Early-creative behavior: the first manifestations of creativity in a developmental agent

Wendy Aguilar [1] and **Rafael Pérez y Pérez** [2]

[1]Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas, UNAM, Mexico City.
weam@turing.iimas.unam.mx
[2]Departamento de Tecnologías de la Información, UAM Cuajimalpa, Mexico City.
rperez@correo.cua.uam.mx

Abstract

In this position paper we are interested in studying the genesis of the creative process. We suggest that the field of developmental robotics might be useful towards this end. That is, artificial agents that start with basic knowledge and abilities, and that through the interaction with their environment they develop new skills of incremental complexity. With this purpose, we built our developmental agent which implements a computational model for early cognitive development, based on the Engagement-Reflection model of the creative process. This model is named *Dev E-R* (Developmental Engagement-Reflection). In the tests we have performed, the agent can learn the first abilities related to vision and touch. Can these first acquired behaviors be considered as creative? We claim that they can as long as they fulfill the criteria of novelty, utility, emergence, adaptation and motivation.

Introduction

Computational Creativity (CC) is the interdisciplinary study of the creative process employing computers as a core tool for reflection and generation of new knowledge (Pérez y Pérez, 2015). Most of the systems that one finds in the literature describes agents able to paint, to develop narratives, to compose music, and so on; that is, agents that employ representations of (domain-specific and general) knowledge as well as skills to perform their tasks. Surprisingly, it is hard to find research projects that focus on studying the genesis of the creative process. That is, computer models that illustrate how an agent that starts with basic knowledge and abilities can develop, through the interaction with its environment, the skills required to perform creative tasks. For example, behaviors needed to solve problems, such as the ability to differentiate between means and ends. We believe that this is an important area that has not received the attention that it deserves. We refer to it as early-creative behavior.

The field of developmental robotics might be useful towards this end. This area of research is interested in creating artificial agents (physical or simulated) that can learn and develop new skills of increasing complexity, in an open-ended fashion. These kind of works usually takes inspiration from psychological, neurological and evolutionary biological theories about how human's intelligence grows. In (Guerin, 2011a) the reader can find a review of these kind of systems. However, none of them considers the creative point of view involved in cognitive development.

On the other hand, several authors have described different features associated to creative activities (e.g Amabile and Collins, 1999; Cohen, 1989; Steels, 1990). We believe that the first step towards studying early-creative behavior is to establish a criteria to evaluate if the conduct showed by developmental agents might be associated to creativity.

Thus, in this position paper we argue that:

- CC requires to study the genesis of the creative process.
- The field of developmental robotics can provide a useful framework towards this aim.
- It is necessary to establish metrics that help to analyze if a developmental agent is showing a behavior that might be classified as early-creative.

To establish an adequate metric is a complex problem that requires the efforts of the whole community. In this paper, based on our work on DevE-R (Aguilar and Pérez y Pérez, 2015), a developmental agent, we would like to suggest some criteria that might help as starting point. We will use our model to illustrate how such criteria might be employed.

The paper is organized as follows. Section 2 describes the works we used as a base for developing our agent and our evaluation criteria; Section 3 describes our model; Section 4 shows some tests we performed and the results we obtained; section 5 discusses how such a results can be linked to the proposed criteria; Section 6 provides some conclusions.

Theoretical foundations

Dev E-R is a computational model which simulates early cognitive development inspired by the theories of Cohen (1989) and Piaget (1952). On one hand, Leonora Cohen describes creativity as a series of adaptive behaviors in a continuum set of seven levels of development. Initially, creativity involves the adaptation of the individual to their surroundings, and in the higher levels, it involves adapting the world to the individual. On the other hand, Piaget describes adaptation as the interaction of two inseparable process called assimilation and accommodation. Assimilation refers to the way in which a child transforms new information so that it makes sense within their existing knowledge base, while accommodation happens when a child changes his or her cognitive structure in an attempt to understand new information. Thus, our approach consists in seen cognitive development from Cohen's perspective, that is, as a creative activity. To capture this idea, we used and extended the computational model of the creative process called Engagement-Reflection (Pérez y Pérez and Sharples, 2001; Pérez y Pérez, 2007). In (Aguilar and Pérez y Pérez, 2015), we presented the results when the agent was only able to see its world, but could not touch it. In this paper we present the results obtained when the agent can touch but not see its environment, and when it could both see and touch. Our main interest is to see which new skills could arise as a result of modifying these sensory abilities, and to discuss whether these can be consider as early creative behaviors.

For the latter objective, based on the work of (Pérez y Pérez and Sharples, 2004; Piaget, 1952; Steels, 1990; Amabile and Collins, 1999) we suggest the following evaluation criteria (see Aguilar and Pérez y Pérez (2014)):

Novelty: A behavior is considered novel if it did not exist explicitly in the initial database of knowledge of the agent (Pérez y Pérez and Sharples, 2004).

Utility: A behavior is considered useful if its serves as basis for the construction of new knowledge that gradually leads the agent to acquire new skills that are typical of the following stage of development. In this context, it is very important that the acquired knowledge be available to be used for subsequent creations.

Emergence: According to the definition given by Steels (1990), our proposal is to consider a behavior has emerged when its origin may not be traced back directly to the components of the system, but rather, is the result of the way in which such components interact with each other.

Motivation: Amabile and Collins (1999) distinguished two types of creativity: 1) intrinsically-motivated and 2) extrinsically-motivated. The first one refers to a behavior that is motivated by internal rewards (e.g., when a child is interested in a task, or finds it satisfactory, or considers it as a personal challenge that he wants to overcome), while extrinsic motivation is focused on external rewards, appraisal or avoiding punishment. Our statement concerning this paper is that a behavior developed by an agent should be considered as creative only if it appeared as a result of an intrinsic or extrinsic motivation.

Adaptation: The ability to adapt ourselves to our environment has been traditionally deemed (probably since Darwin) as a condition needed for the truly creative behavior (Runco, 2007). Aditionally, adaptation and creativity are so much related to one another, that even LeoNora Cohen thinks of adaptation as the closest synonym of creativity (Runco, 2007, p.44), who describes the latter as a series of adaptive behaviors in a continuum set of seven levels of development. In Piaget's theory, adaptation is defined in terms of the processes of assimilation and accommodation.

The developmental artificial agent, and the Dev E-R model

This section provides a brief summary of the description of the virtual agent, as well as the Dev E-R model. For details see (Aguilar and Pérez y Pérez, 2015).

Virtual World

The agent interacts with a 3D virtual world that recreates ordinary places, such as a living room or a playroom. The world contains simple 3D models of typical objects that may be found in real life. For instance, Figure 1 (a) shows a virtual environment consisting of a house filled with furniture, plants, toys, etc., and Figure 1 (b) represents a study room with a sofa, some toys, chairs, and a shelf.

Physical Features

The agent is implemented as a virtual character (see Figure 1c). It can move its head and its hand (see Table 1). It also implements simulated vision and touch sensors, which are used to capture visual and tactile information of the world with which it interacts. The tactile sensor is placed on the palm of its right hand and is implemented as a presence-detecting sensor (determining if a spatial intersection is present between the 3D model representing the hand and any of the objects present in the surroundings).

Name of the action	**Description**
MHLeft	Moves head left
MHRight	Moves head right
MHUp	Moves head up
MHDown	Moves head down
MHRightUp	Moves head up and right
MHRightDown	Moves head down and right
MHLeftUp	Moves head up and left
MHLeftDown	Moves head down and left
close_hand	Closes hand
open_hand	Opens hand
HandLeft	Moves hand left
HandRight	Moves hand right
HandUp	Moves hand up
HandDown	Moves hand down
HandForward	Moves hand front
HandBackwards	Moves hand back
random_external_action	Randomly picks one of the foregoing actions.

Table 1: Initial repertoire of physical actions, also named "external actions", that may be executed by the agent.

Cognitive Features

The agent implements five cognitive features: 1) capacity to "see" and "touch" the world around it; 2) simulating an attention process; 3) simulating affective responses, emotional states and intrinsic motivations pushing it to act; 4) has memory; and (5) simulates a process of adaptation to its environment.

(a) (b) (c)

Figure 1: Two examples of virtual worlds with which the agent may interact, (a) a living room, (b) a study room; and (c) the developing agent.

The agent can "see" its world Inspired by Piaget's theory we implemented our agent in such a way that, when it starts operating, it sees the objects that come into its vision scope as luminous spots, whether static or moving, which are detected from data captured by its simulated visual sensor.

The blurs detected are used to create an internal representation of what the agent is seeing. This representation is termed *Current-Visual-Context*, which includes, among others, the features of the objects seen (e.g. its size and color).

The agent can "touch" its world The agent is capable of touching the world around it through the use of a tactile sensor, which is used to detect: 1) the presence of an object in contact with the palm of the hand (can only touch one element at a time) and 2) its texture. In this paper, we are assuming that the agent has learned to recognize a number of textures, which have been labeled as: "t_1", "t_2", "t_3", etc. The object detected is then used to create an internal representation of what the agent is touching. This representation is termed *Current-Tactile-Context*.

The agent simulates an attention process The agent simulates an attention process which it uses to select which object to interact with from the ones detected. This process takes three criteria into consideration. First, the agent is preprogrammed to have preferences. Thus, it prefers to interact with moving objects over the static ones, and it also prefers the ones with bright colors over the ones with dark colors. Secondly, the agent finds novel objects more attractive than older ones And third, the agent prefers the objects which it has established an affective response to, an emotional state or a certain motivation, as explained in the next subsection.

The agent simulates affective responses, emotional states and motivations that push it to act The agent simulates affective responses, emotional states and motivations which are inspired by Piaget's ideas, associated with the relation between affectivity and development of intelligence. The first responses consist of intensity and valence, represented by the agent through variables that span along a scale of -1, +1, +2, wherein -1 represents disliking and +1/+2 represent two degrees of liking. The rest are represented internally as Boolean variables having a true value when the agent presents such emotional states or motivations.

The agent has a memory The agent has a memory wherein it stores all its knowledge. Particularly, the agent stores in this memory its current perception of the world (represented through the *Current-Context* structure) and how it interacts with that environment (represented through schemas).

Current-Context

The *Current-Context* is a structure composed by two parts (see Figure 2a): 1) a *Current-Visual-Context* or a *Current-Tactile-Context*, and 2) the agent's current expectations, which are defined as an *Expected Current-Visual-Context* or an *Expected Current-Tactile-Context*. In turn, the first ones are composed by two parts (refer to Figure 2b): 1) the features of the object that is in the center of attention of the agent (its color, size, movement and position within the visual field, or the status of the agent's hand whether open or closed and the texture of the object that the agent is touching at the time); and 2) the affective responses, emotional states and motivations triggered in the agent by such object. With the purpose of providing a simpler, more compact notation, henceforth, current contexts composed solely by affective responses are herein represented in the form of Figure 3.

Schemas

Schemas as used herein are knowledge structures representing the sensory-motor schemas described by Piaget. There are two types: basic and developed.

Basic schemas represent innate behaviors and tendencies observed by Piaget in babies, which are present in the agent from its initialization. These are represented as contexts associated to actions (see Figure 4a). Figure 4b shows an illustration of a basic schema, which associates the situation of feeling disliking, triggered by an object of any color = a, of any size = b, with any movement status = c and in any position within the visual field = d, with the action of performing a random external action.

Developed schemas are constructed based on the interactions of the agent with its environment, and represent new behaviors. These are composed by a context, an action to be executed, an expected context and a set of contexts with which the expectations have been fulfilled (named "Contexts Expectations Fulfilled"), and others that were not fulfilled (termed "Contexts Expectations NOT Fulfilled"), as illustrated in Figure 5a. Figure 5b shows an example of a developed schema.

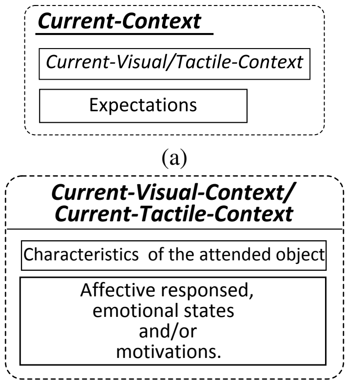

Figure 2: (a) *Current-Context* Structure; (b) *Current-Visual-Context* and *Current-Tactile-Context* structures.

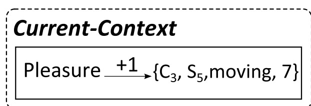

Figure 3: An example of a *Current-Context* structure.

The agent has adaptation mechanisms: the Dev E-R model

The agent has adaptation mechanisms which simulate the processes of assimilation, accommodation and equilibration described by Piaget. The way in which said mechanisms are implemented is through an extended version of the computational model of the creative process named *Engagement-Reflection* (Pérez y Pérez and Sharples, 2001; Pérez y Pérez, 2007). These mechanisms allow the agent to adapt to its world, whether by modifying its perception of the environment so that such perception is adjusted to the knowledge acquired through past experiences (i.e., adaptation by assimilation) or by modifying and creating new knowledge when this is not adjusted to the "reality" (i.e., adaptation by accommodation). These mechanisms are implemented in the *Dev E-R* model (Developmental Engagement-Reflection), which is in charge of using and constructing the knowledge of the agent (represented as sensory-motor schemas). It has two ways of achieving this: 1) automatically, through the *Engagement* process; and 2) analytically, through the *Reflection* process.

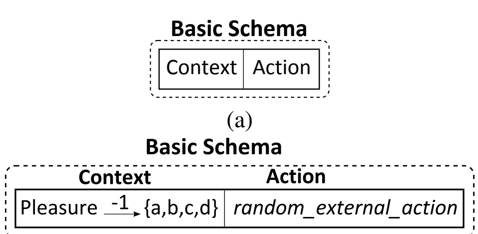

Figure 4: (a) The structure of basic schemas; (b) an example of a basic schema.

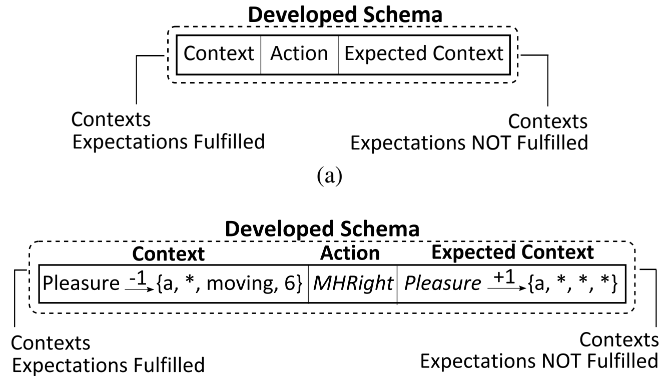

Figure 5: (a) The structure of the developed schemas; (b) an example of a developed schema.

General Functioning The *Dev E-R* model, in *Engagement* mode, searches its memory to find schemas whose contexts represent a similar situation to the one described in the *Current-Context* (see, for instance, the case illustrated in Figure 6, wherein a 100% match exists between both structures). If during this process the agent is found to know more than one way to act given the current situation, then one of those ways is selected. The selection is performed in such a way that the developed schemas are assigned a higher probability of being chosen over the basic ones; and from the developed schemas, the one resulting in the highest number of expectations fulfilled and expected to result in the most pleasure is the one that will most likely be selected. When a schema is selected, its associated action is executed; in case the selected schema is a developed schema, then the expectations are registered in the *Current-Context* (see Figure 2). The agent senses once more its world, updating the structure of the *Current-Context*, and the cycle continues. When no schema may be matched in the memory, i.e., when the agent faces an unknown situation, then an impasse is declared. In this event, an adaptation process is required, whether by assimilation or by accommodation. These processes may be performed automatically or analytically, for instance, through analogic reasoning. However, since we are

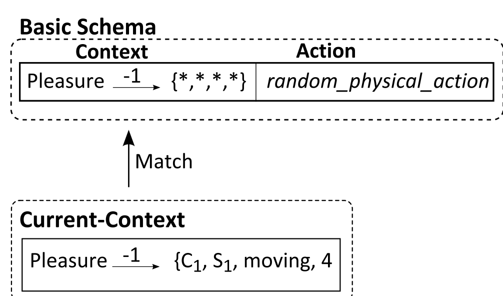

Figure 6: An example of a 100% match between a *Current-Context* and a schema available in memory.

modeling early sub-stages, the agent lacks reflexive skills to help it deal with such type of situations. Consequently, adaptation in this implementation is simulated as an automatic activity that is being performed in *Engagement* mode.

Interaction of the Agent with the World

When the agent begins its execution, it is initialized with a knowledge database that consists in a set of basic schemas, which represent reflex behaviors. From there, the agent begins interacting with the world, following the steps below:

1. The agent senses the environment through its virtual camera and its tactile sensor.
2. It creates a *Current-Context* that represents its actual "perception" of the surroundings.
3. *Dev E-R* uses the *Current-Context* structure to seek in its memory an action to perform. During this process, it is possible to perform certain modifications in the knowledge base (creation, deletion or modification of a certain schema).
4. The agent executes the action selected.
5. The agent goes back to step 1.

Steps 1 to 4 herein above are known as *perception-action cycle*.

Tests and Results

In this paper we are interested in testing the model when the agent can touch but not see the world around it (i.e. is blind), and when it can booth see and touch the environment.

First test: The Agent can only touch its world

In this test the agent interacted within the living room in Figure 1a. All the objects were static, except for 5 balls that were moving as follows: 1) when the agent had its hand open and not in contact with any object, sometimes the system randomly picked any of the 5 balls and placed it in its hand (so that its touch sensor could detect it during the next cycle); 2) when the touch sensor was in contact with any object and the agent executed the action *close_hand*, then it was considered that the object had been grasped; 3) the grasped objects moved accordingly to hand movements, 4) by default, after one cycle the agent automatically opened its hand (unless when, during the current cycle, the action *close_hand* had been selected); and 4) upon the hand being opened, the object that had been grasped could remain in the same position and continue in contact with the touch sensor, or go back to its initial position (the selection above was made by the system on a random basis).

The agent was initialized with the schemas shown in Figure 7, which represent innate behaviors and tendencies described by Piaget. It was also pre-programed with the capacity of recognizing 5 different textures on the objects it touched, labelled: "t_1", "t_2", "t_3", "t_4" and "t_5". The execution began with the agent sitting in the middle of the environment with its hand open in front of it, and the 5 balls in positions that were out of its reach. We considered that the development of the agent was completed when it remained in a state of cognitive equilibrium during the last 500 cycles. That happens when it shows to have acquired new skills that enabled it to interact with the environment by recovering and preserving the tactile objects that were pleasant for it.

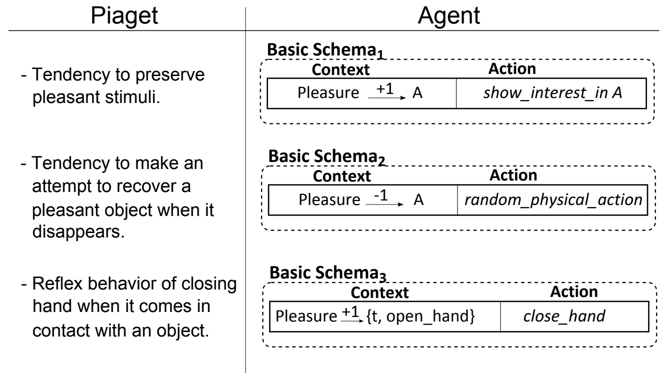

Figure 7: Basic schemas with which the agent was initialized. Letter "A" is a variable that may describe any visual object (defined as {color, size, movement, position}, or any tactile object (defined as {texture, hand_status} wherein said hand status may be *closed_hand* or *open_hand*).

In three independent executions the agent learn the same three schemas shown in Figure 8. This first schema associates the situation of having opposing affective responses caused by the same object (unpleasantness due to the loss of an element that had been grasped, and pleasure for detecting the same object on an ongoing basis, but now with the hand open), with the action of closing the hand and the expectation of recovering the affective response of pleasure resulting from grasping again the object of interest. The second schema associates the situation of having an affective response of pleasure triggered by touching any object with the open hand, with the action of closing the hand and with the expectation of having again an affective response of pleasure caused by touching the same object, but now with the closed hand. The construction of this second schema caused the agent to begin closing its hand when it came into contact with any of the objects of interest, but not as a result of a reflex behavior, (through the use of a basic schema), but rather as a result of a developed behavior having an expectation associated therewith. The third and last schema associates the situation of having an affective response of pleasure triggered by touching any object with the closed hand, with the action of closing the hand and with the expectation of maintaining the affective response of pleasure caused by holding the same object. The construction of this third schema resulted in that, from that point onwards, the agent began to maintain its hand closed when it was holding an object of its interest, which was then released when an emotional state of boredom was triggered. In other words, the agent learned to hold on to the objects of its interest.

Second test: The Agent can see and touch its world

In (Aguilar and Pérez y Pérez, 2015) we presented the results obtained when the agent could see but not touch the living room of Figure 1a. In that environment all the objects were

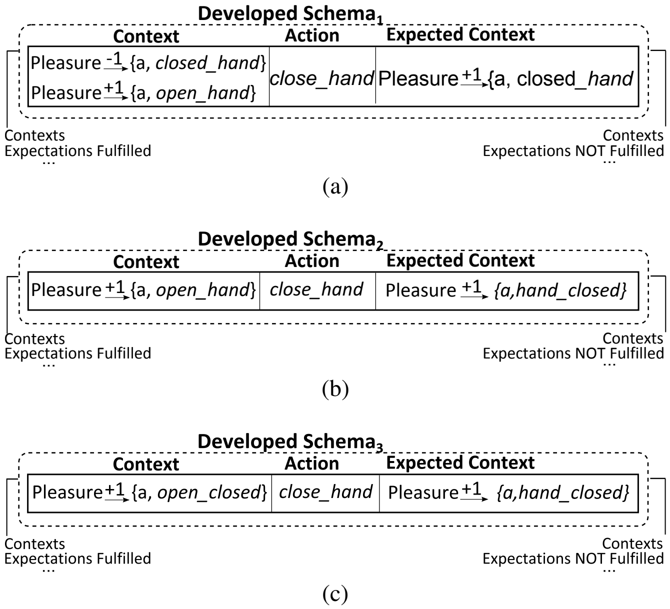

Figure 8: Schemas created when the agent was blind and it could only interact with the living room by using its sense of touch.

static, except for 5 balls of different colors, which began to move at different times and in different pre-defined directions (sometimes they rolled from left to right, and back; other times, they bounced). In that test the agent was initialized with the first two schemas of Figure 7, and at the end of its development it had learned to: 1) visually following the objects in motion, 2) centering them within its field of vision, and 3) staring at static objects in the center of its field of vision.

For this test the agent interacted again with the living room of Figure 1, but this time it was initialized with the 3 basic schemas shown in Figure 7, the schemas develped when it could only see its world, and with the schemas developed when it could only touch its world (shown in Figure 8). In other words, the agent started the execution with the knowledge of how to visually following the objects of interest, centering them in the visual field, as well as to hold on to the objects that come in contact with the hand and keeping them held until another object attracted its attention or until it became bored. The reason for the above is that, in this test we are interested in observing the set of behaviors that arise when the agent has constructed and stabilized both its visual and tactile schemas. This time, the agent started sitting in the middle of the environment, with the head looking to the front and with its hand outside the visual field. All the objects were static, except for agent's hand, which was moving in random directions at some points in time. Later in this run, the balls began to move in the same way they behaved during the first test.

Upon starting, the first observation we found was that, when agent's hand came into the visual field, that part of its body caught its attention and it began to follow that luminous element with head movements (using the developed schemas that were available at initialization). It is important to note that, up to this moment, the agent sees its hand moving, not exactly because it is a part of itself (as it has not developed any knowledge structure which allows it to distinguish its own body from the rest of the objects in the environment), but because the hand catches its attention due to the color, size and movement of the hand itself, as if it were any other element present in the virtual world.

After 500 cycles, the balls began to move so as to enter into contact with the agent's hand. From that moment, the behavior of the agent consisted in holding the objects that were in contact with its sensor, and then, releasing the items when it lost interest in them, and in following the visual elements that caught its attention. In other words, the agent continued to interact with the environment by using all the knowledge it was initialized with. After 1500 additional cycles, the agent reached a state of cognitive equilibrium, causing the schemas stored in memory to be considered stable, thus being the agent capable of: 1) representing in a same *Current-Context* both visual and tactile data; and 2) finding partial matches with the stabilized structures. These new capacities opened room for the creation of 32 new schemas, 4 per each position of the peripheral areas within the visual field. When the agent used together all its acquired knowledge, we could observe the emergence of the following behaviors: 1) visually following its hand by moving its head, 2) centering within its visual field (by moving its head) the object being held, 3) seeing within its visual field how its hand grabs and releases the object of interest, 4) seeing how its hand grabbing an object goes out of its visual field, and then recovering that image by moving its head, and 5) seeing how its hand grabbing an object goes out its visual field, and then recovering that image by moving its hand.

Discussion

In (Aguilar and Pérez y Pérez, 2014) it is presented a set of useful criteria to assess whether the behaviors generated by an agent may be considered as creative. We will discuss each of them to evaluate the results obtained in this paper.

Novelty: As presented in the previous section, when the agent could only see but not touch its world, it learned different behaviors related to visually following the objects of its interest and in centering them in its field of vision. When it could only touch but not see, the behaviors it learned were related to object grasping based only on its hand information, and when it could both see and touch it learned new skills related to grasping involving its sight and hand. All these new skills represent different behaviors from the reflex conducts defined at the beginning of the execution.

Hence, under this criteria, all behaviors it learned are considered novel.

Utility: To assess the usefulness of the behaviors developed by the agent, lets consider that it was initialized with reflex conducts wich are typical behaviors of the first sub-stage of the sensory-motor period. From there, it constructed the first schemas referred to the recovery of the interesting objects. These structures were subsequently used as basis of knowledge, partially applying them to new situations faced by the agent, for the construction of the next schemas referred to maintaining the pleasant items. The use in conjuntion of visual and tactile schemas led the agent to the acquisition of new behaviors associated with coordination of vision and touch. Hence, the knowledge structures developed by the agent are considered useful, as they allowed it to go from predefined or "innate" behaviors (typical of the first sub-stage of the sensory-motor period) to body-based behaviors (typical of the second sub-stage of the sensory-motor period) and to behaviors involving external objects (typical of the third sub-stage of the sensory-motor period).

Emergence: In the *Dev E-R* model, the learning of different behaviors depends on a number of factors, notably: 1) environmental properties, 2) physical characteristics of the agent, and 3) current knowledge. Regarding item one above, if the agent lived in a world where the task of recovering an object implied having to move the head up, then the agent would develop schemas that would represent this feature of the environment surrounding the agent. Regarding item two, when the agent was blind, it developed behaviors different from those developed when it was granted with the ability to see (using exactly the same processes of adaptation in both cases). Regarding the third point above, as discussed in the previous criteria for creativity, the behaviors developed by the agent are based on previous developed skills. Hence, we may conclude that the behaviors developed by the agent emerged as a result of the way in which the different system components interacted with each other, as the new behaviors are not pre-programmed and, furthermore, they are all context-dependant.

Motivations: One of the crucial components of the agent is that it simulates affective responses, emotional states and an intrinsic motivation of cognitive curiosity that prompt the agent to act. In particular, regarding the development of new schemas, these are created, modified or deleted as a result of: 1) an emotional state of surprise (e.g., caused by the unexpected recovery of an object of interest), or 2) a motivational cognitive curiosity that is triggered when the agent faces a conflict situation when dealing with unknown circumstances which contradict its current knowledge of the world). Hence, in this model, the emotional state of surprise and the intrinsic motivation of cognitive curiosity trigger in the agent the need to modify or construct new schemas.

Adaptation. The ability to adapt ourselves to our environment has been traditionally deemed (probably since Darwin) as a condition needed for the truly creative behavior (Runco, 2007). Aditionally, as we mentioned in the introduction, adaptation and creativity are so much related to one another, that even LeoNora Cohen thinks of adaptation as the closest synonym of creativity (Runco, 2007, p.44), who describes the latter as a series of adaptive behaviors in a continuum set of seven levels of development. In Piaget's theory, adaptation is defined in terms of the processes of assimilation and accommodation. The schemas developed by the agent were created as a consequence of it facing unknown situations an reacting to them: 1) by assimilating the new circumstance to the previously acquired knowledge (through a process of searching the memory for a schema which represents a situation similar to the one being faced in the *Current-Context*); or 2) by accommodating the knowledge in such a way that it may adjust to the new experience (thus creating a new schema, or differentiating, generalizing or deleting an existing one). Accordingly, the construction of new structures of knowledge was carried out as a result of the simulation of a complementary process of assimilation and accommodation. In other words, they are originated as a result of the agent's adaptation to its world.

Conclusions

Dev E-R is a computational model of early cognitive development, implemented as a creative process. It is inspired by the theories of Piaget (1952) and Cohen (1989). In a prior paper (Aguilar and Pérez y Pérez, 2015), it was explored its functionality in an artificial agent which could only see but not touch the world around it. In this paper, we had two main interests: 1) to explore what new behaviors could emerge when the agent was granted with the ability to touch but not see the world, by using exactly the same *Dev E-R* model and initial knowledge of the previous experiments, and 2) when it was able to see and touch. The results from the tests have allowed us to observe the generality of said model, in the sense that it, based on the sensorial capabilities of the agent, was able to learn new skills associated with vision, others associated with the sense of touch; and others related to both touching and seeing. These latter behaviors represent the first eye-hand coordination skills identified by Piaget, which are the base conducts needed to the developing of abilities related to goal-oriented behavior, and thus for problem solving.

Additionally, in this paper we have described features that some authors associate to creative conduct. We have employed such characteristics to suggest a criteria for the evaluation of early-creative behavior. This is an interesting problem for several reasons. Developmental agents start with few very basic knowledge-structures. Through interaction with their environment they develop new knowledge that allows them to acquire abilities that were not originally programmed. Can this behavior be considered as creative? We claim that it can as long as it fulfills the criteria of novelty, utility, emergence, adaptation and motivation. We speculate that early-creative behavior might eventually lead towards agents able of complex creative performance. If someday we are able to create a developmental system that ultimately acquires the capacity of composing music, writing poems or progressing plots, our understanding of the creative process will significantly increase. We believe that this scenario is possible. In Dev E-R we used the ER-Model that we employed in building MEXICA (Pérez y Pérez, 2007; Pérez y Pérez and Sharples, 2001), the ERI-Designer (Pérez y Pérez, Aguilar, and Negrete, 2010), and Tlahcuilo, our visual composer (Pérez y Pérez, González de Cossío, and Guerrero, 2013). So, we have the two poles of one continuum. Now, we only have to figure it out how to connect them. Probably this will take several years. This is only the first step.

Acknowledgments

This research was sponsored by the National Council of Science and Technology in Mexico (CONACYT), project number: 181561.

References

Aguilar, W., and Pérez y Pérez, R. 2014. Criteria for evaluating early creative behavior in computational agents. In *Proceedings of the fifth international conference on computational creativity. Ljubljana, Slovenia.*

Aguilar, W., and Pérez y Pérez, R. 2015. Dev e-r: A computational model of early cognitive development as a creative process. *Cognitive Systems Research* 17–41.

Amabile, T. M., and Collins, M. A. 1999. *In: R.J. Sternberg (Editor) Handbook of creativity*. Cambridge University Press, Cambridge. chapter Motivation and creativity, 197–312.

Cohen, L. 1989. A continuum of adaptive creative behaviors. *Creativity Research Journal* 3.

Guerin, F. 2011a. Learning like a baby: a survey of artificial intelligence approaches. *The Knowledge Engineering Review* 26:209–236.

Guerin, F. 2011b. *Sensorimotor Schema(s). In Encyclopedia of the Sciences of Learning, Norbert Seel (ed.)*. Springer Science+Business Media.

Ormrod, J. 2012. *Essentials of Educational Psychology: Big Ideas to Guide Effective Teaching*. Boston, MA: Pearson Education Inc.

Pérez y Pérez, R.; Aguilar, A.; and Negrete, S. 2010. The eri-designer: A computer model for the arrangement of furniture. *Minds an Machines* 20(4):483–487.

Pérez y Pérez, R., and Sharples, M. 2001. Mexica: a computer model of a cognitive account of creative writing. *Journal of Experimental and Theoretical Artificial Intelligence* 13(2):119–139.

Pérez y Pérez, R., and Sharples, M. 2004. Three computer-based models of storytelling: Brutus, minstrel and mexica. *Knowledge Based Systems Journal* 17, number 1.

Pérez y Pérez, R.; González de Cossío, M.; and Guerrero, I. 2013. A computer model for the generation of visual compositions. In *Fourth International Conference on Computational Creativity*, 105–112.

Pérez y Pérez, R. 2007. Employing emotions to drive plot generation in a computer-based storyteller. *Cognitive Systems Research* 8(2):89–109.

Pérez y Pérez, R. 2015. A computer-based model for collaborative narrative generation. *Cognitive Systems Research* 36-37:36–37.

Piaget, J. 1952. *The Origins of Intelligence in Children*. London: Routledge and Kegan Paul, 1936 (French version published in 1936, translation by Margaret Cook published 1952).

Runco, M. A. 2007. *Creativity Theories and Themes: Research, Development, and Practice*. Academic Press in an imprint of Elsevier.

Steels, L. 1990. Towards a theory of emergent functionality,. In *From Animals to Animats: First International Conference on Simulation of Adaptive Behaviour*, 451–461. Bradford Books (MIT Press).