presented in Table 1.

Table 1. Total number **(total)** of articles published annually by scientists from Croatian universities, indexed in SCI-Expanded, and the number of these articles for which the corresponding author **(corr)** was from the respective university.

Year	Univ. Zagreb		Univ. Osijek		Univ. Rijeka		Univ. Split	
	Corr	*total*	*corr*	*total*	*corr*	*total*	*corr*	*total*
1996	441	616	32	45	26	39	44	57
1997	386	576	9	13	9	17	17	22
1998	361	560	38	48	53	70	68	95
1999	465	678	45	60	42	63	61	75
2000	484	657	47	60	53	77	69	92
2001	518	744	29	51	58	84	57	77
2002	575	803	40	62	47	73	56	90
2003	532	821	47	69	49	72	73	108
2004	511	799	44	64	64	86	54	81

The University of Zagreb was several times more productive than the other three Croatian universities. Among the universities in Split, Rijeka and Osijek, the one in Split was consistently somewhat more productive than the other two. There is a tendency of increasing number of articles published during the nine years. The Universities of Dubrovnik and Zadar had too few indexed articles to be taken into account[1].

Taking the number of published papers in 2004 and the number of teachers as potential authors in that year, one can arrive at the average number of papers per author in the Universities. The productivity per teacher was highest for the University of Zagreb (0,94 papers/author), whereas it was similar for other Universities: Split (0,22), Rijeka (0,21) and Osijek (0,18). In other words, almost every teacher at the University of Zagreb published at least one paper in 2004. In the other three Universities only one of five teachers authored one paper in the same year.

As additional indicators of the quality of articles published by researchers from Croatian universities, we used two more parameters (see ref. [3]): one was high citation of the published articles; another was publication of articles in Nature and Science. We found no authors from Croatian universities that were highly cited [15] during the observation period of nine years. During the same interval, there were two texts published in the two journals. Nature published a letter commenting science policy (Jonjić and Traven **429** (6992): 601, 2004), whereas an article, with one of 14 authors being from Croatia, appeared in Science (Semino et al, **290** (5494): 1155-1159, 2000). There were no Croatian scientists among Nobel Prize or Fields Medal winners [16, 17].

DISCUSSION

Our intention was to assess the research output of scientists ("hard sciences") at all six Croatian universities, indexed in the Thomson Scientific/ISI WoS-Science Citation Index-Expanded, during the nine years after the Independence War in Croatia (1996-2004). We concentrated on "hard sciences" as previous studies consistently indicated strong predominance of these sciences [6, 7].

Our data demonstrate that the University of Zagreb was by far the most productive in the time interval. This is expected, since Zagreb University is the oldest and the largest of the six. It also has the largest number of faculties (20) in "hard sciences". Other universities are several times less productive, with the University of Split being slightly more productive than the other two. Here one should also take into account the number of faculties in hard sciences: Osijek has 7, Rijeka 4 and Split 6. The productivity of the six universities showed increasing tendency during the observation period of nine years. It constituted about 68 % of the total productivity of scientists with Croatian address. The University of Zagreb was the most productive in terms of the total number of papers published.

The small number of articles found eligible for consideration from the Universities of Dubrovnik and Zadar can be explained by the fact that Dubrovnik is the youngest university that, although it offers 4 study programs within the category of "hard sciences", has no organized faculties similar to the other universities, while the University of Zadar, on the other hand, has only one faculty, that of Arts.

Previous studies [6, 7] indicated that, in general, the productivity of scientists with addresses in Croatia was below the world's average. Further, papers published by these researchers were less cited than the world's average. In this study we did not attempt to assess the citation rate of papers published by scientists working at Croatian universities. However, since the universities contributed about 68% of all the papers published by Croatian scientists, it would be difficult to expect that their citation rate is significantly above the average citation rate of all papers published by Croatian scientists.

According to Bayers [18], in the period 1998-2002, ISI index included approximately 3,6 million papers: 1,3 million came from the EU member states (37 %), 1,2 million from the US (34 %). Contributions of some European countries were as follows: Netherlands 2,6 %, Sweden 2,1%, Switzerland 1,9% and Belgium 1,4%. Croatia contributed 0,18 %.

To comply with the described methodology (see [7]), we have taken three additional criteria employed in that study: the number of Nobel Prizes and Fields Medals, the number of highly cited authors, and the number of articles published in Nature and Science, the two prestigious science journals.

Croatia has no Nobel laureates in science. This statement requires a comment because two Croatian chemists actually received the Nobel Prize: Leopold Ružička (in 1939) and Vladimir Prelog (in 1975). Leopold Ružička was born in Vukovar (Croatia), and attended secondary school in Croatia, but his higher education and research, leading to the Prize, occurred outside of his homeland. Vladimir Prelog was born in Sarajevo (Bosnia and Herzegovina), studied chemistry and obtained his Ph.D. degree at the Technical High School in Prague (Czech Republic). Since 1935 Prelog was professor of Organic chemistry at the University of Zagreb, from where he migrated to Switzerland at the beginning of the Second World War.

As for the Fields Medal, no Croatian scientist was listed among the winners. Also, no scientists with a Croatian address were ranked by the Thomson-ISI Highly cited ranking. As we have mentioned above, there was one letter (not a new scientific information) published in Nature by the author employed at one of the universities. Also one of 14 authors of an article appearing in Science has an address at one of the universities.

Our study indicated that, among scientists doing research in "hard sciences" at the six universities in Croatia, those at the University of Zagreb were most productive. This university is also the oldest and the largest in Croatia. The universities in Osijek, Rijeka and Split had a similar productivity, with the slightly higher productivity of the University of

Split. The productivity of the six universities had an increasing tendency during the observation period of nine years.

We concluded that the relatively low productivity of researchers from the Croatian universities, lack of highly cited papers and of Nobel Prize and Fields Medal winners can explain that none of the Croatian universities was included among the world's 500 most prestigious universities (see ref. [7]). Based on the present study, we will continue tracing the same parameters to detect their possible changes. Also, we will try to use them for more in-depth analyses of individual scientific disciplines within the universities. These data are particularly relevant at the time of implementation of the Bologna Process in Croatia in the context of pre-accession negotiations for European Union membership.

NOTE

[1]We also intended to present the average number of papers per author at individual universities, however, we were unsure whether the available official data on the number of teachers were standardized enough to allow such a comparison.

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ZNANSTVENA PRODUKTIVNOST HRVATSKIH SVEUČILIŠTA OD 1996. DO 2004., REGISTRIRANA U *SCIENCE CITATION INDEX-EXPANDED*

M. Jokić[1], J. Stepanić[2], B. Kamenar[3] i V. Silobrčić[4]

[1]Nacionalna i sveučilišna knjižnica
Zagreb, Hrvatska
[2]Fakultet strojarstva i brodogradnje – Sveučilište u Zagrebu
Zagreb, Hrvatska
[3]Prirodoslovno matematički fakultet – Sveučilište u Zagrebu
Zagreb, Hrvatska
[4]Zagreb, Hrvatska

SAŽETAK

Namjera nam je bila ustanoviti znanstvenu produktivnost znanstvenika koji se bave „čvrstim znanostima” na šest hrvatskih sveučilišta (Dubrovnik, Osijek, Rijeka, Split, Zadar i Zagreb). Rezultati bi mogli poslužiti kao polazište za buduće praćenje i dublje analize znanstvene produktivnosti na Sveučilištima. To bi moglo biti posebno važno pri primjeni Bolonjskoga procesa u Hrvatskoj. Primijenjena je metodologija iz *Academic Ranking of World Universities* (2004.) (http://ed.sjtu.edu.cn/rank/2004/Methodology.htm). Izbrojen je broj članaka koje su, od 1996. do 2004., objavili znanstvenici iz šest hrvatskih sveučilišta, registriran u *WoS – Science Citation Index – Expanded*. Uz to se tražilo ima li među tim znanstvenicima onih koji su citirani osobito često, koji su objavili svoje članke u Nature i(li) Science, koji su dobili Nobelovu nagradu ili Fieldsovu medalju. Znanstvenici na hrvatskim sveučilištima objavili su 7527 članaka od ukupnih 11068 članaka kojima je bar jedan autor s adresom u Hrvatskoj. Od šest Sveučilišta, Sveučilište u Zagrebu bilo je nekoliko puta produktivnije od preostalih pet; i po apsolutnome broju članaka i po broju članaka po pojedinome znanstveniku. Među znanstvenicima sa Sveučilišta nije bilo osobito često citiranih autora, ni dobitnika Nobelove nagrade, ni Fieldsove medalje. Jedan je od 14 autora jednoga članka objavljenog u Science imao adresu na jednom od Sveučilišta. Pored toga, jedan je od dvojice autora pisma o znanstvenoj politici, objavljenoga u Nature, bio sa hrvatskoga sveučilišta. Zaključeno je da su znanstvenici koji se bave „čvrstim znanostima” na šest hrvatskih sveučilišta, u odabranome razdoblju, objavili oko 68 % svih članaka koje su objavili hrvatski znanstvenici. Pri tome je Sveučilište u Zagrebu bilo najproduktivnije.

KLJUČNE RIJEČI

sveučilišta, rang, Hvatska sveučilišta, znanstvena produktivnost, bibliometrijsko istraživanje

Interdisciplinary Description of Complex Systems 4(1), 51-62, 2006

VISUALIZATION OF COMPLEX NETWORKS BASED ON DYADIC CURVELET TRANSFORM

Marjan Sedighi Anaraki[1,]*, Fangyan Dong[1], Hajime Nobuhara[2] and Kaoru Hirota[1]

[1]Department of Computational Intelligence & Systems Science, Tokyo Institute of Technology
Yokohama – Tokyo, Japan

[2]Department of Intelligent Interaction Technologies,
Graduate School of Systems and Information Engineering, University of Tsukuba
Ibaraki, Japan

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SUMMARY

A visualization method is proposed for understanding the structure of complex networks based on an extended Curvelet transform named Dyadic Curvelet Transform (DClet). The proposed visualization method comes to answer specific questions about structures of complex networks by mapping data into orthogonal localized events with a directional component via the Cartesian sampling sets of detail coefficients. It behaves in the same matter as human visual system, seeing in terms of segments and distinguishing them by scale and orientation. Compressing the network is another fact. The performance of the proposed method is evaluated by two different networks with structural properties of small world networks with $N = 16$ vertices, and a globally coupled network with size $N = 1024$ and 523 776 edges. As the most large scale real networks are not fully connected, it is tested on the telecommunication network of Iran as a real extremely complex network with 92 intercity switching vertices, 706 350 E1 traffic channels and 315 525 transmission channels. It is shown that the proposed method performs as a simulation tool for successfully design of network and establishing the necessary group sizes. It can clue the network designer in on all structural properties that network has.

KEY WORDS

visualization, complex network, human visual system

CLASSIFICATION

PACS: 89.75.-k

*Corresponding author, η: msedighi@hrt.dis.titech.ac.jp; +81 45 924 5686, +81 45 924 5682;
G3-49, 4259 Nagatsuta, Midori-ku, Yokohama-city 226-8502, Japan

INTRODUCTION

Complex networks are being studied across many fields of science [1 – 4] inspired by empirical studies of networked systems such as the internet, biological networks like brain neural networks and so on. Scientists think they know most of the elements and forces of networks [5, 6]. But networks are inherently difficult to understand because of structural complexity. For a network with millions of vertices direct analyzing by sketching the structure of network and looking at them by eye is hopeless. Having some static displays for instance vertex map or matrix, data filtering as an interactive control, or smooth zooming can be useful.

The recent development of statistical methods for quantifying huge networks is to a large extent an attempt to find something to play the part played by eye for complex networks. Furthermore it usually is assumed that the network architecture is static. These simplifications allow us to sidestep any issues of structural complexity and propose a visualization method based on an extended Curvelet transform named Dyadic Curvelet Transform (DClet) for understanding the topology of complex networks. The proposed method gives us the matrix of network in dyadic scales, filters data by the coarse to fine strategy and brings us smooth zoom without losing the structural properties of a network. This modification is done to solve the Curvelet transform [7, 8] inconvenience of decomposition into components at different scales.

One potential of this proposal might be the optimization of a network by removing redundant edges in the network without changing the desired properties of it.

The aim of this research is showing that the proposed visualization method with directional sensitivity can be considered as an efficient tool for investigating the structural properties of complex networks. It can be considered as a simulation tool, or a compression method. It does not have the geographical displays of a network. As the topology of network is robust in any scales of the DClet, it can be worked on a smaller matrix and modeled the real network with the DClet reconstruction.

The performance of the proposed method is evaluated in two different networks with structural properties of small world networks with $N = 16$ vertices, and a globally coupled network with size $N = 1024$ and 523 776 edges. As the most large scale real networks are not fully connected, it is tested on the telecommunication network of Iran as a real extremely complex network with 92 intercity switching vertices, 706 350 E1 traffic channels and 315 525 transmission channels. It is presented that the proposed method provides a natural way of analyzing a complex network due to analyzing the network at a coarse level and then increasing the resolution in dyadic scale, if necessary. The experiments have been done in Matlab on a personal computer with processor Pentium IV 2.4 MHz, RAM 256 M, and HDD 60GB. The details of evaluation of the proposed method on the telecommunication network of Iran is not shown here just the final outputs are considered as an Annex.

The proposed method based on the DClet is presented in second section. In third section, experimental results are shown. The article is concluded with some discussion and an outlook.

VISUALIZATION METHOD BASED ON THE DCLET

The idea of the DClet is first to decompose the input data into a set of wavelets bands and analyze each band by a non-redundancy Finite RIdgelet Transform (FRIT) [9]. This idea makes a directional wavelet that outperforms wavelet for orientation. It is scale sample of wavelet transform following a geometric sequence of ratio 2. The input is decomposed into smooth blocks of side length l units in such a way that adjacent blocks are square array of size $l \times l$ although it is possible to be rectangular array of size $l \times l/2$ without overlapping. Fig. 1 shows the general concept of the DClet. It achieves non-redundancy transformation with invertibility via the FRIT. The FRIT is ridgelet transform based on the Finite RAdon Transform (FRAT) that uses the orthogonal symmlet wavelet with four vanishing moments. For the FRAT, first the set of normal vectors is obtained which indicate the represented directions.

The decomposition transform for an input matrix with size $M \times M$ is done according to the following procedure:

First, the 2D wavelet transforms ${}^{(\bullet)}W_A{}^r(b)$ of a matrix A with size $M \times M$, $A \in Z^{M \times M}$ at scale r and translation b with the mother wavelet ψ is given by:

$$^{(\bullet)}W_A{}^r(b) = A(p_1, p_2) * {}^{(\bullet)}\psi_b{}^r(p_1, p_2), \tag{1}$$

where $b = \{1, 2, \ldots, M/2^r\}$ and $(\bullet)$ shows the approximation or details and $*$ denotes convolution operation:

$$^{(\bullet)}W_A{}^r(b) = \sum_{p_1=1}^{M}\sum_{p_2=1}^{M} A(p_1, p_2)\, {}^{(\bullet)}\psi_b{}^r(p_1, p_2). \tag{2}$$

Then, subband decomposition:

$$A(p_1, p_2) \Rightarrow {}^{(LL)}W_A^r(b) + {}^{(LH)}W_A^r(b) + {}^{(HL)}W_A^r(b) + {}^{(HH)}W_A^r(b), \tag{3}$$

where a high pass filter (H) and a low pass filter (L) are applied to the input in both horizontal and vertical directions, and three orientation selective high pass subbands, HH, HL, LH, and a low pass subband LL are generated. Afterwards, smooth partitioning is done via windowing each subbband into Δ windows of size $l \times l$ as well as $l \times l/2$. The coarse description of the input data is not processed that it makes an anisotropic (bi-)orthogonal transformation without redundancy:

$$^{(\bullet)}\Delta(p_1, p_2) = \Delta[{}^{(\bullet)}W_A{}^r(b)], \tag{4}$$

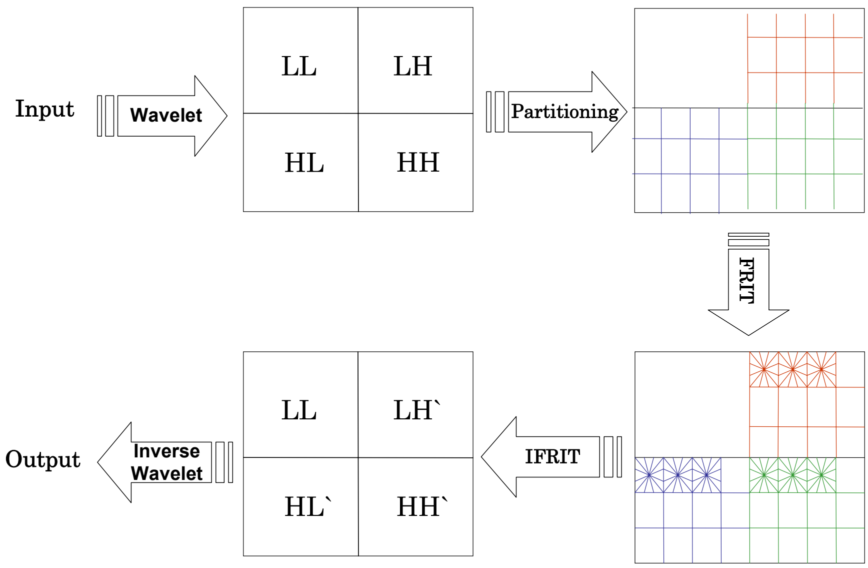


Fig. 1. The conceptual model of the extended Curvelet named the DClet.

Finally, the function is oriented at an angle θ and the FRIT is applied to each window:

$$^{(\bullet)}R_{A}^{r}(b,\,\theta) = \sum_{p_1=1}^{M/2^r}\sum_{p_2=1}^{M/2^r} {}^{(\bullet)}\Delta(p_1, p_2) * {}^{(\bullet)}\psi_{b,\,\theta}^{r}(p_1, p_2), \quad (5)$$

$$^{(\bullet\Delta)}R_{\bullet\Delta}^{r}(b,\,\theta) = {}^{\bullet}\Delta(p_1, p_2) * \psi_{b,\,\theta}^{r}(p_1, p_2), \quad (6)$$

therefore, for $M = 2^r$, $r - 1$ level of the DClet will be held.

There is an analogy scaling with wavelet algorithm. Using (bi-)orthogonal wavelet causes to have dyadic scaling layers instead of fixed scaling numbers for analyzing and decomposition. The construction of (bi-)orthogonal wavelets is equivalent to the synthesis of perfect reconstruction filters having a stability property. This class of wavelets is characterized by a maximal number of vanishing moments for some given support. With each wavelet of this class, there is a scaling function called father wavelet which generates an orthogonal multiresolution analysis.

This extension helps the Curvelet transform to make smoother strategy, also may solve a significant redundancy problem of Curvelet:

- Fixed subband definitions is changed to muliresolution transformation using the DClet. Via Curvelet transform an input matrix with size 256 × 256 partitioned the frequency domain into only 3 subbands indexed by $r = 1, 2, 3$ [7].
- The need of subband filtering is slightly removed via the DClet, while to actually implement Curvelet decomposition into subbands the wavelet transform should be used. First the object must be decomposed into its 8 wavelet subbands, then to form Curvelet subband r, partial reconstruction should be performed [7].
- The Curvelet transform is a redundancy transformation. The spatial partitioning introduces a redundancy factor equal to four for it. Using non-redundant wavelet and applying non-redundant FRIT makes the DClet applicable for different applications such as compressing a complex network, representing a huge network with less data as possible.
- The theory imposes a down sampling on the set of orientations by a factor two as one proceeds to the coarser scale via the FRIT. In some sense, the digital implementation increasingly over samples the angular variable at coarser scales.

Fig. 2 shows how the proposed method filters the input data in dyadic scales and optimizes a network by removing redundant edges. Using the DClet a high pass filter (H) and a low pass filter (L) are applied to a the network in both horizontal and vertical directions, and the filter outputs sub-sampled by a factor of two, generating three orientation selective high pass subbands, HH, HL, LH, and a low pass subband LL. Afterwards smooth partitioning is done via windowing each subbband, and the FRIT is applied to each window. As the FRIT uses the FRAT, first we obtain the set of normal vectors which indicate the represented directions. The information contained in subband LL_1 can be viewed as a coarse description of the network; the others correspond to higher resolution and involve the finer details of the network at different smaller scales.

The method enjoys exact reconstruction and stability, because each step of the transform is both invertible and stable. For reconstruction, first subband recomposing is done. Then we apply the Inverse FRIT (IFRIT) to each block, finally via subband synthesis the input is reconstructed.

This method gives the possibility to work on a small among of data or information in dyadic scales and get the real modified data that shows the exact points of changes on the network.

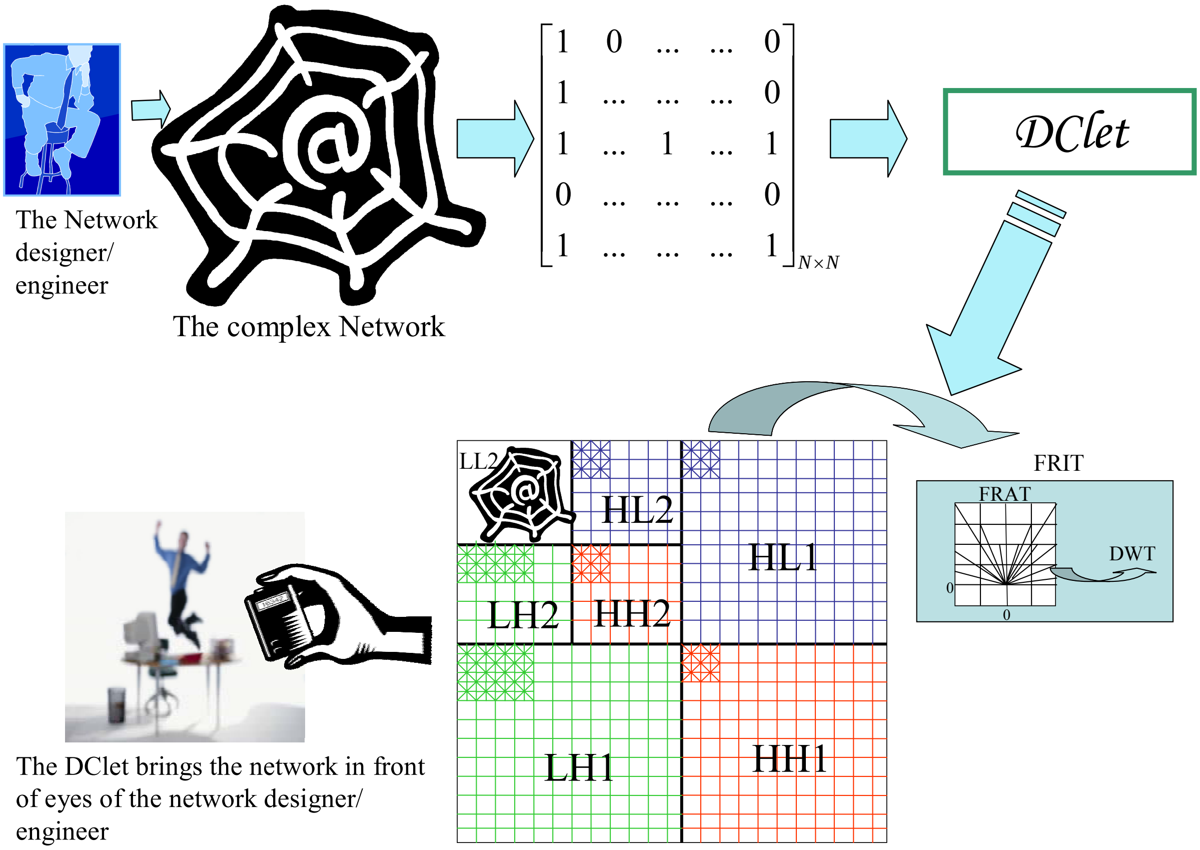


Fig. 2. Visualization of complex networks via the DClet filtering. The upper left square labeled *LL* corresponds to the lowest resolution subspace. The other regions involve higher resolution subspace.

To analyze complex networks via the DClet, it is assumed a network with vertices makes the input matrix with size . In this approach, each vertex is represented as a pixel and the edge weight is assumed as the distance between the visual properties of each pair of pixels in the matrix for instance gray level in an image.

In the construction of the FRIT, we need wavelet bases for prime length signals. Let be the nearest dyadic number to prime length that is smaller than or equal to the prime length window used as the input. This is because of definition of the FRAT as summations of pixels of input matrix over a certain set of lines. Those lines are defined in a finite geometry in a similar way as the lines for the continuous Radon transform in the Euclidean geometry.

Compared to wavelet [10, 11], the DClet adds orientation and operates by measuring information about an object at specified orientation. This provides more details information about the network and outperforms wavelet.

EXPERIMENTAL RESULTS FOR VISUALIZATION METHOD

A set of vertices joined by edges is only simples type of network, there are many ways in which networks may be more complex. To evaluate performance of the proposed method, it is applied to two networks with different structural properties, first a network with structural properties of small world with size $N = 16$, and afterwards a globally coupled network with $N = 1024$ vertices. The globally coupled network has the smallest average path length and the largest clustering coefficient. As most real networks are neither fully connected nor entirely random a small world network is chosen as a network that describes a transition from a regular fully connected network to a random graph.

A SMALL WORLD NETWORK

A network with structural properties of small world network is represented with rewiring probability p by its adjacency matrix $A \in Z^{N \times N}$ and represents the coupling configuration of the network, if there is a connection between vertices i and j ($i \neq j$) then $A_{ij} = A_{ji} = 1$, otherwise $A_{ij} = A_{ji} = 0$. The DClet is applied to this network with frame elements indexed by scale and location parameters. As it is a multiresolution dyadic transform, it is repeated on the LL subband, generating the next level of the decomposition.

Suppose that a vertex i in the network has k_i edges. Clearly the most $k_i(k_i - 1)/2$ edges can exist among them and this occurs when every neighbor of vertex i connected to every other neighbor of vertex i. The average path length L of the network is defined as the mean distance between two vertices, averaged over all pairs of vertices:

$$L = \frac{2}{N(N+1)} \sum d_{ij} , \tag{7}$$

where d_{ij} is distance between two vertices. More precisely, one can define a clustering coefficient C as the average fraction of pairs of neighbors of a vertex that is also neighbors of each others. The clustering coefficient C_i of vertex i is defined:

$$C_i = \frac{2E_i}{k_i(k_i - 1)} , \tag{8}$$

where E_i is the number of edges that actually exist among these k_i vertices. They found that for small p, L drops rapidly while C remains almost unchanged.

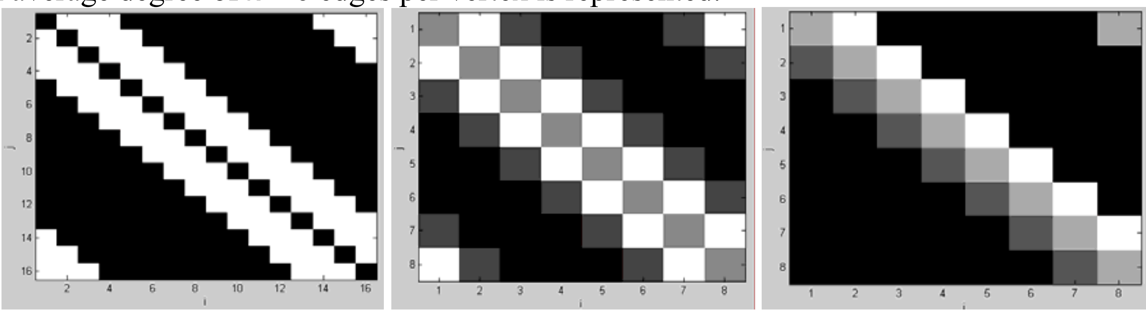
To show that the properties of the network can be derived from coarse part of the subband, N vertices of the complex network is divided to $N/2^r$ groups while the detail parts are divided to $N/(l \cdot 2^r)$ where l is number of windows Δ, therefore:

$$^{(LL)}W_A^r(b) = \sum_{i=1}^{N/2^r} \sum_{j=1}^{N/2^r} A(i,j)\, {}^{(LL)}\psi_b^r(i,j) = \sum_{i=1}^{N/2^r} \sum_{j=1}^{N/2^r} E(i,j)\, {}^{(LL)}\psi_b^r(i,j) \ , \tag{9}$$

$i, j = 1, 2, \ldots, 2^r$ where $E(i, j)$ is the number of edges between group i and j ($i \neq j$) or is the number of edges within group i. It is noted that $E(i, j)$ is considered as one pixel of $^{(LL)}W_a^r(b)$. The detail parts are calculated based on (6). A in r scale corresponds to a division of the lattice into $N/2^r$ groups and the diagonal elements in the lowest frequency subband LL of the DClet transformation represents the normalized number of edges within each group, while the non-diagonal elements in LL represent the normalized number of edges between different groups. Here the normalized constant is 2^r.

The non-diagonal element $W_a^r(b)$ characterizes the connection property between two different groups i and j ($i \neq j$). $^{(LL)}W_a^r(b) \neq 0$ if and only if there is at least one edge between the two groups. Higher value of $^{(LL)}W_a^r(b)$ implies more edges between the two groups and among vertices within the group illustrated in Fig. 3. A vertex in the new network corresponds to a group in the original network, and there is an edge between two different vertices i and j in the new network if and only if there is at least one edge between groups i and j in the original network for example $^{(LL)}W_a^r(b) \neq 0$. The figure represents details of original network and helps the reader observes the qualitative similarities between the proposed method with different probabilities and original data. The white blocks stand for edges and the black parts no edges. In the DClet view the gray parts represent the negative number that in the network analyzing can be considered as no connection or on the other word no edge. Light gray, with a high approximation, can consider as an edge; by this order the network designer can extract exact meaning of different levels of grayness. Also the size of output is considerable. The DClet decomposition gives us a smaller matrix of the input data with the same properties of the real network. It is a solution for visualizing complex networks in different smooth zooms.

The clustering property of the network can be derived from LL. If value of element ${}^{(LL)}W_a^{r}(b)$ of LL is much bigger than the value of ${}^{(LL)}W_a^{r}(b)$ for all i and j ($i \neq j$), then the edges within each group would be much more than the edges between different groups, which implies that the network is highly clustered. In simulation, the DClet decomposition of a network with $N = 16$ an average degree of $k = 6$ edges per vertex is represented.



a) b) c)

Fig. 3. The DClet representation of the lattice as small world network. The DClet view of the network gives similar structural properties of the network. a) Original matrix (p = 0,8), b)LL subband of the DClet (p = 0,8, r = 1), c) LL subband of the DClet (p = 0,38, r = 1).

Choosing the number of zero non-diagonal elements in *LL* instead of *L*, and error between the minimum diagonal elements and the maximum non-diagonal elements in *LL* instead of *C* give us similar properties. Small value of number of zero non-diagonal elements and large value of error imply small characteristic path length and large clustering coefficient of the original network.

GLOBALLY COUPLED NETWORK

A globally coupled network with $N = 1024$ vertices is chosen for evaluating the performance of the proposed visualization method. This network with the smallest average path length and the largest clustering coefficient is a dynamical network which is suitable for testing the chaotic state [12]. That is a simple network, which has $N(N-1)/2$ edges. It is outlined mainly for sake of clarity of performance of proposed method. The proposed method is applied to the coupling matrix $\boldsymbol{A}$:

$$A = \begin{bmatrix} -N+1 & 1 & \dots & \dots & 1 \\ 1 & -N+1 & 1 & \dots & 1 \\ \dots & \dots & -N+1 & \dots & \dots \\ 1 & \dots & \dots & -N+1 & 1 \\ 1 & 1 & \dots & 1 & -N+1 \end{bmatrix}_{N\times N}.$$

Fig. 4 illustrates the results in the different scales. These observations display that the DClet gives an inclusive topology of a complex network via a coarse to fine strategy for characterizing and classifying networks by processing minimum amount of information. In this figure white background is equal to 1 and the diagonal line stands for no edge. The DClet decomposition of the coupled network gives the similar properties of the network to a network designer. It brings a small understandable dimension view of the network to his/ her eye. Having a perspective of network is better than designing based on guess. As the structural properties of the network are robust in different scales, it can be a trustable platform for tracking the behavior of the network through the smaller matrix and find the exact points of changes by the DClet reconstruction.

The evaluated coupling network is a fully connected network with 1024 vertices and 523 776 edges, while the most large scale real networks appear to sparse, that is most real networks are not fully connected and their number of edges is generally of order N rather than N^2.

As a side comment, it is noted that for the above reason, it is tested on the intercity network of telecommunication network of Iran as a real complex network too. This network has been distributed in a country having the area of 1 648 000 km^2, more than 18 million fixed telephone lines, 92 primary and secondary switching vertices and 7171 homing. The total 636 900 input and output traffics as totals 706 350 E1 traffic channels are distributed through this network. The result exhibits that the telecommunication network designer can get similar information through the DClet decomposition, make different traffic behaviors, compare the results and make final decision only via a smaller matrix. It yields a general view of network to designer that usually is enough to see the traffic behavior of the network. See Annex A.

It is observed:

- the DClet provides a coarse to fine strategy for characterizing and classifying a complex network by processing minimum amount of information,

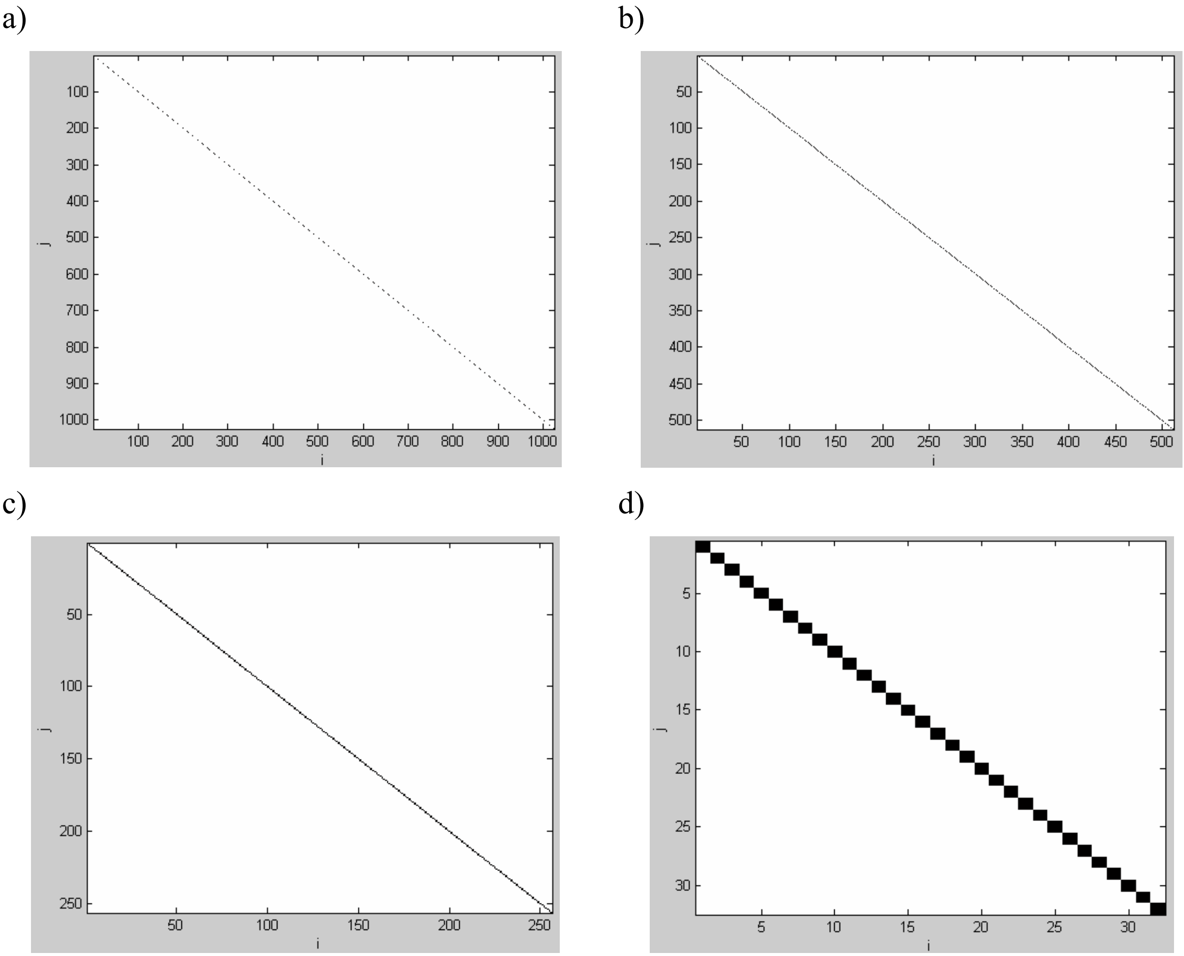


Fig. 4. Simulation results of visualization of the coupling network via the DClet. a) Original input with size 1024 × 1024, b) LL subband of the DClet (r = 1), c) LL subband of the DClet (r = 2) and d) LL subband of the DClet (r = 5).

- it behaves like the brain in terms of segments and distinguishes them by scale and orientation,
- the DClet enjoys superior performance over the FRIT, regardless of block size,
- properties of a complex network will be derived using the DClet regardless of the structure of the network,
- information in approximation parts can be viewed as a coarse (large scale) description of the network and the other regions correspond to higher resolution and involve the finer details of the networks in vertical and horizontal directions with different orientations,
- as it is zoomed in smaller scales, details can be seen that before could not. The DClet outperforms wavelet for orientation, deriving more information from the detail parts. Accordingly, highly localized features can be detected without exhaustive searching of the entire high resolution input,
- in comparison, every structure in the input which is visually detectable is clearly displayed in the DClet reconstruction by adding orientation. Indeed, it has been suggested that the analogy between the DClet and human vision is no accident, and that our neurons filter visual signals in a similar way of the DClet.

The results prove that the DClet can be considered as a simulation tool for successfully designed network topology and established necessary group sizes.

As a side comment, it is noted that output size is unexpected sometimes. This mismatching comes via the FRIT which accepts only inputs with the size of prime numbers. Fixing this mismatching issue is a job in the future.

The DClet gives the network designer a general view of network. It helps the designer to configure the network. It as a simulation tool provides the opportunity to see different view of network. It gives the possibility of working with less data to trace the properties and behaviors of network. For example as the topology of the network is robust in any scales of the DClet, we can work on a smaller matrix and sketch the topology of network. It is a trustable efficient tool for surveying. We can model the real network with the DClet reconstruction. Doing some changes in the small dimension of the network, and extract a real dimension of the network with reconstruction and find the exact points of changes for further designs is another fact.

CONCLUSION

Networks are inherently difficult to understand because of structural complexity. Making reasonable the knowledge of scientists about the elements and forces of networks without having a view of network is difficult. Understanding complex networks can be possible by sketching their structures with actual points and links and then looking at them by eyes. However for a network with millions of vertices such a direct analyzing by human eyes is hopeless. It is impossible drawing a meaningful picture of the network. Assuming that the network architecture is static allows us to sidestep any issues of structural complexity and to propose a visualization method for understanding the topology of complex networks. The proposed method is based on an extended Curvelet transform named Dyadic Curvelet Transform (DClet). This extension makes it possible to generate the multiscale non-redundant Curvelet transform that provides a coarse to fine strategy for characterizing and classifying networks by processing the minimum amount of information. This statistical method quantifies huge networks and plays the part played by eyes for small networks.

The performance of the proposed method is evaluated in a network with structural properties of small world network with size N = 16 vertices and a coupled network with N = 1024. It is observed the connectivity of complex networks is robust in sense that the networks are still connected even when a high percent of randomly selected vertices and or edges are removed so that some desired properties of the network remain unchanged. This strategy reduces the computational complexity by starting at low resolution and increasing the resolution when it is necessary; also provides the minimum among of data which are necessary to perform a qualitative task. Since the coarse coefficient processing can be performed quickly, it gets higher computational efficiency.

It is expected the DClet to be widely applicable, especially in fields of image processing and computer vision. In image analysis for example, the DClet may be used for compression, enhancement and restoration of images, and for post processing applications such as extracting patterns from large digital images and detecting features embedded in noisy image. The experimental results show that the proposed filtering method can behave in the same matter as human eyes, processing an object by filtering the input data into a number of bands and levels. It can be a new way for controlling dynamical characteristics such as synchronization of complex networks. It can suggest a way of compressing complex networks, representing a huge network with as less data as possible.

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ANNEX A

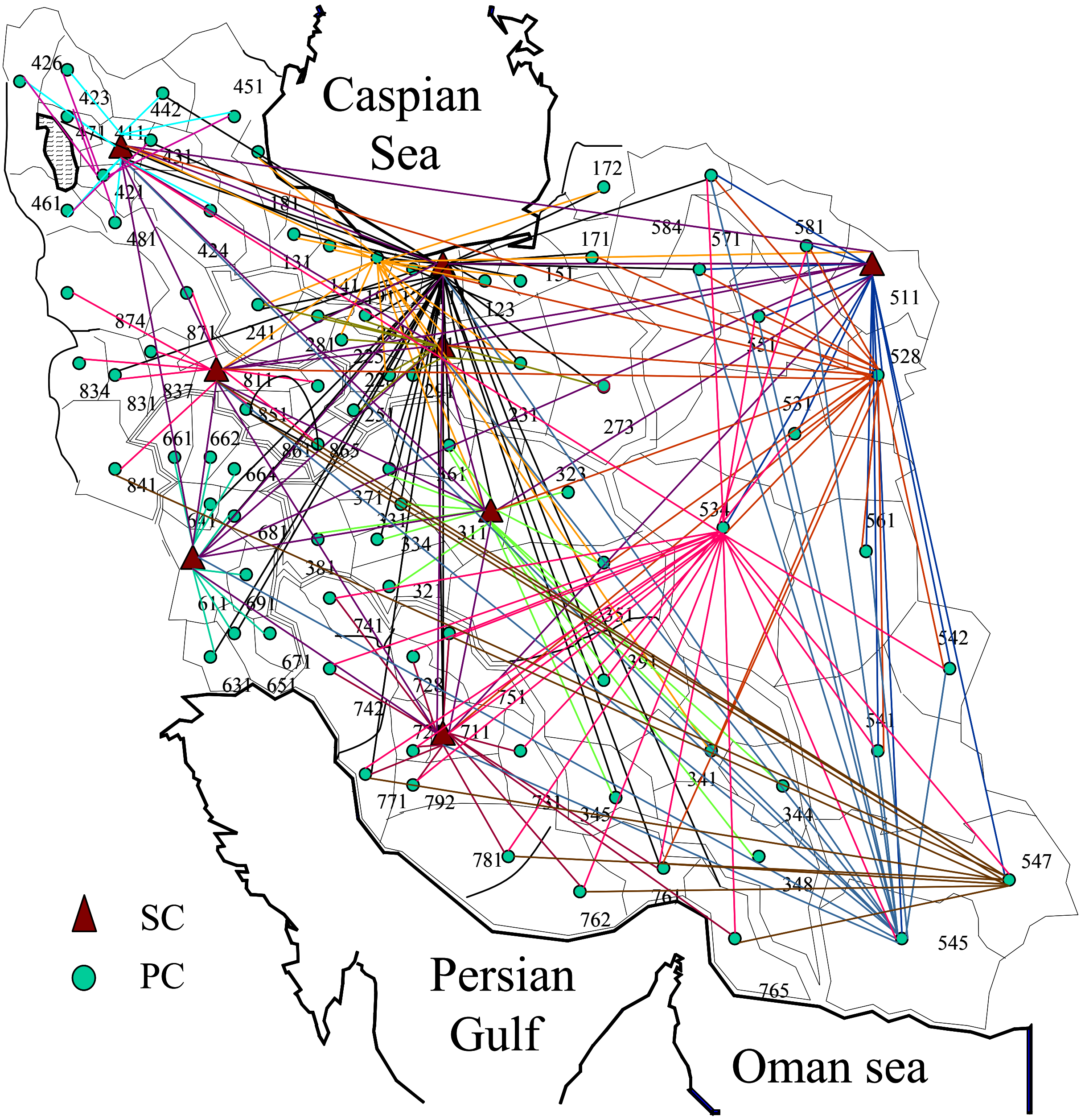
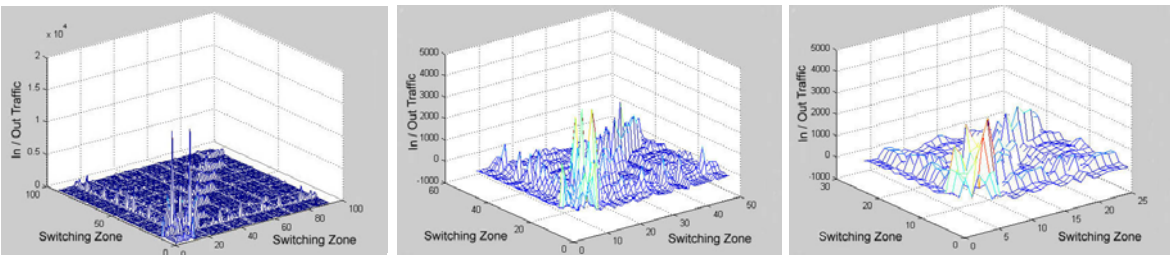


Fig. 5. Configuration of the trunk network of telecommunication network of Iran. The trunk network is extremely complex that understanding the structure of this network by eyes is impossible.



a) b) c)

Fig. 6. Simulation results of the trunk network in Iran using the DClet. a) Trunk network, b) Level 1 of the DClet (LL), c) Level 2 of the DClet (LL).

VISUALIZATION OF COMPLEX NETWORKS BASED ON DYADIC CURVELET TRANSFORM

M. Sedighi Anaraki[1], F. Dong[1], H. Nobuhara[2] and K. Hirota[1]

[1]Odjel računalne inteligencije i znanosti o sustavima, Tokijski institut za tehnologiju
Tokio - Jokohama, Japan
[2]Odjel za inteligentne tehnologije međudjelovanja,
Viša škola za sustave i inženjerstvo informacija, Sveučilište u Cukubi,
Ibaraki, Japan

SAŽETAK

Predložena ja metoda vizualizacije za razumijevanje strukture kompleksnih mreža, koja se temelji na proširenoj transformaciji *Curvelet* pod nazivom diadska Curvelet-transformacija. Predložena metoda doprinosi odgovaranju na pitanja o strukturi kompleksnih mreža preslikavanjem podataka u ortogonalne lokalizirane događaje s usmjerenom komponentom određenom putem uzorkovanja skupa koeficijenata. Time je postignuta sličnost sa sustavom za viziju čovjeka, jer vidi u segmentima koje razlikuje po dimenziji i orijentaciji. Posebno je pitanje komprimiranje mreže. Djelovanje predložene metode ispitano je pomoću dvije mreže strukture mreža malog svijeta s N = 16 čvorova i globalno vezane mreže s N = 1024 čvorova i 523 776 bridova. Budući da većina stvarnih mreža velikih skala nije potpuno povezana, metoda je provjerena na telekomunikacijskoj mreži Irana. To je ekstremno kompleksna mreža s 92 čvora, međugradska preklopnika, 706 350 kanala E1 i 315 525 prijenosnih kanala. Pokazano je da predložena metoda djeluje kao simulacijskih alat za učinkoviti dizajn mreže i postavljanje potrebne veličine grupe. Metoda upućuje dizajnera mreže na sva strukturalna svojstva mreže.

KLJUČNE RIJEČI

vizualizacija, kompleksne mreže, sustav za viziju čovjeka

MANUSCRIPT PREPARATION GUIDELINES

Manuscript sent should contain these elements in the following order: title, name(s) and surname(s) of author(s), affiliation(s), summary, key words, classification, manuscript text, references. Sections acknowledgments and remarks are optional. If present, position them right before the references.

SUMMARY Concisely and clearly written, approx. 250 words.

KEY WORDS Not more than 5 key words, as accurate and precise as possible.

CLASSIFICATION Suggest at least one classification using documented schemes, e.g., ACM, APA, JEL, PACS.

TEXT Write using UK spelling of English. Preferred file format is Microsoft Word. Provide manuscripts in grey tone. For online and CD-ROM versions, manuscripts with coloured textual and graphic material are admissible. Consult editors for details.

Use Arial font for titles: 14pt bold capital letters for titles of sections, 12pt bold capitals for titles of subsections and 12pt bold letters for those of sub-subsections.

Include figures and tables in the preferred position in text. Alternatively, put them in different locations, but state where a particular figure or table should be included. Enumerate them separately using Arabic numerals, strictly following the order they are introduced in the text. Reference figures and tables completely, e.g., “as is shown on Figure 1, *y* depends on x …”, or in shortened form using parentheses, e.g., “the *y* dependence on *x* shows (Fig. 1) that…”.

Enumerate formulas consecutively using Arabic numerals. In text, refer to a formula by noting its number in parentheses, e.g. formula (1). Use regular font to write names of functions, particular symbols and indices (i.e. sin and not *sin*, differential as d not as *d*, imaginary unit as i and not as *i*, base of natural logarithms as e and not as *e*, x_n and not x_n). Use italics for symbols introduced, e.g. $f(x)$. Use brackets and parentheses, e.g. {[( )]}. Use bold letters for vectors and regular GoudyHandtooled BT font (for MS Windows) or similar font for matrices. Put 3pt of space above and below the formulas.

Symbols, abbreviations and other notation that requires explanation should be described in the text, close to the place of first use. Avoid separate lists for that purpose.

Denote footnotes in the text by using Arabic numerals as superscripts.

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