

# A Computer Model of a Developmental Agent to Support Creative-Like Behavior

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## Abstract

This paper reports a model of a developmental agent. It is inspired by some characteristics of Piaget's sensorimotor stage. During this stage essential skills for creative thinking are developed. Our computational model attempts to shed some light about how these abilities arise and, in this way, contribute to the study of the developmental side of computational creativity.

## 1 Introduction

Creativity is an important characteristic of human beings. There are several approaches to its study. In this work we are interested in contributing to the understanding of the genesis of the creative behavior. Inspired by Piaget's ideas about children's development, we are working on a computer model of a developmental agent. That is, an agent that is initially provided with basic knowledge structures and skills and that, through interaction with its environment, develops novel behaviors that allow it to adapt to its surroundings and to solve novel problems.

Piaget (1952) observed that children from birth to 24 months old are able to develop new behaviors of increasing complexity. He referred to this period as the sensorimotor stage of cognitive development, and is divided in six sub-stages: 1) reflexes, where the child understands his environment through a set of inborn knowledge structures (that he called schemas) that correspond to reflexive behaviors (e.g. closing the hand when an object makes contact with the palm); 2) primary circular reactions, where the child uses his reflexes to adapt to the environment, inborn schemas are replaced by new constructed schemas, and actions are repeated because they have pleasurable effects to the infant (e.g. when a baby sucks its thumb by accident, causing him a pleasurable sensation, so he repeats the action due to the pleasure); 3) secondary circular reactions, in which the child intentionally repeats actions in order to trigger a response in the environment (e.g. when a baby squeezes a rubber ducky by accident and it sounds "quack", the baby does it again because he considers the quack sound an interesting result); 4) coordination of reactions, where the child begins exploring his environment and imitating the behavior of others, often

combining different schemas in acting to obtain a desired effect; 5) tertiary circular reactions, in which the child tries out trial and error experimentation to discover new methods of meeting challenges (e.g. when a baby steps on a toy and it makes a nice sound, then he tries to squeeze the toy to get a similar result); and 6) early representational thought, that marks the beginning of the development of symbols representing objects or events, and the understanding of the child's world begins to be done through mental operations, and not merely through actions.

In this developmental stage, children's behaviors start to be goal oriented (where the goal is to reproduce and preserve an interesting result); this is the beginning of means-end differentiation, a basic skill to become capable of solving problems. In this way, children become able of developing new behaviors using known schemas in new situations. Children start using mental skills for depicting and solving a problem. In other words, they become able of learning from mental simulation instead of from actual experimentation. This is the beginning of problem solving.

Scandura (1977) defines problem solving as the generation and selection of discretionary actions to bring about a goal state; Runco (1994) considers problem solving as a form of creativity. As mentioned before, in Piaget's view, infants develop their earliest abilities necessary to solve novel problems in the sensorimotor stage. Thus, one might conclude that during this stage the first children's manifestations of creative behavior arise. Implementing an agent that allows observing how such abilities emerge from "innate" (predefined) knowledge structures, and from the interaction of the agent with its environment, hopefully would contribute to a better understanding of the origins of the creative behavior. Although it is possible to find works on early developmental AI (e.g., see Guerin 2011 for a review) and works that models the creative process (e.g. see Pérez y Pérez and Sharples 2004), it is hard to find computational models of creativity that include developmental characteristics and vice versa. This work represents our first step in that direction.

## 2 The Developmental Agent

The developmental agent is mainly inspired by Piaget's theory about cognitive development. Following his theory, the agent is initialized with basic knowledge structures called schemas, which represent some of the innate beha-

vivors in children described by Piaget. From there, the agent is capable of creating new schemas, representing some of the typical behaviors of the first and second substages of development of the sensorimotor period. The agent is capable of creating new knowledge structures, by being situated into a 3d virtual world with which it interacts, and by being provided with simulated physical and cognitive characteristics, as explained in the following sections.

## 2.1 Agent’s Virtual World

The agent lives in a 3D virtual world that represents common places such a living room, a game room, a park, or the forest. Every time that the system is executed, the environment can be modified. Thus, sometimes the agent may develop in a house, and some other times in the forest. It contains simple 3D models of typical objects you can find in the real world. Figure 1 shows two examples of virtual environments. The first environment consists of a house with 3D models of furniture, plants, toys, etc. The second environment shows a second example of a virtual world, which consists in a city road with two moving cars. All objects have the following relevant characteristics. They are luminous or non-luminous, graspable or non-graspable (e.g. a small toy may be graspable while a big couch may not), static or in motion, and they have a color and a size. Additionally, some of the objects have been designed to promote the development of the agent, so they do not necessarily follow the physical laws of the real world. For instance, a ball may sometimes start rolling or bouncing, and then it suddenly stops (the trajectories of objects in motion are previously defined).



Figure 1: Two examples of virtual worlds in which the agent can interact.: (a) the living room of a house, and (b) a city road with two moving cars.

## 2.2 Agent’s Physical Characteristics

The agent is physically implemented as a virtual character which has the appearance of a child-like robot (see Figure 2). It has a head with two eyes, two arms with hands, two legs with feet, and a trunk. It can move its head (to the left, right, up, and down), as well as its right arm (to the left, right, up, down, back and forth), and right hand (close and open). The rest of its body stays immobile. These movements represent the initial repertoire of physical actions, also known as external actions, that the agent can perform.

The agent is provided with simulated vision and tactile sensors, through which it is capable of capturing visual and tactile information from the virtual world. The visual sensor (which is implemented as a virtual camera with a field of vision of 60 degrees) is set in its right eye, and the simulated tactile sensor is set in the palm of its right hand. So, the

agent can only receive visual information with one eye, and tactile information with one hand. This characteristic helps to reduce the complexity of the agent and, at the same time, allows studying its behavior when one sense is deactivated. In this way, we expect to answer questions like: how is the cognitive development of the agent affected when it can only perceive visual (or tactile) information?

The agent visually senses its world by taking a picture of it with its virtual camera. This picture is internally represented as a 180 x 120 x 3 matrix: 180 pixels width, 120 pixels height, and 3 values (in the [0-256] range) corresponding to the red, green, and blue color components of each pixel. The agent’s field of vision is divided into the nine areas shown in Figure 2b, and the agent is capable of determining in which of the nine areas a visual object is located.

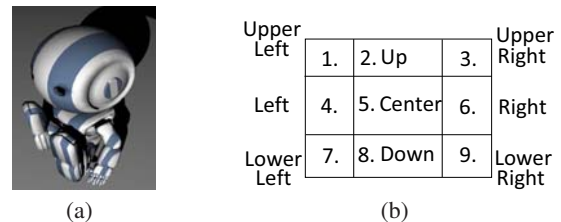


Figure 2: (a) The virtual developmental agent, and (b) division of the agent’s field of vision.

## 2.3 Agent’s Cognitive Characteristics

**The Agent Can “See” and “Touch” its World.** The agent has functions to process the visual and tactile data that it captures through its simulated sensors. The result of this processing is an internal representation of what it is seeing and/or touching, which is called current-context. This current-context includes (among other things) descriptions of the objects the agent detects within its environment. Such descriptions are defined in terms of the visual (color and size) and tactile (texture) features the agent is able to recognise in the objects (the context also includes representations of the affective responses, emotional states and motivations which are explained below). When the agent is set on, it is not able to recognise any visual or tactile features. It needs to interact with its environment to steadily acquire such abilities. Therefore, at the beginning, the agent sees the objects in the world as bright stains within its field of vision; they might move (because the objects move independently) or they might disappear (because the objects move out of its field of vision). Also, at the beginning it can only detect if an object is touching or not its hand, but it is not able to describe its texture. Later on, as the agent interacts with its environment (by seeing and touching the objects around him), it steadily gets the ability to recognise different colors, sizes and textures. The kind of colors, sizes and textures it learns to recognise depend on the characteristics of the objects it interacts with; therefore, if the agent lives in a green environment (the rainforest, for instance), then it will develop the ability to recognise a wide range of green tones. Whereas if it lives in a more

heterogeneous environment (like a city), then it will be less sensitive to green shades, but it will be able to distinguish and recognise a wider spectrum of colors. Furthermore, since the agent uses the characteristics of its environment to create its knowledge structures (i.e. its current contexts and its schemas), different environments create different contexts and schemas.

### **The Agent Simulates an Attention Process.**

Every time the agent senses its world, it detects the captured objects through its vision and tactile sensors, and selects one of them. The selecting process consists of assigning a value to each sensed object, representing how interesting the object is to the agent and then choosing the one with the highest value. This value is called interest value. The agent is preset to have visual and tactile preferences. For example, it assigns a higher interest value to the moving objects than to the static ones; or to those in bright colors compared to objects in dim colors. The current-context structure is then built from the information related to the selected object only, that is, the object of interest.

### **The Agent Simulates Affective Responses, Emotional States, and Motivations Causing it to Act.**

The agent simulates two kinds of affective responses (like and dislike), three emotional states (interest, surprise and boredom), and an innate motivation (cognitive curiosity). The affective responses are represented by variables with values -1 or +1, where -1 stands for dislike and +1 stands for like (future versions will include a bigger range of values for the affective responses). The emotional states of interest, surprise and boredom, as well as cognitive curiosity are represented by a Boolean variable which is true when the agent presents such emotional state or motivation. The general process through which different affective responses, emotional states and motivations are triggered is explained below.

In this work, all the objects that the agent selects as its focus of attention automatically trigger an affective response of pleasure in the agent (“like”). This means the agent “likes” focusing its attention to bright objects (see Figure 3a for an example of this situation).

As part of the agent’s repertoire of initial actions, it is provided with one internal action named *show\_interest\_in A*. The result of the execution of this action is the triggering of an emotional state of interest in object *A*. This action is useful to keep the agent engaged with a particular object, by maintaining the agent interested in it. When the agent is interested in an object and this object “disappears” (e.g. the object is moving and goes out of its field of vision), a dislike affective response is triggered, defined by a variable with a -1 value. This represents that the agent “dislikes” losing the objects of interest. See Figure 3b for an example of this situation. When this happens, the system is preset to run a random external action (e.g. turn its head left). In this way, any of the random actions, called “recovery action”, eventually and “accidentally” causes the missing object to return to the field of vision (e.g. turning its head left will usually cause an

object moving to the left to return to the field of vision). The accidental recovery of the object of interest causes the activation of a surprising emotional state. Figure 3c exemplifies this situation.

The agent considers as “new experiences” the situations when it recovers by accident a pleasurable object, that is, when a surprise emotional state is triggered. New experiences are recorded in agent’s memory through new schemas. New schemas are structures which associate its feeling dislike for losing a pleasurable object to the recovery action, and to the situation of feeling pleasure again after recovering the object of interest. The latter situation is called expectation. Thus, continuing with the example of Figure 3, from now on, every time the agent faces a similar situation (i.e. every time an object of interest disappears), it will use the experience recorded in the new schema by executing the recovery action (moving its head to the left) expecting to have the object back. Nevertheless, sometimes this action recovers the object, but it does not some other times (e.g. it will not be able to recover objects moving right by turning its head left). When the action gets to recover the object of interest, the description of the object it recovered (e.g. its color and size) is saved as part of the schema. This group of objects is called “objects expectations fulfilled”. Whereas when it fails to recover the object, it saves the description of the object in another group called “objects expectations NOT fulfilled”. Using Piaget’s terminology, these two groups are called objects assimilated to the schema.

When the agent fails to recover the object it likes by executing the recovery action, its expectations are considered not met, and a motivation called “cognitive curiosity” is automatically triggered (see Figure 3d-f). This motivation causes that the agent modifies the experience recorded in the schema. Such modification depends on the characteristics of the objects that have been assimilated to the schema so far; which the more is used to recover objects of interest, the larger diversity of objects it assimilates (objects of different colors, sizes, and positions within its field of vision). So, every time that the expectations associated to an schema are not met, the agent steadily modifies it by considering the similarities and the differences of the characteristics of the objects it has assimilated so far. Up to the moment in which, for example, the modified schema represents that the recovery action of turning its head left only recovers the objects having the characteristic of being on the left of its field of vision.

Finally, the emotional state of boredom is triggered when the agent detects the same objects consecutively (e.g. 10 times).

In general, this is how the different affective responses, emotional states and motivations are triggered. Once they have been triggered, they are used for building the current-context structure. In other words, the agent represents what it is seeing and/or touching in terms of the affective responses, emotional states and motivations caused by the object within its center of attention (see Figure 4).

**The Agent Has a Memory.** The agent has a memory where it stores all its knowledge, e.g. its knowledge on the

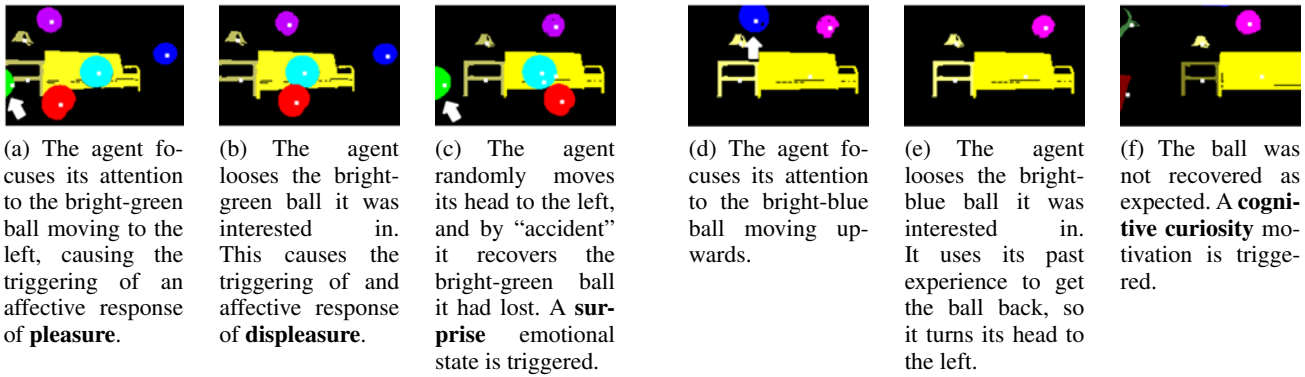


Figure 3: Examples of situations when some affective responses, emotional states, and motivations are triggered.

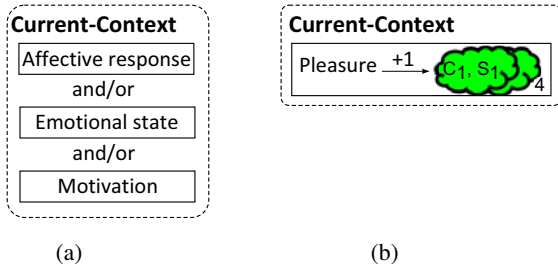


Figure 4: (a) The current-context structure. (b) An example of a current-context structure, which represents the moving, big, bright, green ball that the agent likes of Figure 3a;  $C_1$  represents the color of the object;  $S_1$  represents the size of the object; the number 4 on the bottom-right indicates the location of the object within the agent’s field of vision.

current state of its world, and on how to interact with it. Regarding the latter, it is stored in a particular type of structures called “behavioral schemas”, of which there are two types: basic schemas and developed schemas.

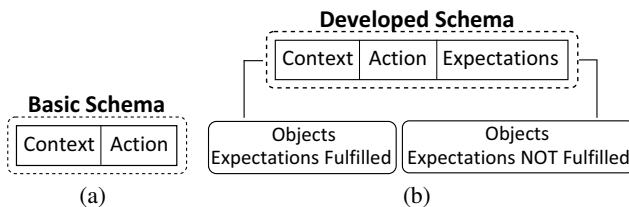


Figure 5: Types of behavioral schemas: (a) Basic schema (b) Developed schema.

Basic schemas represent some of the innate behaviors Piaget observed in young babies, such as automatically closing their hands when an object makes contact with their palms; we represent them as contexts associated to actions (see Figure 5a). Developed schemas are built by the agent as it interacts with its environment. They represent new behaviors. An example of a developed schema representing the new behavior of recovering a pleasant object the agent has lost on the right side of its field of vision was presented

in section 2.3. Thus, developed schemas are comprised by a context, an action, a series of expectations, a set of descriptions with which its expectancies were met, and another one with which they were not (see Figure 5b).

**The Agent Has Adaptation Mechanisms.** The agent’s adaptation mechanism is inspired by Piaget’s ideas about children’s adaptation to its environment. According to Piaget, adaptation is comprised by two processes: assimilation and accommodation. Assimilation is about interacting with the world employing all the available schemas in memory; while accommodation is about the modification or creation of new schemas as a result of dealing with unknown situations in the world. Piaget states that when children employ their schemas to interact with the world, they are in a situation known as a state of equilibrium. However, sometimes they face unknown situations (which are not represented in their schemas) producing a state of disequilibrium. Piaget suggests that the movement from equilibrium to disequilibrium and back again to equilibrium promotes children’s development. In this work, we extend and adapt the Engagement-Reflection model (Pérez y Pérez and Sharples, 2001) to implement some of the Piaget’s ideas about the children’s adaptation mechanism.

Engagement works as follows. It takes the current-context, and employs it as cue to probe memory in order to match a behavioral schema with an associated similar context. If the matching process fails, engagement modifies the current-context and tries again to match a schema in memory. In Piaget’s terminology, engagement tries to assimilate the current situation to its actual knowledge. When a schema is matched, the agent executes the associated action. The agent senses again its world, updates the context, and the cycle continues. Engagement ends in three situations: 1) when the agent cannot associate any schema in memory (an impasse is declared) and therefore it does not know how to act, 2) when the agent executes an action with associated expectations that are not fulfilled, and 3) when the agents recovers a pleasant object, and it was not expected. In these cases, the agent switches to reflection. During reflection the agent attempts to analyze the current situation and, with the help of some predefined heuristics, attempts to deal with

the unknown situation either modifying schemas or creating new ones. Thus, conflict (dealing with unknown situations) triggers the necessity of modifying and building new schemas. The creation of novel structures is one of the core components of this model.

Therefore, engagement represents an automatic process while reflection represents an analytical thoughtful process.

### 2.4 Agent’s Information-Processing System

The agent is provided with an information-processing system which is comprised by three modules: 1) a memory module, 2) a sensory processing module, and 3) an adaptation module (see Figure 6). They work as follows:

1. The agent starts.
2. The agent senses its environment.
3. The sensory processing module uses the captured data to create the current-context structure.
4. The adaptation module switches to Engagement and uses the current-context to try to retrieve from memory a schema representing a situation similar to the one expressed in its current-context.
5. The schema’s associated action is executed, and the system goes back to step 3.

If during step 5 the system cannot retrieve any action from memory, or if the agent executes an action with associated expectations which were not fulfilled, then the system switches to Reflection. During Reflection, the system employs a set of predefined heuristics, to attempt to deal with the unknown situation either modifying current schemas or creating new ones. In this work it is considered that steps 3 to 5 form what is called “a perception-action cycle”.

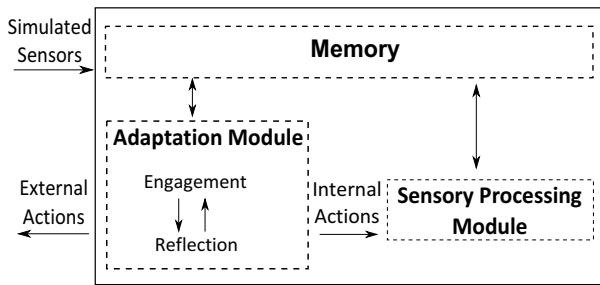


Figure 6: Agent’s information-processing system.

## 3 Experiments and Results

A virtual world was created (see Figure 1a) with which the agent interacted for 9000 cycles. It simulates the living room of a house. This environment is compound with objects in different bright colors and sizes, which were placed there in order to get the agent’s attention. In this particular environment there are balls in different colors and sizes, moving from the left to the right and downwards, independently. So, some balls roll while others bounce, and the ones that bounce, suddenly start to roll. Nevertheless, they never make contact with the agent’s hand.

### 3.1 Initial Knowledge

The agent was set up with three basic schemas which are shown in Figure 7, and they represent the initial behaviors the agent knows for interacting with its world. The first two represent two innate tendencies (regarding the maintenance of the pleasant stimulations) Piaget observed in young babies. The first of them lets the agent keep its attention on a sole object of interest for a certain period of time. In this way it can preserve its affective response of pleasure. The second one makes it possible for the agent to reach out for the object of interest it has just lost, in order to recover it. The third basic schema represents the palmar grasp reflex when an object makes contact with it.

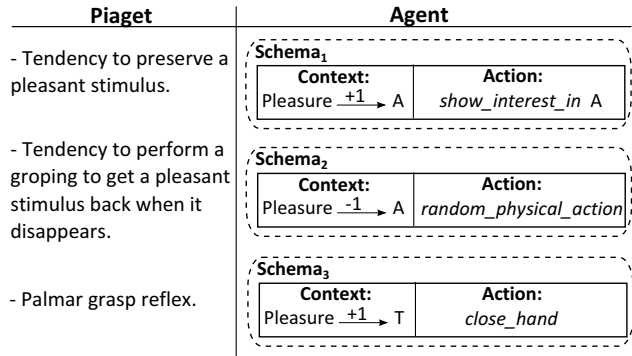


Figure 7: Initial basic schemas.

### 3.2 Development of the Agent in the Living Room of a House

The agent interacted with this environment three different times (each for 9000 cycles). It is important to remember that during the development stages considered in this model (the first and second substages of Piaget’s sensorimotor period), the new abilities the agent acquires are based on learning how to recover the emotional reactions of pleasure caused by certain object, and on learning how to keep them.

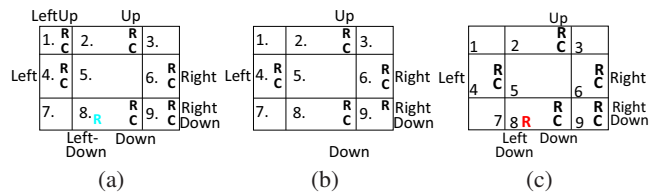


Figure 8: New abilities acquired by the agent when it developed in the living room, for three different runs.

Figure 8 shows the abilities the agent acquired during the three runs. Letter “R” indicates the positions within the field of vision where the agent learned how to recover lost pleasant objects; letter “C” indicates the position where the agent learned how to conserve pleasurable objects; finally, a label with the name of an action (out of the box representing the field of vision) indicates the action that the agent learned to perform in that position in order to conserve or recover objects. For example, during the first run (see Figure 8a), the

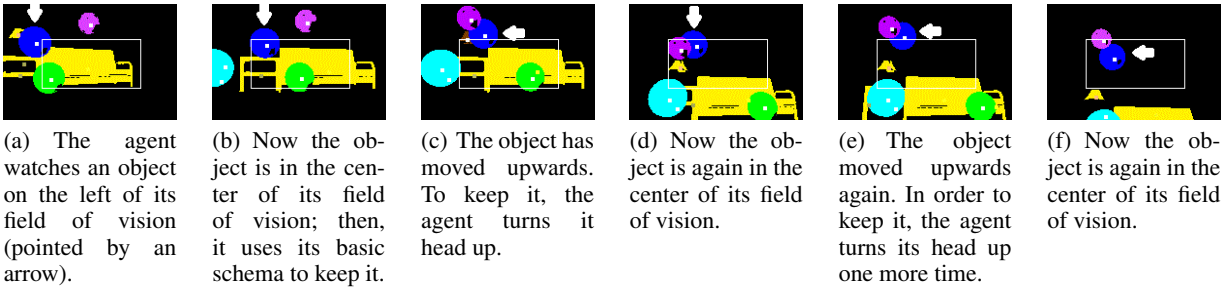


Figure 9: An example of the agent watching the object of interest.

agent learned it could recover and conserve the pleasant objects it was seeing or stopped seeing in the position 6 by turning its head right. It also learned it was possible to recover the cyan colored objects leaving its field of vision through position 8 by turning its head left and downwards. In this way, during the first run the agent created 13 new schemas (7 of them to recover objects in different positions, and the other 6 to keep them). During the second run, it created 9, and in the third run it created 11 new schemas in total (see Figure 8b and 8c). In this model, these new schemas represent the agent's primary circular reactions.

After the agent created and used these new schemas for some time, it was possible to observe how a new behavior emerged: the agent started to follow visually interesting objects. Furthermore, when we analysed the positions within its field of vision, where the agent watched the objects, we observed that a new ability had come up: centering the objects of interest within its field of vision. Figure 9 shows an example of the last part of the first run in which the agent gets to keep the object of interest within its field of vision, most of the times in the center of it. In addition, Figure 10 shows the number of times (in groups of 250 in 250 cycles) the agent watched the objects in the center of its field of vision versus the number of times it watched them in the surroundings. These two new abilities that the agent acquired were described by Piaget as two of the main abilities related to vision which children develop during the second substage of the sensorimotor period.

## 4 Conclusions

This work describes a computational model of a developmental agent inspired by some characteristics of Piaget's sensorimotor stage ideas. So far, our agent autonomously develops new behaviors that resemble the characteristics of the first and second substages of the sensorimotor period. Such substages are responsible for producing the essential abilities that later allow developing problem solving skills, a core component of the creative process.

If we are interested in understanding creativity, it is necessary to study the genesis of such a process. We believe that our work contributes in that direction. Hopefully, it will encourage other researches to study the developmental aspect of computational creativity

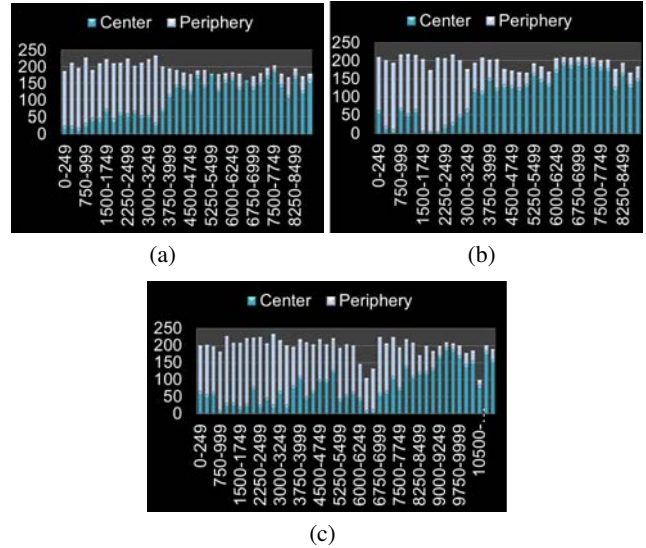


Figure 10: Graphs showing (in groups of 250 in 250 cycles) the number of times the agent watched an object in the center of its field of vision vs the number of times it watched it in the surroundings.

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