Cohesion and Complex Systems Structure

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Abstract : In the self-organizing complex dynamical systems that form holarchies, the decisions (or reactions) of their components (constituents) sometimes are crucial because they may involve the proper existence of the system. Additionally, in the real world, these components are immersed in highly complex environments of which have an incomplete or inadequate knowledge and they can't be completely consistent about their preferences and their beliefs, can show a bounded rationality, etc.. All these circumstances affect the way in which the components not only behave, but also emerge and disappear. In this work the necessary and sufficient conditions previously given for the holons formation are reviewed in the light of these facts using for the uncertainty/randomness handling the fuzzy probabilities theory (thus modeling the decision making process through the fuzzy decision making under risk theory), and, from these conditions, the concept of holon cohesion is derived and introduced as a generalization of the reliability of a system.

Keywords: emergence conditions, fuzzy probabilities, holon, holon cohesion, informon, self-organization

1. Introduction

The holonic paradigm [1-3] is based in the concept of decision (or reaction): a holon is an entity that decides/reacts based on information (informons) that interprets from data obtained from its environment [2]. These decisions are neither always deterministically determined by the informons in use nor they are always coherent: for example, in the case of human holons, it's well known that sometimes the decision that produces the greatest utility is ignored. This variability in the chosen actions can be modeled using type-2 fuzzy sets as it has been already done in or, in this case, using the fuzzy probabilities theory [6-7]. Using this formalism for the handling of the uncertainty and randomness we re-state the emergence conditions for a holon from a set of other holons, in a more detailed (and perhaps realistic) way than the originally given in [17].

This work is organized as follows: next the concept of holon and informon are briefly outlined together with the related work; in the section III the conditions for the emergence of a holon are reviewed, using fuzzy probabilities, then the section IV introduces the concept of cohesion and next, in

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the section V, an example is given, and in section VI many conclusions and ideas about possible future work are stated. The bibliography completes this work.

2. Preliminary Concepts and Related Works

2.1 Self-organization

In this work we continue the study of the structuring of complex systems from the standpoint of the beliefs and decisions of its elements. In the special case of a multi-agent system (MAS), self-organization will be understood as the "process enabling a systems to change its organization without explicit command during its execution time" instead of "… execution time". We can generalize this definition for any self-organizing system by rephrasing it as "… during its lifetime" in order to include living systems, such as human social groups.

2.2 Holon

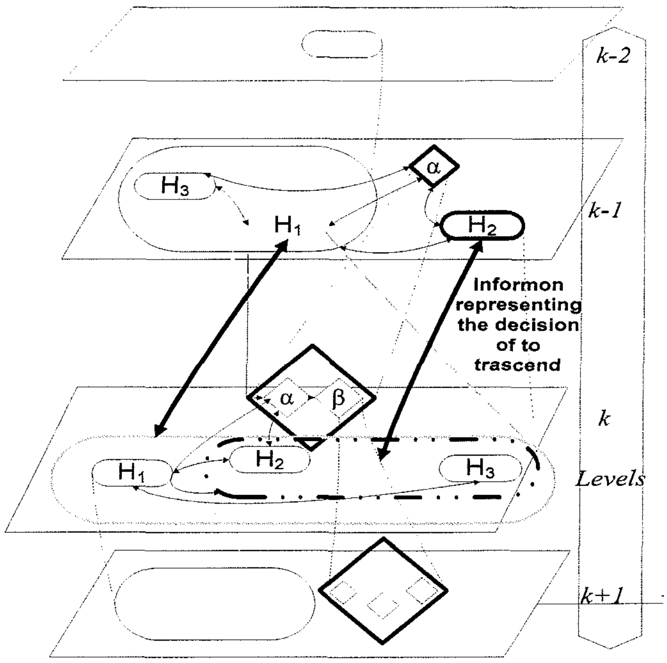
The concept of holon was introduced by Arthur Koestler referring to entities such as living systems or social organizations that can be considered as a whole and as a part at the same time [10]. Holons forms dynamic hierarchies called holarchies which are characterized by making efficient use of the available resources, being highly resilient to disturbances and adaptable to changes in their environments [4]. Holonic applications in the manufacture industry are being broadly studied: see for example [4, 13, 18]

Turnbull [20] distinguishes between strong holons and weak holons. Strong holons can exist autonomously while weak holons cannot exist without the rest of the holarchy. In this work we'll only consider the strong ones. Examples of natural holons are a cell, a human liver, a workgroup or the solar system; an autonomous multi-agent system or a (holonically organized) factory could be examples of artificial holons.

Holons can be seen as embodied abstract agents (that is, agents that have a physical part interacting with their environment).

2.3 Informon

The concept of informon was defined by Williams Sulis in the context of complex dynamical systems [19]. In this work, we'll adopt a definition similar to the Sulis' one given by Alonso et al.[2]: "informon is the basic element of information that has sense for a holon and that allows it to make the right decisions and to execute the proper actions" . These decisions and actions will generate new informons that will affect the own holon and the ones in its environment. Holons react to, and plan based on, informons. Informons can be seen as perturbations from the environment to the holons, a series of stimuli that are received and affects the holons and can be considered as distributed in semantic layers which correspond approximately to the levels of the affected holons. For example, a news (say, the birth of a son) will affect significantly the behavior of the boy's father (a human holon), in less degree the functioning of his working environment (a higher level holon) but almost surely it won't affect the behavior of a whole nation or continent: the informon is meaningful (or, to be precise, exists) only for a certain set of holons grouped in levels (see Figure 3).



Influence of informons α and β in different levels of holons. Note that α in the level k is a different informon respect to α in the level k-1: $\alpha^{(k-1)}$ can be interpreted as formed by $\alpha^{(k)}$ and $\beta^{(k)}$

Figure 3.

Informons can be equated to the information granules of the granular computing paradigm [3].

2.4 Emergence and Dissolution

Two processes characterize holons: emergence and dissolution. Holons emerge from others and disintegrate later in its components in a continuous process [22]. When a holon participates in the emergence of another, one says that the former transcends. In [17] were presented conditions (necessary and sufficient ones) for the emergence of a new holon from a set (system) of holons that

a) are supposed to do what gives them more utility
b) are coherent (the greater the utility, the stronger the preference)

and assuming that the conditions for the auto-organization of the system are present [8].

By utility we mean a number associated to the consequences of an action (or attitude), not necessarily an economic value. These consequences could include aspects such as related with faith or emotions and would represent the holons preferences [12]. Utility doesn't describe completely the consequences, it is just a number, and can be seen as related to a set of goals to be reached, that is, the holon has many goals at a given instant, being active or in use only some of them. Many authors have proposed vectorial utility functions **U** (for example; with one dimension for each goal, as in [1]); in such a case, our utility U would be a certain scalar function of the vectorial utility function: $U=U$ (**U**) so we could define a total order for the utilities (U would be the "world utility" of the COIN framework [1]).

Ulieru [21] has proposed the minimization of the fuzzy entropy related to the achievement of a goal as a criterion for the structuring of holons: holons will tend to group in a way such this entropy is minimized.

2.5 Uncertainty and Randomness

A tremendous amount of work has been done on the representation and handling of the uncertainty and randomness specially in the last decades; a brief discussion from the holonic standpoint can be found in [17]. A very recent approach has been the use of fuzzy probabilities [6] which allows to represent probabilities of which there is no certainty; one important application of it is the fuzzy decision making under risk theory with which we'll model the incongruities that appear in the human and organizational decision making processes; other authors have done this using type-2 fuzzy sets [15-16].

2.6 Preliminary Notation

a) Given a crisp number X, its fuzzy version will be denoted as $\overline{X}$ and, in turn, the α -cuts of $\overline{X}$ will be denoted as $\overline{X}[\alpha]$.

b) An expression of the form **a**|C should be understood as "**a** provided the condition C holds" [7]

c) The relators $\leq$, $<$ and $\approx$ are the extensions for fuzzy numbers corresponding to $\leq$, $<$ and $=$ for crisp numbers as defined, for example, in [7].

3. Utilities, Decision Making and Holons Structuring

In [17], given a set of holons $\{H_1^{(k)}, H_2^{(k)},...H_n^{(k)}\}$ of the level k, and considering that a holon emerges so at least some of its components can reach a goal or improve their utility, its concluded the necessary condition for the existence (or emergence) of a holon of higher level, let's call it $H_i^{(k-1)}$ at a given instant (the instant at which the informon is considered)::

$$E(U(H_i^{(k-1)})) \geq \min_j\{E(U(H_j^{(k)}))\} \tag{1}$$

while the sufficient condition is

$$E(U(H_i^{(k-1)})) > \max_j\{E(U(H_j^{(k)}))\} \tag{2}$$

where U is the before mentioned scalar utility function and $E(\bullet)$ the expected value.

Note that when stating these conditions we are assuming that there are no external forces or restrictions affecting the self-organization of the system: for example, the fusion of two companies might not take place due to anti-trust government regulations; a person may join workgroup just because every area of the company must be represented in it, although some of its integrants (the representatives) don't do anything to increase the goals reaching capacity of the group.

These perhaps obvious equations were obtained under the assumptions given in 2.4, which are not always valid for a specific holon. To represent this and the related lack of certainty in the decisions made (implying the emergence and dissolution of the holon), we can use an extension the fuzzy probabilities theory (more precisely, of the decision making under risk theory, see [6-7]) using a fuzzy utility function. Thus, given

(a) a set of informons $\{\beta_1^{(k)}, \beta_2^{(k)} \ldots \beta_m^{(k)}\}$ each of one can be present with an uncertainty represented by $\overline{\Lambda}_i \quad i=1,...p$,

(b) which influence a holon to make a decision (or to react with a reaction) chosen from a set of actions (reactions) $\{a_1, a_2 \dots a_p\}$

(c) the probabilities $p_{i,j} \quad j = 1,\dots n$ that action a_j is chosen given the (fuzzy) presence of informon $\beta_i^{(k)}$,

(d) an utility $U_{i,j} \equiv U(\beta_i^{(k)}, a_j) \in \overline{U_{i,j}}[\alpha]\ \forall \alpha \in [0,1]$ being $\overline{U_{i,j}}$ a fuzzy function that assigns an utility to the execution of an action a_j when the informon $\beta_i^{(k)}$ is present,

the problem of decision making for the holon $H_r^{(k)}$ lies in finding the action a_j such as $E(U(\beta_i^{(k)}, a_j)) \equiv E_{i,r}^{(k)}$ is maximum:

$$E_{i,r}^{(k)} \in \overline{E_{i,r}^{(k)}}[\alpha] = \sum_j U_{i,j} p_{i,j} \mid \begin{cases} p_{i,j} \in \overline{p_{i,j}}[\alpha], \ U_{i,j} \in \overline{U_{i,j}}[\alpha] \\ \alpha \in [0,1], \ \sum_i p_{i,j} = 1 \end{cases}$$

(we omitted the index r in the function U to avoid a even more recharged notation). Different values of α in the α–cuts will allow us to model the cases of bounded rationality in the holons, lack of coherence in the utility, etc. Given this scenario, we can rewrite equations (1) and (2) as (3) and (4):

$$\begin{cases} E_{i,r}^{(m)} = E(U(\beta_i^{(m)}, a_j)) & \forall m \quad for\ H_r^{(m)} \\ E_{i,r}^{(m)} \in \overline{E_{i,r}^{(m)}}[\alpha] & \forall m, i\ \forall \alpha \in [0,1] \\ \overline{E_{i,r}^{(k-1)}} \geq \min_j \{\overline{E_{i,j}^{(k)}}\} & \forall i, r, k \in \mathbb{N}^+ \qquad (3) \\ \overline{E_{i,r}^{(k-1)}} > \max_j \{\overline{E_{i,j}^{(k)}}\} & \forall i, r, k \in \mathbb{N}^+ \qquad (4) \end{cases}$$

Different definitions (choices) of $\leq$ and $<$ would allow to increase the cases that are comprised by the equations (such as when the best option is not chosen). For example, for two fuzzy numbers $\overline{X}, \overline{Y}$ with membership functions $X(\bullet), Y(\bullet)$ we could have:

(a) $\overline{X} < \overline{Y}$ *iff* $\overline{X}[\alpha] < \overline{Y}[\alpha] \quad \forall \alpha \in [0,1]$

(b) $\overline{X} \leq \overline{Y}$ *iff* $\overline{X}[\alpha] \leq \overline{Y}[\alpha] \quad \forall \alpha \in [0,1]$ *and taking as definition of "$\leq$" between two intervals* $I_1 \equiv [a,b]$ *and* $I_2 \equiv [c,d]$ *:* $I_1 \leq I_2 \Leftrightarrow \quad a \leq c \wedge b \leq d$ (and analogously for <).

(Definition 3.1)

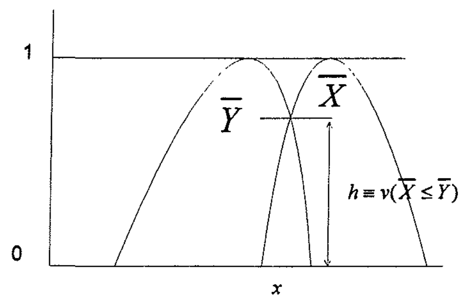
Another option could be to use as definition of < the one given in [7, 9]:

Be $v(\overline{X} \leq \overline{Y}) \equiv \sup_y \{\min_x \{\overline{X}(x) \leq \overline{Y}(y) \mid x \leq y\}\}$. *We say that*

(a) $\overline{X} \leq \overline{Y}$ *iff* $v(\overline{X} \leq \overline{Y}) = 1$

(b) $\overline{X} < \overline{Y}$ *iff* $v(\overline{X} \leq \overline{Y}) = 1 \ \wedge v(\overline{Y} \leq \overline{X}) < \eta$ *being* η *a fixed real in (0,1]* (Definition 3.2)

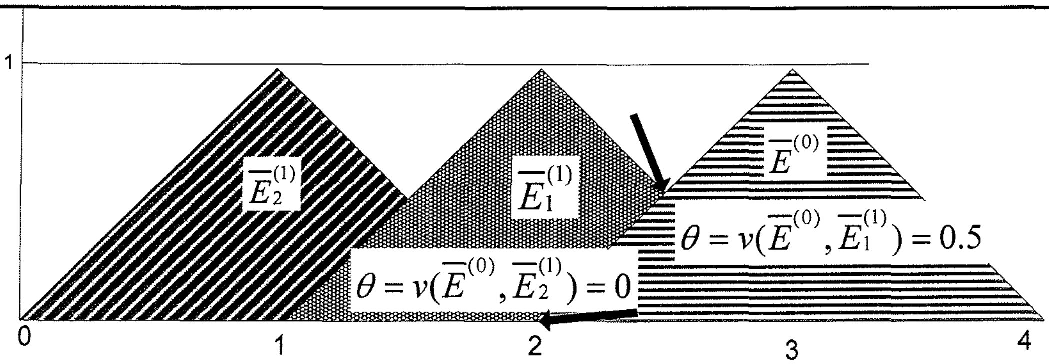
Here η can be seen as the "degree of discrimination" used to classify the numbers [9].
The use of different values of η could allow to model the inconsistencies in the holons' choice of an optimal solution (that is, in the emergence of a new holon), meaning η the "degrees of rationality" in the holons. If $\overline{X}, \overline{Y}$ are values of the utility function, the decision that leads to obtain an utility $\overline{X}$ over the one leading to $\overline{Y}$ is preferred, without doubts, if $\overline{X} > \overline{Y}$; therefore, for a given holon $H_1^{(k)}$ using η_1 may be that $\overline{X} > \overline{Y}$ while for another $H_2^{(k)}$ using η_2 is $\overline{X} \not> \overline{Y}$ [1] so there is no motive (for $H_2^{(k)}$) of preference of $\overline{X}$ respect $\overline{Y}$ and the decision associated to $\overline{Y}$ is made, which could seem irrational for the other (observing) holon $H_1^{(k)}$:



Graphical meaning of $v(\overline{X} \leq \overline{Y})$ when deciding if $\overline{Y} < \overline{X}$ (from [9])

Figure 1.

[1] And, of course, $\overline{Y} \not> \overline{X}$



Given the utilities of H1 and H2 at level 1, the utility of the holon formed by them can be seen as greater than the utility of H1 (so its choice of acting as part of the super holon instead of individually is clear) only when $\theta < \eta$

Figure 2.

Additionally, the choice of the semantic for $<$ and $\leq$ may be associated to the ontological level being modeled: Def. 3.1 is more restrictive than Def. 3.2 and might be used in an ontology (or level of an ontology) where holons behave more "rationally" or "coherently" (e.g. in an ontology ruled only by physical laws) and Def 3.2 in the case of human groups).

3. Cohesion of a Holon

Given the conditions (3) and (4) for the emergence of a new holon, let's considerer the fuzzy sets:

$A_i^{(k-1)} \equiv$ set of all the informons such as condition (3) holds [at a given instant] for the holon *i* in the level *k-1* , namely $H_i^{(k-1)}$

$B_i^{(k-1)} \equiv$ set of all informons such as condition (4) holds [at a given instant] for the holon *i* in the level *k-1* ,

Be

$$C_i^{(k-1)} = \frac{\left|B_i^{(k-1)}\right|}{\left|A_i^{(k-1)}\right|}$$

Inspired by the meaning of the word cohesion in other sciences (for example, psychology and sociology [5, 14]) , we define the number $C_i^{(k-1)}$ as the *instantaneous cohesion* of the holon $H_i^{(k-1)}$

Note that

(a) the quotient is defined as long the holon exists and if and only if their components don't act if they don't have a non-null expectation of the obtained utility of their actions

(b) given the bounded rationality that exhibit the real complex systems, both cardinal numbers are finite

(c) intuitively is $0 \le C_i^{(k-1)} \le 1$, as the traditional crisp reliability is.

(d) generaly the number of informons that can influence the behavior of the holon is unknown, making this measure rather theoretical. We could have a point estimate of it by considering the *observed* informons rather all of them.

We can see $C_i^{(k-1)}$ as giving an idea of how "sound" or "robust" is the behavior of a holon respect the different informons (conditions of its environment).

A related (and perhaps more useful) definition is the *mean cohesion* of $H_i^{(k-1)}$ in the time interval $[t_1, t_2]$: it is the quotient of the cardinals of

$\overline{A}_i^{(k-1)}$ ≡ set of all the informons such as condition (3) was held in $[t_1, t_2]$ for the holon *i* in the level *k-1*, namely $H_i^{(k-1)}$

$\overline{B}_i^{(k-1)}$ ≡ set of all informons such as condition (4) was held in $[t_1, t_2]$ for the holon *i* in the level *k-1*

As in the previous case, we could have an *estimated* mean cohesion. The cohesion (instantaneous or mean) can be thought as a kind of endogenous reliability: instead of talking of "specific purpose" of the component (item) under study and of saying that it is executed "properly" as it is done in the traditional reliability theory (see for example [11]) only conditions related to the inner values, desires and goals of the holons are used.

We can see that, in the case of autonomous self-organizing complex dynamical systems (or, more specifically, autonomous holonic systems), cohesion can be considered a generalization of the notion of reliability if we take as the most advantageous decision for a holon the achievement of its [designed] goals. Given that the property of "autonomy" is itself fuzzy, cohesion will exist (and be) a generalization of reliability in a varying degree depending on the specific system studied. For example, we can talk of the cohesion (estimated, mean) of an ants colony but it makes no sense to talk about its reliability. In the case of a human designed holonic system, with a rather limited autonomy, the cohesion would equate approximately the reliability and an instantaneous cohesion ≈ 0 would mean an non-operative system; a cohesion ≈ 1 implies a perfectly working system and an intermediate value would indicate a system working with fails or discordances respect to what was planned for it. Additionally, the cohesion could be seen as a measure of the "generalization capacity" of a system (by analogy with a neural network formed my non-autonomous neurons: the greater the generalization capacity it has, the better the output it will provide for an entry never seen previously).

4. An Example

Let's consider an organization that has an information technology (IT) area where it exits a help desk which resolves incidents coming from both the own IT sector as from the rest of the organization (for example, the crash of the e-mail server or the blocking of a user). The help desk can be seen as having many levels (first level help, second level help, etc.), which are used depending on the degree of expertise required to solve the problem. Additionally, there are in the IT area, outside the help desk, groups of specialists in the handling of specific type problems (security, data bases, telecommunications , etc.) that cn be consulted or asked to help by the help desk. Sometimes help is asked to other organizations (for example, supliers of telecommunications services). The help desk coordinates all the activities involving people inside and outside it in order to achieve the incident resolution. As it can be seen, this way of fixing the problems is typically holonic, where the holons are formed by people/workgroups, software, machines belonging to the own organization or to external ones; each incident (and all its related data) is an informon. The holon in the highest level (help desk) tries to solve the incident (that is, to process the informon "incident") which is asked by another holon (for example, the manufacturing facilities of the company) and for that invokes the workforce of other holons (workgroups of in-house specialists, external companies, etc.). A high cohesion would mean, roughly, that the number of incidents for which the benefit (in costs, time, corporate image, etc.) of solving it as a team is greater than the quantity of incidents for which it can be better to solve them separately (by some holon's component); given an incident, for example the fail of the corporate mail server, if the cohesion is high then the help desk will be the best way of solving the problem, very possibly . Techniques and criteria to divide the holons (or to group them) so the [average] cohesion is maximum should be sought.

5. Conclusions And Future Work

In this work we have analyzed the emergence conditions of new holons using the fuzzy probabilities theory. In this case one can express such conditions so that special cases (such as when the chosen action doesn't give the maximum utility) can be modeled.

The concept of holon cohesion was defined as a general case of reliability for self-organizing complex systems. A more formal study of its properties is needed.

Additional questions are:

a) given an informon, how to group the holons so the behavior of the emergent holon is optimum, in the sense that the expected utility is maximum
b) is the previous decomposition dynamically robust? that is, little variations (how to measure them?) of the informon have almost no effect in the structure of the emergent $H_i^{(k-1)}$ (if it exists).

The ideas exposed in [17] about the possible measurement of the uncertainty in getting the desired goal (using some variation of the Transactions Byte Analysis of Turnbull, from the amount of exchanged data between the holons) are still valid. Also the relation of this measure and the fuzzy entropy is an interesting topic to be researched. Finally, from a software engineering point of view, the use of the cohesion as an indicator of the quality of a multi-agent system (MAS) seems attractive.

Some of all these issues will be addressed in future works.

Acknowledgment

This work has been partially funded by the grant S-C-BE 55/18, Préstamo BID OCUR /1296-PDT, Ministerio de Educación y Cultura, R.O del Uruguay.

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