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CONCEPTUAL MODELS FOR INFORMATION AND KNOWLEDGE

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Abstract. *The paper aims to clarify some contradictory aspects that appear in studies on Information Science, proposing their approach with the new concept of the General Theory of Information (GTI). The main achievement of this theory is to provide a comprehensive and relevant definition of information, to whom in the present work is added an analysis of the direct relationship is established between information and knowledge. Starting from axiological and ontological principles proposed by the initiator of GTI, Mark Burgin, various theoretical approaches are analyzed, looking for common elements and unifying instances and how to evaluate their properties through adequate information measures. As a conclusion, it is argued that many other known directions of information theory may be treated inside GTI as its particular cases.*

Key words: information theory, informational system, information measures, knowledge meanings, information meanings

1. Introduction

In order to create a framework to study the conceptual models of information, it is mandatory to answer to two main problems related to it. The first one is to define what information is and to find what basic properties it has. The second problem is how to measure and evaluate information. From the beginning of the development of information theory, it was known more how to measure information than what information is. Hartley and Shannon gave effective formulas for measuring the quantity of information.

However, without understanding the phenomenon of information, these formulas bring misleading results when applied to irrelevant domains. At the same time, a variety of information definitions have been introduced. Scientists created a diversity of information theories: statistical (Shannon's theory of communication), semantic, algorithmic, qualitative, dynamic and so on. Naturally some of them have tried unification of these approaches into a general theory of information (GTI).

One of the first proposals was advanced by Burgin [1]. Burgin's GTI is built as a system of ontological and axiological principles that represent intrinsic properties of information and information processes. They reflect the most essential properties of information as a natural, social, and technological phenomenon as well as regularities of information functioning.

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2. Formal definitions for Information and Knowledge

Classical information theory was developed based on the principles set by Shannon in his seminal work on the transfer of data from a source to a receiver through a communication channel [2]. From the point of view of the general theory of communication, information should be seen as an intrinsic feature of a system, and not only transmitted information.

However, without reducing the degree of generality, we will consider the amount of information in a *receiver* system ***R*** varies with the changes in that system, i.e. information ***I*** for a system ***R*** is any essence causing changes in the whole system ***R***, or in an informational subsystem *IF(**R**)* of this system.

A. Information and its different meanings

The meaning of "information systems" has been growing in diversity and complexity; therefore a first step in the description of a systemic notion of information is to identify the meaning of information.

In the following the word "meaning" is used in its pragmatic sense, i.e. the *meaning* we will looking for the term "information" will be both its conceptual definition, as well as its respective practical consequences in the field of Information Systems and Informing Sciences.

The term "information" has been widely and increasingly used, but not always with a clear idea about its meaning. The word "information" is one of the most used, and much abused, words. Different scientific disciplines and engineering fields provide diverse meanings to the word, which is becoming the umbrella of divergent, and sometimes dissimilar and incoherent homonyms. When concepts are not clear, the use of homonyms might be intellectually and pragmatically dangerous.

We will try, here, to make an initial step, attempting first a conceptual definition of information that underlines its two aspects: subjective and objective.

Information has been frequently defined as "interpreted data" and, as such, the same data might cause different interpretations. An interpretation is, by its own nature, *subjective*. Consequently, it is easy to conclude that according to this kind of definition there is no IS without a subjective sub-system, i.e. any IS should have at least two subsystems: an *objective* (mechanical and/or electronic data processing subsystem) and a *subjective* one (biological/human data/information processing: a user, a manager, etc).

One can consider that the objective information is external to human beings, but is created by them. What might be called *objective information* is a representation of the real information, which always is a subjective one in its origin and essence.

Therefore, the conclusion is evident: information is generated inside the mind of a person, a subject. It is not an objective entity independent of any person. It is dependent on the person where it is generated by the data stimulus, as well as on his/her individual experience.

Callaos [3] defined information as “decision-relevant data”, which makes of it something requiring a special kind of subjectivity, a strict subjectivity that exclude the possibility of trans-subjectivity, due to the personal nature of “decision” and “relevant decision”, because decisions are always subjective, and relevancy is always related to a given subject.

Consequently, we can observe that subjective reception of the data is a *necessary* condition for in-formation generation, but it is not a *sufficient* one. It is important to find out the additional conditions that data should comply with, in order to be informative. So, we can draw the following conclusions:

- a datum is a “*given*” thing, not any “given” thing, but the one that makes a *difference*
- information is a cognitive content, not any cognitive content, but the one related to the *association of data and a relevant question*, be it implicit or explicit
- data and information are like the two sides of the same coin: datum is the *objective* side of the coin and information is its *subjective* side. This relation might be seen as analogous to the relation between the *signifier* (the objective/material side of a sign) and the *signified* (its subjective/mental side), in semiological terms.

B. Knowledge and its different meanings

In the most used interpretation, knowledge is what makes people able to perform actions, and in this way we can say that knowledge is what makes organisations (structures, systems) work. Viewing knowledge as a critical asset implies efforts to utilise, improve, and disseminate knowledge in the organisation.

Going back to the origin the word “knowledge”, one early epistemological philosopher who has put forward a distinct approach to knowledge is Aristotle. Aristotle builds on Plato’s definition of knowledge, which is said to be *true, justified beliefs*. In a strict sense this form of knowledge is theoretical-scientific knowledge (*episteme*) and represents *knowledge about something*. *Techne* is another form of knowledge that Aristotle presents, which concerns skills and ability to do something. While *episteme* comes from true, justified beliefs, *techne* emanates from what we do, i.e. individuals’ actions. Thus *techne* is connected to a pragmatic dimension of knowledge.

The third form of knowledge Aristotle talks about is *phronesis*, which is also a form of practical knowledge that has its starting-point in knowledge-in-action, just as *techne* is. *Phronesis* concerns practical sense making and aims at enhancing humans' well being. Hereby, *phronesis* includes both political and ethical dimensions.

If we look at these two forms of knowledge, they have been used as foundations for several different epistemological approaches. For example, Popper asserts that knowledge in its objective (and for science the only interesting) sense is knowledge without anyone who knows, i.e. knowledge without a knowing subject [4]. This view of knowledge might be equivalent to *episteme*. *Techne*, on the other hand, represents the pragmatic tradition of knowledge and one author who has asserted this approach is Peirce [5].

The question is whether knowledge is always subject-related, or if knowledge could take the shape of an object. The interpretation, understanding, and use of knowledge are different knowledge-focused processes. In this way knowledge is often, if not always, related to a specific context.

Nevertheless, knowledge is not exclusively situated or completely bound to its context. What needs to be emphasised is that knowledge descriptions should not be considered as knowledge *per se*, it is just representations of someone's personal knowledge. The translation of objective knowledge to subjective knowledge within the receiver always requires interpretation, understanding, and the use of language.

C. The relations between information and knowledge

Information and knowledge are important part of the world surrounding us, as well as part of ourselves. There are a large number of definitions of information in relation with knowledge. Drucker says that information is data endowed with relevance and purpose. The conversion of data into information thus requires knowledge, and knowledge is specialized [6].

Turban et al. have a similar definition, and mean that one of the primary goals of an information system is to process data into information and knowledge [7].

These authors refer to data as elementary descriptions of things, events, activities, and transactions that are recorded, classified, and stored but not organized to convey any specific meaning. They treat information as data that have been organized so that they deliver meaning and value to the recipient.

Finally, they say that "knowledge is said to consist of data or information that have been organized and processed to convey understanding, experience, accumulated learning, and expertise as they apply to current problem or activity".

The relations between data, information, and knowledge are often used in order to describe the meaning of and relation between the three words.

In spite of the great number of definitions that are available in order to explain the meaning of information (and data, and knowledge), the notion is still not very clear.

One can actually say that the definitions stated above are more mystifying than clarifying. The major basis of this criticism is that the definitions leave us uncertain as to when information, data and knowledge exist (their ontological determination).

But not much has been done regarding the notion of meaning by itself, whatever the information associated to it or the system managing it. It is this aspect of relations linking information and meaning we are interested in.

We propose that there can be some common ground for most types of meanings, and that this common ground can be explicated by defining a basic system managing the information and the associated meaning.

Therefore, let's formulate some characteristics relative to the notion of meaning we are trying to conceptualize, in order to bring up a "systemic aspect" for the framework of the relations between an information processing system and information received by this system.

1) A meaning is associated with information which is incident on a system capable of processing the information.

2) Meaning is generated because the information processing system possesses a constraint linked to its nature.

3) A meaning is generated because the incident information has a connection with the constraint of the system.

4) A meaning is meaningful information relatively to the constraint of the system.

5) The meaningful information is going to participate to the determination of an action that the system is to implement in order to satisfy its constraint.

Based on these five characteristics, let now define a mixed concept of the informational system IF(R) that dissolves the objective-subjective dichotomy and focus on what relates and communicates them, i.e. what is common to both of them.

Definition 1. A subsystem *IF*(***R***) of the system ***R*** is called informational system of ***R*** if *IF*(***R***) contains informational elements place it not just in the subject, or in the object, but in both of them and in what relates them.

In the next section are presented the basic principles that allow considering *IF*(***R***) compatible with the requirements of Burgin's general theory of information.

These principles explain how to evaluate information and what measures of information are necessary in this aim.

3. Basic Principles of the General Theory of Information

According to the ontological principles ([8]), it is natural to assume that measure of information is determined by the results that are caused by reception of the corresponding portion of information.

Principle 1 (the ontological principle). An arbitrary complex system ***R*** has, as a rule, different informational subsystems. Fixing one of these subsystems, we determine what information for ***R*** is and changing our choice of IF(***R***) we change the scope of information entities.

This principle implies that for a complex system there are different kinds of information. Each informational system determines a specific kind of information. For example, information that causes changes in the system of knowledge is called cognitive information.

Distinction between knowledge and cognitive information implies that transaction of information does not give knowledge itself. It only causes such changes that may result in the growth of knowledge.

Principle 2 (the relational principle). Considering (***R, L, E***) a triadic complex where ***R*** is a system which receives information, ***E*** is the environment of this system and ***L*** represent different links between ***R*** and ***E***, there are three structural types of measures of information: external, intermediate, and internal.

An internal information measure reflects the extent of inner changes caused by ***I***. An intermediate information measure reflects the extent of changes caused by ***I*** in the links between ***R*** and ***E***. An external information measure reflects the extent of outer changes caused by ***I***, i.e., the extent of changes in ***E***.

Principle 3 (the axiological principle). There are three constructive types of measures of information: abstract, realistic, and experiential. An abstract information measure is determined theoretically under general assumptions.

A realistic information measure is determined as subject to realistic conditions. Quality of information is an example of such measure. An experiential information measure is obtained through experimentation.

According to this principle a unique measure of information exists only for oversimplified system. Any complex system ***R*** with a developed informational subsystem *IF(**R**)* has many parameters that may be changed. So, such systems demand many different measures of information in order to reflect the full variety of these systems properties as well as of conditions in which these systems function.

Principle 4 (the communication principle. Measure of information ***I***, which is transmitted from a source of information ***S*** (Sender) to a system ***R*** (Receiver), depends on interaction between ***S*** and ***R***. A system ***R*** receives information ***I*** only if some carrier ***C*** of ***I*** transmits this information through some channel ***CH***.

This principle corresponds to the traditional communication model defined by Shannon. Communication process as a total event has been a subject of many studies, and consequently many models have been suggested, but in all cases a measure of information transmission reflects a relation between measures of information that is accepted by the system ***R*** in the process of transmission and information that is presented by ***S*** in the same process.

4. Theoretical approaches in the Information Science

We consider Information Science as a most appropriate term than Information Theory to cover the multifaceted models for information and knowledge.

In the same time, we consider that the various developed theoretical approaches in Information Science are particular cases of the General Theory of Information because they explicitly or implicitly consider treat information from the functional point of view as a kind of transformations in a system.

To prove this, we find in each case a relevant informational system *IF(**R**)* and demonstrate that in each of these approaches information is what changes this system.

<u>The Statistical Information Theory</u>

The *statistical* approach is now the most popular direction in the information sciences. It is traditionally called Shannon's information theory or, as it was at first named by Shannon, the theory of communication.

It is a mathematical theory formulated principally by the American scientist Claude E. Shannon to explain aspects and problems of information and communication.

The basic problem that needed to be solved, according to Shannon, was the reproduction at one point of a message produced at another point. He deliberately excluded from his investigation the question of the meaning of a message, i.e., the reference of the message to the things of the real world.

While the statistical theory of information is not specific in many respects, it proves the existence of optimum coding schemes without showing how to find them.

For example, it succeeds remarkably in outlining the engineering requirements of communication systems and the limitations of such systems.

In the statistical theory of information, the term information is used in a special sense: it is a measure of the freedom of choice with which a message is selected from the set of all possible messages.

Information is thus distinct from meaning, since it is entirely possible for a string of nonsense words and a meaningful sentence to be equivalent with respect to information content.

Shannon proposes also a measure unit: information is measured in bits. One bit is equivalent to the choice between two equally likely choices. A special measure that is called quantity of information of a message about some situation is defined by the informational entropy *H(p)*, $H(p) = -\sum_{i=1}^{N} p_i \log p_i$ where N is the number of possible cases of the situation in question and p_i is the probability of the case i.

So, information is considered as elimination of uncertainty, i.e., as a definite change in the knowledge system that is the informational system *IF(**R**)* of the receptor of information. Since the information content is, in general, associated with a source that generates messages, information is often called the entropy of the source.

To this day, there is no measure in information theory that is as well-supported and as generally accepted as Shannon's quantity of information.

On the other hand, Shannon's work is rightly seen as lacking indications for a conceptual clarification of information. As a result, other directions have been suggested in information science.

The Semantic Theory of Information

The semantic theory of information tries to encompass semantic aspects of information because some experts in information sciences consider meaning as the essence of information. This approach is based on the assumption that every piece of information has the characteristic that it makes a positive assertion and at the same time makes a denial of the opposite of that assertion.

In the semantic information theory**,** transformations of such informational system as thesaurus ***T***, or system of knowledge, are treated as information. The founders of this approach, Bar-Hillel and Carnap build it as a logical system [9]. Thus, the informational systems in this theory are sets of logical propositions. These propositions are used to describe and represent the state of an arbitrary system.

The corresponding measure of information is defined for a separate proposition as the probability that this proposition is a part of the description of the real state of a system under consideration. Thus, information causes change in knowledge about this state.

The Qualitative Information Theory

In the qualitative information theory, the following definition is given: Information is a transformation of one communication of an information association into another communication of the same association [10]. So, here the informational system *IF(**R**)* is some information association and information is a transformation of ***R***.

The Algorithmic Theory of Information

The principal aim of the algorithmic theory of information is the development of more realistic concepts of randomness and probability than those that are in the traditional theory of probability. This new approach was suggested in the works of three authors: Solomonoff [11], Kolmogorov [12], and Chaitin [13]. The main idea was that algorithms play a leading role in many processes, including people behavior. Consequently, theory of algorithms has to be central in a study of such processes.

In the algorithmic information theory, there are two kinds of measures of information. The first one is called the entropy, or information content, or complexity of finite constructive objects (like strings of symbols). Such algorithmic measure of information is defined to be the number of bits (or symbols) needed to specify the object in question so effectively that it can be constructed.

This measure is called the Kolmogorov complexity of *x* and is denoted by ***K**(x).* By the definition, this is the measure of such a transformation as a construction of some object. It is an external measure of information that acts on such informational system *IF(**R**)* as thesaurus, or the system of knowledge.

Knowledge in this system is represented by strings of symbols (texts) that have meaning. It is possible to define a more general measure of information of the first type. It is called a generalized Kolmogorov complexity measure.

Generalized Kolmogorov complexity measures reflect a measure of resources needed to construct the object in question. Generalized Kolmogorov complexity measures are dual to computational complexity measures.

The Pragmatic Theory of Information

The concept of pragmatic information was introduced by Ernst Ulrich von Weizsäcker [14] and further developed by von Lucadou [15], Kornwachs [16] and some others. This concept relies on the two notions: *firstness* (“Erstmaligkeit”) or originality or novelty, and *confirmation* (“Bestatigung”) or redundancy to already known. Weizsäcker suggests that a message that does nothing but confirm the prior knowledge of a receiver will not change its structure or behaviour.

Thus, with confirmation up to 100%, a message gives no pragmatic information. On the other hand, a message providing only original/novel material completely unrelated to any prior knowledge also will not change structure or behaviour of the receiver, because the receiver will not understand this message.

Thus, with firstness up to 100%, a message gives no pragmatic information. Only a relevant mixture of firstness and confirmation allows the receiver to get pragmatic information from the message.

Thus, pragmatic information, according to Weizsäcker, is related to changes of structure or behaviour of the receiver. In such a way, pragmatic information acts on the observed system. This entirely corresponds to the concept of information in the general theory of information.

However, the general theory of information allows us to go further and to consider two opportunities of change. In one case, behavior of the system under observation changes. It corresponds to an action on the behavioral informational system. In the other case, changes only information that we get from the system under observation. It corresponds to an action on the representational informational system.

The Utility Theory of Information

In the utility theory of information [17]**,** the measure of information is called the quality of information. It is defined for mission oriented systems ***R***. If ***I*** is some portion of information, then the quality of this information is equal to the caused by ***I*** change of the probability *p(**R**, g)* of achievement of a particular goal *g* by the system ***R***.

If we consider objective probability, then the corresponding informational system is the state space of the world in which system ***R*** functions. If we consider subjective probability, then the corresponding informational system is the belief space in which probabilities for different events involving system ***R*** are represented. In both cases, information appears as a change in the corresponding informational system.

The Dynamic Theory of Information

The principal aim for the development of the dynamic theory of information was investigation of biological information and information processes in living systems [18].

In the dynamic information theory, the notion of information is taken as a basic one. Information is considered as a sequence of two operations: choice of one alternative from a collection of possible alternatives and saving the chosen alternative. Thus, information is also treated as an action causing transformations.

The Evolutionary Information Theory

Evolutionary information theory [19] is a constructive approach that studies information in the context of evolutionary processes, which are ubiquitous in nature and society. It corresponds to Burgin interpretation of the Dynamic Theory of Information as component of the General Theory of Information, which built several measures of evolutionary information based on mathematical models of evolutionary computations, machines and automata.

The first class of measures is the evolutionary information size of symbolic objects relative to classes of automata or machines.

The second class of measures for evolutionary information in symbolic objects is studied by introduction of the quantity of evolutionary information about symbolic objects relative to a class of automata or machines.

As main applications, this theory allows to study relations between evolutionary information and quantum information and to study biological information in general and genetic information in particular from the evolutionary information perspective.

The Integrated Information Theory.

Integrated information theory (IIT), despite its name, has nothing to do with the term “information” as it has been previously discussed, but indirectly refers to knowledge, specifically how someone becomes aware (conscious) of what he know. IIT attempts to explain what consciousness is and why it might be associated with certain physical systems.

Given any such system, the theory predicts whether that system is conscious, to what degree it is conscious, and what particular experience it is having.

According to IIT, a system's consciousness is determined by its causal properties and is therefore an intrinsic, fundamental property of certain causal systems. IIT was proposed by neuroscientist Giulio Tononi in 2004, and has been continuously developed over the past decade. The latest version of the theory, labeled IIT 3.0, was published in 2014 [20].

IIT argues that the existence of an underlying causal system with these same properties offers the most parsimonious explanation. The properties required of a conscious physical substrate are called the "postulates".

A "physical system" is taken to be a set of elements, each with two or more internal states, inputs that influence that state and outputs that are influenced by that state (neurons or logic gates are the natural examples).

Given this definition of "physical system", the postulates are:

- *Intrinsic existence:* To account for the intrinsic existence of experience, a system constituted of elements in a state must exist intrinsically (be actual).

- *Composition:* The system must be structured: subsets of the elements constituting the system, composed in various combinations, also have cause-effect power within the system.

- *Information*: The system must specify a cause-effect structure and a specific set of specific cause-effect repertoires. A cause-effect repertoire characterizes in full the cause-effect power of a mechanism within a system by making explicit all its cause-effect properties.

- *Integration:* The cause-effect structure specified by the system must be unified: it must be intrinsically irreducible to that specified by non-interdependent sub-systems obtained by unidirectional partitions. Intrinsic irreducibility can be measured as integrated information (“big phi” or Φ, a non-negative number), which quantifies to what extent the cause-effect structure specified by a system’s elements changes if the system is partitioned (cut or reduced) along its minimum partition (the one that makes the least difference). This postulate also applies to individual mechanisms: a subset of elements can contribute a specific aspect of experience only if their combined cause-effect repertoire is irreducible by a minimum partition of the mechanism (“small phi” or ϕ).

- *Exclusion:* The cause-effect structure specified by the system must be definite: it is specified over a single set of elements - the one over which it is maximally irreducible from its intrinsic perspective (Φ^{max}). This implies that a mechanism cannot specify a cause-effect repertoire at a particular temporal grain, and additional effects at a finer or coarser grain, otherwise the differences a mechanism makes would be counted multiple times.

Let’s finally note that in order to apply the IIT formalism to a system, its full transition probability matrix (TPM) must be known. The TPM specifies the probability with which any state of a system transitions to any other system state.

5. Conclusions

It is necessary to remark that the modern approaches consider information as some kind of knowledge. More exactly, in modern information theory, a distinction is made between structural-attributive and functional-cybernetic types of theories. The representatives of the former approach conceive information as structure, like knowledge or data, variety, order, and so on; members of the latter understand information as functionality, functional meaning or as a property of organized systems. The general theory of information treats information from the functional and, more exactly, dynamic perspective. A structural-attributive interpretation does not represent information itself but relates to information carriers. Consequently, structural-attributive types of information theories are also included in the scope of the general theory of information because structures and attributes are represented in this theory by informational elements and their properties and systems.

As conclusion, we can observe that the general theory of information makes it possible to solve many open problems related to information and achieve a new profound understanding of information as a natural, technological, and social phenomenon. It provides for systematization of almost all other approaches in information sciences eliminating many of their shortcomings.

In particular, a new, more adequate definition of information is obtained. In addition, it allows us to discover new types of information: cognitive, conditioning, and regulative information. Cognitive information gives knowledge and thus, it is what people know under the name of information.

Two other types are new and help to understand many phenomena in system functioning. This discovery of new types of information makes possible to determine the role of information for system functioning.

Conditioning information is basic for any system from the perspective of its inner evolution. Regulative information is basic for any system from the perspective of its interaction with environment. Cognitive information appears only on higher levels of system development.

The role of cognitive information increases with the development of a system and becomes decisive on some level of this development.

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