CHAPTER 10

COMPUTATION ON INFORMATION, MEANING AND REPRESENTATIONS. AN EVOLUTIONARY APPROACH

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Abstract:
Understanding computation as "a process of the dynamic change of information" brings to look at the different types of computation and information. Computation of information does not exist alone by itself but is to be considered as part of a system that uses it for some given purpose. Information can be meaningless like a thunderstorm noise, it can be meaningful like an alert signal, or like the representation of a desired food. A thunderstorm noise participates to the generation of meaningful information about coming rain. An alert signal has a meaning as allowing a safety constraint to be satisfied. The representation of a desired food participates to the satisfaction of some metabolic constraints for the organism. Computations on information and representations will be different in nature and in complexity as the systems that link them have different constraints to satisfy. Animals have survival constraints to satisfy. Humans have many specific constraints coming in addition. And computers will compute what the designer and programmer ask for.

We propose to analyze the different relations between information, meaning and representation by taking an evolutionary approach on the systems that link them. Such a bottom-up approach allows starting with simple organisms and avoids an implicit focus on humans, which is the most complex and difficult case. To make available a common background usable for the many different cases, we use a systemic tool that defines the generation of meaningful information by and for a system submitted to a constraint. This systemic tool allows to position

information, meaning and representations for systems relatively to environmental entities in an evolutionary perspective.

We begin by positioning the notions of information, meaning and representation and recall the characteristics of the Meaning Generator System (MGS) that link a system submitted to a constraint to its environment. We then use the MGS for animals and highlight the network nature of the interrelated meanings about an entity of the environment. This brings us to define the representation of an item for an agent as being the network of meanings relative to the item for the agent. Such meaningful representations embed the agents in their environments and are far from the Good Old Fashion Artificial Intelligence type ones. The MGS approach is then used for humans with a limitation resulting of the unknown nature of human consciousness.

Application of the MGS to artificial systems brings to look for compatibilities with different levels of Artificial Intelligence (AI) like embodied-situated AI, the guidance theory of representations, and enactive AI. Concerns relative to different types of autonomy and organic or artificial constraints are highlighted. We finish by summarizing the points addressed and by proposing some continuations.

1. Information and Meaning. Meaning Generation

1.1. *Information. Meaning of information and quantity of information*

Information, meanings and representations are part of our everyday life. We receive information from everywhere: environment, newspapers, other persons,… We interpret the received information to generate meanings that will be associated to it. The received information may be already meaningful or not, and the meanings that we generate are specific to ourselves.

Different persons will associate different meanings to the news on the radio. A thunderstorm noise will generate different meanings depending if we are on the beach or in our house. Thunderstorm noise is not meaningful by itself. It is the interpretation we make of it that generates a meaningful information. In addition to all these more or less conscious meanings, there is the world of our unconscious meanings that we cannot access directly.

Important work has been done on questions related to the meanings of signs, words, sentences or emotions (semiotics, linguistics, analytic philosophy, psychology, …), and through the intentionality and aboutness of mental states (phenomenology).

Important work has been done also regarding the measurement of the quantity of information. C. Shannon has theorized in the middle of the xxth century on the calculation of the quantity of information in order to evaluate the transmission capacity of communication channels [Shannon, 1948]. Such measurement of information is widely used in today communication systems. But things are different regarding the meaning of information. We do not know how to measure a meaning. The quantity of information has no relation with the meaning of the information, “semantic aspects of communication are irrelevant to the engineering aspects.”

Among animals also there is management of information and meaning. Ants build up paths toward food by depositing pheromones which are interpreted by other ants as indicating an already used path. The dance of a bee indicates a source of pollen to the other members of the hive, but it will not generate that meaning to a passing by butterfly also looking for pollen. There, the pheromones and the bee dance are already meaningful. Meaningful information is a key element in the relation of an organism with its environments. Jacob Von Uexkull (1864-1944) has introduced the notion of internal world for organisms as an Umwelt. All animals have their individual phenomenal world that characterizes the interpretation and meaning they give to their sensations. Von Uexkull work is being 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].

These questions relative to meaningful information and representations are also to be looked at in the world of artificial systems. Can a computer attribute some meaning to the information it processes? And does a robot, designed to avoid obstacles, generate a meaning when facing an obstacle? All these subjects relative to information and meaning for different systems like humans, animals and robots bring us to consider that there may be some interest to look at meaning generation following a systemic approach. The meaning would be generated by and for a system in a given environment, taking into account the specificities of the system.

This would allow us to characterize a meaning as specific to a system with a common background usable for all systems.

1.2. *Meaningful information and constraint satisfaction. A systemic approach*

The above rapid overview highlights that meaningful information can be considered as related to some purpose and action for the system that uses it or creates it.

Meaningful information does not exist by itself, for free, but has a reason of being for the system that generates it or uses it. The sight of a prey creates a meaning for an animal. But this meaning will be of different value if the animal is hungry or not. The meaning associated to an outside entity depends of the entity and also of the internal state of the system.

But such a statement is very general. The purposes and actions can be very many. The actions of simple animals are mostly immediate on the quasi-reflex mode (a frog catching a fly with her tongue). The action can also be an alert signal for other members of the species. More complex animals will build up actions using the results of passed experiences, some may also simulate several options to compare the different outcomes and implement the best solution. There are also cases where there is no immediate action and where the memorized meaningful information is stored for further usage.

The case of humans is even more complex as conscious free will comes in addition to modify the biologic meanings inherited from our animal history. And we do not really know what free will is. As of today, the nature of human mind is a mystery for science and philosophy. Many researches are in process on this subject in various fields like philosophy, neurobiology, psychology, cognition and computer science. But the question is still to be answered. We do not know the nature of human mind.

In the case of robots, it looks natural to say that the actions implemented come from the designer of the robot and from its environment.

As introduced above, meaningful information is system dependant. Different systems can generate different meanings when receiving the same information. Incident information can be meaningful or meaningless[1].

An important characteristic of meaningful information is that it establishes a relation between the system that creates it and its environment. Such relation has two aspects. First the build up of the meaningful information which links the system to the information received from the environment. And second, the action implemented by the system on its environment. The action implemented is an interactive and dynamic link as it will modify the environment, and consequently impact the meaning generated by the system. Meaning generation creates an interactive relation between the system and its environment. Such creations of links by meaning generation are obvious in any social life where interactions between organisms are intertwined with creations of meanings. These meanings have effects on the environment, on other organisms, as well as on the organisms that generated the meaning. Meaning generation is a relational phenomenon.

Information and representations are tightly linked. We will show that a meaningful representation of an item for a system can be defined as made of meaningful information. Our focus will first be on the nature and origin of meaningful information from which we will deduce the nature and content of a meaningful representation.

We have introduced above that a meaningful information is related to the purposes and actions of the system that creates it or uses it. On an evolutionary standpoint, animal life brings us to consider that organisms generate meanings to satisfy constraints related to their nature, basically survival constraints for the animal itself or for the species. These constraints are internal to the organism. For humans, the subject is more complex. We can agree that the meanings that we humans deal with have some reasons of being, but identifying these reasons is not easy. The

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[1] Our usage of meaningful information is different from the Standard Definition of semantic Information linked to linguistics where information is considered as meaningful data [Floridi 2003]. Our systemic approach brings a different perspective by introducing the possibility of meaningless information participating to the generation of meaningful information.

meaningful information we process are very many and are not always clearly related to constraints that are to be satisfied. What type of constraint do we satisfy when getting the meaning of a sentence in a book? Is it about knowing more on a subject in order to be more performant? Or is it only about implementing a needed Pascalian diversion? Whatever the answers to such questions, we will use as a background the idea that a meaning is generated by a system submitted to a constraint and that it is a meaning about an entity of the environment of the system.

The identification of the constraint will be addressed on a case per case basis depending on the nature of the system. We will use an already presented systemic tool on meaning generation [Menant, 2003]. It allows an evolutionary approach, starting with a very small organism that gives us a frame to define a Meaning Generator System (MGS) based on constraint satisfaction. We use the MGS for more complex organisms through evolution up to humans. Artificial systems are also taken into account with the MGS approach.

A system can be defined as a set of elements standing in interrelation. So we first identify the elements constituting the MGS in order to get clear enough an understanding of its functions. We will then be in a position to link it with other functions and integrate it in higher level systems.

2. Information, Meaning and Representations. An Evolutionary Approach [2]

2.1. *Stay alive constraint and meaning generation for organisms*

Our starting point for the introduction of a systemic and evolutionary approach to meaning generation is a simple organism. We choose a unicellular organism: a paramecium. Organisms have constraints to satisfy in order to maintain their nature. Life being "the sum of the functions by which death is resisted" [Bichat], the basic constraint that an

[2] This paragraph reproduces and complements the content of a 2003 publication [Menant, 2003] and of a 2005 presentation [Menant, 2005].

organism has to satisfy is to resist death, to stay alive.

It has been shown experimentally 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 in water where there is less acid. This reaction of a paramecium moving away from a hostile environment brings us to introduce the notion of meaning for an organism. The acidity of the environment is an incident information received by the paramecium that will participate to some generation of meaning within the paramecium. A meaning that "has sense of", that "wants to say": "the environment is becoming hostile versus the satisfaction of vital constraints". And this meaning is going to trigger within the paramecium an action aimed at putting her at distance from the acid environment. It is clear that the paramecium does not possess an information processing system that allows her to have access to an inner language. But a paramecium has usage of sensors that can participate to a measurement of the environment acidity. The information made available with the help of these sensors will be part of the process that will generate the move of the paramecium in the 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 her vital constraints. This example brings up several characteristics relative to the notion of meaning that we want to conceptualize. We can formulate them and bring up a "systemic aspect", more general than the small living organism that we have taken as example:

1) A meaning (the environment is becoming hostile versus the satisfaction of vital constraints) is associated to an information (level of acidity) received from an entity of the environment (drop of acid).
2) The meaning is generated because the system possesses a constraint linked to its nature (stay alive) that has to be satisfied for the system to maintain its nature.
3) A meaning is generated because the received information has a connection with the constraint of the system (too high an acidity level impacts the satisfaction of the vital constraints).
4) A meaning is a meaningful information generated by the system relatively to its constraint and to its environment (the environment is becoming hostile versus the satisfaction of the vital constraint).

5) The meaning is going to participate to the determination of an action that the system is to implement (move away from acid area) in order to satisfy its constraint and maintain its nature (stay alive).

These five characteristics lead to a systemic definition of a meaning for a system submitted to a constraint that receives an information from an entity of its environment:

"A meaning is a meaningful information that is created by a system submitted to a constraint when it receives an incident information that has a connection with the constraint. The meaning is formed of the connection existing between the received information and the constraint of the system. 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 of the system".

This definition of a meaning tells what the meaning is and what the meaning is for. The definition is illustrated in Figure 1.

In the following text, we will use indifferently the expressions "meaning" or "meaningful information".

2.2. The Meaning Generator System (MGS). A systemic and evolutionary approach

The above example of meaning generation in a simple organism makes available the elements needed for our systemic approach to meaning generation. The Meaning Generator System (MGS) is introduced as made of:

- A system submitted to a constraint and able to receive information from an entity of its environment.
- An information coming from an entity of the environment and incident on the system (that information can come from the natural presence of the entity (shape, color, ...) or be the result of an action of the system (displaced element, frightened animals,…). The incident information can be already meaningful or not).
- An information processing element, internal to the system and capable of identifying a connection between the received information and the constraint.

The generated meaning is precisely the connection existing between the received information and the constraint. It will be used to determine an action that will be implemented in order to satisfy the constraint of the system. The action implemented will modify the environment of the MGS and bring the generation of new meanings in order to coordinate the satisfaction of the constraint through time. The MGS participates to a sensori-motor coordination articulated on constraint satisfaction.

A MGS is represented in Figure 1 where a system submitted to a constraint S generates a meaningful (S) information about an entity of its environment.

It is to be highlighted here again that meanings do not exist by themselves. Meanings are generated by systems that have constraints to satisfy in order to maintain their nature (the nature of a system being what it does when it is functional. Stay alive for an organism, avoid obstacles for a robot). The meaning generation process is constraint satisfaction driven.

Meanings are generated by the systems and for the systems in their environments. Meanings link the systems to their environments. As the

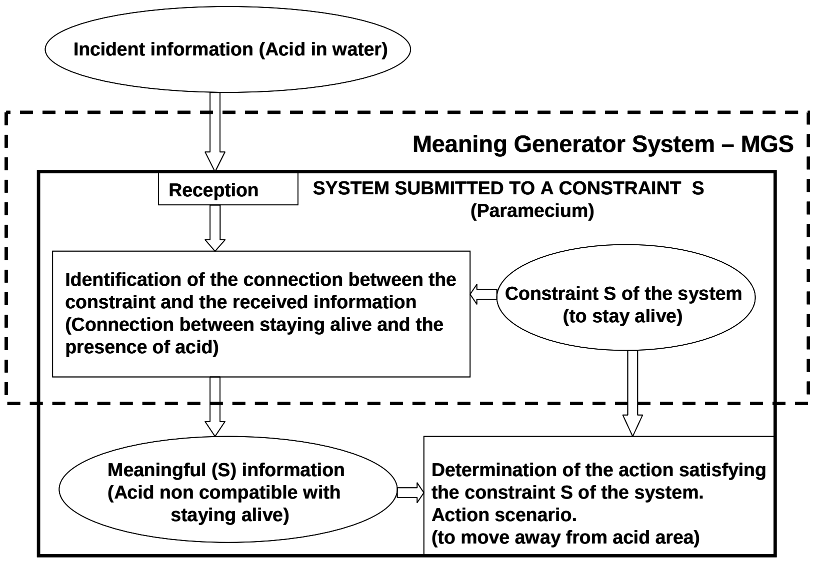

Fig. 1. The Meaning Generator System

meaning generation process links the system to its environment by the received incident information and by the implemented action, it is natural to look at the grounding of the generated meaning. An overview of the information and functions related to the meaning generation brings to consider that the generated meaning is naturally grounded by the MGS.

The meaning is grounded in the MGS by the functions present in the MGS, and the meaning is grounded out of the MGS by the received information and by the action. The grounding by the action has two components: the action scenario and, on a dynamic standpoint, the consequences of the action in terms of receivable information. Figure 2 illustrates this point.

Such groundings in and out of the MGS allow to present on a same picture the objectivist and constructivist aspects of perception. The incident information that will be received by the MGS is an objective component of the outside reality of the MGS, as is the action implemented on the environment. And the meaning generation process, by comparing the received information to the constraints of the system,

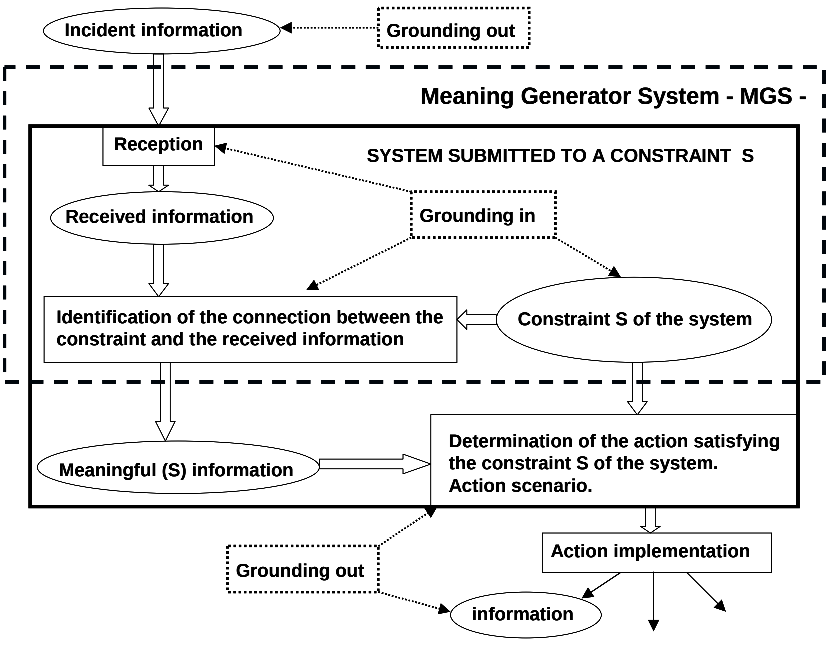

Fig. 2. Groundings of meaning by the MGS

brings the constructivist aspect of the generated meaning.

In real life, the MGS is most of the time part of a higher level system. Such integration of the MGS in a higher level system brings to highlight the following points:

a) The MGS is simple. It is a simple tool usable for a bottom-up approach to meaning generation. It is a building block for higher level systems capable of actions (agents) which have constraints to satisfy in order to maintain their nature (the constraint of the MGS can be considered as a subset of the constraints of the agent).

The nature of the agent can be biological or artificial. Biological constraints and biological meanings are intrinsic to the biological agent. In the case of artificial agents, the constraints are not intrinsic to the agent as they come from the designer. Artificial agents generate artificial meanings. In both cases, constraint satisfaction goes through meaning generation which links the agent to its environment.

b) The agent can contain other functions like memory, scenarios simulation, action implementation, other receivers, other MGSs. These functions are linked together as part of the agent. A memory will contain action scenarios coming from past experiences where different updatings can be compared through simulation. The receivers bring feedbacks from the results of actions and provide information on constraint satisfaction level. An agent will use its MGSs to interface directly with its environment by sensori-motor processes or indirectly by using higher level performances like simulation and optimization. The former is related to reflex and insect type situated behaviours. The latter covers cases involving a more centralized data processing. Both types have existed through evolution of organisms up to humans, and are still active. The MGS is usable with both types of agents where it participates to the sensori-motor coordination.

c) An agent submitted to constraints has a nature to maintain in an environment through the satisfaction of its various constraints. Constraints satisfaction is implemented by the actions resulting of the generation of meanings that link and adapt the agent to its environment in a permanent and dynamic process. The agent is naturally embedded in its environment by the generated meanings which bring it to be permanently coping with its environment.

d) The participation of the meaningful information to the determination of an action can be indirect. Several actions and meanings generations can be chained before the final constraint satisfaction. As the various action scenarios are linked to the entities of the environment and to the constraints, they are to be considered as meaningful (we call them indirect meanings).

Animal life gives examples of such combinations of meanings generations. When a group member receives information about the presence of a predator, she generates a meaning “presence of predator as incompatible with survival of the group”. This meaning triggers an action (alert) to inform the group members about the threat. When the other members of the group receive the alert information, they generate a meaning “presence of predator incompatible with survival” which in turn triggers individual hiding or escape actions. The well known case of vervet monkeys alert process is an example [Manning, and Stamp Dawkins, (1998)]. Such chaining of meanings contributes to the build up of networks of meanings (see hereunder).

e) The actions implemented to satisfy the constraints of an agent can be of many types (physical, chemical, nervous, data processing, signalling, conscious or unconscious cognitive processes, …). Actions will modify the environment of the agent and consequently modify the received information and the meaning generation. On a dynamic standpoint, the results of the implemented actions that can be received by the agent are part of the meaning generation process. As a MGS is internal to an agent, a generated meaning can participate to actions internal to the agent. A constraint satisfaction process can internally modify the agent.

Some of the relations of a MGS with higher level systems elements are represented in Figure 3.

The definition of meaning proposed here above has been built up with an example coming from the animal world that has been formalized into a system. As said above, a meaning does not exist by itself. A meaning is a meaningful information about an entity of the environment, and it is generated by and for a system submitted to a constraint. Such approach is close to a simplified version of the Peircean theory of sign. Peirce's theory is a general theory of sign, and the present approach is centred

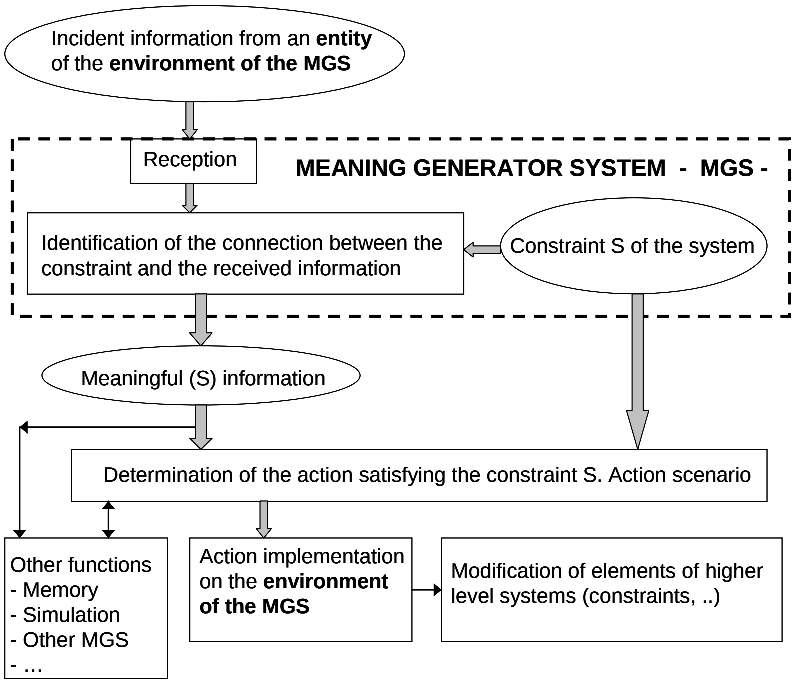

Fig. 3. MGS as building block

on meaning. The element of this approach that can be related to the Peircean theory of sign is the MGS: the generated meaning combines an objective relation with the environment (the received incident information) and a specific build up of the system (the connection with the constraint). This can be compared to the Sign relating the Object to the Interpreter that will produce the Interpretant. The MGS can be compared to a simplified version of the Interpreter where the incident information is the Sign coming from the Object, and the meaningful information is the Interpretant. In the Peircean theory of sign, the Interpretant is also a sign available for another interpretation, and so on. The Interpretant is at the same time the third term of one triadic relation and also the first term of another triadic relation. This “necessarily involves chains of triads” [Queiroz, El-Hani, 2006].

On the same token, the meaning generated by a MGS can become an incident information on other MGSs. In terms of MGSs, the “chains of triads” are part of the networks of meanings (see hereunder).

Meaning generation by an organism as presented here has some similarities with the build up of a subjective world by animals as proposed by J. von Uexkull. Von Uexkull studied the problem of how living beings subjectively perceive their environment and how this perception determines their behaviour (with the key notion of "Umwelt" as an internal world). Umwelt has been re-actualized as a support for several studies on artificial life and artificial intelligence [Ziemke, Sharkey, (2001)].The MGS is usable for meaning generation processes existing in the world of animals, humans or artificial systems, assuming we define precisely enough the agent with its constraints and the corresponding MGSs. Such generality is the purpose of a systemic approach.

2.3. *Meaning transmission*

We have seen that the action resulting of meaning generation may sometimes implicate other agents. The formal action that will satisfy the constraint comes after the transmission of the meaningful information and its reception by other agents. These other agents can also be submitted to specific constraints, different from the constraint of the transmitting agent. In order to take these cases into account, we need a new notion that can characterize the possibility for the transmitted meaningful information to participate to the determination of an action within other agents having possibly different constraints to satisfy. The notion of "efficiency of a meaning" has been introduced to address such cases [Menant, 2003].

2.4. *Individual and species constraints. Group life constraints. Networks of meanings*

A given agent can have different constraints to satisfy. In addition to individual vital constraints, most organisms are submitted to species vital constraints which bring them to reproduce and protect the young in order to maintain the species alive. Group life constraints are also to be considered as being constraints related to group life stability and not directly identifiable as individual or species constraints. Social hierarchy is a reality in animal group life where it generates specific constraints. Corresponding meanings generations will determine actions like access to food or mating. These different constraints are active at the same time and can be conflicting. The satisfaction of individual constraints can become incompatible with the satisfaction of species constraints. For an ant colony to cross water, several ants may sacrifice themselves and get drowned to allow the build up of a bridge usable for the ant colony. The species constraints are here stronger than the individual ones.

Regarding the environment of an agent, a given entity can make available different information to the agent (sound, odor, …). As a result, the different information received by an agent and the different constraints that the agent has to satisfy bring the agent to generate many different meanings relatively to an entity, including the indirect meanings like action scenarios. These meanings will be spread around through the various MGSs or centralized, depending on the structure of the agent. All these meanings relative to a given entity are available to the agent for the build up of a network of meanings relative to the entity. These networks of meanings also contain the dynamic aspect of meaning generation with the consequences of implemented actions, as well the action scenarios with past experiences or simulations making available anticipation performances. These networks connect entities, constraints, scenarios, actions outcomes and are inter-related. Agents are permanently embedded in their environments by networks of meanings that link them to their environment by real time information exchanges as well as by past experiences or anticipated action scenarios. Human and animal societies are societies of communication that are organized and embedded in their environments by such networks of meanings.

Regarding artificial systems, meaning generation is simpler to analyze in its content as we, the designers, can decide of the constraints and of their interdependences.

Networks of meanings fit with the Peircean triadic theory of sign as a generated meaning can become an incident information for another MGS, and so on. These natural interdependencies of meaningful information show that a given meaning barely refers to a single entity but that meanings are naturally interrelated in networks of meanings. As the MGS is also a tool for an evolutionary approach to meaning generation, networks of meanings can be used in an evolutionary background. Understanding that species are linked through evolution from simple living organisms up to us humans, we can look at applying such continuity to networks of meanings. A given MGS at a stage of evolution can be considered as linked to MGSs of lower evolutionary stages. But the constraints of an organism at a given stage of evolution have to be clearly defined for the evolutionary network of meaning to be applicable (we again highlight here the problem related to the level of human in evolution where human mind with its constraints is still a mystery for today science and philosophy).

Networks of meanings link agents to entities of their environments through constraints that have to be satisfied. Such links limit the dimension of the networks. Networks of meanings based on constraints satisfaction is a subject which is to be developed beyond the scope of this paper.

2.5. *From meaningful information to meaningful representations* [3]

The generation of meaningful information for constraint satisfaction by organisms has become more elaborated through evolution. The increasing complexity of the organisms has allowed the built up of richer networks of meanings about entities of the environment, the purpose still being to satisfy constraints as well as possible.

We have seen that a network of meanings is relative to an entity for an agent submitted to constraints, and that it dynamically links the agent to the entity. Networks of meanings relative to entities populating the environment of an agent embed that agent in its environment and allow it to maintain its nature by the satisfaction of its constraints. We would like to use these networks of meanings to introduce the notion of MGS based meaningful representation.

A representation can be considered as being "any entity (object, property, state, event) that designates, denotes, or stands in for another" [Anderson, 2005]. Representations haves been initially introduced in AI

[3] This paragraph is a continuation of a 2006 presentation, with adds relatively to the initial version of a meaningful representation [Menant, 2006, a].

as meaningless symbols processed centrally by computers. Such "traditional AI" has faced practical limitations in some applications. Philosophical analysis came up to bring anti-representationalism as a position supported by some researchers in AI and cognition. We feel that the notion of representation should not be put aside but needs to be re-addressed and reformulated in terms of meaningful element build up by an agent submitted to constraints.

We would like here to define a meaningful representation of an entity for an agent submitted to constraints as being the network of meanings relative to that entity for the agent. Such meaningful representation has the properties of a network of meaningful information as highlighted above:

- A meaningful representation is generated by an agent in order to maintain its nature in its environment by the satisfaction of its constraints. A meaningful representation of an entity for an agent is not an abstraction or a mirror image of the entity but it is made of constraint satisfaction oriented information about that entity.

- A meaningful representation contains the meaningful information that dynamically links the agent to its environment. It includes the dynamic aspect of meaning generation with the consequences of implemented actions, as well as the action scenarios with past experiences or simulations making available anticipation performances.

- Meaningful representations exist by and for the agent and embed it in its environment. As an example, the meaningful representation of a mouse for a cat can be imagined as containing the real time perception of the mouse when the cat is experiencing it, with also the past experiences of the cat with mice and action scenarios that can be used for simulation (action anticipation). As a consequence of our evolutionary usage of MGSs, we want to consider that meaningful representations of entities of the environment were progressively built up by organisms through evolution as needed relatively to the satisfaction of the constraints of the organism.

- A meaningful representation avoids the combinational explosion as the dimension of the meaningful network is limited by the relations to constraints satisfactions.

3. Meaningful Information and Representations in Humans

Meanings and representations are important parts of our human lives. They can be conscious or unconscious. We build internal mental representations by our thoughts and external ones like maps and paintings. We live in a society of communications where interacting by meanings and representations happens all the time, language being a key tool. But analyzing the content and nature of meaningful information and meaningful representations in humans is not an easy task.

We as humans are embedded in networks of meanings, in meaningful representations as defined above. And most of what has been said for animals does apply. But what comes in addition in terms of constraints specific to humans is difficult to define. These difficulties come from the fact that we do not know our own nature. As said, the nature of human mind is a mystery for today science and philosophy.

Strictly speaking, the analysis of meaningful information for humans can only be incomplete due to our lack of understanding of human mind. What is known today about meaningful information for humans can be investigated using constraints satisfactions in two directions at least:
List the constraints we know as belonging to today human being and take them as a base for deducing the possible generations of meanings, or take the animal constraints as a starting point and try to identify what evolution may have brought in addition or modified.

The first approach belongs to psychology and to philosophy of mind. It can be addressed in a very simplified way by the Maslow pyramid of needs: physiological needs, needs for safety and security, needs for love and belonging, needs for esteem and the need to actualize the self, in that order. Considering these needs as constraints that humans have to satisfy makes possible a usage of the MGS for humans in their environment. But we have to be careful with such a process and highlight its limits: all the interferences of free will actions and conscious feelings with the Maslow pyramid needs will have to be taken into account as they are: with a limited understanding of their meanings.

Regarding the second approach, an evolutionary scenario can be proposed where a constraint of anxiety limitation is introduced [Menant, 2006 b]. The scenario is about the coming up of self-consciousness during evolution. The performance of intersubjectivity that existed at pre-human primate level is used as a thread to explain the build up of a conscious self. But the resulting identification with conspecifics also led to identifying with endangered or suffering conspecifics which produced a significant increase of anxiety at these times of survival of the fittest. Such anxiety increase had to be limited. The hypothesis developed is that anxiety limitation came up as a key constraint for our pre-human ancestors and played a significant role as an evolutionary engine up to today human nature. The evolutionary scenario proposes that the actions implemented to limit anxiety have favored the development of empathy, imitation, language and group life which brought obvious evolutionary advantages and allowed a positive feedback in the evolutionary process. In terms of meaning generation, the hypothesis is that an anxiety limitation constraint has been a high contributor through human evolution (and still is today, as shaping many of our thought and behaviors). More work in needed on this subject as anxiety generations and limitations are today beyond identification with suffering conspecifics. Following the same thread, other pre-human and human specific constraints are also to be identified.

Figure 4 gives a summary of the proposed scenario about the evolution of self-consciousness.

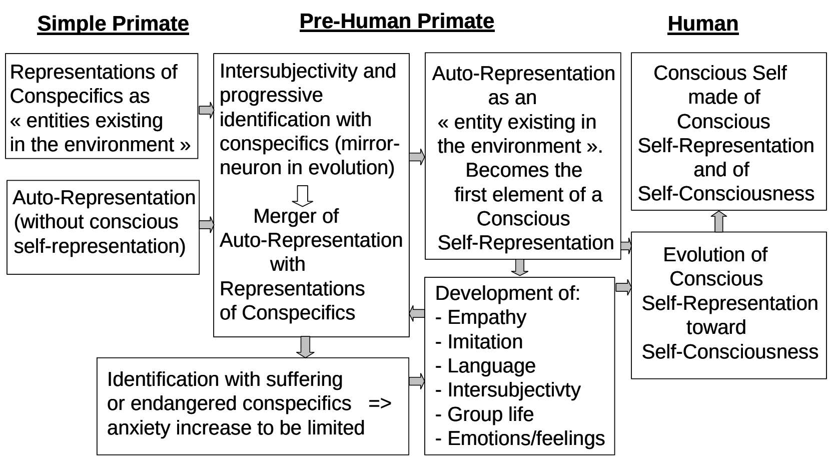

Fig.4. Evolution of self-consciousness

The proposed scenario positioning anxiety limitation as a key item in the coming up of self-consciousness during evolution opens a new path for an evolutionary approach to consciousness.

Self-consciousness can be defined as “the possession of the concept of the self and the ability to use this concept in thinking about oneself” [Block, 2002]. It is different from phenomenal consciousness which can be understood as “experience; the phenomenally conscious aspect of a state is what it is like to be in that state” [Block, 2002]. The presence of phenomenal consciousness has also to be taken into account in this type of evolutionary scenario. Work is in process on this subject [Menant, 2008].

4. Meaningful Information and Representations in Artificial Systems

Our definition of meaning generation has been introduced as based on the performances of life (stay alive constraint) and has been generalized into a system (maintain a nature by constraint satisfaction). This approach allowed us to define a meaningful representation of an item for a system.

We want here to see how this systemic approach to meaning generation can be used for artificial systems. In that case, the systems and the constraints are artificial as coming from the designer. The constraints and meanings are not intrinsic to the system as they were in the case of organisms. We will look at the compatibility of the MGS approach with different stages of AI from traditional AI to the enactive approach.

4.1. *Meaningful information and representations from traditional AI to Nouvelle AI. Embodied-situated AI*

Representations were first introduced in traditional AI and cognitive sciences as meaningless symbolic elements standing for the represented entities and processed by a central system “A symbol may be used to designate any expression whatsoever. That is, given a symbol, it is not prescribed a priori what expressions it can designate.” [Newell, Simon, 1976].

Such meaningless and centralized symbols were assumed to be “at the root of intelligent action” and usable to simulate human intelligence in computers. The mind was compared to a computational system (the “computational metaphor of the mind”). But it is now clear that such computational metaphor has been misleading. The brain is more than a computer. Computation alone cannot generate meaningful information. Such meaningless characteristic of symbolic representations has been illustrated by the Chinese room argument where Chinese characters are manipulated by a non Chinese speaking person using correspondence tables [Searle, 1980]. The meaning of the symbols is in the correspondence table which comes from the designer of the experience. The meaning does not come from the computation. The Chinese room experience has been answered by the symbol grounding problem (connecting the symbols to what they are about) [Harnad, 1990].

Traditional AI has been successful for computing on large numbers of symbols using precisely defined rules (chess playing, expert systems, trajectories simulations, ...). But besides important successes, traditional AI has encountered limitations due to its brittleness and limited flexibility, and also to the risk of combinational explosion when dealing with complex subjects. Traditional AI follows a Cartesian approach to problem solution where a complex problem is subdivided into smaller problems easier to solution (“divide each of the problems I was examining in as many parts as I could”). Following the same rule, entities to be represented are divided into sub entities down to a level where they are simple enough to be symbolized. Such process becomes highly consuming in computing power and lacks flexibility. Calculation overload is at risk by combinational explosion when the represented entities are complex. The limitations of traditional AI were the cost of looking for a detailed symbolic representation of the environment. Such traditional AI has been dubbed GOFAI (Good Old Fashion AI) [Haugeland, 1989].

To go beyond the limitations of GOFAI, new concepts had to be looked for. They came from the world of robotics through a “Nouvelle AI” where the symbolic model of the environment is replaced by multiple continuous sensing implemented by the agent when needed. Central control is not the rule any more. The agent has the possibility to continuously use its sensors to feel its environment rather than referring to a centralized model: “the intelligent system is decomposed into independent and parallel activity producers which all interface directly to the world through perception and action” [Brooks, 1991 a]. The construction of internal models of an outside reality is not needed any more. Intelligence is then considered as emerging from the interaction of simple behaviours. Symbolic representations are put aside. “It turns out to be better to use the world as its own model” [Brooks, 1991 a]. The agent is now “situated” and “embodied” in its environment. “The robots are situated in the world—they do not deal with abstract descriptions, but with the “here” and “now” of the environment that directly influences the behaviour of the system”…“The robots have bodies and experience the world directly. Their actions are part of a dynamic with the world, and the actions have immediate feedback on the robots' own sensations”. [Brooks, 1991 b].

The situated and embodied approach does not use the notion of meaningful information because it is not needed for the functioning of the robots. Direct sensori-motor loops link the robot to its world without needing to explicit a meaningful aspect of the processed information. However, meaning generation could be introduced in each sensori-motor loop, bringing in information related to the local constraint satisfaction of each sensori-motor loop. Such add would not bring anything to the robot as it is now but it could make available spread meanings regarding environmental entities. These meanings could be used in a higher level system as meaningful representations of the environment for the robot. It may look quite surprising to propose reintroducing representations in Nouvelle AI. But these representations are not the symbolic ones that Nouvelle AI has put aside. We are talking about using meaningful information that link the system to its environment. As said, embodied-situated robotics does not need this meaningful information, we just note that the generation of such artificial meaningful information is possible in embodied-situated robotics. But it should be clear that these meanings are not intrinsic to the robot, they are artificial meanings generated with artificial constraints coming from the designer of the artificial agent.

On the same token, the performances of the sensori-motor loop of an artificial system, even if processing meaning generation, are far from covering the performances of life. Despite all the progress made by the AI field, we are still "not good at modelling living systems" [Brooks, 2001]. A possible reason for this may be that we are missing some important property or characteristic of life still to be discovered. In order to overcome this point, we may need to "find new ways of thinking about living systems to make any progress".

Among the performances of life that we are not successful modeling is autonomy. Autonomy is a performance of life that we have difficulties to describe. The nature of autonomy is not clearly understood and efforts are deployed to characterize it as constitutive (or intrinsic, as internally generated) or behavioural (or extrinsic, as externally imposed). It is agreed that the autonomy of today artificial systems is far from the autonomy of living systems: "despite all biological inspiration and self-organization, today's so-called "autonomous" agents are actually far from possessing the autonomy of living systems." [Ziemke and Sharkey, 2001].

4.2. *Meaningful representations versus the guidance theory of representation*

The guidance theory of representation (GTR) [Anderson, Rosenberg, 2008] is a theory of representational content which focuses on action. It proposes that "the content and intentionality of representations can be accounted for in terms of the way they provide guidance for action". The notion of representation is linked to what the representation does for the agent: "what a representation does is provide guidance for action". This focus on action goes with grounding the content of a representation in the action on the environment. "Representations come into existence and derive their content from their role supporting the basic intentionality of action". Constraints are considered as "associated with assigning motivating reasons".

The GTR and the MGS approach are close as they both take into account the action of an agent on its environment and are rooted in biological behaviour. There are some differences however. Differences are in the nature of the representations and in the level at which the action is taken into account.

For the GTR, a representation is mostly considered by what it does in terms of providing guidance for action. The GTR focuses on the usage of the representation more than on its nature or origin. “We ask first not what a representation is, but what it does for the representing agent, and what the agent does with it; what is a representation for? Our contention is essentially that representations are what representations do”. The MGS approach, on its side, defines the nature of the representation as made of meaningful information. The representation is defined as resulting of meanings generations by a system submitted to constraints.

For the GTR, the action is the key contributor to the definition of the representation. The guidance theory presumes “that the intentionality of representation can be grounded in the intentionality of action”. A percept becomes a representation because it provides guidance for action. For the MGS approach, it is first the presence of a constraint to be satisfied that generates the build up of meanings and representations. The action comes after.

Also, as the MGS approach is rooted in constraint to be satisfied as source of meaning generation, the organic or artificial nature of the constraint allows to differentiate the organic and artificial natures of the generated meanings and representations in the agent.

GTR and MGS approach are on the same ground as maintaining a role for representations in AI and cognition.

4.3. ***Meaningful information and representations versus the enactive approach***

The enactive approach to cognition and AI has been initiated in the 1970s by the work of H. Maturana and F. Varela. The enactive approach is the baseground of significant current research activities. The word “enact” links cognition to action, to the doing and experiences of the agent. The knowledge that the agent has of its environment comes from the interactions that links it to its environment: “…enaction asserts that cognition is a process whereby the issues that are important for the continued existence of a cognitive entity are brought out or enacted: co-determined by the entity as it interacts with the environment in which it is embedded” [Vernon, Furlong, 2007].

This perspective introduced by enaction as linking agents to their worlds is applied to the field of cognition for organisms including humans and also to the field of AI with the new domain of enactive AI: "enactivism can have a strong influence on AI because of its biologically grounded account of autonomous agency and sense-making" [Froese, 2007].

We will look first at the compatibility of the MGS based meaningful information and representations with enaction, and then with the enactive AI.

The enactive approach can be characterized by five themes [Torrance, 2005]:

(a) Minds are the possessions of embodied biological organisms viewed as autonomous – self-generating and self-maintaining – agents.
(b) In sufficiently complex organisms, these agents possess nervous systems working as organizationally closed networks, generating meaning, rather than processing information as inner representations of the external world.
(c) Cognition, conceived fundamentally as meaning-generation, arises from the sensori-motor coupling between organism and environment.
(d) The organism's world is "enacted" or "brought forth" by that organism's sensori-motor activity; with world and organism mutually co-determining one another, in ways that have been analyzed by investigators in the continental phenomenology tradition.
(e) The organism's experiential awareness of its self and its world is a central feature of its lived embodiment in the world, and therefore of any science of the mind.

The compatibility of MGS based meaningful information with enaction is to be addressed first by looking at the compatibility with the two themes expliciting the notion of meaning generation.

Meaningful information is compatible with b): the MGS is part of a higher level system (an agent) where meaning generation exists for the system to maintain its nature in its environment. We however do not oppose meaning generation to information processing as meaning generation by the MGS is information processing (see Figures 1, 2 & 3). And our meaningful representations, made of meaningful information, come from meaning generation.

Meaningful information is compatible with c) as the MGS links and couples the agent with its environment by a permanent interaction through perception and action.

This brief comparison based on the characteristics of the MGS brings to consider that MGS based meaningful information looks compatible with the two themes of enaction that explicitly deal with meaning generation. The compatibility with the other themes is difficult to address as they introduce concepts from phenomenology and science of the mind which are beyond a systemic approach to meaning generation. This brings us to limit the compatibility of the MGS approach with enaction to the generation of meaningful information. It should also be noted here that the five themes characterise enaction for organisms, not for artificial systems. The MGS on its side is a systemic approach that can apply to organisms as well as to artificial agents.

Regarding the compatibility of meaningful representations with enaction, one could assume that it can be deduced from the proposed compatibility of meaningful information generation with enaction, as meaningful representations are made of meaningful information. But several researchers and philosophers are reluctant to use the notion of representation in enaction. There are several reasons for that: one is the origin of representations in AI as meaningless and centrally processed symbols which limits their possible usage. Another reason goes with the rooting of enaction in phenomenology [Depraz, 2007] which brings several philosophers to argue that the notion of representation should not be used with enaction. H. Dreyfus has been holding for long that the usage of representation in AI is a mistake and that the importance of the body behavior should be taken as key : “Heidegger’s crucial insight is that *being-in-the-world* is more basic than *thinking* and solving problems; it is not representational at all.” [Dreyfus 2007]. Francisco Varela also has been arguing against the notion of representation. When coining the word “enactive”, he wrote [Varela and all, 1991]: “We propose as a name the word *enactive* to emphasize the growing conviction that cognition is not the representation of a pre-given world by a pre-given mind but is rather the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs”.

Consistent with such positions, some today philosophers and researchers in the enactive area tend to reject the notion of representation: “there are certain ideas in cognitive science that the enactive approach clearly rejects, e.g., homuncularity, boxology, separability between action and perception, and representationalism” [Di Paolo & all, 2007].

We consider that such a rejection is mostly a rejection of the GOFAI type of representations (symbolic and meaningless) and that it should not apply to the meaningful representations as defined here. So we consider that the proposed compatibility of meaningful information generation with enaction can be extended to meaningful representations. Meaningful representations that embed agents in their environments by constraint satisfactions are to be considered as compatible with enaction in terms of meaning generation.

But the above sentence about enaction as rejecting boxology and separability between action and perception brings in some concern about the MGS compatibility with enaction in terms of building block. As said above, the MGS is a building block modelling meaning generation in agents. The fact that enaction is reluctant to use a building block approach has to be highlighted as it limits the compatibility of the MGS approach with enaction.

Enactive AI is a new and maturing domain proposing to go beyond some limitations of embodied AI. Among these is the fact that “the presence of a closed sensori-motor loop *does not* fully solve the problem of meaning in AI” [Di Paolo, 2003]. The MGS approach is compatible with such a position as the generated meaning comes from the connection existing between the sensed information and the constraint of the system, not from a closed sensori-motor loop alone.

Enactive AI is looking for a system having the capacity “to actively regulate its ongoing sensori-motor interaction in relation to a viability constraint.” [Froese and Ziemke, 2009]. The MGS approach where the generation of a meaning is directly related to the satisfaction of a constraint is compatible with such linking of a system to its environment by a constraint.

Beyond these first elements of compatibility, enactive AI considers two “necessary systemic requirements”: constitutive autonomy and adaptivity [Froese, Ziemke, 2009]. Enactive AI takes them both as necessary for meaning generation (sense making).

Constitutive autonomy is basically the autonomy of organisms as the applicability of the constitutive approach is "mainly restricted to actual organisms. " [Froese and all, 2007]; The MGS approach, as a systemic tool, is usable for organisms and for artificial systems. The performance of autonomy that applies to the MGS is the one of the agent hosting it. In the case of organism, the MGS will deal with the autonomy of organisms, which is compatible with constitutive autonomy.

The performance of adaptivity[4], "reflects the organism's capability – necessary for sense-making – of evaluating the needs and expanding the means towards that purpose" [Di paolo, 2005]. There are tight links between adaptivity and meaning generation as "a careful analysis of sense-making shows that different properties of adaptivity (self-monitoring, control of internal regulation, and control of external exchanges) are implied by assuming that organisms have a meaningful perspective on their world". The MGS approach looks compatible with the performance of adaptivity as constraints satisfactions can go by internal or external actions from the agent.

As introduced above, the compatibility of the MGS approach with the phenomenological concepts used by enaction and by enactive AI still needs to be addressed. Phenomenology calls for first person point of view and lived experience that are significantly beyond the horizon of the proposed systemic approach on meaning generation. The MGS approach does not need first person point of view nor lived experience (which does not mean that it is incompatible with them). Also, regarding lived experience, we consider that there still may be a need to look for "something unknown" in our models for understanding the nature of life. Probably "we might be missing something fundamental and currently unimagined in our models of biology" [Brooks 2001] in order to get clear

[4] Adaptivity is defined in Enactive AI as [Di Paolo, 2005] "a system's capacity, in some circumstances, to regulate its states and its relation to the environment with the result that, if the states are sufficiently close to the boundary of viability, 1. tendencies are distinguished and acted upon depending on whether the states will approach or recede from the boundary and, as a consequence, 2. tendencies of the first kind are moved closer to or transformed into tendencies of the second and so future states are prevented from reaching the boundary with an outward velocity".

enough an understanding of organic autonomy and corresponding intrinsic meaning generation. The MGS approach can be a thread for further investigations in this area by using constraints positioned between physico-chemical laws and biological ones. The introduction of "pre-biotic constraints" to be defined could open a path for the evolution of material constraints toward organic ones. (see Walter Riofrio, this volume).

5. Conclusion and Continuation

5.1. *Conclusion*

In this chapter we have extended to meaningful representations the existing systemic approach on meaningful information based on the Meaning Generator System (MGS) [Menant, 2003].

Our starting point is a meaningful information about an entity of the environment as generated by a system submitted to a constraint. The meaningful information (the meaning) is the connection existing between the constraint and the information received by the system from the entity. It is used by the system to produce an action that will satisfy its constraint. The generated meaning links the system to its environment. An agent having several constraints to satisfy and receiving different information from an entity will generate a network of meanings relative to the entity, including the actions scenarios. We call this network of meanings "meaningful representation of the entity for the agent". The meaningful representations of entities of the environment embed the agent in its environment.

The notion of meaningful representation has been applied to animals, humans and artificial systems. For artificial systems, the constraints and meanings are artificial and come from the designer. For animal and humans, they are intrinsic to the agents. Our lack of understanding about human mind highlights the existence of unknown items about human representations in terms of constraints satisfactions. Openings are proposed on this subject by an evolutionary scenario.

The MGS approach has been positioned relatively to embodied-situated AI, to the guidance theory of representations, and to the enactive AI.

It has been proposed that the MGS approach can be added to embodied-situated AI, and that it has some common grounds with the guidance theory of representations.

The comparison of the MGS approach with enaction has shown that meaningful information and representations, as embedding an agent in its environment by constraint satisfactions, are compatible with enaction in terms of meaning generation. Comparison with enactive AI has presented the MGS approach as compatible with constitutive autonomy and with adaptivity.

Some concerns have been highlighted relatively to the rejection of boxology by enaction that makes difficult the usage of the MGS as a building bock. Also, the compatibility of the MGS approach with phenomenological concepts like first person point of view and lived experience is to be analyzed.

5.2. *Continuation*

The positioning of meaningful representations within AI as introduced here brings up subjects that deserve some further analysis:

- Provide a more detailed description of networks of meanings as based on constraints satisfaction. Consider if it could be an entry point for ontologies based on systems having constraints to satisfy to maintain their natures

- Investigate the notion of constraint and look if it could be related to physico-chemical laws in order to position a link between artificial constraints and biological ones. (Introduction of pre-biotic constraints).

- See how a better understanding about the nature of life could shed some light on the nature of organic (intrinsic, constitutive) autonomy and make available a reference for the definition of artificial (behavioural) autonomy. (This may be related to the hypothesis [Brooks, 2001] that "there may be some extra sort of 'stuff' in living systems outside our current scientific understanding").

- Look at how the notion of autonomy could be related to the notions of constraint satisfaction and of meaning generation.

- See how the build up of an identity could be based on constraints that an agent has to satisfy in order to maintain its nature in its environment.

- Identify human specific constraints in order to relate them to an evolutionary approach on human consciousness.
- Investigate the evolution of the anxiety limitation process beyond the phylogenetic thread of identification with suffering or endangered conspecifics.
- Analyse the compatibility of the MGS approach with phenomenological concepts like first person point of view and lived experience.

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