INFORMATION, ENERGY, AND EVOLUTION

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Abstract: Within the current theory of evolution, the development in the direction of higher complexity is taken to be a necessary condition. This gives birth to a problem why this direction is prevalent for evolution. Philosophers and scientists tried to substantiate this condition and to explain it, yet the question still remains open. Our aim is to find specific regularities in nature that make complexity the chosen direction. Three main causes for this direction are deduced from initial principles, assuming that information and energy are the vital nutrients for evolution. Consequently, we base our explication and explanation of causes on the principles of information theory, Ashby's principle of requisite variety/complexity, as well as we suggest and ground some additional principles of the system development. This makes possible to separate three principal stages for evolution of living organisms: biological, neurological, and epistemological.

Keywords: information, energy, evolution, variety, complexity, principle, development, infological system, infological element

The scope of this paper is to show the relationship between evolution and complexity in connection with information and energy as mechanisms that drive evolution. We begin with the term 'evolution,' which in spite of its popularity has not acquired a unique and indisputable meaning. When one introduces a new term that may help provide a better understanding of a new thought, then language becomes a better tool for communicating information.

However, when that term is cleverly used to promote someone's agenda by given it multiple meanings, then there is a danger of leading to misunderstandings. In some cases the abuse of language is quite obvious as in the example, "you made a decision not to make a decision." Not quite as apparent is the use of the term "evolution." For example, evolution is also a common term used in celestial mechanics that refers to the decomposition of a body into two parts: evolution as a directed change, and oscillations that are relatively small (Arnold, 1997). Futuyama (1986) wrote: "In the broadest sense, evolution is merely change, and so all-pervasive galaxies, languages, political systems, etc., evolve." Contrary to this, the most popular understanding is that evolution is not "merely change," but possesses some additional properties. For example, many consider evolution as emergency or creation of new structures or species (Haken 1983) rendering in such a way the innovative meaning of the term "evolution." However, even in a more restricted sense evolution refers to the main aspects of reality. We can speak of galaxies and chemical elements that evolve. People discuss such subjects as, the evolution of computers and its software, evolution of political systems and laws.

Thus, with the assumption that "we would rather not be understood than misunderstood," we will now continue with what we believe is a viable approach to a better understanding of complexity in evolution.

It was probably Herbert Spencer who, in his "The Development Hypothesis" (1852), and "Principles of Psychology" (1855), first suggested the application of evolution to every field of study. As Durant wrote (1951), mathematics had dominated philosophy in the XVII century giving to the world Descartes, Hobbs, Spinoza, Leibnitz and Pascal. In the XVIII century psychology influenced philosophy, as noted in the writings of Berkeley, Hume, Condillac and Kant. In the XIX century the writings of Schelling, Spencer, Schopenhauer, Nietzsche and Bergson showed that biology was the background of philosophical thought.

The main impact on philosophy in the XX century came from physics. At first, it was quantum mechanics and relativity theory. Closer to the end of the century synergetics formed the central issues in ontological discourse. However, in all aspects of reality, evolution has been a prime issue of philosophical importance for a long period of time. Explicitly or implicitly, on the stage or behind the curtains, evolution was always a part of philosophical discourse.

We can get a better understanding of evolution if we set aside the notion that its is merely a process of change or transformation, as well as development and progress. The term "evolution," as used in science and philosophy suggests that it is a dynamic process of gradual transformations during some specific periods of time. Many scientists and philosophers have observed that the following principles may apply to evolution.

Enrichment Principle (**EP**). Evolution is a hierarchical process that increases in complexity over time.

As an example, let us look at the evolution of elements. Starting with the basic elements that form in young stars such as our Sun, we may note that the simplest element, hydrogen, is converted into helium, a somewhat more complex element. It is the first step of element evolution and it takes the immense amount of heat that is generated in the interior of a star to bring about that transformation. For example, what we see on the surface of the Sun are storms produced by this action. What happens inside the star is that from time to time a pair of nuclei of heavy hydrogen collides and fuses to make a nucleus of helium. As a matter of fact, helium was first identified by a spectrum line during the eclipse of the Sun in 1968. At that time such an element was unknown on earth. That is why it was called helium.

In time any star and our Sun grows older and become mostly helium. At the same time it becomes hotter and hotter. It involves collision of many helium nuclei. Heavier atoms result from these collisions. Among them are such elements as oxygen, silicon, sulfur, mercury, carbon, etc. Since those elements are composed of subatomic particles (electrons, protons, neutrons), we can readily see that there is a hierarchy of complexity within the stars themselves.

McShea (1996), who has studied different components of living organisms, has collected a great deal of scientific data in support of **EP**. His data are supported by biologists Kauffman. For example, complexity of cells have gone immensely up in the last four billion years.

Thus, there are good reasons for considering complexity as the foremost direction of evolution. At the same time, some authors assert even stronger principles. Simon (1980, 1999), suggests that, much like the elements are being "pressured" towards higher levels of complexity in the Sun, biological organisms here on earth are being "pressured" in the direction of ever-increasing complexity. This brings us to the following principle:

Enforced Enrichment Principle (**EEP**). Evolution in nature is forced to go in the direction of increasing complexity.

As McShea wrote, if evolution favored complexity, something was driving evolution in that direction. To be scientific rather than indulge in speculations, such principles need grounded explanations and supportive arguments. In what follows, we are going to provide such arguments and explanations.

Since “complexity” is difficult to define and the many definitions that have attempted to do so fall short in one respect or another, rather than discuss them, we refer the reader to the writings of Heylighen (1996; 1997). Here we consider two aspects of complexity. First will be the structural complexity, which reflects the variety of elements and connections. The second will be the functional complexity, which reflects the variety of function and behavior. From these basic aspects of complexity, we derive the following principle:

Environmental Speed-Up Principle (**ESUP**). The complexity of the environment *E* increases more rapidly than the complexity of organisms (autonomous systems).

As we know, any environment *E* is at least one hierarchical level of complexity higher than that of any organism/autonomous system in this environment. As complexity increases (usually at an exponential rate), we can equate the process to **ESUP**. For example, let us consider three types of elements {a,b,c} that may be connected by two types of ties {u,v}. It is then possible to form more than $3^5.2^{10}$ different five-element systems. The complexity of one of these systems is 5.2^{10}=320 or less, if the complexity SC(*R*) of a system *R* is the number of elements times the number of connections. At the same time, the complexity of the environment is larger than 245,000 even if there is only one possible relation between two such systems.

To understand the implications of **ESUP**, we refer to one of the central principles of cybernetics suggested by Ashby (1964):

Principle of Requisite Complexity/Variety (**PRCV**). To achieve complete (relevant) adaptation/control, the complexity/variety of a system must be of the same order as the complexity of its environment.

The emergence of new species, as well as new individual organisms, increases diversity and thus, the complexity of the environment. Consequently, as suggested by **ESUP**, the complexity of the environment grows when new species emerge and grow faster than the complexity of these species. Then, in accord with **PRCV**, to cope with this increase in complexity, organisms have to become more complex. This gives us one of the basic mechanisms driving evolution in the direction of increasing complexity. The second basic mechanism lies within the following principle.

Niche Principle (**NP**). It is easier to fill a lower level of complexity than a higher level.

If you take for example the measure of complexity of a system as SC, then there are much less systems with lower values of SC than systems of higher values of SC.

NP may become more meaningful if we take into account the stability of systems and complement it by the following principle suggested by Bronowski (1973):

Principle of Stratified Stability (**PSS**). Evolution is the climbing of a ladder from simple to complex by steps, each of which is stable in itself.

On the first level, subatomic particles (electrons, protons, quarks, neutrons, etc.) appear. They combine to form the elements for the building of atoms that appear at the next level of complexity. Physics predicts that there are not more than one hundred stable atoms. Thus, on the next level in the hierarchy atoms begin to consolidate into molecules. There are much more different kinds of molecules than atoms.

System that evolved on one level form the base for the next level. Nature works by steps. Subatomic particles form atoms, atoms form molecules, molecules constitute chemical bases for organism, these bases direct the formation of amino acids, amino acids form proteins, and proteins work in cells. Then, on the next hyperlevel, cells make up first of all simple organisms, then more sophisticated ones and so on. Organisms consolidate themselves in groups, groups form communities, and on the level of human beings communities aggregate into society.

Thus, **NP** implies that, while some level of the hierarchy is filled due to the stability limits, or to the overall possible variety of combinations, the next level provides a niche for further transformations and development. This is the second basic mechanism directing evolution in the direction of complexity. However, to go in this direction, evolution has to occur continually. Therefore, to explain this process we need to find the driving force that is responsible for evolutionary change.

But first we have to go back in the history of philosophy and to state the main principle of dialectics suggested by Democritus and developed by Hegel.

Principle of Dialectics (**PD**). All things forever flow and change.

But what is perpetuating change ad infinitum? In (Simon, 1980), it is suggested that the principle driving mechanism, the nutrient of evolution, is energy. A new development of information theory, which is called the general theory of information (Burgin, 1997), allows us to extend this conjecture, making it more complete and relevant to scientific data. First of all, the general theory of information states (Principle O1) that it is necessary to separate information in general from information for a system. In other words, empirically, it is possible to speak only about information (or a portion of information) for a system.

Why is this principle so important? The reason is that all conventional theories of information assume that information exists as something absolute, like time in the Newtonian dynamics. Consequently, this absolute information may be measured, used, and transmitted. In some abstract sense it is true, but on practice, or as scientists say, empirically, this is not so.

To demonstrate this, let us consider a book in Japanese. For a person who does not know Japanese, it contains no information. At the same time, its information for those who know Japanese may be immense.

According to the general theory of information (Principle O2) - in the broadest sense - *information for a system is any essence that causes changes in that system*. Consequently, information, by this definition, is a source of all changes.

However, many of the changes in the physical world are a result of work. Work, in turn, requires energy. Thus, in the broad sense, energy becomes a form of information. This correlates with the idea of the famous physicist, von Weizsäcker that *energy might, in the end, turn out to be information*.

In a general picture of nature, matter and energy constitute two main aspects of physical reality. We know that the famous Einstein formula, $E = mc^2$, has been interpreted as equivalence of matter and energy. The more pertinent understanding is that the formula gives a quantitative estimate of this energy content and the statement that matter contains energy is more precise.

At the same time, as Wiener stated (1961) "*information is information, not matter or energy*." It appears then that there is a contradiction. On the one hand, energy is a form of information, yet energy and information are essentially different.

To resolve this paradox, the general theory of information introduces the concept of information in the strict sense (Burgin, 1997). It is based on the concept of an infological system.

Definition 1. A subsystem IF(R) of the system R is called an infological system of R if IF(R) contains infological elements from R.

Infological elements are different kinds of structures (Burgin, 1997). Standard examples of infological elements are knowledge, data, images, ideas, fancies, abstractions, beliefs, etc. If we consider only knowledge and data, then the infological system is the system of knowledge. This system is very important, especially, for intelligent systems. The majority of researchers believe that information is intrinsically connected to knowledge. Consequently, we take the system of knowledge of R to be a model example of an infological system IF(R) of an intelligent system R. It is called in cybernetics the thesaurus Th(R) of the system R.

When R is a material system, its infological system IF(R) consists of three components: a material component, which is a system of physical objects; a functional structure realized by the material component; and the system of infological elements, which are structural objects (tentatively, on material carriers). For example, the material component of the infological system of a human being is her/his brains. The corresponding functional structure complements the brain to the mind of this person. Infological elements in this case will be, in particular, knowledge units of the individual. Another example of an infological system is the memory of a computer. This memory is a place in which data and programs are stored.

Thus, we come to the central concept of the general theory of information:

Information in the strict sense or, simply, information for a system R, is everything that changes the infological system IF(*R*) *of the system R*.

In turn, this makes it possible to formulate and support the following principle:

Transformation Principle (**TP**). Change/transformation is always caused by information/energy.

As energy causes material change in nature, it can be seen as a material nutrient for evolution. As Simon (1999) suggests: "between each level in the hierarchy of complexity the environment first becomes saturated with a new "complexity-promoting nutrient." For example, free oxygen had to be in place before aerobic organisms could emerge. Information in the strict sense causes structural changes in nature, thus being a structural nutrient of evolution. However, in nature, information and energy act as a unified whole: energy plays the role of a carrier of information and a performing agent for information, while information directs and structures the impact of energy.

If we apply this understanding to the evolution of life, we come to the following conclusions. It is possible to separate three principle stages of the evolution of organisms: *biological*, *neurological*, and *epistemological*.

The biological stage is the primary development of organisms - from virus to bacteria to plants to animals. The leading source and nutrient in this stage is energy, although information is also important as it directs the process of evolution.

At the neurological stage, which includes the evolution of the nervous system as a whole as well as the brain, priorities change. At this level of evolutionary complexity, energy and information share the leading roles.

At the epistemological stage, we are dealing with the evolution of the mind with the emphasis on systems of knowledge. At this level of complexity information becomes the leading force of evolution, although energy supports changes. For example, even reading a book or writing a paper demands some energy.

Thus, we come to the following conclusion. Going in a multidimensional phase space of transforming systems, evolution has a vertical aspect and a horizontal aspect. The horizontal aspect refers to changes associated with the continuing growth and development of a species as noted by their size, strength, quickness, etc. We may even consider the emergence of new species as a horizontal evolution if those species belong to the same level of complexity as other extant systems. Vertical evolution refers to increasing complexity. This paper pertains mostly to the latter, explicating three main causes for this direction. Namely, energy and information (*the first cause*) evoke emergence of new organisms/systems, and as lower levels of complexity are filled (*the second cause*), new organisms/systems come forth on a higher level to be able to cope with the environment (*the third cause*).

References

1. Arnold, V.I. *Mathematical Aspects of Classical Celestial Mechanics*, Springer-Verlag, Berlin/New York, 1997
2. Ashby, R. W.R. *An Introduction to Cybernetics*, Barnes&Noble, London, 1964
3. Bronowski, J. *The Ascent of Man*, Little, Brown and Co., Boston/Toronto, 1973

4. Burgin, M.S. (1997) *Fundamental Structures of Knowledge and Information*, Academy for Information Sciences, Kiev (in Russian)
5. Durant, W. *The Story of Philosophy*, Simon&Schuster, 1951
6. Futuyama, D.J. *Evolutionary Biology*, Sinauer Assoc., 1986
7. Haken, H. *Advanced Synergetics: Instability, Hierarchies of Self-organizing Systems and Devices*, Springer-Verlag, Berlin/New York, 1983
8. Heylighen, F. *What is Complexity*, http://pespmc1.vub.ac.be/COMPLEXI.html, 1996
9. Heylighen, F. *The Growth of Complexity*, in "The Evolution of Complexity," Kluwer, Dordrecht, 1997
10. McShea, D. (1996) Meatzoan Complexity and Evolution: is there a trend?, *Evolution*, **50**, 477-492
11. Simon, I. *Centropy: The Evolution of Energy*, Los Angeles, 1980; second edition, 1999
12. Spencer , H. *Essays, Scientific, Political and Speculative*, London, v. 1 Longmans&Roberts, 1858; v. 2 and 3, Williams&Norgate, 1863
13. Spencer, H. *Principles of Psychology*, London, Longmans&Roberts, 1855
14. Wiener, N. *Cybernetics, or Control and Communication in the Animal and the Machine*, New York/London, MIT Press, 1961