Constraint satisfaction, agency and meaning generation as an evolutionary framework for a constructive biosemiotics

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Abstract

Biosemiotics deal with the study of signs and meanings in living entities. Constructivism considers human knowledge as internally constructed by sense making rather than passively reflecting a pre-existing reality. Consequently, a constructivist perspective on biosemiotics leads to look at an internal active construction of meaning in living entities from basic life to humans.

That subject can be addressed with an existing tool: the Meaning Generator System (MGS) which is a system submitted to an internal constraint related to the nature of the agent (biological or artificial) containing it. Simple organisms generate meanings to satisfy a "stay alive" constraint. More complex living entities manage meaningful representations with more elaborated constraints. The generated meanings are used by the agents to implement actions aimed at satisfying the constraints. The actions can be physical, biological or mental and take place in the agent or in its environment.

The case of human agency is introduced with meaningful representations that may have allowed our ancestors to become self-conscious by representing themselves as existing entities (such process has been proposed in an evolutionary scenario for self-consciousness with the introduction of anxiety management constraints). This paper proposes to use the MGS as a thread to address the above items linking biosemiotics to constructivism with relations to normativity, autonomy and agency. Possible continuations are introduced.

Keywords

meaning, constraint, representation, Meaning Generator System, biosemiotics, constructivism, agent, evolution, normativity, autonomy, anxiety

1. Introduction

The purpose of this paper is to present a constructivist perspective of biosemiotics by focusing on meaning generation where "meanings" are generated by and for living entities in order to satisfy internal constraints. Organisms are then agents that internally construct their relations with the world, thus they can be studied following a constructivist approach.

We begin by recalling how meaning generation is related to both biosemiotics and constructivism.

A simple example of meaning generation for a "stay alive" constraint satisfaction leads to an elementary version of meaning generation and brings to position constraint, meaning and action relatively to each other. The Meaning Generator System (MGS) is introduced as part of an agent in an evolutionary perspective. The MGS offers a link between biosemiotics and constructivism and also a potential link with the Peircean triadic approach to semiotics.

In this paper I discuss the relations of the MGS with normativity, autonomy and agency. Then I present the evolutionary factors that have possibly resulted in the development of self-consciousness in humans. This evolutionary scenario accounts for the MGS and introduces human specific constraints related to anxiety management. At the end I provide conclusions and perspectives for future studies.

2. Meaning and internal constraint satisfaction. The Meaning Generator System (MGS)

2.1. "Meaning" as a key notion for biosemiotics and for constructivism

Biosemiotics and constructivism both focus on meaning generation in agents.

Constructivism emphasizes active role of humans in the learning process, where the learner "constructs" meanings through his/her learning experience (Ballard 2003).

Constructivism considers humans as builders of their knowledge rather than just receivers of pre-existing information on the status of the world. Knowledge is constructed by agents who are also sense makers or meaning generators.

The notion of meaning is at the foundation of biosemiotics (Kull 2014). In his paper "the theory of meaning" Von Uexkull presents the concept of Umwelt as a subjective universe where "The question of meaning is, therefore, the crucial one to all living beings" (Von Uexkull 1940).

The Umwelt is the meaningful world for an organism, i.e. the perceptual world in which the organism exists and acts as a subject. Von Uexkull considered meaning as interconnection between meaning-carrier, meaning-utilizer and meaning-receiver. It appears clear that the Uexkull's theory of meaning is on the constructivist side, where meaning and knowledge are built up by the organisms and are not simply acquired from a pre-given external world. As noted by Andreas Weber "Uexkull thus creates a biological constructivism avant la lettre" (Weber 2004).
Uexkull's work has been continued by biosemiotics, an "interdisciplinary science that studies communication and signification in living systems", as a specialized branch of semiotics focusing on communications in living systems (Sharov 1998). Meaning is a key notion in biosemiotics and the main challenge is to naturalize biological meaning (Sharov et al. 2015).
Several biosemioticians have chosen to use the Peircean semiotics triad (object, sign, interpretant) as a framework for biosemiotics, and considered that "meaning is nothing more and nothing less than the formation of interepretants in the Peircean sense" (Hoffmeyer 2010).
Other authors follow a different approach and consider that meaning making involves polysemy and may include incompatibility. Meaning generation is then poorly predictable and physical modeling becomes mostly inadequate (Kull 2012).
Another option is to apply the Peircean model of semiosis to animals, and consider an alternative model of semiosis based on coding rather than on interpretation at the level of cells (Barbieri 2009).
What I propose in this paper is to use an existing model of meaning generation in a way that combines the Peircean approach with an evolutionary viewpoint. We show that this approach links biosemiotics to constructivism and can be used to address the notions of normativity, autonomy, and agency.
Before presenting the model it is worth recalling that meanings do not exist by themselves. Meanings are generated by agents that have internal constraints to satisfy. For example a mouse has a "stay alive" constraint to satisfy (like all animals have). If the mouse sees a cat, the sensed information is connected with the constraint and produces meaningful information: "danger". And this meaning leads to action like hiding or running away in order to satisfy the "stay alive" constraint.

2.2. Meaning generation in unicellular organisms via evolution. The Meaning Generator System (MGS) [1]
Meaning generation exists in animals, humans and artificial agents. The Meaning Generator System (MGS) is a system approach that can cover these various cases. We begin with a case of elementary life to introduce the MGS.
Biosemiotics encompasses all living systems from the single-cell organisms to humans (Brier, 2005). Following an evolutionary lineage backwards brings us to meaning generation in simple unicellular organisms like paramecia. Paramecium life is bound by the "stay alive" constraint which is the major foundational constraint of all living entities.
It has been shown that a drop of acid in the water at the vicinity of a paramecium will make her move away, looking for a less hostile location. That simple reaction can be used to formalize the notion of meaning for an organism relative to its internal constraints. (This is close to Varela and Hoffmeyer examples of bacteria swimming up a nutrient gradient (Varela 1997, Hoffmeyer 1997). What a meaning generation process brings in addition is a modeling of the significance of the chemical gradient for the organism). The acidity of the environment as sensed by a paramecium is an incident information that participates in the generation of some meaning within the cell. Figuratively speaking, the meaning is what a paramecium "wants to say": "the environment is becoming too hostile for the satisfaction of the vital constraint". And this meaning then produces an action by the paramecium aimed at putting her away from the acid environment. It is clear that a paramecium does not possess an information processing system to use such an inner language. But she has sensors that participate to the identification of the danger in the environment. The information generated by the sensors evokes processes that propel the paramecium in a direction of less acid water.
So we can say that the paramecium has created a meaning related to the hostility of her environment in connection with the satisfaction of a vital constraint. This example highlights several issues related to the notion of meaning generation that we need to explicit for the MGS.
1) A meaning (the environment is becoming hostile versus the satisfaction of a vital constraint) is associated with information (level of acidity in water) which is directed to an entity capable of processing information (the paramecium).
2) Meaning is generated because the entity receiving the information possesses a constraint linked to its nature (vital constraint that is to be satisfied in order to maintain a living nature).
3) Meaning is generated because the incoming information has a connection with the constraint of the entity (too much acid in the water impacts the satisfaction of the vital constraint of the paramecium).

[1] *The MGS approach has been published in 2003 (Menant, 2003b). It has been part of Biosemiotics Gatherings 2002, 2003, 2015, 2016 (Menant 2002, 2003a, 2015, 2016).*

4) "Meaning" is meaningful information relatively to the constraint of the entity (information meaning that the environment becomes hostile versus the satisfaction of the vital constraint).
5) The meaningful information is used to initiate an action (movement towards a less acid location) in order to satisfy its constraint.
These five characteristics introduce a definition of meaning generation in the framework of a relation between an information processing entity submitted to an internal constraint and information received by that entity:
Meaning is meaningful information that is created by an entity submitted to an internal constraint when it receives information that has a connection with the constraint. The meaning is the connection existing between the received information and the constraint. The function of the meaningful information is to participate to the determination of an action that will be implemented in order to satisfy the constraint.
In the above example the paramecium receives information, generates meaning and acts.
We want to use that simple example to build a model of meaning generation based on a system approach where a system is a set of components linked by a set of relations, whatever the components and the relations.
For that we need to isolate in our example what is not strictly part of meaning generation, like components associated with sensing and action.
Such system approach leads to the Meaning Generator System (MGS) represented on Fig.1 with the paramecium example.

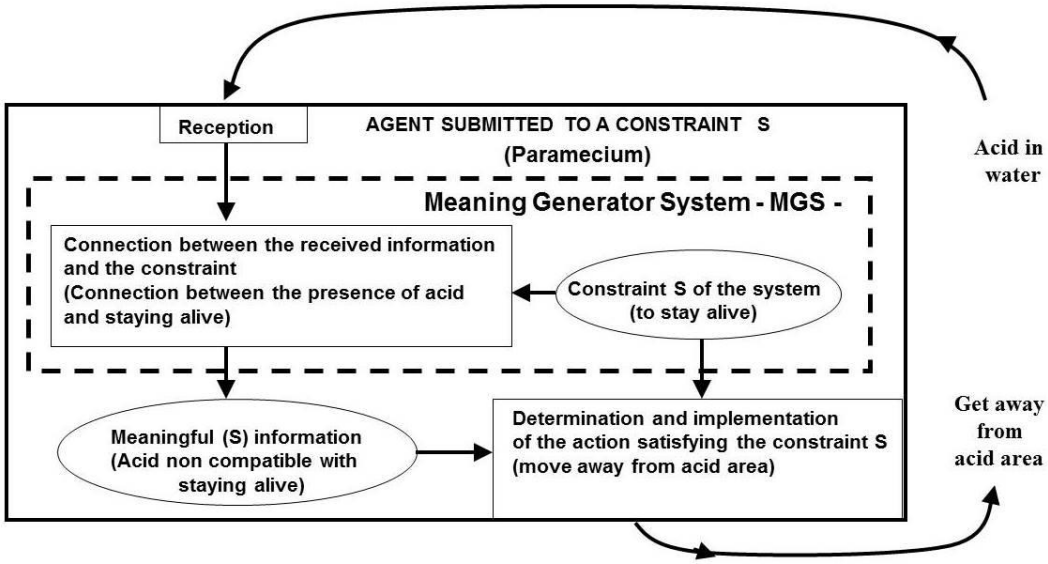

Fig. 1. Meaning Generation in Paramecium

The proposed definition of meaning as generated by a system part of an agent is general and does not depend upon the type of agent (biological, human or artificial). It is a system approach where the agent can be any entity submitted to an internal constraint.
I propose to consider the MGS as a part of biosemiotics as it addresses, in the words of Uexkull, the "question of meaning" which is "the crucial one to all living beings". The MGS is also close to constructivism as meaning generation is internally done by agents and does not need a pre-existing external reality[2]. Thus the MGS highlights the constructivist aspects of biosemiotics.

2.3. Characteristics of the MGS

The MGS has been introduced with a simple example of a unicellular organism submitted to a "stay alive" constraint. The MGS as part of an agent brings in characteristics that complement the above introduction.

2.3.1. The MGS is driven by internal constraint satisfaction

The internal constraint of the MGS is a constraint of the agent containing it and is related to the nature of the agent (like "stay alive" for animals). A relationship is established between internal constraint, meaning and action. The constraint produces the meaning that determines the action which will be implemented by the agent

[2] *The MGS can also receive information that corresponds to an external pre-given reality (ex: alert signal sent by conspecifics).*

to satisfy the constraint. The constraint and the meaning initially exist before the action which can be internal or external to the agent and can be physical, biological or mental depending on the nature of the agent.
The internal constraint brings normativity to the agent because the constraint can be satisfied or not depending on whether the nature of the agent is maintained[3].
There are different types of internal constraints which characterizes the type of agent containing the MGS. Biological agents are bound by natural constraints like the foundational "stay alive" constraint which applies to individuals and to species. At individual level the constraint leads to actions like avoiding predators or regulating metabolism. At species level the constraint leads to actions like reproducing and saving offspring. Actions implemented to satisfy the constraint may exist only in a given moment but the constraint is always active on interactive and survey modes. Also, constraints can be conflicting. For an ant colony to cross water, several ants may sacrifice themselves and get drowned to allow the buildup of a bridge usable for the colony. The species constraints are there stronger than the individual ones.
"Live group life" is another constraint that takes into account the integrity of composite agents like multicellular organisms and animals in groups.
Human specific constraints include "limit anxiety" and "look for happiness"; these constraints are more complex and linked to the nature of human mind (see section 4).
Artificial agents are submitted to derived constraints that come from the human designer. The distinction between natural and derived constraints makes it possible to compare artificial intelligence with living organisms and human mind. Also it helps to discuss ethical problems associated with agency (Menant 2013).

2.3.2. The MGS links agents to their environment

The MGS and the agent are local entities. The constraint is local and internal to the agent containing the MGS. The constraint does not apply to the environment of the agent (in the paramecium example the "stay alive" constraint is applied to the paramecium, not to the water surrounding it). Constraints are local and internal factors applied to agents in addition to the physico-chemical laws which are applied globally (Pattee, Kull 2009).
The consequences of agent actions may initiate the generation of new meanings establishing an interactive loop that adapts and link agents to their environment. Meaning generation and constraint satisfaction are dynamic and interacting processes that are permanently active and embed agents in their environments. The MGS specifies what the meaning is and what the meaning is for.
The same information received by different agents can produce different meanings (a sound of thunder generates different meanings in people on the beach as compared to people in their houses). Also, information can be already meaningful before being received. For example, alert signals are meaningful for the tribe before being received by members of the tribe where they generate individual meanings.

2.3.3. The MGS for higher level systems. Representations. Autonomy

The MGS within an agent is linked with other functions (e.g. memory, other MGSs, simulations of scenarios, selection of action and their executions, etc.).
In a given agent the meanings generated about an entity are networked into a representation of that entity. Such meaningful representation contains past experiences (including emotions for organic agents). These meaningful representations participate to the build up of the agent's cognitive content.
Among the features of agents, autonomy is among the most important. Autonomy is a rich and complex notion which is discussed in various disciplines such as biology, philosophy, evolution and artificial intelligence. An autonomous agent can be defined as "a system able to act on its own behalf" (Kauffman, Clayton 2006). Such ability to act using its own tools and resources is presented differently in plants, animals, humans and artificial agents. Plants and animals are autonomous agents as they can survive without external help. Humans possess a higher level of autonomy as they can, in addition, execute their free will and consciously choose their actions. Artificial agents display autonomy by action management based on the programmed resources and tools they carry. Looking at autonomy with a focus on actions informs us about what the agent can do but it does not tell much about what the agent is, about its nature. This highlights the interest for a definition of autonomy based on internal constraints because these constraints are related to the nature of the agent and are part of the action determination through meaning generation[4].
This brings us to define an autonomous agent as "a system that can satisfy its internal constraints by its own". This definition also opens a possibility to characterize the type of autonomy as related to the type of constraint (natural or derived for organisms or artificial agents). Defining autonomy by constraint satisfaction also allows the MGS to introduce the concept of autonomy into biosemiotics.

2.3.4. Comparison of the MGS with other approaches

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[3] *Another approach to define normativity is to consider the emergence of norms in agents (Barandiaran, Matthew 2014). Such perspective is different from the one presented here where constraints are linked with the nature of the agents.*

[4] *Alternatively, autonomy can be introduced as self-constraining processes that correspond to constraints generated by the system. (Ruiz-Mirazo, Moreno 2012).*

The MGS theory is compatible with the evolutionary theory because the satisfaction of constraints can be supported by natural selection. The constraints and the data processing functions can be considered as aspects of the evolution of the agents. More generally, the MGS can be used for all agents submitted to internal constraints, assuming we have clear enough an understanding of these constraints.
The MGS has also some compatibility with the Peircean triadic approach where it can be related to a simplified version of the Interpreter leading to the Interpretant[5].
The MGS can also be positioned relatively to different stages of Artificial Intelligences with the introduction of ethical concerns (Menant 2011, 2013).
Figure 2 extends Fig. 1 by positioning the MGS as part of an agent where the meaning is generated relatively to the constraint S of the agent. Human constraints are different from animal ones and come in addition to them. Artificial agents are submitted to derived constraints coming from the human designer. In all cases the generated meaning is constraint dependent.

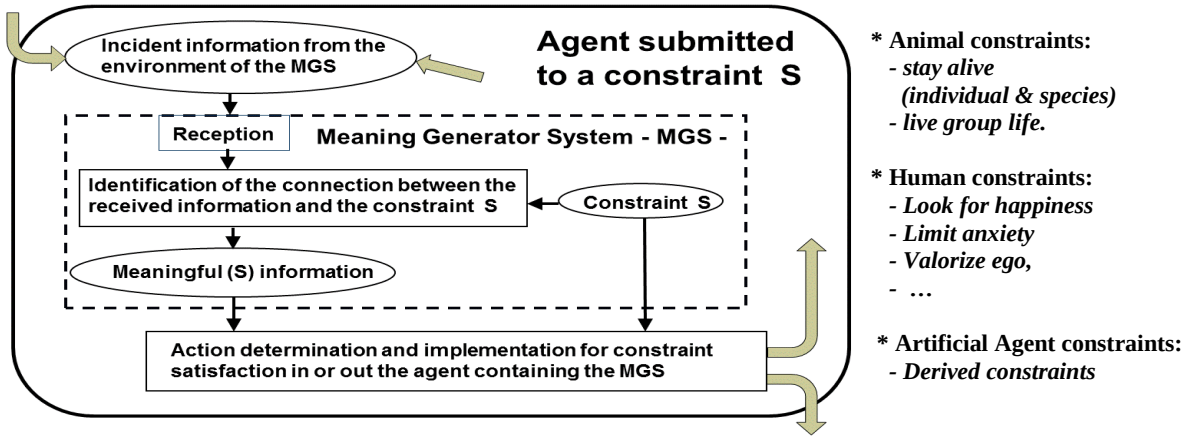

Fig. 2. Meaning Generator System in agent

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3. Internal constraint satisfaction and agency

Agency is a key notion in biosemiotics and its significance is increasing as some biosemioticians propose to shift the focus from living organisms to agents in general (Sharov 2010).
We have been so far using the word "agent" without defining it. Agents can be items of different natures like animals, humans or robots. The purpose of this section is to use the system approach to relate agency with internal constraint satisfaction in order to cover both natural and artificial agents.
Two papers about agency can be outlined in relation to our approach. The first is "Defining Agency: Individuality, Normativity, Asymmetry, and Spatio-temporality in Action" (Barandiaran et al. 2009). It is proposed in that paper that to be a genuine agent a system must meet three conditions:
a) A system must define its own individuality (...distinguishing itself from its surroundings; in doing so, it defines an environment in which it carries out its actions).
b) It must be the active source of activity in its environment (interactional asymmetry) and
c) It must regulate this activity in relation to certain norms.
These conditions integrate the environment, action capability and normativity of agents.
The other paper summarized the results of a questionnaire on the understanding of agency by biosemioticians and concluded that "most respondent agree that core attributes of an agent include goal-directedness, self-governed activity, processing of semiosis and choice of action, with these features being vital for the functioning of the living system in question" (Tønnessen 2015).
These core attributes are close to covering the three conditions of the first paper: difference versus environment, action capability and normativity (internal constraint satisfaction).
The consistency of the constraint satisfaction process of the MGS with the analysis of agency in the two papers brings us to define an agent as "an identifiable entity submitted to internal constraints and capable of actions for the satisfaction of the constraints". This definition can be applied to all types of agent: organisms with natural

[5] *Peirce defined the Interpretant as "something created in the mind of the Interpreter", the Interpretant being Peirce's term for the meaning of a sign (Noth 1990)*

(intrinsic) constraints and artificial agents with derived constraints.
Such definition for agency based on internal constraint satisfaction brings to look at what could have been present at pre-biotic times in terms of local constraint, introducing a possible pre-biotic agency. Even if it is difficult to address the concept of agency for inert matter it is possible to consider a defined volume in a far from thermodynamic equilibrium. Such volumes exist but do not last (ex: tornadoes, fires). What looks worth being investigated is the concept of local constraint maintaining such local status (see continuations)

4. Biosemiotics, meaning generation and self-consciousness. Anxiety management

Biosemiotics encompasses all living systems, including humans. Thus, positioning the MGS as part of biosemiotics brings to look at how it can be used for humans, more precisely for human consciousness in an evolutionary perspective. The science of consciousness is an active domain of research addressing different types of consciousness among which we favor here self-consciousness as it appears specific to humans. Evolutionary approaches currently occupy a modest place in the science of consciousness. This is partially due to the fact that at the end of the 20th century the philosophy of mind was focusing on phenomenological approaches, where evolutionary explanations of consciousness were viewed as a hard problem (Polger, Flanagan 1999).
In the same context it is also worth noticing that at the end of the 20th century the study of self-consciousness "has fallen on hard times. Though once regarded as the very essence of mind, most philosophers and psychologists today treat it as a marginal and derivative phenomenon" (Van Gulick, 1988). But the beginning of the 21st century opened new perspectives where self-consciousness is becoming a subject of interest in multiple disciplines (Crone et al., 2012). Some authors discuss human self-representations (Vosgerau, 2009). Others take the evolution into account (Carruthers et al., 2012, Menant 2014a). We consider these developments as a comeback of the science of self-consciousness and present here a corresponding evolutionary scenario based on meaningful representations with anxiety management as a key contributor[6].
The scenario starts at the level of our non self-conscious pre-human primate ancestors and reaches an elementary version of self-consciousness by associating meaningful representations to the evolution of intersubjectivity[7].
The scenario is presented on Fig. 3 and can be summarized as follows (detailed scenario at Menant 2014a, b):
Our non self-conscious pre-human ancestors had representations of their conspecifics as global entities existing in the environment. Our ancestors had also some limited representation of themselves (seen parts of the body, heard shouting, perceived actions, ...) that we call "auto-representation".
We consider that the intersubjectivity of our ancestors has evolved into an identification with conspecifics that has led them to tune some aspects of their auto-representations to resemble the representations of conspecifics[8].
More precisely we focus on the auto-representation accessing the characteristic "existing in the environment" attached to the representation of conspecifics.
This has led our ancestors to represent themselves as global entities existing in the environment. We consider that our ancestors becoming aware of themselves as entities existing in the environment have acquired an elementary and primitive version of self-consciousness that we name "ancestral self-consciousness".
The identification with conspecifics has also produced a huge anxiety increase coming from the identifications with suffering or endangered conspecifics[9].
To limit that anxiety increase our ancestors have increased their efforts to support conspecifics and develop efficiency tools like imitation, communication, and cooperation.
This has been a specific behavioral change for our pre-human ancestors whose social life, comparable to the one of today great apes, was structured more by competition than by cooperation (Tomasello et al. 2005, Tomasello 2016).
The evolutionary advantages coming from the anxiety limitation tools and a positive feedback from intersubjectivity have produced an evolutionary engine that has powered the evolution from ancestral-self-consciousness to our contemporary human self-consciousness[10].

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[6] *This scenario has been presented at TCS and ASSC conferences and has been partly published (Menant 2011).*
[7] *It is accepted by the scientific community that our pre-human ancestor were quite similar to today great apes and were capable of some level of intersubjectivity (Menant 2014a)*
[8] *The expression "'identification with others" comes from psychiatry where it is about modifying the self to resemble the other (Olds 2006). It has been used with different meanings by primatologists (Tomasello 2000, de Waal 2008) and by linguists (Zlatev et al. 2005). We use that term here for our pre-human ancestors with a meaning close to its original one by using "auto-representation" in place of "self".*
[9] *That anxiety comes in addition to normal anxiety which is a positive emotion that has been shaped by natural selection to allow early alerts against threats (Marks & Nesse 1994).*
[10] *Such perspective positions the first evolutionary benefits related to self-consciousness as coming from its evolutionary history rather than from performances produced by self-consciousness.*

This evolutionary scenario introduces anxiety limitation as a key human constraint which is still active today and participates (unconsciously most of the time) in meaning generations, thoughts and actions.
The evolution of self-consciousness from its ancestral form to its contemporary status included phenomenal consciousness and self-consciousness as object and as subject. That evolution has also transformed anxiety limitation items into more elaborated processes of anxiety management. These topics are my work in process (Menant 2014 a, b).

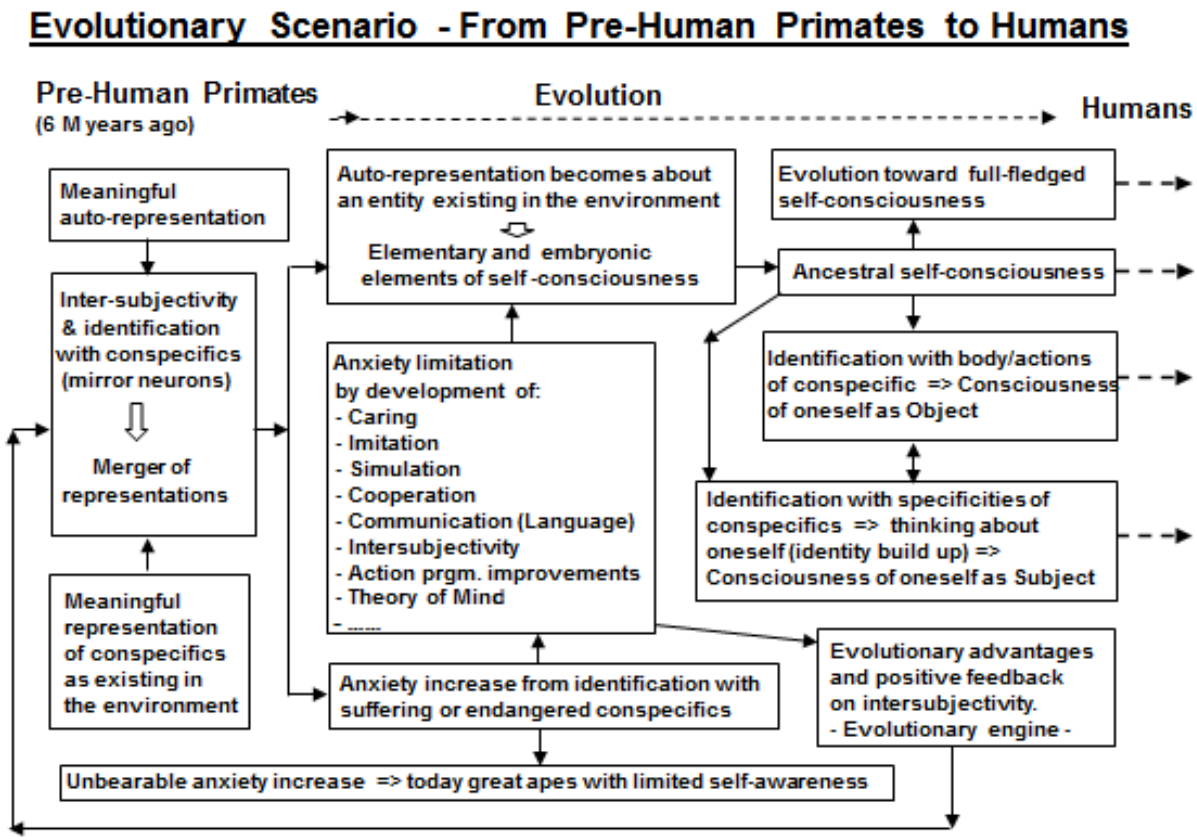

Fig. 3. Evolutionary scenario for self-consciousness

The evolutionary scenario positions ancestral self-consciousness and anxiety increase as both coming from a common evolutionary event: identification with conspecifics. As our ancestors have limited the anxiety increase by tools offering evolutionary advantages, we can say that anxiety limitation is interwoven with the nature of self-consciousness. In other words, anxiety management and self-consciousness share the same evolutionary history. Such perspective is new and deserves more theoretical developments. It can bring insight into the emergence of human emotions and into the nature of human anxiety disorders. But more work is needed on these subjects as human mind presents enormous challenges for science and philosophy.
The evolutionary scenario presented here can provide connections between biosemiotics and the science of consciousness [11].

5. Conclusion & continuations

5.1. Conclusion

In the paper we have highlighted the constructivist aspects of biosemiotics by using a model of meaning generation based on internal constraint satisfaction (the Meaning Generator System). Meaning generation is viewed as the core of biosemiotics and the MGS has links with constructivism as the meaning generation process belongs to the agents and does not need pre-given meanings. It has been shown that the MGS is related to normativity, autonomy and agency. Definitions based on internal constraint satisfaction have been proposed for autonomy and agency. These definitions apply to any agent submitted to an internal constraint, be it natural or

[11] *Relations between biosemiotics and human mind have been introduced in a 2013 Biosemiotics book about "what mindedness is from a naturalistic, scientifically informed perspective." (Swan 2013). The evolutionary nature of self-consciousness as presented here comes in addition to the content of that book.*

artificial. Distinguishing natural and derived constraints has allowed us to differentiate and characterize meaning generation in organisms and in artificial agents.
The system structure of the MGS makes it possible to describe the evolution of agents.
To complete the biosemiotic spectrum of meaning generation we have presented an evolutionary scenario for a possible nature of self-consciousness in humans. The scenario proposes a connection between biosemiotics and the science of consciousness. It also highlights anxiety limitation as a key human constraint by positioning anxiety management and self-consciousness as sharing the same evolutionary history.

5.2. Continuations

Several points in the paper require more work. The ones related to an evolutionary approach to self-consciousness have been listed elsewhere (Menant 2014 a, b).
Other continuations are to examine:
- Possible links between biosemiotics and phenomenal consciousness.
- Specificities of human constraints and their relations with the ones that can be considered as extensions of animal ones.
- Local constraint satisfaction as an evolutionary thread introducing the possibility for a pre-biotic agency (Menant 2016, 2017).
- Internal constraint satisfaction as linking biosemiotics to constructivism, ahead of meaning generation.

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