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ON BUILDING A BIOLOGICALLY-INSPIRED EXPERIMENT ON SYMBOL-BASED COMMUNICATION

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ABSTRACT

We describe our methodology for building a computational experiment for the investigation of the emergence of self-organized symbol-based communication involving distributed interactions between artificial creatures. Constraints from Peircean pragmatic philosophy of sign and empirical and neuroethological evidences are applied in the set-up, design and synthesis of our creatures, environment and processes. We claim that the construction of synthetic experiments from empirical and theoretical constraints permits to better understand the natural phenomena under study.

KEYWORDS

Neuroethology, communication, semiosis, symbol process, self-organization, emergence, computer simulation.

INTRODUCTION

Computational models, simulations, and creatures of all kinds are implemented in many ontologies, by means of 'synthetic strategies' (as opposed to analytical ones) (cf. Braitenberg, 1984). They are based on different tools, being heavily influenced by meta-principles (formal theoretical constraints) and biological motivations (empirical constraints) in the design of the environment and the morphological definitions of sensors, effectors, cognitive architecture and processes of the conceived creatures. This theoretical basis influences modeling on different degrees depending on how it constrains the model being built and what decisions it leaves to the experimenter. Constraints entail a reduction in the degrees of freedom that we can assume while building the experimental set-up, by 'setting values to experimental parameters' following definitions and motivations from more reliable sources than naïve or arbitrary decisions. If theoretical foundations and constraints are used to develop computational experiments, these experiments may also provide contributions back to the theories and studies they were based upon. Simulations test hypotheses, the internal consistency of their theoretical background, and offer the opportunity to implement experiments that would be more/too costly or even impossible otherwise.

Computational approaches have been used to model and simulate *meaning processes (semiosis)* from many different perspectives, including Evolutionary Robotics, Artificial Life, Synthetic Ethology, and Computational Semiotics (for some examples, see section IV). 'Meaning' is certainly a great challenge to computer scientists, and it is related to two classical problems regarding the construction of artificial systems: symbol-grounding problem and frame problem. According to Deb Roy [Roy 2005a], 'developing a computationally precise and tractable theory of language use which simultaneously addresses both referential and functional meaning is a grand challenge for the cognitive sciences'. An established approach describes that meaning process should be contextually grounded and acquired during local interactions among artificial distributed agents.

Here we present our methodology for the investigation of the emergence of self-organized symbol-based communication involving distributed interactions between artificial creatures. The set-up, design and synthesis of our creatures, along with the digital ecosystem, are theoretically based on the Peircean pragmatic philosophy of sign and empirically informed by neuroethological evidence. We view the emergence of communication as a self-organizing process in a complex system of sign users interacting locally and mutually affecting each other, leading to an ordered state. Our methodology simulates the emergence of symbolic predator-warning communication among artificial creatures in a virtual world of predatory events. In order to build the digital ecosystem, and infer the minimum organizational constraints for the design of our creatures, we examined the well-studied case of semiosis in East African vervet monkeys (*Cercopithecus aethiops*), and its possible neuroanatomical substrates.

THEORETICAL AND EMPIRICAL CONSTRAINTS

Constraint A. Semiosis and Communication in semiotics

According to Peirce's pragmatic approach, semiosis (meaning process) is an interpreter-dependent process that cannot be dissociated from the notion of a situated (and actively distributed) communicational agent. It is an interpreter-dependent process in the sense that it triadically connects sign (representation), object, and an effect on the interpreter (interpretant). The object is a form (habit, regularity, or a 'pattern of constraints') embodied as a constraining factor for interpretative behavior – a logically 'would be' fact of response. The notion of semiosis as a form communicated from object to interpreter through mediation of a sign allows us to conceive meaning, and meaning change, in a processual (non-substantive) way, as a constraining factor of possible patterns of interpretative behavior through habit and change of habit.

Semiosis is also pragmatically characterized as a pattern of behaviors that emerges through the intra/inter-cooperation between agents in a communication act, which concerns an utterer, a sign, and an interpreter [Peirce 1967]. Meaning and communication processes are thus defined in terms of the same "basic theoretical relationships" [Ransdell 1977], i.e., in terms of a self-corrective process whose structure exhibits an irreducible relation between three elements. In a communication process, "[i]t is convenient to speak as if the sign originated with an utterer and determined its interpretant in the mind of an interpreter"[Peirce 1967].

Constraint B. Sign model and classes

In his "most fundamental division of signs", Peirce characterized icons, indexes, and symbols as matching, respectively, relations of similarity, contiguity, and law between sign and object. Icons are signs which stand for their objects through intrinsic similarity or resemblance irrespective of any spatio-temporal physical correlation that the sign has with an existent object. In contrast, indexes can only occur when the sign is really determined by the object, in such a way that both must exist as concurrent events. Finally, in a symbolic relationship, the sign refers to the object by a determinative relation of law or convention, a "habit (acquired or inborn)", regardless of "the motives which originally governed its selection." In this symbolic sign process, the object In terms of cognitive processes, icons are associated with sensory tasks. They are present in the sensory recognition of external stimuli of any modality, and in the cognitive relation of analogy. By contrast, the notion of spatio-temporal co-variation between sign and object is the most characteristic property of indexical processes. The examples range from a demonstrative or relative pronoun, which "forces the attention to the particular object intended without describing it"[Peirce 1958], to physical symptoms of diseases, weathercocks, thermometers. We have claimed elsewhere that the alarm-call system used by African vervet monkeys (Cercopithecus aethiops), a well-known case of vocal communication in non-human primates, logically satisfies the Peircean definition of symbol [Ribeiro et al 2007]-[Queiroz & Ribeiro 2002]. Generally speaking, a symbolic sign communicates a habit embodied in an object to the interpretant as a result of regularity in the relationship between sign and object.

Constraint C. Referential communication in non-human animals

An analysis of semiotic behavior we have made point out that some non-human animals can be seen as communicating using symbols as defined by Peirce's theory [Ribeiro et al 2007]. They mostly constitute simple cases of symbol usage without further symbol-related properties, such as recursion or compositionality. The case of predator-warning alarm-calls in vervet monkeys constitutes a well-characterized example of referential communication. Field studies [Seyfarth & Cheney 1980]-[Struhsaker 1967] have revealed three main kinds of alarm-calls used to warn about the presence of (a) terrestrial stalking predators, (b) aerial raptors, and (c) ground predators. The correct use of alarms calls depends on some sort of learning processes since adult vervets are able to do so, while infant vervets initially do not, but gradually develop this ability [Seyfarth & Cheney 1986]. The assumption that the mapping between signs and objects can be learned is also supported by the observation that cross-fostered macaques [Cheney & Seyfarth 1998]. The alarm-call system in vervet monkeys is a useful example of a symbolic semiotic system, which can be simulated through a community of agents that implement the 'minimum brain model' presented below, subjected to empirical constraints not yet applied in developing experiments for the emergence of symbol-based communication (see [Ribeiro et al 2007]).

Constraint D. Neural representation domains and association rules

For an adequate development of our semiotic creatures, it was crucial to determine the minimum set of neurobiological constraints to be implemented in programming code in order to generate the desired final behaviors. A minimum vertebrate brain was modeled as being composed by three major representational relays or domains: the sensory, the associative and the motor. According to such minimalist design, different first-order sensory representational domains (RD1s) receive unimodal stimuli, which are then associated in a second-order multimodal representation domain (RD2) so as to elicit symbolic responses to alarm-calls by means of a first-order motor representation domain (RD1m). The process by which a virtual creature learns to associate representations was modeled to follow the rules first postulated by Donald Hebb [Hebb 1949], by which synchronous pre-synaptic inputs generate synaptic reinforcement. The functions performed by associative representational domains include the combinatorial association of sensory and motor representations (e.g. cross-modal perceptual processing in the cerebral cortex [Calvert 2001][Andersen & Buneo 2002][Lloyd et al 2003]), the attribution of adaptive value to sensorimotor representations (e.g., emotional processing in the amygdale [Rodrigues et al 2004][McGaugh 2004]) and the implementation of short-term, fast-retrieve, erasable memory (e.g., working memory in the orbitofrontal cortex and hippocampus [Suzuki 1999]-[Rolls 2000]). As discussed below, a neurosemiotic model of the alarm-call system in vervet monkeys assuming just such minimum neural constraints reveals the emergence of symbol-based referential communication [Ribeiro et al 2007][Queiroz & Ribeiro 2002], and allows for the investigation of different semiotic stages of behavior ontogenesis.

Constraint E. Self-organization and emergence of communication processes

Self-organization is a process that mainly occurs in complex systems composed of many interacting entities that mutually affect each other's state, leading the system to an 'ordered' state, i.e. a state of reduced variability and ambiguity, with increased redundancy. Communication processes can be viewed as self-organizing if utterers and interpreters mutually affect each other, through local interactions in communicative acts, such that their future communication interactions are dependent of the past ones. In fact, sign users capable of learning though communicative interactions with others, correspond, in self-organizing systems, to entities capable of affecting others (as utterers) and of being affected (as interpreters) in a self-correcting process. By means of these ongoing processes, an ordered stated can be produced such that communicative variability (such as sign usage repertoire) or ambiguity is reduced, without any external or central control.[1]

We claim that the digital scenario we developed in our experiment leads to the emergence of self-organized symbol-based communication among artificial creatures. In the context of the sciences of complexity, the concept of 'emergence' has become very popular, to the extent that these fields are often described as dealing with 'emergent computation'. We employ the analysis of emergence applied to semiotics put forward by Queiroz & El-Hani (2006) and extended in Loula et al (in preparation).

Applying the hierarchical model for semiotic systems developed in [Queiroz & El-Hani, 2006] to explain emergent semiotics processes, we should consider (i) a focal level, where an entity or process we want to investigate is observed in a hierarchy of levels; (ii) a lower level, where we find the parts composing that entity or process; and (iii) a higher level, into which the entities or processes observed at the focal level are embedded. Both the lower and the higher levels have constraining influences over the dynamics of the processes at the focal level. The emergence of processes (e.g., symbol-based communication) at the focal level can be explained by means of the interaction between these higher- and lower-level constraints so as to generate its dynamics. At the lower level, the constraining conditions amount to the possibilities or initiating conditions for the emergent process, while constraints at the higher level are related to the role of a selective environment played by the entities at this level, establishing boundary conditions that coordinate or regulate the dynamics at the focal level.

Semiotic processes at the focal level are described here as communication events. Accordingly, what emerges at the focal level is the product of an interaction between processes taking place at lower and higher levels, i.e., between the relations within each sign-object-interpretant triad established by individual utterers or interpreters and the embedment of each individual communicative event, involving an utterer, a sign and an interpreter, in a whole network of communication processes corresponding to a semiotic environment or context.

The macro-semiotic (or higher) level regulates the behavior of potential S-O-I relations; it establishes the patterns of interpretive behavior that will be actualized by an interpreter, among the possible patterns it might elicit when exposed to specific signs, and the patterns of uttering behavior that will be actualized by an utterer, among the possible patterns it might elicit when vocalizing about specific objects. This macro-semiotic level is composed of a whole network of communicative events that already occurred, are occurring and will occur; it characterizes the past, present, and future history of semiotic interactions, where utterers are related to one or more interpreters mediated by communicated signs, interpreters are related to one or more utterers, and interpreters turn into utterers. We can talk about a micro-semiotic (or lower) level when we refer to a repertoire of potential sign, object, and interpretant relations available to each interpreter or utterer, which might be involved in interpreting or uttering processes. Thus, in the micro-semiotic level we structurally describe the sign production and interpretation processes going on for an individual involved in a communicative act and, therefore, we talk about S-O-I triads instead of sign-utterer-interpreter relations. When an utterer, mediated by a sign, is connected to an interpreter, and thus a communication process is established, we can talk about a focal level, which necessarily involves individual S-O-I triads being effectively formed by utterer and interpreter. But in a communicative event, the actualization of a triad depends on the repertoire of potential sign, object, and interpretant relations and also on a macro-semiotic level, i.e., to networks of communication processes, which defines a context for communicative processes establishing boundary conditions that restrict the actualization from possibilities (for more details, see [Queiroz & El-Hani, 2006]).

FROM CONSTRAINTS TO A SYNTHETIC EXPERIMENT

A. An experiment on symbol-based communication emergence

The creatures are autonomous agents inhabiting a virtual bi-dimensional environment. This virtual world is composed of preys and predators (terrestrial, aerial and ground predators), and of things such as trees (climbable objects) and bushes (used to hide). The preys are not divided into apprentices and tutors, as with infants and adults in the vervet monkeys case and as we have previously simulated [Loula et al 2004]. Here we go beyond the ethological case proposing a scenario in which no previous repertoire of alarms calls would be known and no symbol-based communication occurs yet.

Creatures are equipped with sensors (visual and auditory) and actuators (e.g. move, vocalize, change gaze direction), and are controlled by a behavior-based architecture [Mataric 1998], with multiple parallel behavior modules such as wandering, visual scanning, fleeing or chasing. This control architecture allows the creature to choose between different conflicting actions, given the state of the environment and the internal state of the creature.

Associative learning is the mechanism used by preys to gradually establish connections between auditory and visual data. The development of these associations relies on no explicit indication of the correct referent to be associated with

[1] The idea of communication/language as a self-organizing process have been presented also by other authors, e.g.[Steels 2003],[Keller, 1994].

alarms or whether the connection made was mistaken. The constitution of alarm-predator association mainly depends on the statistical co-occurrence of events, such as alarms being vocalized in the presence of nearby predators.

Working and associative memories were implemented in prey creatures, to allow them to learn temporal and spatial relations from the external stimuli and thus acquire association rules necessary to interpret signs as symbols. In the working memories, stimulus-related information is kept for a few instants, allowing different stimuli received in close instants to co-occur in memory. The associative memory holds associations (with strength values between 0 and 1) that are created, reinforced and weakened according to the co-occurrence of stimuli in the working memories. In our model, associative memory formation follows Hebbian associative learning principles [Hebb 1949].

As associations are learned, preys use them to emit specific alarms when a predator is seen (if more than one the strongest one is used); if no alarm is known for the predator, a new one is randomly created and associated with the predator. When a prey hears a nearby creature vocalize a specific alarm-call, it initially scans the surroundings, searching for possible co-occurring events. A feedback may also be provided by the associative memory to the control mechanism, if the vocalization heard is already associated with a specific predator type. Depending on the association strength, it can influence the creature's behavior as if the related predator was actually seen, eliciting an escape response.

More technical details about the experiment can be found in [Loula et al 2004]

B. The constraints of the experiment

We simulate an ecosystem that allows the cooperative interaction of agents, including intra-specific communication by alarm calls to alert about the presence of predators (Constraint C). For the emergence of symbol-based communication and a global coherent repertoire of alarms, preys should rely only in local communicative interactions that affect individuals through learning, setting conditions for self-organization (Constraint E). Associative learning is the mechanism used by preys to gradually establish connections between auditory and visual data, in line with the evidence that alarm-calls are learned (Constraint C).

The associative learning conception was aided by several constraints. First, symbols are an interpretant-mediated sign-object relation, i.e. a mental association or a habit that has to be built in the creature to associate sign-object, in such a way that no external clue is needed for the creature to connect that sign to that object (Constraint B). Communication can play a major role in the constitution of such habit, as habits are transmitted from an utterer to an interpreter in a communication event (Constraint A). To help this process of habit transmission, an indexical relation between an alarm call and the possible scanned referents at the given episode is available, upon which symbols can be built. The prey, however, must be able to find out which referents are suitable, i.e., it should generalize an association for future occurrences, and, thus, engage in symbol-based communication.

An architecture relying on two separate unimodal representation domains and a higher order multimodal representation domain where associations are established must be involved, thus our architecture follows this general model as a plausible scheme (Constraint D). The memory architectures of the artificial creatures were in essence the same as the minimum brain described before: creatures have working memories (RD1s) and an associative memory (RD2). Hebbian associative learning principles are a simple mechanism widely found in non-human animals (Constraint C). Associations established in RD2 may produce effects in the motor control architecture (RD1m), producing an immediate escape response after alarm hearing.

Self-organization is the process that describes the underlying dynamics of the emergence of symbol-based communication as much as a global pattern for a common repertoire of symbols (Constraint E). By communicating, a vocalizing prey affects the sign repertoire of the hearing preys, which will adjust their own repertoire to adapt to the vocalized alarm and the context in which it is emitted. Thus, the vocal competence will also be affected as it relies on the learned sign associations. This implies an internal circularity among the communicative creatures, which leads to the self-organization of their repertoires. This circularity is characterized by positive and negative feedback loops: the more a sign is used the more the creatures reinforce it, and, as a result, the frequency of usage of that sign increases; in turn, the less a sign is used the less it is reinforced, and, consequently, its usage is decreased.

In this self-organizing system, a systemic process (symbol-based communication), as much as a global pattern (a common repertoire of symbols), emerges from local communicative interactions, without any external or central control. This complex system of communicative creatures can be viewed as a semiotic system of symbol-based communication with three different hierarchical levels, based on the model described in section 4. The semiotic processes of symbol-based communication emerge at the focal level through the interaction of a micro-semiotic level, containing a repertoire of potential sign, object, and interpretant relations within an interpreter or an utterer, and a macro-semiotic level, amounting to a self-organized network of all communication processes that occurred and are occurring, involving vocalizing and hearing preys and their predators. It is in this hierarchical system that things in the environment become elements in triadic-dependent processes, i.e., alarms (signs) come to be associated with predators (objects) in such a manner that their relationship depends on the mediation of a learned association (i.e., they become symbols). In order to give a precise meaning to the idea that symbol-based communication emerges in the simulations we implemented, we argue that the semiotic processes at stake are emergent in the sense that they constitute a class of processes in which the behavior of signs, objects, and interpretants in the triadic relations actualized in communication processes cannot be deduced from their possible behaviors in simpler relations. That is, their behaviors, and, consequently, the semiotic process these behaviors realize, are irreducible due to their non-deducibility from simpler relations.

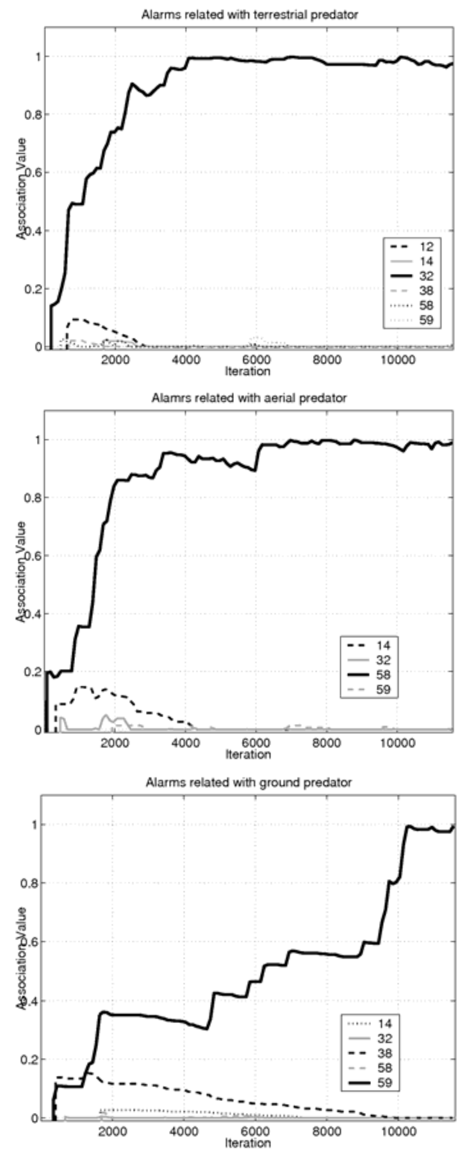
The system can be seen as moving in a state space defined by all individual sign repertoires. The system moves from point to point each time a creature adjusts its repertoire, i.e. when learning takes place. In this search space, attractors are defined as point where all individual repertoires converge to a common one, thus stabilizing the system. When the system stabilizes, creatures will be relating predators and alarms in the same way, and vocalizing and interpreting sign in the same manner.

C. Simulations of interactions among creatures

In order to study the self-organizing dynamics in communicative acts, we performed experiments by placing together preys and predators in the environment. During the execution of the simulations, we observed the associative memory items and the behavior responses of the preys to alarm calls.

At first, preys vocalize random alarms when predators are spotted by, and since no associations have been established yet, the hearing preys responds indexically to an alarm call through the visual scanning behavior that allows them to search for co-occurring events, and, thus, helping the learning process. After a while, no more new alarms are created since every prey already knows at least one alarm for each predator. Finally, after the association between alarm and predator gets near maximum value, it is used to interpret the sign and an internal feedback can activate the fleeing behavior, even if a predator is not seen. Hence, at this optimum value, the prey stops scanning after an alarm is heard, and flees right away; consequently, the communicative behavior can be interpreted as a symbol-based one. Now, the interpretation of a sign (alarm), i.e., the establishment of its relation to a specific object (a predator type) depends solely upon an acquired habit, and not on a physical correlation between sign and object, a property that qualifies the alarm sign to be interpreted as a symbol.

Simulation results show that there was a convergence to a common repertoire of associations between alarms and predators. This is a repertoire of symbols that make the preys engage in escape responses when an alarm is heard, even in the absence of visual cues. Here we present results from a typical simulation run, using 4 preys and 3 predators, together with various bushes and trees. We let the simulation run until the community of preys converged to a common sign repertoire for the predators. As noted before, preys can create alarms by randomly selecting one out of 100 possible alarms (from 0 to 99), when no alarm is known for a seen predator, and initially none of the preys have alarms associated with predators. Therefore, at the beginning of the simulation, new alarms are randomly created when preys meet predators. This creates an explosion in the available alarms, that tends to be in greater number than the existing predator types. In figure 2, we see that various alarms were created to refer to each predator at first, but soon they stop appearing because every prey will know at least one alarm for each predator. In the graph of figure 2a, the terrestrial predator is associated with alarms 12, 14, 32, 38, 58 and 59, but only alarm 32 reaches the maximum value of 1.0, and the competing alarms are not able to overcome it at any time. Similar results were found in the case of alarms 14, 32, 58 and 59 associated with the aerial predator (figure 2b): only alarm 58 reached a maximum value. But among the alarms for the ground predator (figure 2c), there was a more intense competition that led to the inversion of positions between alarms 38 and 59. They were created almost at the same time in the community, and initially alarm 38 had a greater mean value than alarm 59. But between iteration 1000 and 2000, the association value of alarm 59 overcame the value of alarm 38, which slowly decayed, reaching the minimum value after



(a)

(b)

(c)

Fig. 2. The mean association values of the alarm-referent associations for 4 self-organizers: (a) terrestrial predator, (b) aerial predator, (c) ground predator.

iteration 9000. This 'competition' between signs and the convergence to a unique one is mainly due to the self-organizing dynamics.

As preys are both sign users and sign learners, they work as media for signs to compete. If they are successful, i.e. if the interpreter associates the sign with the referent the utterer used it for, they will be reinforced, but if not, they will be weakened. The stronger the sign association is, the more it will be used, and the more it is used, the more it will be reinforced. This positive feedback loop allows the self-organization of the community sign repertoire, with alarm-referent associations getting stronger, leading, at some point, to the transformation of indexes into symbols, i.e., a habit shared by the entire populations of preys.

RELATED WORKS

There are connections of this work with experiments concerning the symbol grounding problem, and the self-organization and emergence of shared vocabularies and language in simple (real or virtual) worlds [Steels 2003]-[Sun 2000] (for a recent review of other works, see [Wagner et al 2003]). As a typical project in ALife, we simulate an ecosystem that allows cooperative interaction between distributed agents, including intra-specific communication, a process that can raise the fitness of individuals in the face of predatory events.

Some of related work follow empirical constrains as biological motivations (e.g. [MacLennan 2002],[Noble 1998]), but none apply neurobiological constraints. Others present theoretical foundations by referring to Peirce's work [Cangelosi et al 2002][Vogtl 2002][Jung & Zelinsky 2000][Sun 2000][Roy 2005b], but they just borrow his definition for a symbol or a sign without any further consequences to the designed experiment. In addition, some make incompatible changes to the Peircean models, with no support whatsoever in Peirce's work, and others follow Deacon's[Deacon 1997] reading of Peirce's theory. However, Deacon's description of humans as the only 'symbolic species', based on the assumption that symbols necessarily have combinatory properties, is in fact incongruent with Peirce's theory and frontally collides with several empirical lines of evidence (for a discussion of this point, see [Ribeiro et al 2007]-[Queiroz & Ribeiro 2002]).

Just bringing forward a definition out of Peirce's theory when describing an experiment but not deriving any consequence or constraint to the experimental setup certainly reduces the explanatory power of the proposed model. Recognizing the interrelatedness of Peirce's models such as his sign model and the derived sign classification, his communication model and its relatedness with meaning processes as semiosis will enrich computational experiments that simulate semiotic processes. Experiments with stronger theoretical constraints, besides empirical ones, allows them to have further explanatory power once the proposed model searches for a computational formalization of a series of strongly interrelated but irreducible processes, and moreover will permit it to draw further conclusions and consequences from the results obtained.

CONCLUSION

The simulation of virtual ecological communities formed by synthetic cognitive creatures constitutes a powerful tool for the investigation of communication, allowing for the generation and testing of hypotheses. This approach, however, is extremely sensitive to a priori choices of theoretical and empirical constraints, which ultimately determine the occurrence of the phenomena of interest. The definition brought forth to describe, for example, what constitutes a symbol, may change the way the whole experiment itself or even not allow the experimenter to recognize the phenomena when it happens. A project that constructs a simulation from theoretical and experimental constraints, is also an implementation of the underlying models and thus a test bed for hypotheses derived from these models, thus allowing a new way of falsifying or confirming the proposed models.

In our experiment, the simulation of a virtual community lead to the emergence of symbolic communication and representations, suggesting that the constraints adopted are sufficient to implement symbol-based communication. An analysis of cognitive processes observed in vervet monkeys suggests that symbol acquisition starts with learning indexical relations, which reproduce spatial-temporal regularities, detected during this process. Simulations indicate that the learning process will, eventually, result in law relations, which can be generalized in other contexts, particularly when a sign stands for a class of objects, formally satisfying the establish conditions to describe symbolic semiosis. Symbols thus result from simple mechanisms of associative learning and self-organizing interactions, where sign users mutually affect each others communicative behavior but feedback loops (both positive and negative) conduct the system to an ordered state where symbol-based communication can be achieved.

In fact, self-organizing principles is a common feature in many biological systems as many studies have demonstrated (see [Morgavi et al 2005]). As we are simulating communication processes among biologically inspired creatures, it is expected that self-organizing dynamics would play a major role in this distributed process. Moreover, self-organization is also compatible with Peirce's theory, especially with his communication model accompanied by habit change processes, its self-correcting dynamics and the circular relations between interpreters and utterers. Self-organization can be seen as an important element in the emergence of new systemic processes in semiotic systems, where a hierarchy of levels can be described and used to better understand the generation of the phenomena. Emergence theory in the context of complexity sciences and applied to semiotic systems, and computational experiments that simulate this process will be better described elsewhere (see [Loula et al, in prep]-[Queiroz & El-Hani, 2006]).

In summary, our synthetic experiment involves a virtual community characterized by random inter-specific predation and intra-specific cooperative referential communication among preys. The simulation is based on a well-documented case of communication by means of predator-warning alarm calls in African vervet monkeys, and is shaped by carefully selected semiotic and neurobiological constraints. We propose that virtual neurosemiotic communities are a flexible and fruitful tool for the generation and testing of hypotheses regarding the ontogeny and phylogeny of animal communication. Indeed, we have previously used this simulation scenario to further explore the robustness of communication processes and how it could be related to ethological interactions in the real environment [Ribeiro et al 2007].

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