2018

Initiating language in LIDA: learning the meaning of vervet alarm calls

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Abstract

This paper initiates language in LIDA by using the Learning Intelligent Decision[1] Agent's (LIDA) perceptual learning mechanism to suggest how an infant vervet, *Chlorocebus pygerthrus*, learns the meanings of vervet monkey alarm calls. We consider a multiple meanings approach which includes a feeling-based meaning, an action-based meaning, and a referential meaning. Simulations first test the learning of the meanings of these alarm calls while the infant is physically attached to the mother. The second simulations study the infant's understanding of these alarm calls while the infant is detached physically from the mother. Our results confirm that a LIDA based agent simulating a vervet infant is capable of learning such multiple meanings. The agent learned in sequence the feeling-based meaning, the action-based meaning, and the referential meaning. The LIDA agent achieved a good understanding of each of these meanings. This work can be seen as a starting step toward modeling the learning of human language in the LIDA cognitive architecture. Such modeling of language use would be a significant addition to the LIDA model.

***Keywords*:** Vervet alarm calls, primate vocalizations, cognitive architectures, protolanguage, meaning assessment.

1. Introduction

Motivated by the question, How do minds work?, where a mind is taken to be the control structure of an autonomous agent (Franklin & Graesser, 1997), the LIDA cognitive model (Franklin et al., 2016) fleshes out, and partially implements, Global Workspace Theory (Baars, 1988), as well a number of other psychological theories (Baddeley, 1993; Barsalou, 1999; Conway, 2001; Ericsson & Kintsch, 1995; Glenberg, 1997; Minsky, 1985; Sloman, 1999). The first dozen years of research on LIDA were devoted almost entirely to exploring and explicating what goes on in the extremely short term (200-500ms) of a single LIDA cognitive cycle (see Section 3). Having produced a relatively comprehensive account of the activity occuring during a single cycle (Franklin, et al., 2016), we are now able to look at such more complex, multi-cyclic processes as deliberation, reasoning, planning and even language.

This paper reports on the beginnings of our effort to add the learning of language to our LIDA model by simulating how vervet monkeys learn their alarm calls (see Section 2). Such simulations require that the model postulate how the vervets may represent the alarms sounds and their meanings. Such simulations cannot be expected to replicate field studies (as some simulations do simpler laboratory experiments), but they must serve to explain, and not contradict, the field studies. Although our work

[1] For historical reasons, this word was previously "distribution". It has been recently changed to better capture important aspects of the model in its name.

assumes that alarms calls such as those of the vervets may well have been among the earliest instances of processes in primates that led to human language, it does not add any validity to such an assumption. We make no claims here about the evolution of language.

A particular issue faced by research on communication evolution is related to the symbol grounding problem (Glenberg & Robertson, 2000; Harnad, 1990), namely, how the meanings of vocal symbols are acquired. In this work, we use the LIDA model, a cognitive architecture that can control autonomous software agents "living" in complex and dynamic environments. LIDA is a hybrid system of cognition, with all symbols being grounded in the physical world in the sense of Brooks and Stein (Barsalou, 1999; Brooks & Stein, 1994). LIDA has various modules for perception, working memory; declarative memory, emotions, semantic memory, episodic memory, action selection, and conscious-like behavior (see Section 3). Despite the cognitive richness of the LIDA model that makes the realization of multiple human and primate tasks feasible, LIDA has been criticized as focusing on low level intelligence tasks such as object recognition, and lacking high level cognitive functions such as language understanding (Duch, Oentaryo, & Pasquier, 2008). Our main contribution is beginning to overcome this gap by modeling vervet alarm calls. Accomplishing such work may be a first step toward solving the human language understanding problem for the LIDA model. Using the various LIDA cognitive modules, the INFANT learner agent, controlled by LIDA, learns the meanings of the vocal symbols (vervet alarm calls) by linking them with external objects of its environment (predators), corresponding escape actions, and feelings. We assume all the objects and categories are grounded in its Perceptual Associative Memory.

The work presented in this paper aims to start overcoming the gap of the lack of the language processing in the LIDA architecture. The implementation of a software agent controlled by the LIDA model that learns the meaning of vervet alarm calls represents the first step toward adding language learning to the LIDA architecture. The simulated agent uses the LIDA perceptual learning mechanism to associate the alarm calls with their corresponding meanings.

This article is organized as follows: The next section introduces language understanding and vervet alarm calls. Section 3 concisely describes the LIDA model and its cognitive cycle. Section 4 describes the LIDA-based perceptual learning mechanism by which the vervet infant learns the meaning of the alarm calls. Section 5 briefly highlights the LIDA computational framework, especially the modules used in implementing our simulation. It then describes the design and the implementation of the two-dimensional grid environment. Finally, it explains the design and the implementation of the LIDA agent. Section 6 describes the experiments, their results and their interpretation. Finally, Section 7 summarizes our work, describes our findings, and introduces some future directions.

2. Language understanding and vervet alarm calls

Several researchers in the language evolution field have agreed on the existence of an early form of communication preceding human language (Bickerton, 1990, 2017; Wray, 1998) known as protolanguage. According to Bickerton (1990), a protolanguage is a simple form of communication involving little structure, emerging from primate vocalizations by means of evolutionary pressures, perhaps eventually leading to a full-fledged human language. Bickerton also states that infantile human speech and protolanguage share common mechanisms and characteristics, such as a limited vocabulary. Chomsky and colleagues (1965) were among the few language theorists claiming that human language is entirely different from animal communication.

Because animal communication is a product of biological phenomena and the gradual evolution of processes involving neurobiology (Loula, Gudwin, Ribeiro, & Queiroz, 2010), modeling non-human primate communication may give insight into solving the problem of human language understanding. Oller and colleagues (2004) claim non-human primate communication systems belong to the fixed signals category. However, Campbell's monkey alarm calls contradict this claim (Lemasson, Gautier, & Hausberger, 2003; Lemasson, Hausberger, & Zuberbühler, 2005; Schlenker et al., 2014). Oller and colleagues also suggest that natural selection couples a fixed signal to a function that is not modifiable by the individual. For example, a primate call serving as an alarm cannot be reassigned as a courtship signal. There are a limited number of these functions, such as threat, greeting, contact, affiliation, invitation, etc. Fixed signals also appear in very early stages of human infant vocalization. Thus, modeling and implementing fixed signals could be a starting step toward modeling and implementing human language in a cognitive architecture.

For this purpose, we take the vervet alarm call system as a case study of animal communication, in which fixed signals serve a warning function against dangerous predators. Additionally, vervet alarm calls comprise a well studied case among primate communications. Vervet monkeys are indigenous to southern and east Africa. They are semiarboreal, inhabiting savanna, riverine woodlands, coastal forests and mountains in groups of up to 30 members. Field studies (including the play-back experiments done by Seyfarth and colleagues), revealed the existence of distinct vervet alarm calls (Price et al., 2015; Seyfarth, Cheney, & Marler, 1980). These calls are acoustically distinct, and are used in different contexts. In this work, we focus on those serving a warning function of danger from predators. They are typically used by adults to warn the rest of the group of dangerous predators in the vicinity. There are three classes of predators. Avian, such as eagles, serpentine, such as snakes, and terrestrial, such as leopards. These predators threaten a group of vervets quite rarely and independently, not more than one at a time. Cheney and colleagues claimed that vervet alarm calls incorporate both reference to an object, as well as a disposition to behave toward that object in a particular way (Cheney & Seyfarth, 1997). They refer to a particular sort of immediate danger, and they function to designate particular classes of predators. In fact, vervet juveniles emit an eagle call for avian predators, a leopard call for the terrestrial predators, and a snake call for serpentine like objects. Each alarm call typically triggers a specific escape behavior into a location safe from a specific type of predator. Vervet adults climb to small limbs at the tops of trees in response to a leopard call, run into the bushes when an eagle call is sounded, and stand bipedally and search the area upon hearing a snake call. An important result of their experiments is that the vervet infants and juveniles often produce alarm calls in the wrong context. In fact, infant vervets give eagle alarm calls to a very broad class of visual stimuli found in the air above (e.g., birds, failing leaves, etc.), leopard calls to various terrestrial mammals, and snake calls to long and thin objects. Through time and experience, they gradually use the alarm calls correctly, and they respond appropriately to each of them (Cheney & Seyfarth, 1998; Zangenehpour, Ghazanfar, Lewkowicz, & Zatorre, 2009). This provides direct evidence that vervet infants learn the meanings of these alarm calls.

In linguistics, a meaning represents the information conveyed by a sender in its message to the receiver, modified by any inference the receiver makes as a function of the current context. Controversy has permeated a debate about the meaning of vervet alarm calls. John Smith described vervet alarm calls as "referring to different escape actions," while the psychologist John Marshall (Cheney & Seyfarth, 1990) has averred on the basis of plausibility that vervet alarm calls refer to the predator type rather than the fearful emotions aroused by predators. To analyze the meaning process, several approaches have been used. Franklin introduced (1995) the quadratic understanding concept. In Franklin' words: "*A system's understanding of a concept, or of collection of concepts, seems to vary with the complexity of its connections from the given concepts to other knowledge. Roughly, the more connections, the more understanding*" (p.348). According to this concept, each vervet alarm call can have multiple meanings, through multiple connections. One connection is established from an alarm call to the corresponding predator, another one to the escape action, and another one to the fear feeling.

In recent decades, the use of computer simulations has increased in the language evolution field (Cangelosi & Parisi, 2002). Multi-agent simulation methodology is pertinent to the understanding of language origins and the evolutionary dynamics of whole languages (Steels, 1997). In fact, linguistic behaviors emerge through the interaction between diverse components of the complex system, their neural, cognitive, communication properties and their physical environment. In this work, we focus on the emergence of simple communication systems in an animal context involving vervet monkeys. Using computer simulations has the benefit of testing the internal validity of theories, in this case by studying language or protolanguage as a complex system. However, a drawback of this approach is the simplifying assumptions required to decrease the computational cost, and the arbitrariness of some details. This can have an impact on the realism of the experiments as well as the results. In this work, we adopt a two dimensional grid-based simulation composed of a main LIDA controlled (see the next section) cognitive agent labeled INFANT that learns the meaning of vervet alarm calls through interacting with other autonomous agents in a highly predatory environment. Further details about the environment, design, and implementation of the simulation will be provided later.

3. The LIDA model and its cognitive cycle

The LIDA model is a systems-level, conceptual model that covers a large portion of human cognition while implementing some ideas of Global Workspace Theory (GWT) (Baars, 1997; Baars, 1988). This section is intended to give the reader a consise overview of the LIDA model. Further details needed for this work will be introduced in subsequent sections. Many pre-conscious processes are implemented by various codelets, which are small pieces of code, each running independently. These are specialized for some simple tasks, and often play the role of a daemon watching for an appropriate condition under which to act. These codelets operate asynchronously, independently of other processes in LIDA

The LIDA model and its ensuing architecture are grounded in the LIDA cognitive cycle. The cognitive cycle (as illustrated in Figure 1) is based on the fact that every autonomous agent (Franklin & Graesser, 1997) continually senses its environment, understands its current situation, and then selects an appropriate response (action). The agent's "life" can be regarded as consisting of a continual sequence of these cognitive cycles. Each cycle comprises three main phases of understanding, attending, and acting.

The understanding phase is initiated after receiving a sensory stimulus, either internal or external, which activates low level feature detectors that pre-process the received data, and add an initial meaning to it. The preprocessed data is sent directly to the Workspace and to the Perceptual Associative Memory (also called recognition memory) where higher level entities, such as objects, feelings, events, categories, relations etc. are recognized. The entities (nodes or links) in this long-term perceptual memory, whose activations rise above a threshold, form the current percept. This resulting percept is moved asynchronously to the preconscious Workspace. Here, a preconscious model of the agent's current situation, labeled the Current Situational Model (CSM), is updated. This percept and items from the Current Situational Model cue both Transient Episodic Memory and Declarative Memory (autobiographical and semantic) producing local associations from these short-term and long-term episodic memories. These local associations are combined with the percept to update the Current Situational Model. This process typically requires Structure Building Codelets (Hofstadter & Mitchell, 1994), which have the role of monitoring the Workspace to fulfill their specified tasks. This newly updated model constitutes the agent's best understanding of its current situation within its world.

The attention phase starts when the attention codelets bring portions of the Workspace content to the Global Workspace by forming coalitions. All attention codelets are tasked with finding in the CSM structures matching their own content of concern. A competition for consciousness among the formed coalitions, takes place in the Global Workspace in order to select the most salient coalition. The winning coalition is broadcasted globally. This causes the initiation of the acting and learning phase.

The acting and learning phase involves multiple and parallel learning processes of the broadcasted conscious content as shown below in Figure 1. Procedural Memory, the memory of what to do when, is one of the primary recipients of this conscious broadcast. It instantiates behaviors whose contexts match sufficiently with this conscious broadcast. These instantiations are passed to the Action Selection module, which chooses a single action from one of them. The chosen action then goes to Sensory Motor Memory, where it is executed by an appropriate algorithm called a motor plan. The action taken affects the environment, completing the cycle.

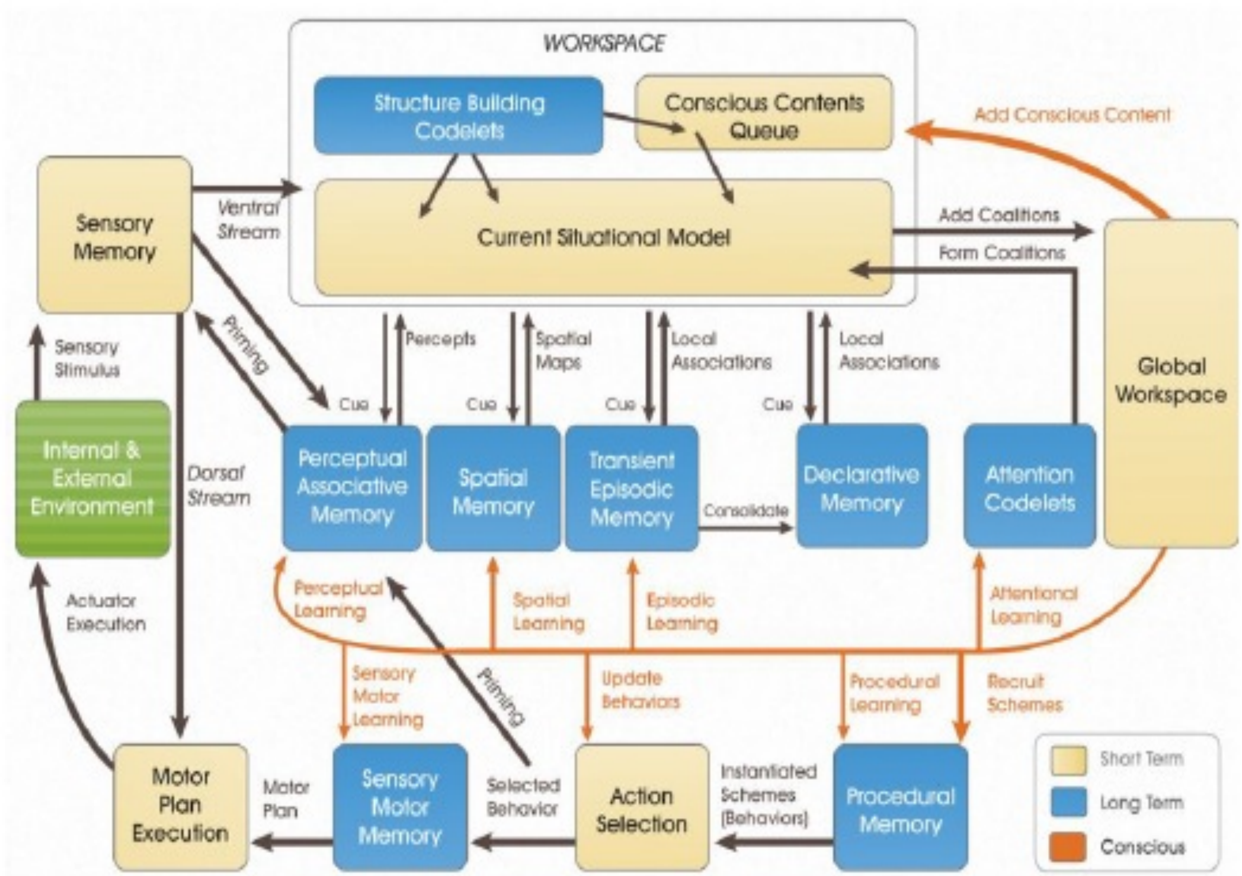

Figure 1: The LIDA Cognitive Cycle

4. Learning the meanings of vervet alarm calls

4.1 Multiple meanings of vervet alarm calls

Multiple meanings of a concept refer to its multiple connections to other knowledge. The more connections, the more understanding. According to this approach to meaning assessment, multiple relationships to other concepts should be built in the vervet mind from an alarm call. Field experiments (Seyfarth, et al., 1980) revealed the occurrence of various events while the infant learns the meanings of various alarm calls. One type of event can be the vocalizing of an alarm call by an adult vervet. Another type of event can be an adult vervet executing a specific escape action into a location safe from a predator. Alarm calls also trigger some fearful reactions in the adult vervets such as body shaking and fearful face expressions. These events can be translated into two distinct causality relationships. The first one is between each alarm call and its corresponding escape action, and the second one is between each alarm call and the fear feeling. The fear feeling is of particular importance, since every action by a LIDA agent is motivated by some feeling (Franklin & Ramamurthy, 2006). In particular, every action by the INFANT in response to a predator is motivated by fear.

In addition, field studies revealed the referential functionality of the vervet alarm calling system. Vervet alarm calls provide vervet listeners with sufficient contextual information to enable them to respond suitably to particular alarm calls as though they had direct sensing of the presence of the predator. This is implicit evidence that the referential relationship between each alarm call type and its corresponding predator class is already learned in the adult vervet's mind. Figures 2, 3, 4 illustrate various meanings of vervet alarm calls.

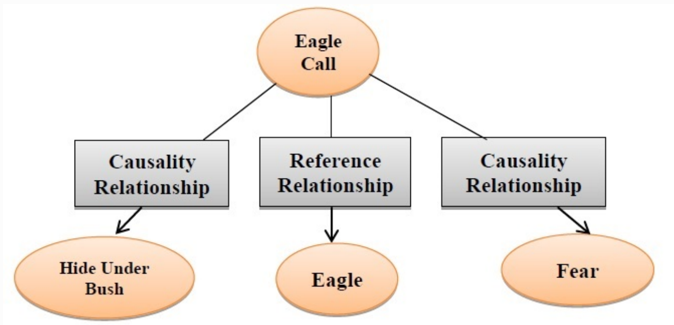

Figure 2: Eagle Call Meaning: consists of eagle as a referent and hiding under bush and fear as results of hearing an eagle alarm call

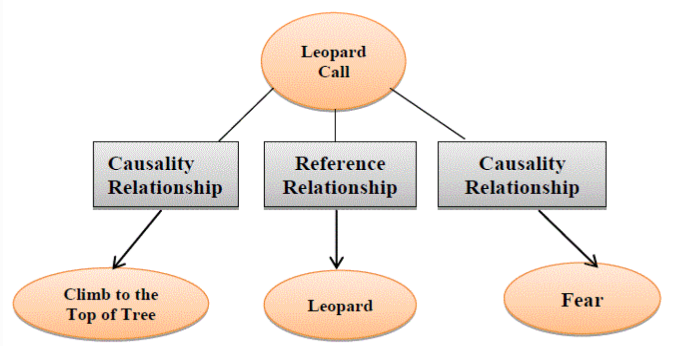

Figure 3: Leopard Call Meaning: consists of leopard as a referent and climbing to the top of a tree and fear as results of hearing a leopard alarm call

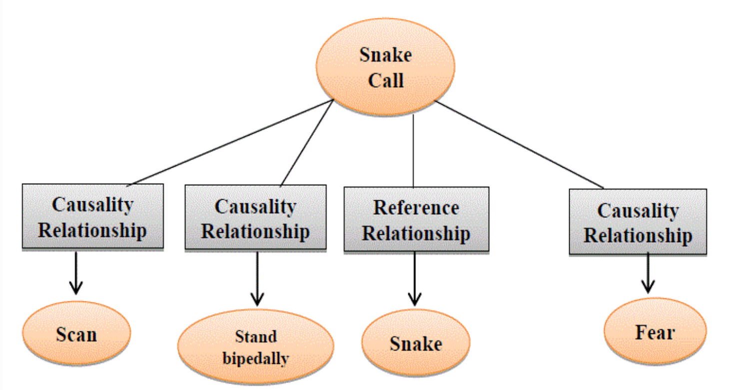

Figure 4: Snake Call Meaning: consists of snake as a referent; standing bipedally and scanning the vicinity and fear as results of hearing a snake alarm call

4.2 LIDA-based perceptual learning mechanism

Perceptual Associative Memory (PAM) is implemented in the LIDA architecture as a slipnet, a semantic net[2] with passing activation (Hofstadter & Mitchell, 1994). Perceptual learning in the LIDA model occurs in response to consciousness. It has two modes: the instructionlist mode, which creates a new item for the first time in PAM with an initial amount of base-level activation, and the selectionnist mode which strengthens an existent item by reinforcing its base-level activation using a sigmoid function (Edelman, 1987). Learning the meaning of vervet alarm calls occurs when new referential and causality relationships from the vervet alarm calls to the predators, escape actions, and fear feelings are established in the vervet's mind. In the LIDA terminology, we talk about adding in the Workspace a new referential link from each alarm call instance node to the corresponding predator instance node, and other causality links to the corresponding escape action and the vervet's fear instance node in the Workspace.

These pre-conscious operations are implemented by Structure Building Codelets (SBC) which are classified into three categories: 1) referential-meaning codelets 2) fear-meaning codelets, and 3) action-meaning codelets. Next, we describe the functionality of each codelet's class.

Referential-meaning codelets

In LIDA, nodes and links with high activation (above a threshold) are instantiated in the preconscious Workspace, and they point to their corresponding root nodes and links in PAM. Referential-meaning codelets add a new referential link in the Workspace's Current Situational Model (CSM) from an alarm call node's instance to its corresponding predator node's instance. Seyfarth and colleagues (1980) pointed out that juveniles sometime produce alarm calls during an incorrect context. They utter eagle calls upon spotting any instance of an avian category (e.g., falling tree leaves, birds etc.), produce leopard calls upon detecting a terrestrial animal (e.g., caracal), and emit snake calls upon noticing any serpentine object. This is direct evidence that vervet infants understand that an eagle call, snake call, and leopard call refers respectively to an avian category, serpentine like category, and terrestrial animal category. In other words, the vervet's mind avoids any association between a specific call and an instance of an object outside of the corresponding category. For example, in an early stage of learning the vervet infant may associate an eagle call with a crow, but not with a lion because it doesn't belong to the avian category. Similar logic is applied for snake and leopard calls. Based on these experimental observations, referential meaning codelets (responsible for adding relationships from alarm calls to their corresponding predators' classes) are inborn in the vervet's mind. Through experience, the infants learn to refine the external referent category to be more specific. In fact, their brains reinforce the correct associations from the alarm call to the corresponding predator, and the inappropriate associations decay away. As a result, the eagle calls are eventually associated with eagles only, leopard calls are associated with leopards, and snakes calls with snakes.

Action meaning codelet

An action-meaning codelet adds a causality link in the CSM from an alarm call node to its corresponding escape action node. The context of this codelet is an alarm call and an escape action. This is a generic codelet, which acts if its context is matched in the CSM.

[2] Labels play no functional role in the LIDA cognitive architecture.

Fear meaning codelet

In the LIDA model, emotions are considered as feelings with cognitive content, such as being angry at a specific person, the shame at saying an inappropriate thing, etc. Franklin and Graesser (1997) state that every autonomous agent must be equipped with primitive motivations that motivate its selection of actions, in order to form its own agenda. Such motivations may sometime be causal or in the form of productions rules (if conditions) in an artificial agent. In the LIDA model, these motivations are implemented by feelings (Franklin & Ramamurthy, 2006; McCall, Franklin, Faghihi, & Snaider, submitted). Vervet agents use fear as a primary motivation to select the appropriate escape action upon hearing an alarm call. We consider a fear-meaning codelet, whose task is adding a causality link in the CSM from an alarm call node to the fear node. In another work context, a generic emotion-meaning codelet or a causality-meaning codelet can be employed. The context of the fear-meaning codelet is presence of the alarm call node and the node representing self-fear, fear which is perceived by the INFANT agent. This may result in associating, in an early stage, the fear with nonthreatening objects (e.g., tree, bush) perceived simultaneously with an alarm call. Thus, the infant's perception of the non-threatening object, at an early time, may trigger its fear feeling.

As the infant grows older, the meaningful relationships are reinforced and the insignificant ones decay away. All the newly created referential and causality links in the CSM are learned into PAM only if they succeed in being brought to consciousness by attention codelets. These conscious referential and causality links are broadcast and added to the PAM node structure with a specific value of base-level activation. If an existing link is broadcast during a later cognitive cycle, its base-level activation is reinforced. The learning of the meaning of each alarm call may take a number of cognitive cycles to be accomplished. The implementation of the base-level activation of the learned link can be done using a sigmoid function, which defines the behavior of the base-level activation of the newly learned links. The sigmoid function is defined as follows:

$$f(x) = \frac{1}{1+\frac{1}{\exp(ax+c)}} \qquad [1]$$

- x: the current base-level activation of the link or node in PAM.
- f(x) : the new base-level activation of the link or node in PAM.
- a and c : are real numbers for linear parameterization. Their default values are 1.0 and 0.0, respectively.

The sigmoid function is used to calculate the new base-level activation of the learned link using its current base-level activation. The learning consists of increasing the base-level activation over time which is the simulation ticks.

Another important concept that affects the base-level activation's behavior of each of PAM's element is the decay concept. All elements in PAM decay over time. The decay rate follows an inverse sigmoidal of the current value of the base-level activation. The higher the base-level activation of an item, the slower its decay rate (Brown, 2006).

5. LIDA framework & simulation design and implementation

5.1 LIDA framework

The LIDA framework (Snaider, McCall, & Franklin, 2011) is a generic computational implementation of the various modules and components of the LIDA cognitive model, using the Java programming language.

An important design element of the LIDA framework is the task manager, which schedules and executes all the tasks of the application such as recognition tasks, attention codelets tasks, structure building codelet tasks, etc. The task manager organizes all the tasks in a task queue to schedule the LIDA tasks for execution. Each position in the task queue represents a discrete instant in simulation time, which is called a tick. A tick is considered to be a time unit, and its duration can be configured by the developer in milliseconds. This mechanism allows the simulation experiments to be run in various modes: -slow mode, step-by-step mode – different speeds. The framework is implemented using an object oriented approach. Thus, while implementing the LIDA agent which represents the vervet infant, we call the generic classes of each module as needed, and we override Java functions to implement specific tasks.
Next, we explain the design and implementation of the LIDA agent modules, and how these modules are related to the LIDA framework.

5.2 ALife environment design and implementation

Artificial life attempts to understand the essential general properties of living systems by synthesizing life-like behavior in software, hardware, and biochemistry. Taking advantage of this approach, we designed and implemented a two-dimensional ALife environment to test learning the meanings of vervet alarm calls. The environment consists of a grid of cells, populated with a LIDA-based autonomous agent labeled INFANT, and other agents (mother agent (MAMA), vervet agents (VERVET), and predators) which are controlled by simple rules in the form of "If condition–Then action".

The agents' control is consistent with Nagal's assumptions (1974). In his words: "Learning "what it is like" to be an animal of a certain sort means learning how that animal goes about deciding where to go next and what to do next". The agents make continuous navigational decisions to minimize the risk of being attacked by predators, and maintain a state of good health. To attain these survival goals, the agents perform various actions, such as escaping into locations safe from predators (e.g., climbing to the tops of trees, or hiding in a bush), vocalizing various alarm calls, and foraging for food. The INFANT depends on the MAMA agent during the first simulation part, where we assumed a physical attachment between them. A band of vervets was simulated that, at a given time, occupies only a small region in the wild, (Seyfarth, et al., 1980). The agents' (MAMA, VERVET, INFANT) vision systems see along a line of sight; given its direction, the agent can see ALL the objects located in every cell along the line. There is an exception for the predators' vision system: an eagle can't see a vervet agent hidden in a bush. On the other hand, the agent's hearing system is extended to every cell in the environment. In other words, any agent in the ALife environment is able to perceive sound regardless of its location. In fact, the sound spreads quickly in the small region occupied at a given time by a small group of vervets.

The ALife environment is generic and flexible. The grid size, the agent's vision, and hearing systems can be adjusted depending on the nature of the experiments. Also, additional features can be added as needed. Therefore, it is an effective computational research and tool to test various theories. The following figure is a snapshot of an ALife grid environment.

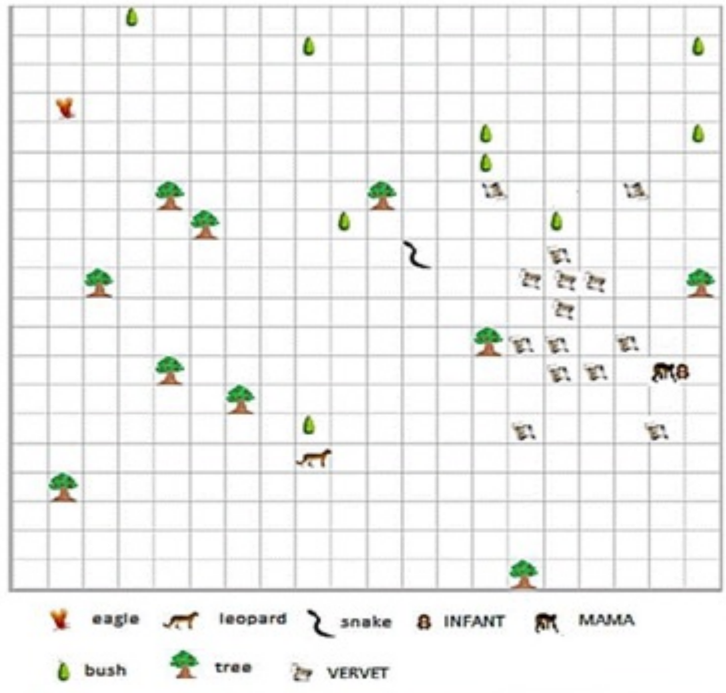

Figure 5: Two-dimension ALife grid

Simulated world operations

In the LIDA model, there are several types of actions: internal actions (e.g., imagining an action), external actions that involve a muscle movement (e.g., run climb a tree, hide under a bush, etc.), and implicit actions such as see and hear. In this simulation, the agents in the ALife environment have interactive abilities. They perform various actions: move, attack, climb to the top of trees, hide under bushes, and vocalize diverse alarm calls. The escape actions are specific to preys, while attacking is performed by predators only.

The following table is a brief description of the main actions available for agents:

Table 1. The actions available for the agents in the environment

Action		Description
Move	-	Instruct the vervet agent to move to the next cell. This results in decreasing the agent's health by a small amount.
MamaMove	-	Instruct the MAMA and the INFANT to move simultaneously to the next cell.
VocalizeAlarmCall	-	Instruct the vervet agent to vocalize an alarm call. Three types are available: VocalizeEagleCall, VocalizeSnakeCall, VocalizeLeopardCall.
HideUnderBush	-	Instruct the vervet agent to move to a cell where there is a bush.
ClimbTree	-	Instruct the vervet agent to move to a cell where there is a tree to climb it.
Stand Bipedally	-	Instruct the vervet agent to stand bipedally.

Attack	-	Instruct the predator agent to attack the vervet agent in the same cell. This results in decreasing the health amount of the attacked agent.
Turn	-	Instruct the agent to change the direction. Three types are available : TurnRight, TurnLeft and TurnAround.
See	-	Instruct the vervet agent to detect all animated and non-animated objects in all cells along its line of sight.
Eat	-	Instruct the vervet agent to ingest a food object in its current cell. The execution of this action results in increasing the health of the agent

Field experiments show that successful predator attacks, which occur rarely in the wild, most often result in the immediate death of vervets. Failed attacks produce serious injuries. In this work, we simulate the common case, so predator attacks result in decreasing the health amount of the attacked agent instead of its death.

5.2.1 LIDA agent design and implementation

Sensory Memory

The LIDA agent's sensory memory is composed of the following sensors:

- **Sound sensors**: allow the agent to detect sound in the environment, more specifically the alarm calls produced by other vervets. The INFANT is able to sense the sound regardless of its location in the environment because the sound is propagated to all cells of the grid environment.
- **Infant-Mother sensors:** simulates mostly touch sensors in vervets; these allow the INFANT to sense emotions and feelings from the mother agent, such as fear, especially during the first simulation stage where the main assumption is physical attachment.
- **OriginCellObjects sensors:** allow the INFANT to recognize all the objects in its cell. A detailed description of the environment, including the cell, will be provided later.
- **NextCellObjects sensors:** allow the INFANT to recognize all the objects in every cell in its line of sight.
- **Health sensors:** allow the INFANT to sense its health. The health system of the agent is implemented as a double variable in the [0.0, 1.0] interval.

Perceptual Associative Memory (PAM)

PAM design. Perceptual Associative Memory (PAM) is implemented as a modified slipnet (Hofstadter & Mitchell, 1994). It allows the agent to distinguish, and identify external and internal information. Oliphant has defined animal communication as follows (1997):

An act of communication is a causal chain of events, whereby one individual, the sender, exhibits a behavior in response to a particular situation, and a second individual, the receiver, responds to this behavior. Such an interaction is communicative if it involves manipulation on the part of the sender and exploitation on the part of the receiver (p.11).

Following this definition, the vervet infants acquire the meanings of distinct alarm calls from observing the following events that occur almost simultaneously in the wild: 1) detection of the predator in the environment; 2) hearing alarm calls; and 3) escape actions into safe locations. The event is considered as the primary representation in the LIDA agent's PAM design. In the LIDA model, event-based representations draw inspiration from research on thematic roles (McCall, Franklin, & Friedlander, 2010). Events are represented as nodes with thematic role links binding to Agent, Object, Location, Feelings and other node types. This representation is consistent with Carlson's definition of thematic roles in event representations (1998). In his words: "The basic idea that there is a smallish, finite number of distinct roles with names like "Agent", "Instrument" , "Goal", "Patient", "Location", and so forth that have direct semantic import..."

We assume that the INFANT has already learned to recognize the events involved in this simulation (detection of predators, hearing alarm calls and escape actions). This recognition can be realized over several cognitive cycles.

As mentioned previously, an event is represented in PAM as a node that has multiple thematic role links that lead to it from multiple other nodes, which play various roles in the event. An event node is activated in PAM based on the amount of activation received from its children nodes through the thematic role links. For this purpose, we consider a new implementation of the propagation task in PAM. This task serves to excite the link's sink (in this case the sink is the event node) based on the link's new activation. If this puts the sink over its percept threshold, then both link and sink will be sent as a percept.

The mathematical equation of the excitation is as follows:

excitation of sink = excitation amount * base-level activation of link

The excitation of the sink is the sum of the activation passed to the event node by each thematic role link which has a specific excitation amount. The base-level activation of each link acts as the weight of that role in the event.

In the initialization of PAM parameters, we set the base-level activation of each thematic role link associated with an event, based on the significance of that thematic role in the event. As mentioned previously, there are three events types:

1- **Detection of a predator**. We generate three events of this type in PAM: 1) I see an eagle; 2) I see a leopard; 3) I see a snake.
2- **Hearing alarm calls**: We generate three events of this type in PAM: 1) I hear an eagle call; 2) I hear a leopard call; 3) I hear a snake call
3- Escape actions. We generate these main events in PAM, perceived by the infant based on his body position: 1) Mother agent hides under bush; 2) Mother agent climbs to the top of a tree. 3) Mother agent stands upright and scans the area.

Detection of predator events

Figures 6, 7, 8 describe the events of seeing various predators.

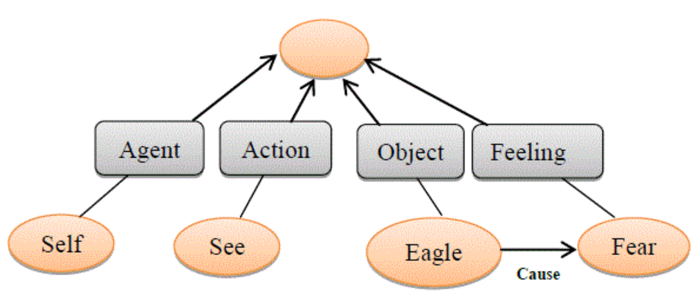

Figure 6: Event Representation in PAM “I see an eagle”

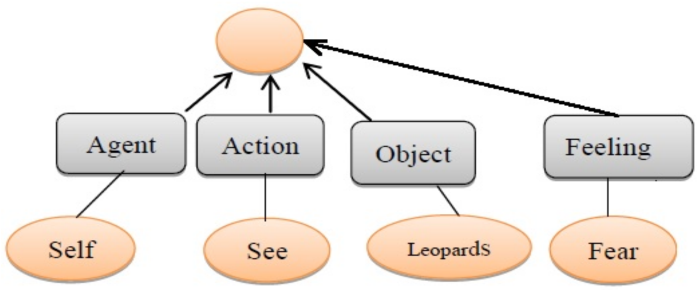

Figure7: Event “I see Leopard”

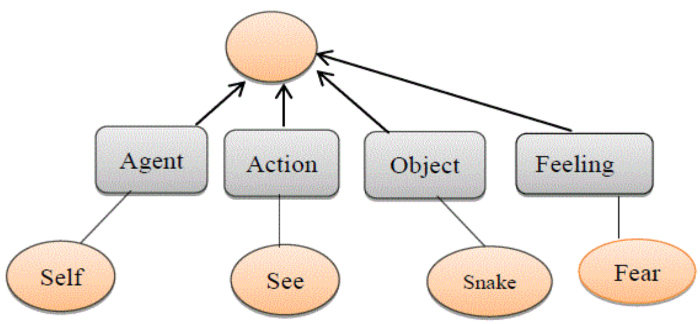

Figure 8: Event “I see snake”

The three events of seeing an eagle, leopard, or snake, share these three thematic roles:

1. The source of the agent thematic role is the agent itself. It is represented by the self-node. The LIDA model supports a self-system composed of three components: the ProtoSelf, the Minimal (Core) Self and the Extended Self (Gallagher, 2000; Ramamurthy & Franklin, 2011). The self-node in this event belongs to the self as-experiencer (the experiencing self). The LIDA agent uses an object feature detector to detect any object in its current cell (animated or non-animated). The self-node is treated like any other object; hence it is always activated in the Current Situational Model.
2. The action thematic role is attached to the see node which is considered an implicit action in the LIDA model. This node is also activated continuously in the LIDA agent’s CSM.
3. The object thematic role is attached to the predator node: eagle, snake, and leopard nodes.

Several researchers in psychology performed various studies and experiments to answer the question “is the fear of specific predators innate or does it involve learning.” Van Le and colleagues (2013) present neuroscientific evidence that the fear of snakes is inborn in a monkey’s brain. We assume then that the fear feeling is part of seeing the snake event. Also, Worden (1996) claims that the vervets are born with an innate fear of birds. According to him; infant vervets innately produce eagle calls in the presence of birds. By observing their adult peers’ reactions, such as facial experiences or body reaction, they reinforce fear for only dangerous birds such as eagles. This justifies the fear feeling thematic role in an “I see eagle” event. Lastly, for the fear of leopards, we assume that the LIDA agent acquires this fear from sensing it in the mother agent. This is attained computationally through the mother-infant sensors.

Now, we describe the representation of the events perceived by the LIDA agent during its physical attachment to the mother.

Hearing alarm calls events

The INFANT agent recognizes three distinct alarm calls events: “I hear an eagle call”, “I hear a snake call” and “I hear a leopard call”. They share a similar representation in PAM. The next figure illustrates an example of the hearing alarm calls events.

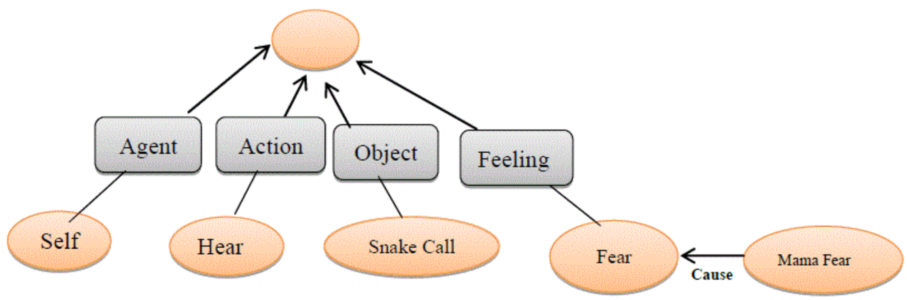

Figure 9: Event representation in PAM “I hear snake call”

The three events of hearing the three alarm calls share these thematic roles:

1. The source of the agent thematic role link is the agent itself. It is represented by the self-node as explained previously.
2. The source of the action thematic role link is hearing. This action node is activated in CSM upon hearing any alarm call or sound in general.
3. The object thematic role link leads from each alarm call node, which is an acoustic node.
4. The feeling thematic role link leads from the fear feeling node. The physical attachment of the vervet infant to its mother in the first stage, allows it to sense the mother’s fear directly by means of the infant-mother sensors, after hearing each alarm call. Many psychological studies have shown that the emotional bond between the infant (human or animal) and its mother (or caregiver) contributes to the infant’s experience of diverse feelings and emotions including fear. This justifies the innate causality link in PAM, from the mother’s fear to the LIDA agent’s fear (Harlow & Harlow, 1969).

Escape actions events

The INFANT agent recognizes three distinct escape actions events. They share similar representations in PAM. The next figure illustrates an example of an escape action event: ”MAMA climbs to top of tree”.

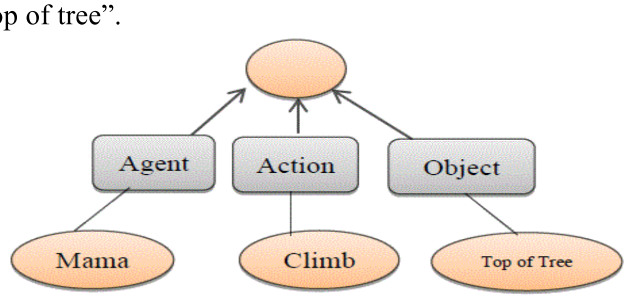

Figure 10: Event representation “MAMA climbs to top of tree”

An agent thematic link leads from the mother node. Because the INFANT is attached physically to the MAMA agent in the first stage, it is more likely to recognize an escape action performed by the mother agent than by any other VERVET agent.

1. Action thematic role. Each different type of alarm call elicits a different escape action. The action thematic role link leads from: 1) hide action node in the event “MAMA hides under the bush ”; 2) climb action node in the event “ MAMA climbs to top of tree”; and 3) stands bipedally action node and searches action node in the event “MAMA stands bipedally and searches”.

2. Object thematic role, whose link is attached to: 1) the bush node in “MAMA hides under bush event” and 2) top of tree node in “MAMA climbs to top of tree” event.

Recognition tasks

Feature detectors in LIDA represent the main mechanism for executing recognition tasks. They descend on the incoming sensation in sensory memory. Those that find features (bits of meaning, single chunks) relevant to their specialty activate appropriate nodes in Perceptual Associative Memory (Franklin, Baars, Ramamurthy, & Ventura, 2005). Five categories are used: 1) object features detectors; 2) mother fear feature detectors; 3) alarm call feature detectors; 4) health detector; 5) action feature detectors (hide under bushes, climb to top of trees, and stand bipedally and search). Listed below is a further description of the functionality of each category.

Object feature detector

The function of the Object Feature Detector is recognizing objects visually in every cell of a line of the sight of the LIDA agent. There are two types of visual objects: 1) animated objects such as mother agent, vervet agent, juvenile agent etc., and 2) non-animated objects such as trees and bushes. All objects are detected by using the same object feature detector algorithm. A supplementary function of this detector is allowing the INFANT to recognize itself by adding a self-node in its Perceptual Associative Memory (PAM). The self-node is considered an animated object just as vervets are.

Mother fear feature detector

The main assumption of the first stage of the simulation is the physical attachment of the LIDA agent to the mother agent. Therefore, the INFANT learns the fear of entities and events (e.g., snake, leopard, alarm calls) by sensing the mother’s fear. Every VERVET quivers when seeing a predator or hearing an alarm call.

Alarm call feature detector

The recognition of vervet alarm calls is one of the most important tasks for the LIDA agent. The sound is computationally implemented as a string variable, sound, associated with each cell of the two-dimensional grid environment. The sound value changes when VERVET agents perform distinct vocalization actions associated with a particular predator. The variable sound of each cell is updated to the following values: 1) “eaglecall” when VocalizeEagleCall action is performed; 2) “leopardcall” when “VocalizeLeopardCall” action is performed and 3) “snakecall” when “VocalizeSnakeCall” action is performed. A VERVET vocalizes an alarm call if it has not heard one when spotting a predator in the vicinity.

Health feature detector

The agent’s health is an internal real variable. The INFANT loses some amount of its health if it experiences a dangerous event such as being attacked by a predator. In the wild, it is rare that vervets are killed by predators. It is vital that the agent maintains a good health during the simulation‘s iterations. Thus, we boost the INFANT’s health by the nursing action or eating food action during both simulation stages of physical attachment and detachment. During all experiments, we tried to maintain a fair health for the INFANT.

Action feature detector

Action feature detectors allow the LIDA agent to recognize the actions performed by the other agents. The observer is not merely contemplating an action of the other agent, it is attempting to understand or predict the outcome of the action it observes. Actions of other agents convey valuable information for learning skills or engaging in communication. Perceiving the escape actions performed by adult vervets plays a role in learning such actions. The representation of the observed escape actions in the LIDA agent’s PAM allows the infant to learn the action meaning of various alarm calls by building causal relationships from such calls to their corresponding escape actions. Now we describe the Structure Building Codelets module of the LIDA agent.

Structure building codelets

A LIDA structure building codelet is a small process (or daemon) that performs specific tasks in the Workspace, such as modifying existing structures in the CSM, or adding new structures (e.g., nodes, link etc.). A structure building codelet operates asynchronously and independently of other processes in LIDA. Each SBC is triggered when a specific type of representation (structure) is present in the Workspace. As a data structure, a structure building codelet has a base-level activation, a context, and an algorithm. As explained previously, the base-level activation measures the usefulness of the codelet, and is modified by selectionist learning. The context is the node structure or pattern that structure building codelet is “looking for” in the Workspace that triggers it to act. The action or algorithm specifies what the codelet does when activated. As mentioned before, we implemented three structure building codelet categories: 1) referential structure building codelet; 2) action-meaning structure building codelet; and 3) fear-meaning structure building codelet. The referential structure building codelets add a link from each alarm call node to its corresponding predator class node. Three different referential structure building codelets were implemented for several reasons. The EagleCallReferential Codelet and SnakeCallRefrential Codelet are hardwired in the infant’s vervet mind. In fact, field experiments revealed the tendency of vervet infants and juveniles to produce eagle calls and snake calls when seeing, respectively, an avian instance and serpentine like instance. However, the LeopardCallReferential Codelet is not hardwired in the vervet’s mind. The action-meaning SBCs add a causality link from each alarm call node to its corresponding escape action node. The fear-meaning SBCs add a causality link from each alarm call node to a fear node.

Procedural Memory

LIDA’s procedural memory initiates the process of deciding what to do next. It’s implemented using a scheme net data structure which is a directed graph whose nodes are called schemes. This is similar to Drescher’s schema mechanism but with many fewer parameters (Drescher, 1991). A scheme has a context, an action, a result, and a base-level activation. In the first simulation stage, the primary assumption is the physical attachment of the LIDA agent to the mother agent. Consequently, the LIDA agent performs few actions such as turning left, turning right, and turning around. The detached LIDA agent selects these actions when hearing an alarm call or sensing the mother‘s fear. The infant tries to search for more cues to understand these perceived salient events and feelings.

During the second stage of the simulation, the LIDA agent is detached from the mother agent. Thus, we expand the procedural memory to contain additional schemes such as moving, hiding under a bush, climbing to the top of a tree, and standing bipedally and searching.

6. Experiments & results

Learning the meanings of vervet alarm calls was tested by running numerous simulations using a two-dimensional grid-based environment and a LIDA-based agent labeled INFANT implemented using the LIDA Framework's modules (Snaider, et al., 2011). In each simulation, various objects (animated and non-animated) were placed randomly. There are fourteen VERVET agents that have already learned the meanings of alarm calls during their infancy. In addition, the ALife environment was populated with other animated agents such as the MAMA agent, eagles, leopards, snakes and non-animated objects such as trees, bushes and food. The number of the animated and non-animated objects was defined so as to be consistent with a population of a band of vervets that occupies a small region in the wild during a specific time period.

In each simulation, other than the INFANT, all the animated agents are controlled by simple productions rules in the form of "if condition then action". The INFANT agent is controlled by LIDA whose decision making is more complex than the production rules. As explained previously, LIDA-based perceptual learning consists of implementing and reinforcing the base-level activation of new entities and existing ones respectively. Hence, we recorded the base-level activation of the newly learned links

The simulations were divided into two main stages. First, we carried out experiments to test the learning of the multiple meanings of the vervet alarm calls while the INFANT is attached physically to the MAMA agent. Secondly, we performed a set of experiments to determine whether the INFANT understands the meaning of these alarm calls by evaluating the correctness of its escape actions upon perceiving an alarm call. The main assumption in this second stage is the physical de-attachment of the INFANT from the MAMA. The performance of the INFANT's understanding of the alarm calls was assessed.

6.1 Part I: Testing learning of meanings of alarm calls

Simulations were conducted using each predator type (leopard, eagle, and snake) individually in order to test the learning of the meanings of each vervet alarm call. In the wild, it almost never happens that distinct predators appear simultaneously in the vervet's vicinity.

In each simulation, the ALife grid environment is composed of the INFANT agent, the MAMA agent, fourteen VERVET agents, trees, and bushes. During first stage simulations, the INFANT and MAMA are placed in the same cell in order to comply with the assumption of the physical attachment between them.

In the LIDA model, perceptual learning consists of reinforcing the base-level activation of links and nodes in the Perceptual Associative Memory. Hence, the base-level activations of the newly learned referential and causal links that correspond to the meanings of vervet alarm calls are recorded. The occurrence and progress of learning the meanings of vervet alarm calls are depicted in the figures below. We plotted the base-level activation of the learned links (leading from an alarm call to the corresponding predator, escape action and the fear feeling) at the time of the broadcast (in ticks) of each link.

As mentioned previously, we adopt a multiple-meanings assessment approach. Each alarm call has three types of meanings: a reference-based meaning, an action-based meaning, and a feeling-based meaning. We study the temporal order of learning each type of meaning, in order to check whether the INFANT's mind learns, as it is expected to happen in the wild; first the fear meaning, followed by the action meaning, followed by the referential meaning. In fact, the body position of the INFANT (see figure 14 below) permits him to perceive the mother's fear feeling quickly, followed by the mother's escape actions and finally seeing predators. This order was expected to affect the temporal order of learning the multiple meanings.

Another datum collected from the simulations is the length of time required for learning each type of meaning. It was calculated as the difference between the first broadcast time (in ticks) of a learned link and the broadcast time when the learning is saturated. Although, the sigmoid function approaches 1.0 asymptotically, we assume practically that the learning stops at 0.9999. A comparison of timespan of learning was done between the three types of meanings. The figures below provide a visual representation of the results.

Results and discussion

The results in Figure 11 show the capacity of the INFANT agent, controlled by the LIDA cognitive architecture, to learn the relationships leading from the eagle call to the fear feeling, hiding under a bush, and the eagle predator, respectively. Each simulation was performed using one of the same series of 35 randomly generated environments. The INFANT learned the fear-based meaning at an average point of time equal to 372252.9524 (in ticks[3]). Second, the meaning associated with hiding under bush was learned at an average point of time equal to 781230.9 (in ticks). Lastly, the reference-based meaning related to eagle was learned. The base-level activation of each learned link, as shown in Figure 11, is reinforced at each appropriate broadcast using a sigmoid function.

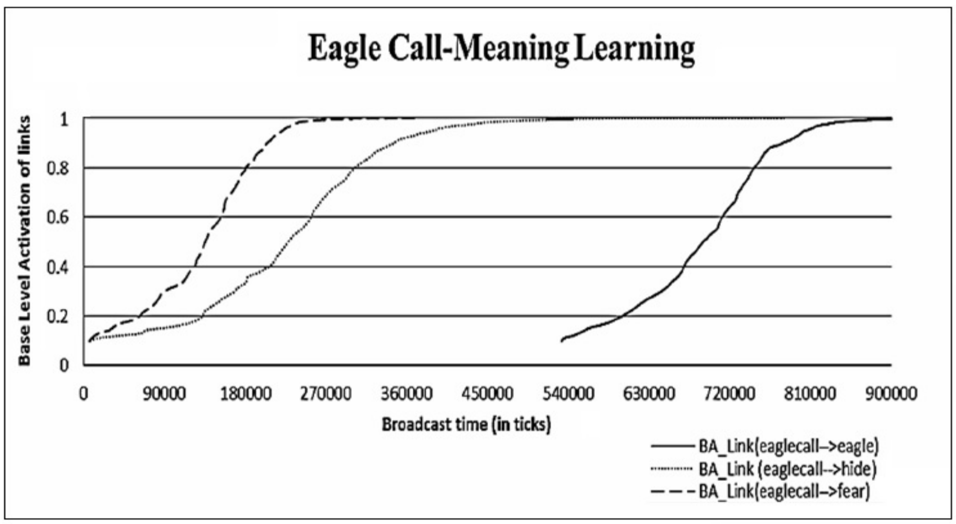

Figure 11: Base-level activations of learned links from eagle call node to the eagle node, the hide under the bush node, and the fear node at each broadcast time.

[3] The framework has a mechanism called the LIDA task manager. It has the responsibility of scheduling and executing all the tasks of the application. The task manager maintains a task queue that is used to schedule LIDA-based tasks for execution. Each position in the queue represents an instant in simulation time, which we call a tick. Ticks are numbered along the simulation (e.g tick1, tick2 etc.) All tasks scheduled for a particular tick are executed before the task manager advances to the next tick (Snaider, et al., 2011).

Figure 12 describes the results of learning the meanings of the snake call.

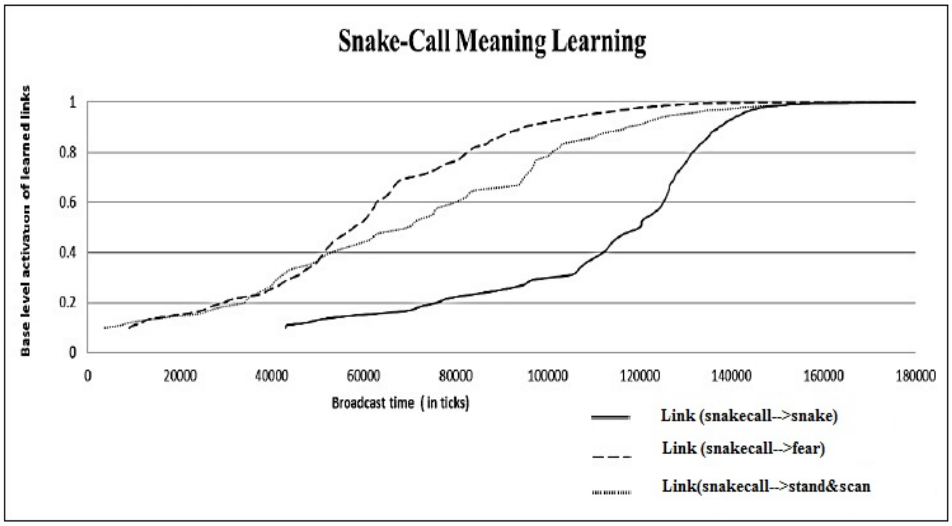

Figure 12: Base-level activations of learned links from snake call node to snake node, stand node, and fear node consecutively, at each broadcast time.

These results show that the INFANT learned the relationships leading from the snake call to the fear feeling, standing bipedally and searching, and the snake itself respectively. Each simulation was performed using the same series of 35 randomly generated environments. The INFANT learned in sequence, the fear-based meaning at an average point of time equal to 149547.619 (in ticks), the action-based meaning associated with standing bipedally at an average point of time equal to 183071.5 (in ticks) and lastly, the reference-based meaning related to the snake predator.

Figure 13 describes the results of learning the meanings of the leopard call.

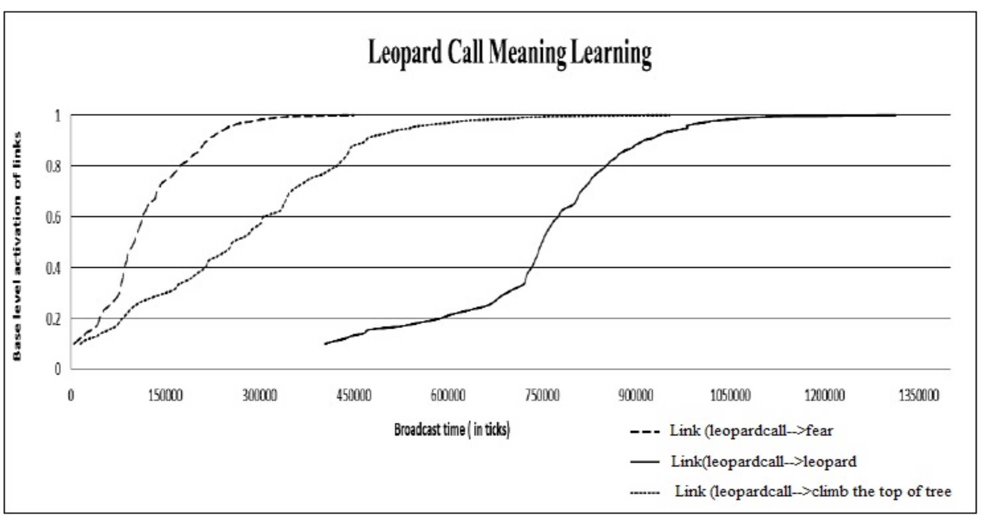

Figure 13: Base-level activations of learned links from leopard call node to leopard node, climb to the top of the tree node, and fear node at each broadcast time.

Another set of results show that the INFANT's mind added new relationships leading from the leopard call to the fear feeling, climbing to the top of a tree, and the leopard itself, respectively. As mentioned previously, each simulation was performed using the same series of 35 randomly generated environments. The INFANT learned the various meanings of the leopard call in the following temporal order: The fear-based meaning at an average point of time equal to 446335.0476 (in ticks), the action-based meaning associated with climbing a tree, and lastly the reference-based meaning related to the leopard predator.

The results of learning the meanings of the three distinct vervet alarm calls differed as follow: In the eagle call and leopard call meanings results (Figure 11 and Figure 13), the vervet's mind quickly associated the eagle call with fear and hiding under bush and the leopard call with fear and climbing to a top of a tree. It takes much more time to associate the eagle call and leopard call with the eagle and the leopard, respectively. These results are consistent with what is expected to be learned in the wild. In fact, most of the time, the vervet infant is held by his mother. Hence, the INFANT is able to feel his mother's fear, perceive her hiding under bush, and climbing the tree faster than seeing the eagle and the leopard. However, the result of learning the snake call meaning (Figure 12) showed that the INFANT's mind associated the snake call with the fear, standing bipedally, and the snake within a short time interval. In fact, the vervet infant is able to see the snake quickly most of the time in spite of being held by the mother.

As explained before, the INFANT is not born with a fear of leopards. Our results show that the INFANT's mind added a causal relationship from the leopard to the fear feeling. This causal association is learned at a late point of time (in ticks) in the simulations. In the wild, the vervet infant is held by the mother most of time. Hence, it's expected that the INFANT will rarely spot the leopard.

In summary, the results illustrate the capacity of the INFANT agent, controlled by the LIDA cognitive architecture, to associate each alarm call with its multiple meanings in the following temporal order: The fear feeling, the corresponding escape action, and the corresponding predator class. This temporal order is in line with the primary assumption of the physical attachment between the MAMA and the INFANT. During infancy, the body position (Picture 1) of the infant allows him to perceive the mother's fear and her escape action faster than spotting a predator in the vicinity.

(Taken by Sajjad Sherally Fazel)

Figure14: Body position of a vervet infant

Modeling the vervet alarm calls using the LIDA model can be viewed as the first step toward modeling human language understanding. Although, the human vocal system is more complex than the vervet vocal system, this work can be a foundation for learning the meanings of spoken words, especially that we adopted a multi-meanings assessment approach.

6.2 Part II: Evaluating the understanding of vervet alarm calls

The main advantage of modeling the learning of the meaning of vervet alarm calls using the computational and cognitive model LIDA is the ability to check the learning through looking at the implemented base-level activations of the learned links in the Perceptual Associative Memory. In the wild, upon detaching from their mother, the vervet infants become capable of escaping appropriately upon hearing an alarm call. In order to simulate the reality of vervet monkeys, several experiments were performed to evaluate the INFANT's understanding of the meanings of alarm calls by gauging the correctness of the escape actions executed by the INFANT upon hearing an alarm call. The Perceptual Associative Memory of the INFANT in this stage contains the newly learned links leading from each alarm call node to the fear feeling node, the appropriate escape action node, and the corresponding predator node.

The INFANT agent is de-attached physically from the MAMA agent in this stage of the simulation. Hence the INFANT learns how to escape appropriately upon hearing an alarm call or spotting a predator in the vicinity. This understanding occurs by the means of the referential and causal relationships established during the first stage of the simulation. The INFANT's performance was calculated as the ratio of the number of correct escape actions of the INFANT after perceiving an alarm call to the total number of the actions of the INFANT including incorrect actions or no actions after perceiving an alarm call.

$$Performance = \frac{Number\ of\ correct\ escape\ actions}{Total\ number\ of\ escape\ actions}$$

Table 2: Performance of understanding the meaning of various alarm calls

Alarm Call	Mean of Performance
Eagle Call	0.77
Leopard Call	0.50
Snake Call	0.66

The INFANT has seven available actions in the ALife grid environment (e.g. hide under bush, climb to the top of a tree, stand bipedally and search etc.). Hence, the probability that the INFANT takes a random action is 0.125. The results show that the INFANT was able to escape correctly upon hearing an alarm call with an average performance. This is a good result in comparison with a randomly chosen action. Additional procedural learning or tuning is needed to improve its overall performance.

7. Conclusion

We studied the vocal alarm calling system of vervet monkeys using a causation mechanism in order to propose an explanation of how the vervet mind learns the meanings of such communicative signals. For this purpose, a two-dimension simulation was designed and implemented using an ALife grid environment populated with an INFANT agent controlled by the LIDA cognitive architecture, and a

MAMA agent, and other VERVET and predator agents controlled by production rules. Simulations were split into two categories: 1- The first stage of simulations were based on the assumption of the physical attachment between the INFANT and the MAMA, and aimed to test the convergence of learning the multiple meanings of distinct alarm calls; 2- The second part of the simulations were based on the assumption of the later detachment of the INFANT from the MAMA, and were done in order to check the comprehension of the alarm calls. This work provides a research contribution in several directions. First, a novel multiple meanings approach was adopted to study the meanings of vervet alarm calls. Three meaning types were considered successively: a feeling-based meaning, an action-based meaning, and a reference-based meaning. Approaching vervet alarm calls with multiple meanings can give us a fundamental insight on modeling human words which convey multiple meanings as well. Second, successful modeling of the meanings of vervet alarm calls using the LIDA cognitive architecture represents a first step toward realizing the goal of language processing in LIDA, which is one of the important and complex high-level cognitive functions. Third, the performed study was a good validation of the LIDA-based perceptual learning mechanism, particularly in learning relationships. The results, and especially the temporal order of learning the meanings of each alarm call, were consistent with the reality of vervet monkeys in the wild. Finally, the two-dimensional ALife grid environment used in this study showed the importance of computational simulations in studying the convergence of meanings of simple communicative acts such as vervet calls, and it may also be an efficient tool in studying more complex vocal systems that have syntax, grammar etc.

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