A proposal for a synthesis approach of semiotic artificial creatures

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Abstract: Here we propose a scenario to simulate sign processing in virtual creatures inhabiting a world of predatory events. In order to 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. This approach allowed us to simulate a case of intra-specific predator-warning communication among those creatures.

1 Introduction

Can an approach based on semiotic synthesis simulate the mechanisms involved in referential and intra-specific communication processes? Here we propose a synthesis methodology to simulate the emergence of predator-warning communication among artificial creatures in a virtual world of unpredictable predatory events. Based on the theoretical framework of semiotics and informed by neuroethological constraints, we developed a computational framework to simulate the emergence of intra-specific referential communication among artificial creatures. The paper is divided into 4 sections:

(i) a summary of Peircean semiotics,

(ii) a neurosemiotic analysis of vervet monkey alarm-calls that illustrates the fundamental neuroethological constraints underlying referential sign processes

(iii) a description of a virtual environment inhabited by an interactive community of artificial creatures, which in this example reproduces some of the behaviors of vervet monkeys and their predators.

2 The Peircean Theoretical Semiotics

According to C.S.Peirce, there are three fundamental kinds of signs underlying meaning processes -- icons, indexes and symbols. The Peircean list of categories (Firstness, Secondness, Thirdness) constitutes an exhaustive system of hierarchically organized classes of relations (monadic, dyadic, triadic) (Houser 1997:14; Brunning 1997). This system is the formal foundation of his architectonic philosophy (Parker 1998:60), and of his classification of signs (Murphey 1993: 303-306, Kent 1997:448). In this context, and relatively to the "most fundamental division of signs" (CP 2.275), these classes correspond to icons, indexes and symbols that correspond to relations of similarity, contiguity, and law between S-O (sign-object) of the triad S-O-I (sign-object-interpretant). The properties associated to these modalities are: (i) S-O dependent of intrinsic properties of S (monadic), (ii) S-O in spatio-temporal physical correlation (dyadic), (iii) S-O dependent of I mediation (triadic).

Icons are signs which stand for their objects through similarity or resemblance (CP 2.276) irrespective of any spatio-temporal physical correlation that S has with existent O – "An Icon is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not" (CP 2.247; see 8.335, 5.73). In contrast, if S is a sign of O by reason of a dyadic relation with O, then it is said to be an index of O. In that case, S is really determined by O, in such a way that both must exist as events, S and O -- “An Index is a sign which refers to the Object that it denotes by virtue of being really affected by that Object. […] [Insofar] as the Index is affected by the Object, it necessarily has some Quality in common with the Object, and it is in respect to these that it refers to the Object. It does, therefore, involve a sort of Icon” (CP 2.248; see 2.304). Finally, if S is in a triadic relation with O, a third term I is required so that I stands for “O through S”. In this case S is a symbol of O, and the determinative relation of S by O, a relation of law -- "A Symbol is a law, or regularity of the indefinite future. […] But a law necessarily governs, or "is embodied in" individuals, and prescribes some of their qualities. Consequently, a constituent of a Symbol may be an Index, and a constituent may be an Icon" (CP 2.293; see 2.299, 2.304, 2.249).[1]

Whether the category of symbolic semiosis applies to non-human animal communication is a matter of theoretical debate and controversy (Janik & Slater 2000) and no experimental evidence exists against or in favor of such a scheme. There is, however, a great deal of descriptive knowledge about vocal communication in non-human primate species, the case of vervet monkeys being perhaps the best studied (Seyfarth & Cheney 1980, Cheney & Seyfarth 1990, Seyfarth & Cheney 1992).

3 A Neurosemiotic Analysis of Vervet Monkey Alarm Calls

In order to get insight into the design of semiotic creatures using our synthesis methodology, we started by performing a neurosemiotic analysis of vervet monkeys' intra-specific communication (Queiroz & Ribeiro 2002). These primates possess a sophisticated repertoire of vocal signs that are used for intra-specific social interactions (confrontation, reconciliation and alliance formation of different sorts) (Cheney & Seyfarth 1990, Hauser 1996), as well as for general alarm purposes regarding imminent predation on the group (Seyfarth *et al.* 1980). Field studies (Strushaker 1967, Seyfarth *et al.* 1980) have revealed three main kinds of alarm calls used to warn about the presence of (a) terrestrial stalking predators such as leopards, (b) aerial raptors such as eagles, and (c) ground predators such as snakes. When a "leopard"call is uttered, vervets escape to the top of nearby trees; "eagle" calls cause vervets to hide under trees, and "snake"calls elicit rearing on the hindpaws and careful scrutiny of the surrounding terrain.

Consider two stimuli available to a vervet monkey: the view of a predator and an alarm-call played through a loudspeaker. The neural responses that code for the physical features of the visual image of the predator and the corresponding alarm-call are iconic representations of their objects (Zaretsky and Konishi 1976, Tootell et al. 1988, Ribeiro et al. 1998), and exist within two independent modalities (visual and auditory) in a representational domain of the brain hereafter termed RD1 (Figure 1). In principle, the mere visualization of [i]a predator should be enough to generate an escape response via the motor system of the brain. In contrast, the physical properties of the acoustic alarm-call (amplitude and frequency) do not stand for the leopard in any intrinsic way.

In the absence of a previously established relationship between that call and the predator, the former will simply arouse the receiver's attention to any concomitant event of interest, generating a sensory scan response directed to the loudspeaker and its surroundings (Seyfarth and Cheney, 1980). At least two things may happen then:

> (i) if nothing of interest is found, the receiver should stay put, and therefore it can be said that the alarm-call was not interpreted as anything else than an index of itself;
>
> (ii) if a predator is spotted stalking nearby, or if other vervet monkeys are observed fleeing to a neighboring refuge, the receiver might be prompted to flee. In these cases the alarm-call could have been interpreted as an index either of the predator or of collective vervet monkey escape, with identical behavioral outcomes.

The experiment described above was performed by Seyfarth and Cheney (1980) in the field: predator-specific alarm calls were played from loudspeakers to groups of wild vervets monkeys, and their behaviors were carefully monitored. All individuals regardless of age or sex responded by looking around in search of a referent. Interestingly, even though there were no predators in the visual scene, adult (but not infant) vervet monkeys proceeded by fleeing to nearby refuges according to the specific type of call played ("leopard" calls evoked tree-climbing, "eagle" calls elicited bush hiding etc).

This simple but well designed experiment allows us to conclude that, at least to one individual in the vervet monkey group[2], alarm-calls hold a previously established relationship to the predators they stand for, be it socially learned or genetically determined (WILSON 1975). If the alarm-call operates in a sign-specific way in the absence of an external referent, then it is a symbol of a specific predator class. In other words, to say that an alarm-call is a symbol of a **type** of predator is equivalent to say that this call evokes a brain representation (of any modality) which stands for the **class** of predators represented in a specific way. This symbolic relationship implies the association of at least two representations of a lower order (i.e. indexes or icons) in a higher-order representation domain, hereafter termed RD2 (Figure 1), which should be able to command escape responses through connections with the motor system of the brain. As discussed above, sensory stimuli present in the world are *iconically* represented in the brain within a first-order domain (RD1) according to specific modalities (visual and auditory, in our example). While the view of a predator represented in RD1 is sufficient to elicit an escape response through the brain's motor system, the representation of an alarm-call alone in RD1 cannot evoke any predator-specific meaning, and therefore will fail to cause an escape response. Presented together, the two stimuli can be interpreted in RD1 as bearing an indexical relationship, i.e. the alarm is an index of the predator's presence, generating an escape response. The existence of a higher-order domain of representation (RD2), which associates responses of both sensory modalities, enables the brain to interpret an alarm-call presented alone as a *symbol* of its referent, i.e. the predators view, and an escape response ensues through the motor system (Ribeiro *et.al.* 2002).

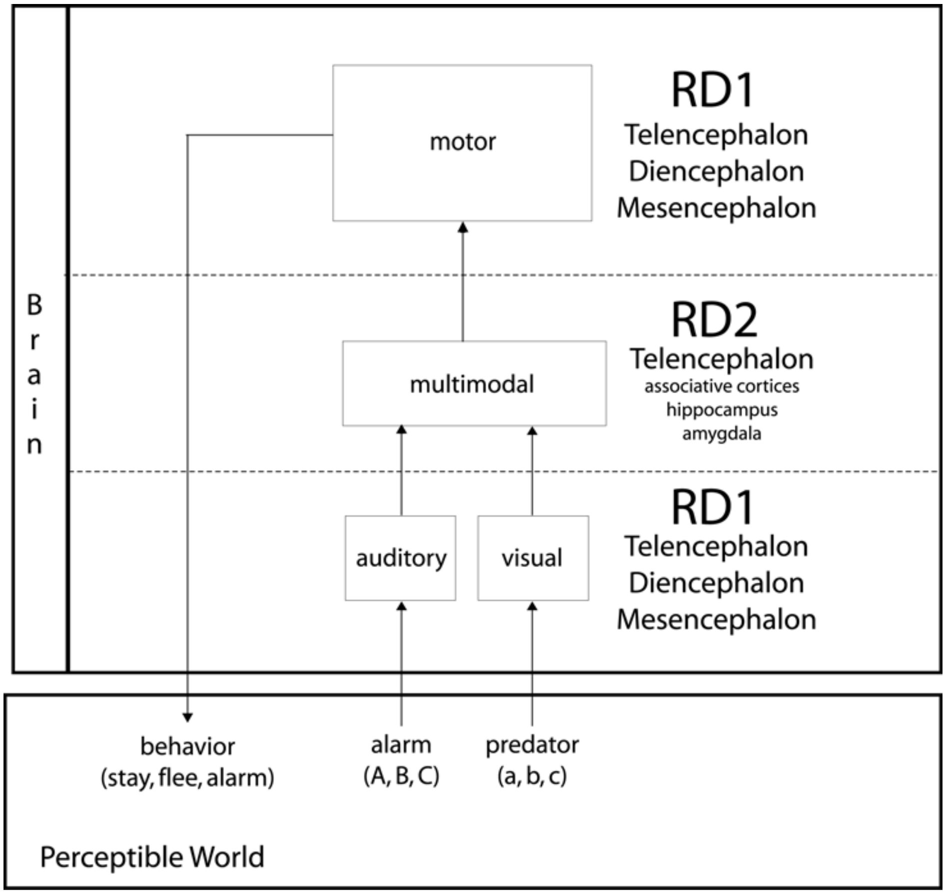


Figure1: Schematic Diagram of World-Brain Interactions Involved in the Interpretation of Signs

According to the hypothesis stated above, RD1 and RD2 should have different neuroanatomical substrates (Figure 1): candidate regions to comprise RD1 are unimodal sensory ascending pathways spanning the mesencephalon, diencephalon and early sensory neocortical areas;

candidate regions to integrate RD2 are located in association areas in the parietal, temporal and frontal neocortices, as well as the hippocampus, basal ganglia and amygdala (Kandel, Schwartz and Jessell 1999).

The argument exposed above generates many questions. For instance, does learning of vervet monkey alarm-calls involve an indexical (non-symbolical) phase? The late ontogenetic maturation of this process suggests its dependency of an indexical phase. If the Peircean hierarchical model is correct (icon > index > symbol), any damage to the neuroanatomical substrate required for the indexical phase must compromise the symbolic performance at later periods, while the converse should not be true.

The analytical framework applied here to the case of vervet monkey alarm calls guided our experiments of simulating semiosis among artificial creatures in a virtual world of unpredictable predatory events.

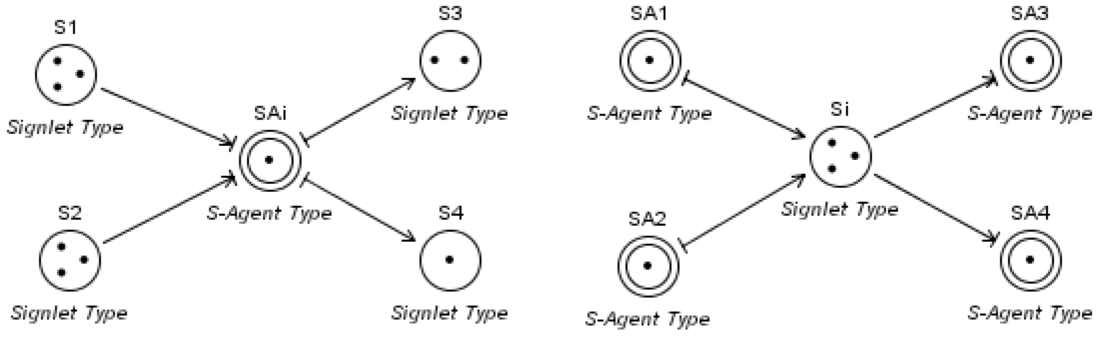
4 Designing a virtual scenario

The virtual world will work as a laboratory to simulate the emergence of anti-predatory alarm call vocalization among creatures under the risk of predation. Each creature acting in the virtual environment will have their own cognitive system constructed by means of semionic networks (SNs).

4.1 Semionic networks

SNs provide a framework for bottom-up designing of intelligent systems (see Gudwin 2001) with emphasis on modeling and integration of its different cognitive modules. All the creature's cognitive abilities (e.g., motor skills, perception, categorization) are controlled by SNs. This framework permits, because of the use of hybrid computational techniques, the study of various factors affecting cognitive ontogenetic processes, such as the mutual influences between different semiotic competences and low level cognitive tasks (attention, categorization, motor skill), the hierarchical presupposition of fundamental kinds of semiotic competences operating on symbol grounding processes, the adaptive role of non-compositional languages, the adaptive advantage of symbolic processes, the hypothetic neural substrate of these processes, and the differences between innate and learned sign systems.

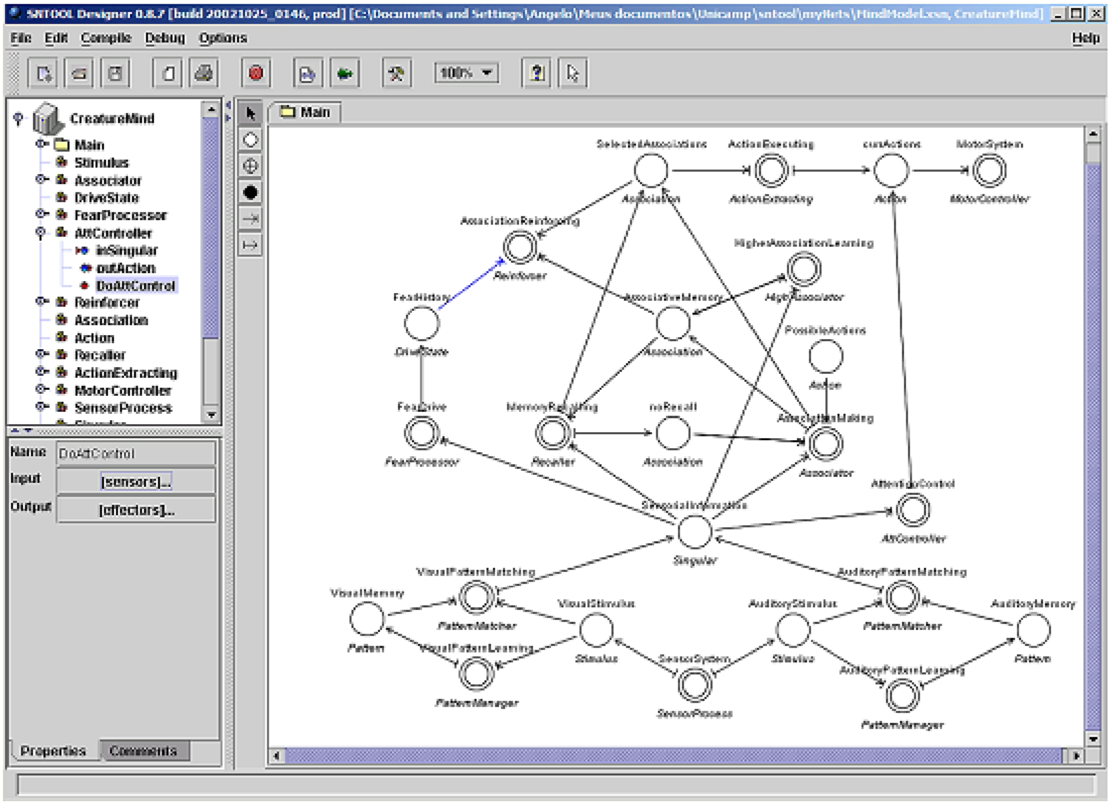
A semionic network is constituted of two types of computational entities, which we call *signlets* and *semionic agents* (or *s-agents*). These entities are located in places[3] which are connected by arcs (Figure 2). An *s-agent* is an information processing unit, designed to be the building block of an intelligent system.



(a) (b)

Figure 2: Connections between places through arcs. (a) *S-Agents* (located in double lined places) can get *signlets* from (put *signlets* in) different places, according to the input arcs and output arcs in the network. (b) *S-Agents* can put *signlets* in (get *signlets* from) the same place, according to the network topology.

We have developed a software (SNToolkit; see Gomes 2000) that is a general tool for building, running and testing semionic networks. (A screenshot of the application is showed in Figure 3) This application was written in Java language, and has its details described in Guerrero *et.al.* (1999).



Name: DoAttControl
Input: [sensors]...
Output: [effectors]...

Figure 3: The Semionic Network Toolkit. The SNToolkit is used to develop the cognitive architecture, both as a model and as a software implementation. After concluding a given architecture, the developer compiles the network, which generates dynamical link libraries in Java (JAR Files). For download and information about the SNToolkit see: http://sntool.sf.net/.

4.2 Virtual Environment and Creatures

Inspired by the well studied case of vervet monkeys behavior (see section 3), our creatures are divided into: preys, predators and others (neither prey or predator). Besides the creatures, there are also objects available for interactions, such as trees (climbable objects), bushes (used to hide) and rocks (just an obstacle). The creatures have sensors and motor abilities that make possible their interactions with the virtual environment. The sensorial apparatus of preys includes hearing and seeing, each of them having parameters that determines the sensory capabilities of each creature. For the sake of simplicity, predators can see but not hear. The visual system parameters are: maximum range, visual field angle, area of attention focus, and a threshold for object recognition. The auditory system parameters are: maximum range and a threshold for vocalization recognition.

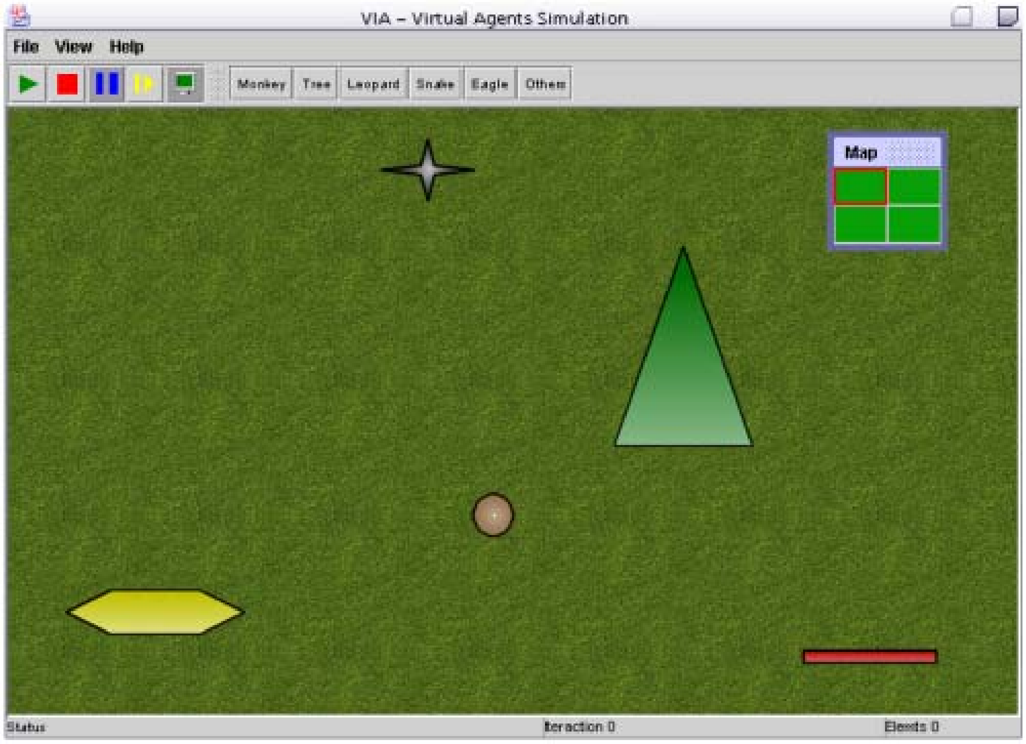


Figure 4: The preliminary simulator. Prey are represented by brown circles, flying predators by gray stars, big terrestrial predators by yellow hexagons, creeping predators by red rectangles, and trees by green triangles.

The creatures also have interactive abilities defined by a set of possible individual actions, such as: adjustment of the attention focus and sensors, walk, and run. Actions specific of monkeys are: climb trees, hide under bushes, and vocalize alarm calls. On the other hand, attacks are specific of predators. These actions are influenced by some of the creatures’ main parameters, such as: maximum speed, actual speed, maximum vocalizing range, actual vocalizing range, and probabilities of failure for each action. The failure probability is a function of the creature’s age and of the amount of training (number of simulation cycles) it has undergone. Other internal parameters for the preys are their internal emotional state and their age. The emotional state is a composition of three graded states -- calm, tense and frightened -- and they can be used to modulate learning. Besides contributing to the action failure probability, the age of a given prey also determines the reliability of its alarm-call for the rest of the prey group. Age is determined basically by the learning stage of the prey and the amount of simulation time passed.

The creatures can also interact with other creatures and with objects like plants, rocks, etc. Plants are static elements with specific locations; they can be trees and bushes of different types. Plants can be climbed by preys (trees only) and can be used as a hiding spot by preys (trees and bushes). The terrain is defined as the ground where animals and plants are placed. It is defined by areas with a certain vegetation density, and with different types of soil, such as plain soil, mud or grass. Each type of soil imposes different limitations to the motion and vision of creatures, e.g. mud would make terrestrial animals move slower and a great density of trees would make vision difficult. There are size parameters associated with each plant that determine the amount of monkeys that can climb over or hide under it. Although the terrain is not an object capable of direct interaction with the creatures, it indirectly influences their movement.

4.3 Simulating the creatures' cognitive architecture

A preliminary design of the creature's cognitive system (Figure 5) models the basic associative capabilities described in Figure 1, so that visual, auditory and motor associations can be learned and used for behavioral interactions. This design makes possible the emergence of iconic and indexical associations such as seeing a predator and then fleeing, or hearing an alarm-call and making a visual scan response. The design may also produce the symbolic relation defined by hearing an alarm-call and fleeing in the absence of a predator view, as described in section 2.

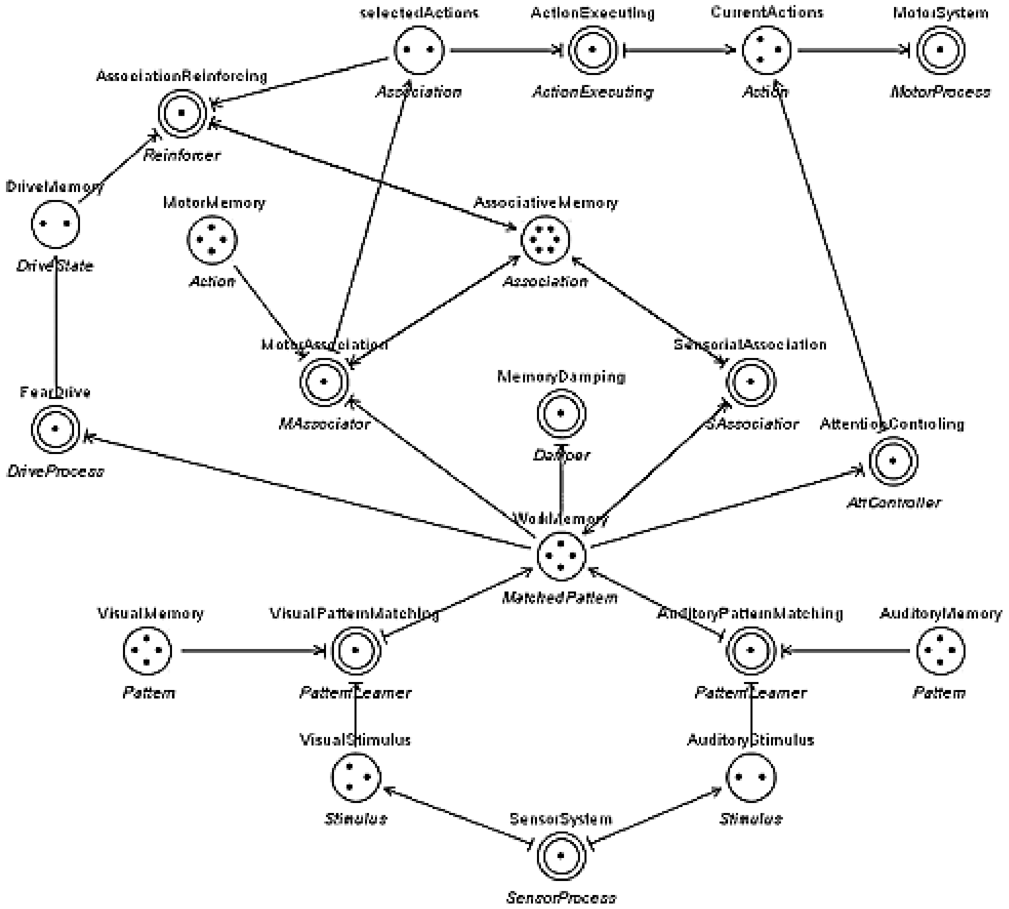


Figure 5: Sketch for a cognitive system.

As inputs to the cognitive system we have an *s-agent* located within the place called *SensorSystem*. As output back to the environment, we have an *s-agent* within the *MotorSystem* place. They are special kinds of *s-agents* that make the connection of the cognitive system to the virtual environment. The *s-agent* within *SensorSystem* periodically drops a *signlet* on the *VisualStimulus* and *AuditoryStimulus* places. The *s-agent* in the *MotorSystem* place checks for new *signlets* in the *CurrentActions* places so as to determine the creature's actions.

The *s-agent* on *VisualPatternMatching* compares the *signlets* in *VisualStimulus* with the patterns on the *VisualMemory*, and when it is able to perform a match, a new *signlet* is created and put within the *WorkMemory* place. The same mechanism occurs with the *AuditoryPatternMatching* and the *signlet* within the *AuditoryMemory*. The *VisualPatternMatching* is also responsible to adjust the pattern *signlets* on the *VisualMemory*, working as a classifier of stimuli. The same also occurs at the *AuditoryMemory* by means of the *s-agent* in *AuditoryPatternMatching*. The *signlets* put on the *WorkMemory* are monitored by the *s-agent* on the *MotorAssociation* place. This *s-agent* is responsible for checking the *AssociativeMemory* for motor relations associated with these *signlets*, selecting them and putting the best ones in the *SelectedActions* place. The same *s-agent* may also create new relations between *signlets* in the *MotorMemory* place and the ones in the *WorkMemory* place, thus producing new relation in the *AssociativeMemory*. The relations in the *AssociativeMemory* are adjusted by the *s-agent* in the *AssociationReinforcing* in a “drive reduction” way, using the *signlets* stored in *FearHistory*. These *signlets* are produced by the *s-agent* in the *FearDrive* place, based on the *signlets* on the *WorkMemory* place that indicates the predators whereabouts. The *SelectedAssociations* place holds the most recent used association used, so it can be adapted (reinforced or weakened) and also used by the *s-agent* in the *ActionExecuting* place, deriving the actions to be done. The *signlets* in the *WorkMemory* are periodically weakened by the *s-agent* in the *MemoryDumping* place, until it is permanently taken off that place. One of the most important roles is played by the *s-agent* in the

SensorialAssociation. It checks the AssociativeMemory place for sensorial indexical relations, recalling the associated *signlets* and putting it into the *WorkMemory*. It is also responsible for creating new associations between sensorial *signlets* located in the *WorkMemory*. There is also an *s-agent* in *AttentionControl* controlling the visual attention of the creature, so it focuses on the important visual objects and creatures.

In order to give a better explanation of how this architecture would work, let's give an example of a situation where our prey creature hears an alarm-call, proceeds with a sensorial scan, sees a predator and flees:

1. Alarm-call hearing: when the creature hears an alarm-call, the *s-agent* in the *SensorSystem* drops a *signlet* in the *AuditoryStimulus* place. This *signlet* is then taken by the *s-agent* in the *AuditoryPatternMatching* to compare with the *AuditoryMemory signlets*. If a suitable pattern is found, a new *signlet* is put in the *WorkMemory* place corresponding to the classified stimulus and the pattern used is adjusted to better describe that stimulus. If no pattern matches the stimulus *signlet*, a new pattern is created and the new *signlet* is also put in the *WorkMemory*.

2. Attention control: having an auditory *signlet* in *WorkMemory*, the *s-agent* in the *AttentionControlling* place puts a new *signlet* in the *CurrentActions* place indicating that the creature should look at the alarm-call source direction. This *signlet* is taken by the *s-agent* into the *MotorSystem* place and it will then change the creature's visual sensor direction.

3. Work memory weakening: the alarm-call *signlet* in the *WorkMemory* place is weakened by the *s-agent* in the *MemoryDumping* place, but since it just came into the *WorkMemory*, it is not dumped completely, leaving a memory there.

4. Seeing a predator: if a predator is seen, the *SensorSystem* drops a *signlet* in the *VisualStimulus* place and a procedure similar to that described in item 1 is performed, generating a visual *signlet* in the *WorkMemory*.

5. Building associations: having a new visual *signlet* in the *WorkMemory* and also an auditory *signlet* from the last iteration, the *s-agent* in the *SensorialAssociation* place creates a new association between these two *signlets*, putting a new relation in the *AssociativeMemory*. This relation will be later adjusted by this *s-agent*, which will check if these two events co-exist in other situations: if they do, then the association is strengthened, otherwise it is weakened.

6. Recalling associations: this procedure is done in parallel by the *MotorAssociator s-agent*, which checks whether the visual *signlet* in the *WorkMemory* is related to any motor action. Let us suppose that the *MotorAssociator s-agent* finds an association between a specific kind of predator and the behavior of other monkeys fleeing. This association is put into the *SelectedActions* places, so the *s-agent* in the *ActionExecuting* place can determine a future related action.

7. Reinforcing drives: The *s-agent* in the *FearDrive* place constantly checks the *WorkMemory* place for visual *signlets* of predators. If is determined that a predator is nearby, it produces a description of how

strong is the fear drive based on how far the predator is. These *signlets* are then used by the *s-agent* in *AssociationReinforcing* to determine if the association in the *SelectedActions* place should be reinforced or weakened. If the drive went down (the predator is farther away then before) the association is reinforced, if not it is weakened.

The representation domains of first- and second-order (RD1 and RD2 respectively; see section 2), can be identified in our cognitive system model. The visual RD1 is represented by the following places: *SensorSystem*, *VisualStimulus*, *VisualPatternMatching*, *VisualMemory* and *WorkMemory*; and the auditory RD1 by the places: *SensorSystem*, *AuditoryStimulus*, *AuditoryPatternMatching*, *AuditoryMemory* and *WorkMemory*. The motor RD1 is related to the places: *MotorMemory*, *CurrActions*, *ActionExecuting* and *MotorSystem*. The multimodal RD2 domain is described by the association tasks places, such as *MotorAssociation*, *AssociativeMemory*, *SensorialAssociation*, *AssociativeMemory* and *AttentionControlling*. This system is just a preliminary example of the research program we are developing, combining the powerful capabilities for the simulation of semiosis given by the Semionic Networks with the neural and behavioral constraints contributed by the vervet monkey ethological case. The system described here produces simple indexical behaviors, like fleeing when a predator is seen, but also generates more complex symbolic behaviors, like fleeing when an alarm-call is heard in the absence of a visual referent.

5 Conclusion

Synthetic methodologies design artificial environments that work as virtual experimental labs where it is possible to test the predictions derived from theories (Parisi 2001). Moreover, these strategies provide us with opportunities to formalize theories, in terms of computer program language (Parisi & Cangelosi 2002), as well as with the tools to implement "thought experiments" (*Gedankenexperiments*) about necessary and sufficient requisites for the observation of emergence, maturation and performance of the phenomena investigated (Dennett 1998, Bedau 1998). Franklin and Graesser (1999) stated the importance of software agents playing a “synergistic role in both cognitive theory and intelligent software”:

> “While a theory is typically abstract and only broadly sketches an architecture, an implemented computational design provides a fully articulated architecture and a complete set of mechanisms. This architecture and set of mechanisms provide a richer, more concrete, and more decisive theory. Moreover, every design decision taken during an implementation furnishes a hypothesis about how human minds work. (…) [T]he concepts and methodologies of cognitive science and of computer science will work synergistically to enhance our understanding of mechanisms of mind (…)”

This work in progress consists of an objective computational experiment aimed at providing a better understanding of how semiotic processes work. We designed a cognitive system for artificial interactive creatures based on fundamental neurobiological constraints and on Peircean semiotic analysis of how non-human primates interpret intra-specific stimuli in their natural environment. This architecture and the ecological scenario may allow to design different conditions where it is possible to observe the emergence of semiotic competences, such as symbolic process.

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Notes:

[1] For an introduction to Peirce´s theory of sign, see: Parker (1998), Liszka (1996), Santaella (1995), Fisch (1986); for an expository of his philosophy, see: Queiroz 2000.

[2] Since in the absence of further data we cannot exclude the possibility that only one individual recognized the alarm call as a sign of the predator, and all other monkeys followed the leader.

[3] The name *place* is inspired in Petri Nets.

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