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Structural and Symbolic Information in the Context of the General Theory of Information

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Abstract: The general theory of information, which includes syntactic, semantic, pragmatic, and many other special theories of information, provides theoretical and practical tools for discerning a very large diversity of different kinds, types, and classes of information. Some of these kinds, types, and classes are more important and some are less important. Two basic classes are formed by structural and symbolic information. While structural information is intrinsically imbedded in the structure of the corresponding object or domain, symbolic information is represented by symbols, the meaning of which is subject to arbitrary conventions between people. As a result, symbolic information exists only in the context of life, including technical and theoretical constructs created by humans. Structural information is related to any objects, systems, and processes regardless of the existence or presence of life. In this paper, properties of structural and symbolic information are explored in the formal framework of the general theory of information developed by Burgin because this theory offers more powerful instruments for this inquiry. Structural information is further differentiated into inherent, descriptive, and constructive types. Properties of correctness and uniqueness of these types are investigated. In addition, predictive power of symbolic information accumulated in the course of natural evolution is considered. The phenomenon of ritualization is described as a general transition process from structural to symbolic information.

Keywords: general theory of information; structural information; symbolic information; correctness; uniqueness; information conservation; prophecy; evolution; ritualization

1. Introduction

Everything has its structure, and according to the contemporary approach in methodology of science, scientists discover structure, rather than the essence and nature of the studied phenomena (cf., for example, [1–3]). As a result of their research, scientists gain and publish information obtained from the structure under investigation. For instance, astronomers, such as Tycho Brahe and Johannes Kepler, watched the changing positions of visible stars and, eventually, in 1627, published related tables with the numbers that described the structure of our planetary system. Extracted structural information was symbolically described by numbers making possible the discovery of dynamic regularities of the solar system made by Kepler. Formulated in terms of mathematical symbols, Kepler's laws permitted, for example, successful predictions of the solar transits of Mercury in 1631 and of Venus in 1639, and eventually the launch of satellites and space probes.

To achieve better understanding of information processes, it is useful to study relations between *structural* and *symbolic information* [4–8], or, synonymously, between *bounded* and *free information* [9], respectively. Symbolic information relies on a convention between the transmitter and receiver. In contrast to this, intrinsic structural information, on the contrary, is not based on conventions. For instance, when astronomers watch the changing brightness of distant stars, they receive structural information about possible planets of those suns. At the same time, when sailors at night watch the changing brightness of a distant lighthouse at the shore, they receive both structural and symbolic information in the form of the optical code as a unique identifier of the beacon.

It is possible to attribute structural information to all physical processes and systems. It may be often quantified in terms of physical entropy [5,8,10–12]. Physical structures, such as moving planets and their shining light, exist independently of life. On the other hand, the prediction of future events, such as solar transits, derived from observations made in the past, is a typical characteristic of life and, in particular, of humans. In order to facilitate future survival, genetic information also acts this way, as "genomes do not predict the future but recall the past: they reflect the exigencies of history" [13]. Information constitutes a bridge between lifeless physics and living beings struggling for survival. It is obtained by "measurement in which a rate-dependent dynamical state is coded into quiescent symbols" [14], and created by trial and error in the course of Darwinian evolution. The emergence of symbolic information may "distinguish the living from the lifeless", as the problem was raised already by Pearson ([15], p. 341). In this context, symbolic information has a purpose, while structural information does not. "Evolution is based on function and—what is really new in physics—the 'purposefulness' of the function involved" [16].

In many cases, portions of symbolic information may be true or false. A lighthouse on the shore, as the transmitter of information, may send a wrong code either as a result of a technical failure or intentional deception by the operators on land. Additionally, the sailor, as the receiver of information, may fail in properly reading or interpreting the code. In the case of structural information, however, if an alien astronomer observes the 11-year brightness cycle of our sun, he may falsely conclude that there is a big planet with an 11-year orbital period, similar to Jupiter. In that case, information extracted by the scientist from the measured signal may be false, but one may not reasonably blame the changing sunlight itself to be wrong, as in the case of the lighthouse code. There may also be "fuzzy" cases of unclear right or wrong, such as "Tabby's star", where the physical structure causing the received light signal remains elusive [17].

The examples above demonstrate, as in the case of light received from a distant source, that the truth of information carried by a light beam is related to the structure of the source, to the structure of the light itself as the transmission medium, as well as to the structure or structural change of the receiver. All these elements represent certain forms of structural information that are physically converted from one into another during the information transfer process.

Before looking in more detail at the roles of the different parts of an information transfer process, we introduce (Section 2) the relations between structures, symbols, information and prediction in the context of the general theory of information (GTI) (cf. for example, [18–21]) and the general theory of structures (GTS) developed in [1]. Different types of information and its comprehension are carefully differentiated in our exploration of structural information presented in Sections 3 and 4. Section 3 deals with descriptive structural information while Section 4 examines inherent structural information. In Sections 5 and 6, we study symbolic information comparing it to structural information.

2. Basic Postulates of the General Theory of Information (GTI)

The general theory of information (GTI) has been constructed by Mark Burgin utilizing the basic postulates of information theory and information technology [18,22,23]. These postulates are presented in the form of principles. They allow to achieve the comprehensive definition of information as a foremost phenomenon in the world, to discern information, information representation and information carrier and to efficiently study information measures, processes, and systems by means of mathematical models and experiments (cf. for example, [19–21]).

Ontological Principle O1 (the *Locality Principle*). It is necessary to separate information, in general, from information (or a portion of information) for a system R.

In other words, empirically, it is possible to speak only about information (or a portion of information) for a system. This principle separates local and global approaches to information definition, i.e., in what context information is defined.

Here a portion of information means information that can be constructively or analytically separated from other information although relations and connections to usually exist.

The Locality Principle explicates an important property of information, but says nothing of what information is. The essence of information is described by the second ontological principle, which has several forms.

Ontological Principle O1 does not necessarily imply that the "system" under consideration is a physical system, somehow localized in space, exchanging information with other systems "out there". The "system" may as well be a mathematical or philosophical construct, such as an abstract automaton or a learning matrix, that exists "beyond space and time" in a sense that for its functioning, physical coordinates of the system's elements are irrelevant, unspecified aspects. However, in the interplay between structural and symbolic information, we shall focus here on systems that physically exist in space and time, at least as thought experiments.

Ontological Principle O2 (the *General Transformation Principle*). In a broad sense, *information* for a system R is a capacity to cause changes in the system R.

Thus, we may understand information in a broad sense as a capacity (ability or potency) of things, both material and abstract, to change other things. Information exists in the form of *portions of information*.

Ontological Principle O2 is fundamental as it intimately links information with time. Changes to R, when they occur by reception of information, are defined here to be the result of a causal process. Causality necessarily implies that the related effect happens strictly after its cause, if observed from any physically possible reference frame in the sense of Einstein's special theory of relativity. Ontological Principle O2 leaves open the question of whether the potential causal changes may or must be irreversible. For example, revealing a secret to somebody R has the capacity to change R, and if so, this change is irreversible for the impossibility to take back the secret.

However, the common usage of the word *information* does not imply such wide generalizations as Ontological Principle O2 implies. Thus, we need a more restricted theoretical meaning because an adequate theory, whether of the information or of anything else, must be in significant accord with our common ways of thinking and talking about what the theory is about, else there is the danger that theory is not about what it purports to be about. To achieve this goal, we use the concept of an *infological system* IF(R) of the system R for the information definition. Elements from IF(R) are called *infological elements*.

The exact definition consists of two steps. At first, we make the concept of information relative and then we choose a specific class of infological systems to specify information in the strict sense. That is why it is impossible and, as well as, counterproductive to give an exact and thus, too rigid and restricted definition of an infological system. Indeed, information is a very rich and widespread phenomenon to be reflected by a restricted rigid definition (cf. for example, [24,25]).

The concept of the infological system plays the role of a free parameter in the general theory of information, providing for representation of different kinds and types of information in this theory. This is why the concept of *infological system*, in general, should not be limited by boundaries of exact definitions. A free parameter must really be free. Examples of infological systems are a dictionary, system of knowledge, thesaurus, database, scientific theory, and encyclopedia.

Identifying an infological system IF(R) of a system R, we can define information relative to this system. This definition is expressed in the following principle.

Ontological Principle O2g (the *Relativized Transformation Principle*). *Information* for a system R *relative to the infological system* IF(R) is a capacity to cause changes in the system IF(R).

When we take a physical system *D* as the infological system and allow only for physical changes, we see that information with respect to *D* coincides with (physical) energy. This kind of information is structural information as physical changes are usually changes of structures.

Taking a mental system *B* as the infological system and considering only mental changes, information with respect to *B* coincides with mental energy. This kind of information is symbolic information if we assume that mental processes operate with symbolic representations of information such as nerve-pulse frequencies or synaptic transmission of symbolic signal molecules. However, it is necessary to keep in mind that there are theories that describe mental processes as subsymbolic operations.

As a model example of an infological system IF(*R*) of an intelligent system *R*, we take the system of knowledge of *R*. In cybernetics, it is called the *thesaurus* Th(*R*) of the system *R*. Another example of an infological system is the memory of a computer. Such a memory is a place in which data and programs are stored and is a complex system of diverse components and processes.

The concept of an infological system allows showing that not only living beings receive and process information. For instance, it is natural to treat the memory of a computer as an infological system. Then, what changes this memory is information for a computer.

There is no exact definition of infological elements although there are various entities that are naturally considered as infological elements as they allow one to build theories of information that inherit conventional meanings of the word *information*. For instance, knowledge, data, images, algorithms, procedures, scenarios, ideas, values, goals, ideals, fantasies, abstractions, beliefs, and similar objects are standard examples of infological elements. Note that all these elements are structures and not physical things. Thus, we can consider structural infological elements per se and use them for identifying information in the strict sense.

Ontological Principle O2a (the *Special Transformation Principle*). *Information in the strict sense* or *proper information* or, simply, *information* for a system *R*, is a capacity to change structural infological elements from an infological system IF(*R*) of the system *R*.

An infological system IF(*R*) of the system *R* is called *cognitive* if IF(*R*) contains (stores) elements or constituents of cognition, such as knowledge, data, ideas, fantasies, abstractions, beliefs, etc. A cognitive infological system of a system *R* is denoted by CIF(*R*) and is related to cognitive information.

Ontological Principle O2c (the *Cognitive Transformation Principle*). *Cognitive information* for a system *R*, is a capacity to cause changes in the cognitive infological system IFC(*R*) of the system *R*.

A special case of cognitive information is epistemic information, which causes changes in the system of knowledge treated as the infological system.

After we outlined (defined) the concept *information*, let us consider how information exists in the physical world.

Ontological Principle O3 (the *Embodiment Principle*). For any portion of information *I*, there is always a *carrier C* of this portion of information for a system *R*.

The substance *C* that is a carrier of the portion of information *I* is called the *physical*, or *material*, *carrier* of *I*.

Ontological Principle O4 (the *Representability Principle*). For any portion of information *I*, there is always a *representation Q* of this portion of information for a system *R*.

Note that any representation of information is its carrier, but not any carrier is its representation. For instance, a text printed on a piece of paper is both carrier and representation of information, but the piece of paper where this text is written is only a carrier but a representation.

Ontological Principle O5 (the *Interaction Principle*). A transaction/transition/transmission of information goes on only in some interaction of the carrier *C* with the system *R*.

Note that interaction can be not only physical.

Ontological Principle O6 (the *Actuality Principle*). A system R accepts a portion of information I only if the transaction/transition/transmission causes corresponding transformations in R or in its infological system IF(R).

For instance, only people with sufficiently high level of knowledge and intelligence will be able to obtain information from it when they will read this paper.

Ontological Principle O7 (the *Multiplicity Principle*). One and the same carrier C can contain different portions of information for one and the same system R.

3. Structural Information in the Context of the General Theory of Information

It is possible to comprehend structural information in different ways. For instance, Bates [26] treats structural information as "the pattern of organization of matter and energy", while Reading [27] defines it as "the way the various particles, atoms, molecules, and objects in the universe are organized and arranged".

At first, we consider the approach developed in the general theory of information. The general theory of information discerns information in the broad sense (Ontological Principle O2) and information in the strict sense (Ontological Principle O2a).

Structural information is a kind of information in the strict sense being defined as a capacity to change the subsystem of knowledge in an intelligent system.

It means that structural information is a kind of epistemic information, which, in turn, is a type of cognitive information (cf. Section 2).

It is possible to differentiate three types of structural information.

1. Inherent structural information is information in structures.
2. Descriptive structural information is information about structures.
3. Constructive structural information is information that allows building knowledge about structures.

In this section, we describe properties of descriptive structural information while inherent structural information is studied in the next section.

These definitions allow obtaining key properties of structural information. Let us consider some of them.

1. Structural information can be more correct or less correct.

Correctness of structural information about a system depends on correctness of knowledge produced by this information [18]. As we know, some knowledge can be more correct, better representing the essence of the system, while other knowledge is less correct, providing a worse representation of the fundamental nature of the system.

Here are two examples:

Example 1. *For a long time, people believed that the Earth was flat, i.e., it had the structure of a plane.*

Then scientists found that the Earth had the structure of a ball.

Then scientists assumed that the Earth had the structure of a geoid.

Example 2. *For a long time, people believed that in the structure of the solar system, the Sun rotated around the Earth.*

Then scientists found that the Earth rotated around the Sun and the orbit had the structure of a circle.

Then scientists assumed that the Earth rotates around the Sun and the orbit had the structure of an ellipse.

2. As a rule, structural information about a system is not unique.

Many researchers believe that each (e.g., a natural) system has a unique structure. At the same time, according to the general theory of structures [1], any system has several structures. For instance, the structure of a table on the level of molecules is essentially different from the structure of this table on the level of its parts, such as legs. In essence, material systems, which people can see with their eyes and touch with their hands, have structural information on different levels.

3. Structural information about a system can be inherent to this system, built into the interaction with the system or innate for an image of the system.

Indeed, as it is stated above, structure makes things such as they are. Naturally, structural nformation reflects this identity of things although structural information about different systems and objects can be similar.

4. Processes in a system can change structural information about this system.

Indeed, the evolution (development) of a system can produce an essentially new structure when the system is changed, even becoming another system. For instance, butterflies have the four-stage life cycle. In it, winged adults lay eggs, which later become caterpillars, which later pupate in a chrysalis, while at the end of the metamorphosis, the pupal skin splits and a butterfly flies off.

5. Structural information about a system describes this system to a definite extent of precision, i.e., structural information can be more precise and less precise.

For instance, the Copernican model (structure) of the solar system is more precise than the Ptolemaic model (structure) of the solar system. Another example comes from mathematics where mathematicians are striving to find the decimal structure of the number π with higher and higher precision.

6. For complex systems, it is possible to consider structural information on different levels and various scales.

For instance, it is possible to treat the structure of a human being on the level of visible parts, on the level of its functional systems, on the level of inner organs, on the level of cells, on the level of chemical compounds or on the level of molecules.

7. Structural information about a subsystem of a system is not always a part of the structural information about this system.

For instance, when we consider an organism as a system of its visible parts, the structure of its nervous system is not a part of this structure.

8. The process of conversion of structural information about a system into knowledge about this system is, in essence, structuration of this system.

Indeed, people get information about different objects in the form of raw data. Only after reception of this information, the brain converts these data into knowledge and this knowledge is often about the structure of studied objects. It is natural to treat data as symbolic representation of structural information, where correct structural information may be represented by symbolic information only within finite uncertainty, or even incorrectly. This may happen in the measuring device, or in the transmission or storage, or in the brain, etc.

Note that the general theory of information provides other possibilities for defining structural information. For instance, it can be information that changes the system of beliefs of an intelligent system.

4. Structural Information as an Intrinsic Property

At the same time, Feistel and Ebeling suggest the vision of structural information, in which structural information may no longer be restricted to changing just "knowledge in an intelligent system", and may more generally be defined as the capacity of a physical system, the "carrier of structural information", to cause changes in a second physical system, the "receiver of structural information" [4,5,7,8].

If in particular, the receiver is the same system as the carrier but at some later point of time, reversible microscopic dynamics described by the Liouville equation is universally understood as "conserving [microscopic] [structural] information" [28–30]. In contrast to this, irreversible macroscopic dynamics is commonly associated with a loss of [macroscopic] [structural] information, directly related to the growth of thermodynamic entropy (cf. [7,8]). In the sense of Planck [31], who wrote that "a macroscopic state always comprises a large number of microscopic states that combine to an average value", macroscopic structural information represents a portion of the microscopic structural information of a given system. This approach is consistent with the approach from Section 3. Namely, a system may have different structures, such as a microscopic structure and a macroscopic structure. In each of those structures, there exists related structural information. While the microscopic information may be conserved, the macroscopic information may decay according to the 2nd law of thermodynamics. That is, the different structures of the same system may possess different symmetries and may follow different laws. Irreducibilities of this kind indicate *emergent* properties or structures (see [8] and Section 5).

In his famous article "The RNA world" about the origin of life, Gilbert [32] wrote about "the useful distinction between information and function," that "information storage needs to be one-dimensional, for ease of copying, but molecules with enzymatic functions tend to be tight three-dimensional structures". This quotation demonstrates that the term "information" is in common scientific use in situations in which "knowledge in an intelligent system" does not exist at all, such as before life emerged on Earth. Gilbert refers to the structural information given by the sequence of building blocks in a chain molecule. This information is received later by the same molecule when it folds into a functioning enzyme, and by other reactants then catalyzed by it. Similarly, the information scientist Fuchs-Kittowski [33] speaks about "information" that was generated in evolution for the first time when life began, and has allowed living structures to survive to the present day. Without retaining this structural information, living beings would be as astronomically rare among random chemical mixtures [34], as are sensible books among the random texts in Jorge Luis Borges' "Library of Babel" [35].

Structural information available from a carrier depends on the receiver determining what portion of this information is actually received. If, for example, the receiver is a thermometer and the carrier is liquid, then all information received is the temperature of the liquid displayed by this thermometer. In essence, structural information can be extracted from a given system by "measurement" when, for example, a sensor is used as a receiver. Structural information also can be quantified when it is comparable to the structural information of a reference system and is reflected in a scale, such as the length scale of a mercury thermometer.

A numerical value being the result of a comparison between the same kinds of structural information available from two different systems, such as by counting their parts, is a "measurement result". Numbers represent information in the symbolic form, or as "symbolic information", see Section 5. The meaning of symbolic information is subject to convention (such as what "reference" system is used) and is no longer a portion of the structural information of the carrier, such as printed symbols on a sheet of paper. Very different structural information carriers can carry the same symbolic information. Symbolic information is restricted to the realm of life [4,7,8], such as having the form of genetic DNA molecules or human knowledge, and emerged from structural information in the course of evolution by a transition process regarded as ritualization.

The origin of life is a famous example for the ritualization transition from structural to symbolic information. Organic chain molecules, see the quotation of Gilbert [32] above, carried structural information in the form of certain sequences of their elements. Some of those resulted in catalytic properties that supported the copying of the chain molecule, such as in an RNA-replicase cycle [7,16,32]. In the course of evolution, the initial chain molecules developed to carriers of symbolic information in a complex multi-step process [7]. Similar features of the ritualization transition are observed, for example, when humans began to speak, or when digital computers replaced mechanical calculators.

The codons of the modern genetic code are the symbols used for representation of genetic information, and the phenotypic traits of the developed organism represent the meaning of that information. The symbols also carry structural information, but due to the arbitrariness of symbols in a mature coding system, this structural information is irrelevant for the meaning they express. The properties of the ink used by Mozart for writing down his music are irrelevant for the beauty of its acoustic performance.

The main distinction between structural and symbolic information is that the meaning of structural information is inseparably bound to its physical structure, while symbolic information is free insofar as arbitrary symbols may take over one and the same role in the information processing system. In this sense, symbolic information possesses the code symmetry, or coding invariance, that emerges during the ritualization transition [6,36]. The structural information of symbols that preserves traces of the evolution of the symbolic information-processing system is related to the code symmetry. Therefore, it is known that many spoken words have onomatopoetic roots. The similarity of words used in the various languages provides structural information about the migration histories of the populations. In the same way, the physical and chemical properties of the genetic apparatus carry structural information about the beginning of life in the ancient past.

5. Symbolic Information

Another important type of epistemic information is symbolic information.

Definition 1. *Symbolic information is information that is represented by systems of symbols.*

Note that it is possible that such a system may consist of one symbol.

For instance, texts form an important type of symbolic information. A printed or written text is typically a physical structure consisting of dark and light dots on the paper. The information carried by the text is in no way reducible to the physical properties of the given spatial distribution of dye or brightness. In this sense, symbolic information is an emergent property of texts.

Usually, the term *symbol* has two main meanings. In semiotics, a symbol is treated as a cognitive structure, which is a special case of signs. On the other hand, a symbol can mean a physical object written on a piece of paper, printed in a book, or displayed on the screen of a computer.

An *emergent property* is a property that exists as a process of its exposition. In this context, *emergence* conveys the empirical fact that "the whole is more than the sum of its parts" [37]. Now, many metaphorically express this phenomenon by the expression 1 + 1 = 3 (cf. for example, [38–40]). As a logical category, an emergent property can be defined as a property that is "novel and robust relative to some natural comparison class" [41]. Less rigorously stated, the term "emergence is broadly used to assign certain properties to features we observe in nature that have certain dependence on more basic phenomena (and/or elements), but are in some way independent from them and ultimately cannot be reduced to those other basic interactions between the basic elements" [42].

Consequently, as a result of the fundamental irreducibility of symbolic information to the structural information of its carrier symbols, which exists in alphabetic languages, such as English or German, it is a mere agreement which particular symbol is in use to represent a certain meaning. If everybody understood under the word "green" the color of the sky and under "blue" the color of leaves, all communication would work quite the same [43]. This explicates invariance as the new fundamental code symmetry of symbolic information with respect to substitution. If we change knowledge of those who communicate, then symbols may be substituted by physically different symbols without affecting the meaning of the message. This invariance is in striking contrast to structural information, where a different physical structure always implies different information.

In contrast to this, in pictographic and logographic languages, such as ancient Egyptian, Chinese, or Japanese, structure of symbols essentially influences their meaning. Such languages represent intermediate stages of the ritualization transition, from original iconic, "bound" structural descriptions, which do not require any special reading skills, to abstract, "free" symbolic descriptions such as computer bits, which cannot be deciphered without knowing the coding conventions [6]. There exist various other incompletely ritualized information systems, for example, human emotional tears.

The code symmetry has several important and general implications which elucidate the reasons for the self-organized emergence of symbolic information, repeatedly and in various forms, in natural evolution history. Symbols may alternatively appear as sequences, such as in languages, or as communication signals, such as neuronal transmitter substances or human gestures. Here are some of those key features:

(i) Discrete symbols are robust against small perturbations, i.e., symbols may be replaced by similar imitations. In simple information-processing systems, the receiver may be a dynamical system to which an incoming symbol appears as an imposed boundary or initial condition. Then, the system will approach an associated attractor state, which physically represents the meaning of the symbol. Often, the *attraction basin*, i.e., the set of conditions leading to the same attractor, is a compact set, and slightly modified symbols within that basin will cause the same attractor to be reached. As an example, written letters are recognized as being equal even if their symbols are displayed in different fonts, sizes, or colors. However, irregular handwriting, distortion or damage can essentially change interpretation of symbols by the receiver.

(ii) Reading a symbol can refresh it, permitting largely *lossless copies* to be produced if the refreshment happens within the physical lifetime of the symbol(s). Multiplying cells and organisms, but also computer memories, implement the refreshment technique for safe long-term data storage.

(iii) Robustness against small symbol perturbations permits *dialects* to evolve which increasingly use modified symbols that are similar in the sense that upon reading, they produce the same results as their originals. In turn, this process permits gradual deformation of the attraction basin, or even spawning of new basins, that is, *drift and diversification* of symbols; "If signals are under selection for efficient transmission between signaler and receiver, then populations inhabiting environments that differ in their effect on signal transmission or detection are expected to evolve different signals—a process known as 'sensory drive'" [44].

(iv) Symbolic information is *conventional*. A system of symbols may be replaced by a completely different set of symbols if this transformation is simultaneously applied to the message, the transmitter and the receiver. On a Chinese tablet computer, Chinese letters, their Latin transcription, and the related binary machine code are permanently exchanged by one another while a tablet is used. Genetic DNA or RNA bases, together with their complementary strains, represent the same information. Symbolic information is invariant against such arbitrary symbol transformations (substitutions).

(v) The replacement of a symbol by a physically different one, either with the same or with a different meaning, is energetically practically neutral. Symbols are "energy-degenerate" [14]. Any forces driving a modified message back to some fictitious distinguished "equilibrium message" are virtually absent. Physically formulated, so-called *Goldstone modes* with vanishing Lyapunov exponents appear along with the emergence of symbols (a process termed the *ritualization transition* [7,8], and permit exceptionally large fluctuations. Thermodynamically, particular messages appear as alternative "microstates" that populate a "Boltzmann shell" of an information processing system; "In principle, a sequence of symbols—such as the text of a given novel—represents a microstate" [16]. In fact the famous Boltzmann formula for the thermal entropy, $S = k \log W$, of an equilibrium system with W microstates equals Shannon's formula for the information capacity if converted to the unit "bit" [5].

(vi) As a result of the coincidence of structural and symbolic information immediately at the ritualization transition, in the Goldstone modes the structural information of the symbols keep a *trace of the evolution history* of the symbolic information system, until this trace may gradually be eroded by fluctuations and neutral drift. The physical form of symbols expresses and reveals their *historicity*.

(vii) Looking at symbols from the symbolic side, the code symmetry *impedes conclusions* to be drawn from the meaning of the information on the physical properties of symbols. Running a computer program does not permit deciding whether the memory bits are stored by, say, charging electrical capacitors or swapping magnetic fields. Introspection of our mind while thinking does not offer any clues on which transmitter substances may be released between synapses, or on the nature of nerve pulse propagation; "The faculty with which we ponder the world has no ability to peer inside itself or our other faculties to see what makes them tick" ([45] p. 4).

(viii) Looking at symbols from the structural side, the code symmetry *impedes conclusions* to be drawn from the structure of the symbols on the meaning of the symbolic message. "Information and computation reside in patterns of data and in relations of logic that are independent of the physical medium that carries them" ([45] p. 24). This means, *symbolic information is an emergent property*. The same message may be expressed by different symbols, tokens or languages; a sequence of symbols may be reversibly compressed or redundantly inflated without affecting the meaning of the message. In order to produce a cup of coffee, a single on/off bit may be sent to a coffee machine, or a long instruction may be given to an unexperienced cook to prepare an equivalent result. The same mathematical problem may be solved by very different program codes whose mutual equivalence remains elusive without knowledge about the receiver, namely the rules how to compile and execute the code and to convert the message back into structural information. This position differs from opinions like that of the sharp thinker Pearson ([46] p. 50) that "we may say … without any dogmatic assumption that psychical effects can all be *reduced* to physical motion".

(ix) Added redundancy, such as partial repetition or embedded grammatical rules combined with orthographic vocabularies, leaves the meaning of symbolic information immediately unaffected but allows additional information-protection tools to evolve for *error-detection* and *-correction* of random perturbations. During later stages after the ritualization, such tools partially counteract the neutral drift of symbols and constrict the set of available Goldstone modes. About half of written English text represents syntactic redundancy [47].

(x) Information processing of discrete symbols is performed by digital computers of any physical kind. Although Turing asserted, "This special property of digital computers, that they can mimic any discrete state machine, is described by saying that they are *universal* machines" ([48] p. 441), this is not true because digital computers cannot simulate (mimic) discrete state machines with an infinite number of states. Some think that computational universality suggests the possibility of simulating the human brain on an electronic computer [49]. However, this is also incorrect because nobody proved that the human brain is a discrete state machine. Moreover, it was demonstrated that even universal Turing machines are not *universal* in the realm of algorithms and automata because there are super-recursive algorithms, which are more powerful than any Turing machine [50,51].

Code symmetry, or coding invariance, is a key property of symbolic information that can be established after a complete ritualization transition. The physical carriers of symbols possess structural information apart from their symbolic meaning. Their physical structures maintain percussions of the symbols' evolution history over a certain characteristic relaxation time until random noise in the language development erases those traces.

Symbolic information has a number of general properties (Feistel and Ebeling, 2011):

(i) Symbolic information systems possess a kind a partial symmetry, the carrier invariance In many situations, it is possible to copy information without loss to other carriers or to multiply it in the form of an unlimited number of physical instances. The information content seems independent of the physical carrier used. However, many linguists doubt a possibility of exact translation of the text from one natural language to another one (cf. for example, [52,53]). This problem is also apparent as the absence of automatic translators between high-level programming languages, such as Fortran, Pascal, or C, demonstrates.
(ii) Symbolic information systems possess a new symmetry, the coding invariance. The functionality of the processing system is unaffected by substitution of symbols by other symbols as long as unambiguous bidirectional conversion remains possible. In particular, the stock of symbols can be extended by the addition of new symbols or the differentiation of existing symbols. At higher functional levels, code invariance applies similarly also to the substitution of groups of symbols, synonymous words or of equivalent languages.
(iii) Within the physical relaxation time of the carrier structure, discrete symbols represent quanta of information that do not degrade and can be refreshed unlimitedly.
(iv) Imperfect functioning or external interference may destroy symbolic information but only life-based processing systems can generate new or recover lost information.
(v) Symbolic information systems consist of complementary physical components that are capable of producing the structures of each of the symbols in an arbitrary sequence upon writing, of keeping the structures intact over the duration of transmission or storage, and of detecting each of those structures upon reading the message. If the stock of symbols is subject to evolutionary change, a consistent co-evolution of all components is required.
(vi) Symbolic information is an emergent property; its governing laws are beyond the framework of physics, even though the supporting structures and processes do not violate physical laws.
(vii) Symbolic information often has a meaning or purpose beyond the scope of physics.
(viii) In their structural information, the constituents of the symbolic information system preserve a frozen history ("fossils") of their evolution pathway.
(ix) Symbolic information processing is an irreversible, non-equilibrium processes that produces entropy and requires free-energy supply.
(x) Symbolic information is encoded in the form of structural information of its carrier system. Source, transmitter and destination represent and transform physical structures.
(xi) Symbolic information exists only in the context of life although this life can be natural or artificial.

Symbolic information is indispensable in the symbolosphere, which is situated as the highest level of existence finalizing the hierarchy *biosphere-sociosphere-noosphere-ideosphere-symbolosphere* [54–56].

Emergence of the *symbolosphere* is related to the development of language. The first oral or signed languages probably changed their form rapidly, leading to a multitude of language systems; "The diversity of human languages is a great example of the arbitrariness of human cultural history" ([57] p. 256). Then, about 5000 years ago, writing developed from iconic pictures in a ritualization process, essentially as a technology that amplified and made persistent the oral, nonmaterial, and invisible language component of the symbolosphere. The symbolosphere also includes, of course, mathematics, painting, music, sculpture, and photography, etc. In general, we can define symbolosphere as a component of our world in which symbols emerge, symbolic systems develop, function, and interact, and where symbolic interaction of people goes on. The symbolosphere includes all living beings that use symbols, as well as their technical and abstract creations.

Mathematics gives the most advanced example of a symbolosphere domain as in it symbolism is made explicit, achieving very high levels of abstraction. Formalism is the most extreme approach going in this direction. The main thesis of formalism is that mathematical statements are not about anything material, but are rather to be regarded as meaningless marks. The formalists are interested in the rules that govern how these marks are manipulated. Mathematics, in other words, is the manipulation of symbols. The fact that (a + b) + c = a + (b + c) is simply a rule of the system. The principle protagonist of this philosophy was David Hilbert.

However, many mathematicians disputed this approach. For instance, Gödel in 1961 wrote that the certainty of mathematics is to be secured not by proving certain properties by a projection onto material systems—namely, the manipulation of physical symbols but rather by cultivating (deepening) knowledge of the abstract concepts themselves, which lead to the setting up of these mechanical systems, and further by seeking, according to the same procedures, to gain insights into the solvability and the actual methods for the solution of all meaningful mathematical problems. Being a Platonist, Gödel represents another extremity in philosophy of mathematics, postulating independent existence of abstract mathematical objects in the sense of Plato Ideas. However, reality of mathematical objects and other structures was supported by philosophical and scientific analysis of reality as a whole [1,58,59].

In a more recent time, electronic technologies have been developed that further amplify the symbolosphere: the telephone, the telegraph, radio, television, fax, the Internet. A storm in the symbolosphere can have the same personal consequences as a storm in physiosphere. This world has a life of its own and cannot be controlled by "operationalizing our definitions", "using language carefully", or attempting to wall off language from "dangerous outside influences". The symbolosphere is subject to manipulation, but all attempts to control it eventually fail.

This realm of our existence must be viewed as part of an ecology that also includes the biological and physical world. Language is but one part of the symbolosphere, and grammar is an even smaller part. In the future, we will explore these ideas in detail, via radio, television, the fax, satellite-enhanced communication, and most recently, the Internet. All these technologies amplify the symbolosphere and maintain it as an open system in far-from-equilibrium states.

Humans inhabit the symbolosphere as much as the biosphere. These spheres of human existence are not separate: they intersect and interact. We must know how to deal with the vagaries of the symbolosphere, just as we deal with the vagaries of the physiosphere (i.e., weather, climate, radiation, tornado, typhoons, earthquakes, etc.).

It is necessary to discern symbolic information from *symbolical* information.

Definition 2. *Symbolical information is information that provides and/or changes knowledge about symbols.*

In other words, symbolical information acts on (impacts) the infological systems that contain knowledge about symbols. For instance, information on how to write letters from the English alphabet is symbolical information.

If we consider words as symbols, then information about meaning of words is symbolical. In particular, definitions of terms contain symbolical information. In essence, understanding of symbolic information is essentially based on symbolical information. Namely, understanding information coded by symbols demands understanding the meaning of these symbols.

6. Relations and Interactions between Symbolic Information and Structural Information

There are intrinsic relations and operational interaction between symbolic information and structural information. For instance, exploring the structure of the surrounding world by trial and error using mutation and selection in the course of Darwinian evolution, biological species accumulate in their gene pools symbolic information as successful recipes for their survival; "The theory of life is a theory for the generation of information" [16]. At the same time, symbolic information in genes is also structural information as it predetermines the inner structure of the evolving organism.

Similarly, scientists observe and investigate the structures encountered in nature and in laboratory experiments. Structural information is extracted and converted into symbolic information, in the form of articles and books, data tables, or oral lectures given to students and colleagues. Although we do not possess a suitable general theory for the formulation of information conservation laws valid for the research process, we feel intuitively that the amount of symbolic information produced cannot exceed the amount of structural information that is embodied by the research target. Formal approaches to such a putative conservation of information are often discussed as "no-free-lunch theorems" [60]. If there were a perpetuum mobile of the fourth kind that does nothing but generate useful symbolic information without input of structural information, a great deal of money could be saved which is currently spent on satellites, particle accelerators, or geological drilling. The invention of such a machine of universal knowledge is very unlikely even though its existence is not forbidden by any natural law we know of. Similar to the overwhelming empirical evidence for the validity of the Second Law, some people believe in the physical impossibility of a perpetuum mobile of the fourth kind based the experience that systematic prophecy and fortune telling often failed in the past. Winners of lotteries are not counted here as prophets. Humans tend to believe in divine beings, oracles, or superstition equipped with the gift of prophecy, but this wishful thinking is not supported by scientific observational evidence. Contemporary science was not able to observe information transfer against the arrow of time. However, science is always in the process of development and growth. As a result, it has been demonstrated that utilization of oracles can be very useful for people [59,61,62].

The assumed conservation of information during the transfer of structural information to symbolic information is also valid for the reverse process. Symbolic information has the purpose of being transformed back to structural information, in the form of actions taken based on the information, or of structures generated by symbolic instructions. The phenotype of an organism is an incarnation of its symbolic genetic information. Similarly, a technical product is an incarnation of symbolic recipes or construction plans. The final product is a structural representation of the former symbolic information—new phenotypic traits do not appear unless the genetic code includes the instructions for their ontogenetic development.

Conservation of information during the conversion processes between structural and symbolic information, as described before, is rather different from conservation of information during transmission processes from structure to structure, and from one symbolic information processor to another.

Structural information is transferred according to physical interaction laws. A quantum state, say, described by a wave function, transfers its information to the subsequent quantum state, as described by the time evolution of the Schrödinger equation. Physical interaction is materialized by the transfer of matter, energy, and entropy, and is governed by their respective conservation laws. The loss of energy of one of the interacting systems is accompanied by the equivalent gain of energy by another system, and so, information gained by such an energy transfer is accompanied by an equivalent energy loss at the other side.

Transfer of symbolic information, however, does not require that the gain of information by a receiver is necessarily at the cost of information loss at the information source. Newspapers, TV, and the Internet demonstrate that symbolic information, once available, may be "shared" by numerous receivers without degrading the original information. Sharing or broadcasting information is possible in ways that conserve the information. However, this process may increase or decrease the value of that information [8]. In this paper, we do not study changes of value in the processes of information transmission.

There are different ways to define the meaning of conservation of information. Two such options are measure-related conservation and transformation-related conservation.

(i) *Measure-related conservation* of information is realized if, in a process of conversion of a portion of information I to a different form I', a certain measure of information, e.g., S, remains the same, i.e., $S(I) = S(I')$. For instance, if I is the structural information of a macroscopic system at some time t, and I' is the structural information of that system at some later time t', and entropy S is the chosen measure of information, then information is conserved with respect to S in reversible processes. Similarly, it is possible to understand conservation of mass, spin, and electric and magnetic charge as the conservation of structural information [63].

(ii) *Transformation-related conservation* of information is realized if in a process of conversion of the form F of a portion of information I to a different form F', while both F and F' have the capacity to cause the same changes in a system R. According to the general theory of information both F and F' represent the same information. For instance, if I is the symbolic information in a textbook F written in a language L and F' is a contextual translation of the textbook F to another language, then for a student R the information is transformation-relatedly conserved if the translation is correct and R knows both languages to the same extent. The translation may be formally written as the operation T: $F \rightarrow F'$. It is possible to interpret conservation as existence of the inverse operator T^{-1}, a backward translation, such that $F = T^{-1}(F')$ and all translations T form a mathematical group. Similarly, structural information in quantum mechanics is subject to conservation in processes governed by a group of unitary evolution operators [28].

Independently of the particular way by which conservation of information may be defined in detail, we may state that, quite generally, conservation of information is understood as a binary relation between two portions of information, I and I'. More precisely, mathematically, this relation is a reflexive *equivalence relation* because it has the properties of *symmetry*, *transitivity*, and *reflexivity*. All portions of information, which pairwise are mutually information-conservative, form an *equivalence class*. If each element of this class can be generated from another, arbitrarily-chosen element by a certain transformation T, then this set of transformations forms a mathematical group.

In the context of this article, considering conservation of information is fundamental as it permits discrimination of processes that violate conservation, namely, processes that destroy or produce information. Several information theories, such as the one of Shannon, aim at suitable formal descriptions of non-conservative processes. Structural and symbolic information differ with respect to processes that generate information; typically, structural information is produced in processes of physical self-organization, while symbolic information is generated during evolutionary processes. Here, evolution is understood as a potentially unlimited succession of self-organization steps [7].

7. Conclusions

Approaches to structural and symbolic information studied here are related to the basic ontological problem of the role of an observer. Namely, the question is whether properties of physical things and relations between them exist by themselves or their existence is dependent on the presence of an observer. In Section 3 of this work, structural information is treated from the perspective of an observer although such an observer can be not only a human being but also any cognitive system. At the same time (in Section 4), structural information is regarded as an intrinsic attribute of physical things independent of any observer. Symbolic information is explored in Section 5 as information created and utilized exceptionally by an observer while interactions between structural and symbolic information are explicated in Section 6.

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