CREATIVITY AND SURPRISE

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Abstract

This paper describes a computational model for creativity in which surprise plays a central role. There is no doubt that creative products, being unexpected and unpredictable products, cause surprise. Supported by recent evidences from neuroscience and psychology, which say emotions are biasing devices in decision-making, we defend that decisions made during the creative process may be, to some extent, surprise-guided in order to make the resulting products surprising. Moreover, when evaluating a product in regard to its creativity, the intensity of surprise that product causes is certainly one part of that evaluation. We illustrate with examples the role played by surprise both in the production of creative products and in the evaluation of already existing creative products.

1 Introduction

Roughly speaking, agents accept percepts from the environment and generate actions. Selecting the "right" action is critical, because agents' performance depends heavily on that. This is one of the main concerns of Decision Theory. Resulting from the combination of Utility Theory and Probability Theory (Shafer and Pearl, 1990; Russel and Norvig, 1995), Decision Theory provides artificial agents with processes to make "right" decisions. One example of those processes may be briefly described as follows: given a set o possible actions that the agent may take, the agent computes their possible results as well as the probabilities of these results and then it selects the action that maximizes a mathematical function, called Utility Function, that models its preferences (its behaviour).

In order to accomplish the task of building artificial agents that act and think like humans (Russel and Norvig, 1995), in addition to other human features, such an artificial intelligent agent should be able both to produce and to evaluate creative products. This means that two main points of view, the creative process and the creative product (solution)[1], may be considered to deal with the problem of modelling creativity in an artificial agent. Actually, creativity has been considered as a multifaceted phenomenon, being distinguished two more perspectives for it in addition to those, namely the creative person and the creative environment (Mooney, 1963; Sternberg, 1988).

[1] The words *product* and *solution* are used in the context of this paper as synonyms.

From the point of view of the process, several theoretical explanation models have been proposed in psychology and philosophy specifically for the creative process, like the ones proposed by: Dewey (1910), Poincaré (1913), Rossman (1931), Wallas (1926), Guilford (1968), Mansfield and Busse (1981), De Bono (1986) etc., (for a review see (Glover et al., 1989)). Generally, most of them split the process into steps, which may be simplified as follows: problem acquisition and knowledge assimilation, conscious or unconscious search for a solution, proposal of a solution, and verification of the proposed solution. Some of these models actually pass the problem of explanation to intangible things such as the unconscious or inspiration, giving evidence of the difficulty of finding a rational explanation for the creative phenomenon. On the contrary, this difficulty seems not to exist in ordinary reasoning models, as opposed to creative reasoning models, and therefore there is no need to invoke such unsubstantial and obscure realities (Glover et al., 1989; Sternberg, 1994; Smith et al., 1995).

Guilford (1968) has claimed that the exploration of creative solutions is mainly due to the mind ability that he called Divergent Production (a concept closely related to the concept of Lateral Thinking proposed by De Bono (1986)). This ability involves the generation of a variety of solutions to a same problem. It is used to solve those kind of problems for which there are multiple correct solutions that may be classified in a continuous evaluation space about their originality and appropriateness. In contrast to Divergent Production, Convergent Production (the closely related concept of De Bono is called Vertical Thinking) was considered by him as the ability to produce logically the right solution to a given problem that can just have one correct solution.

Rumelhart (1980) defended that restructuring is the process that allows the construction of really new schemata. This restructuring is a process in which knowledge fragments are reassembled into new knowledge structures (Armbruster, 1989).

Spiro et al. (1987) claimed that flexible knowledge is a prerequisite for knowledge restructuring and hence for creativity. They sustain that flexible knowledge representation is one in which fragments of knowledge are represented in a way that allows them to be reassembled into new knowledge structures.

In spite of these widely discussed theories, there are other authors who argue that the creative process is in a continuum with ordinary processes (e.g.: Ram et al., 1994; Macedo et al., 1998a). These authors defend the theory that both ordinary and creative products result from ordinary mechanisms. Particularly, Ram et al. state that creative products are outgrowths of ordinary mechanisms improved and applied with strategic conscious control. Furthermore, Ram et al. enumerate such mechanisms in the context of Case-Based Reasoning (CBR) as follows: problem interpretation, problem reformulation, case and model retrieval, elaboration and adaptation, and evaluation.

In opposition to the conflict of ideas from the point of view of the process, as evidenced by the uncertainty about the existence and also the precise location of a frontier between the creative process and ordinary processes, there is a general consensus from the point of view of the product. Actually, originality (usually defined as the unexpected novelty) and appropriateness (defined as usefulness, aesthetic value, rightness, etc.) have been referred to by most of the authors as the most important characteristics of a creative product (MacKinnon, 1962; Koestler, 1964; Jackson and Messick, 1967; Lubart, 1994; Boden, 1992, 1995; Moorman and Ram, 1994; Macedo et al., 1998a).

Taking into account the experiments carried out in psychology evidencing that the intensity of felt surprise increases monotonically, and is closely correlated with the degree of unexpectedness (see (Reisenzein, 2000b) for a review of these experiments), and also the basic definition of surprise ("to encounter suddenly or unexpectedly"; "to cause to feel wonder, astonishment, or amazement, as at something unanticipated"), there seems to be no doubt that those creative products, by being unpredictable, unanticipated or unexpected, cause emotional states of surprise in their viewers (Lubart, 1994; Boden, 1992; 1995). Actually, there is no doubt that both creative artistic products and creative scientific products are surprising. Thus, in order to make something surprising, the sequence of steps taken to build it may be guided by surprise. Therefore, surprise seems to play an important role both in the process of producing and in the process of evaluating a creative product.

Moreover, recent research in neuroscience (Damásio, 1994; LeDoux, 1996; Adolphs, 1996) and in psychology (e.g.: Izard, 1991) has provided evidence indicating that emotions, and hence surprise, play an important role in abilities and mechanisms usually associated with rational and intelligent behaviour such as creativity. For instance, results from recent studies of patients with lesions of the prefrontal cortex suggest an important role of emotions in decision-making (Damásio, 1994; Curchland, 1996; Bechara et al., 1997). These patients are unable to make good decisions. Nonetheless, according to Damásio's experiments, pure cognitive abilities such as the ones measured by the traditional I.Q. rating remained unchanged. Moreover, all those patients shared another common feature: they had a strong impairment on their emotional assessment of situation.

Although research in Artificial Intelligence has almost ignored this significant role of emotions on reasoning, several models for emotions have been proposed in the past years (for a detailed review see Hudlicka and Fellous, 1996; Picard, 1997; Pfeifer, 1998). Particularly in what concerns specifically to surprise, Peters (1998), Ortony and Partridge (1987) and the research group of the Department of Psychology of the University of Bielefeld, in Germany, (e.g.: Meyer et al., 1997) have addressed the subject in their works.

In this paper we present an approach to creativity in an artificial agent, in which surprise plays an important role. The points of view of the process and of the product are considered. From the point of view of the creative process, we consider that it involves a sequence of steps (decisions) guided by surprise emotion. Models of creativity such as those proposed by Wallas, Dewey, Guilford, De Bono, etc., are the background of our model (Macedo et al., 1996; 1997a; 1997b; 1998a; 1998c). Guilford's notion of Divergent and Convergent Production and the closely related De Bono's concepts of Lateral and Vertical Thinking strongly influenced our approach. From the point of view of the product, we argue for a classification of it regarding to the intensity of surprise felt by the agent when perceiving that product.

The next section presents an overview of the architecture that we propose for a creative agent. The main component modules are described briefly. Section 3 illustrates the connection of surprise and creativity in that agent, showing the role played by surprise both in the production and in the evaluation of creative products. Section 4 presents a discussion and further work. At last, some conclusions are made.

2 An Architecture for a Creative Agent

A possible architecture for a creative agent that takes surprise into account in its creative reasoning/decision-making is depicted at a high level in Figure 1. It comprises the following modules: sensors/perception, memory, emotion generation, and creative reasoning/decision-making. In a few words: the external sensors provide the creative reasoning/decision-making and the emotion generation modules with information obtained from the world (which is also recorded); the creative reasoning/decision-making module computes the current state of the world (external and internal), then applies probability theory to predict possible states of the world for the available actions (internal or external) that it can perform, and finally it applies the Utility Function (which makes use of the intensity of the generated surprise emotion) to each one of those states of the world, and selects the available action that maximizes that function.

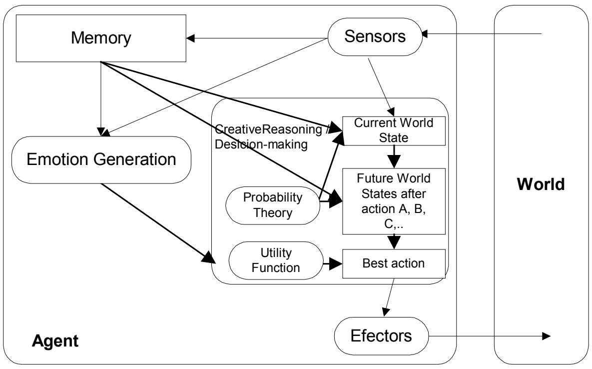

Figure 1: Agent's architecture. The ovals represent processing modules while the rectangles represent information modules.

The following subsections explain in more detail each one of the main modules.

2.1 Memory

At the current stage of development, the agent's memory is of episodic kind, comprising cases of previously perceived objects. This episodic knowledge is graph-based represented (Macedo and Cardoso, 1998b). Figure 2 shows an example of a graph-based representation of a building. In this environment of buildings, three kinds of information of the buildings are represented: structure (shape of the roof, facade, door and windows), function (e.g.: house, church, shop, etc.) and behaviour (e.g.: static, mobile) (Goel, 1992). Notice that for the sake of simplicity the structure of the buildings was confined to comprise only the roof, the facade, a door and a window. Also, for the same reason, their shapes are the very well known geometrical shapes like triangular, squared, rectangular, pentagonal, etc.

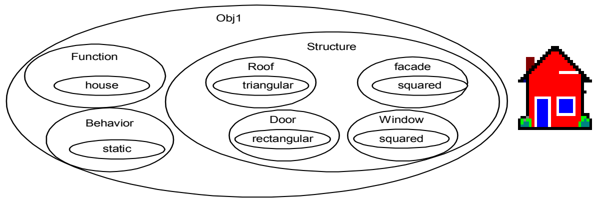

Figure 2: Graph-based representations and respective graphical representation of the shape of a building, which in this case is a house

2.2 Emotion Generation

Although in the more general agent[2] this module may include other emotions, drives and other motivations, in this paper we are only concerned with surprise and its role on creative activity.

We assume that the agent is presented with *input propositions* concerning a particular event (in this case, a product or part(s) of a product), and that it is able to made *expectations* (*passive* or *active*) for a particular event.

Together with Ortony and Partridge (1987), we think that surprise may result from three situations: (i) *active expectation failure*: resulting from a conflict or inconsistence between the *input proposition* and the *active prediction* or *expectation* (i.e., propositions explicitly represented in memory); (ii) *passive expectation failure* (or *assumption failure*): resulting from a conflict or inconsistence between the *input proposition* and what the agent knows or believes (*passive expectation or assumptions*), i.e., propositions that are not explicitly represented but that may be inferred easily; (iii) *unanticipated incongruities* or deviations from norms: resulting from a conflict or inconsistence between the *input proposition* and what, after the fact, may be judged to be normal or usual. Notice that in this last case, there are no *expectations* (*passive* or *active*) with which the *input proposition* might conflict.

In their cognitive-psychoevolutionary model, the research group of the University of Bielefeld (e.g.: Meyer et al., 1997; Reisenzein, 2000a, 2000b) has de-

[2] The model of creativity presented in this paper is only an aspect of a more general agent whose tasks, in addition to creativity, include ordinary activities such as planning. For more details about other aspects of the more general agent and particularly about other roles of surprise see Macedo and Cardoso, 2001.

fended similar ideas to those presented by Ortony and Partridge, namely that surprise (considered by them as an emotion) consists of the appraisal of unexpectedness. In addition, they suggest that surprise-eliciting events give rise to a series of the following mental processes: (i) appraisal of a cognised event as exceeding some threshold value of unexpectedness (schema-discrepancy) - according to Reisenzein (in press), there is a comparator, the appraisal function, that computes the degree of discrepancy between new and old beliefs or schemas; (ii) interruption of ongoing information processing and reallocation of processing resources to the investigation of the unexpected event; (iii) analysis/evaluation of that event; (iv) possibly, immediate reactions to that event and/or updating or revision of the "old" schemas or beliefs. These ideas were also taken into account in the surprise model that we have implemented.

Let us now describe how the intensity of surprise is computed. There is experimental evidence supporting that the intensity of felt surprise increases monotonically, and is closely correlated with the degree of unexpectedness - see (Reisenzein, 2000b) for a review of these experiments. This means unexpectedness is the proximate cognitive appraisal cause of the surprise experience. Considering this evidence we propose that the surprise felt by an agent *Agt* elicited by an object Obj_k is given by the degree of unexpectedness of Obj_k, considering the set of objects present in the memory of the agent *Agt:*

$$SURPRISE(Agt, Obj_k) = DegreeOfUnexpectedness(Obj_k, Agt(Mem))$$

According to probability Theory (e.g.: Shafer and Pearl, 1990), the degree of expecting that an event X occurs is given by its probability P(X), and then the improbability of X, denoted by 1-P(X), defines the degree of not expecting X. Thus, the surprise function is as follows:

$$SURPRISE(Agt, Obj_k) = 1 - P(Obj_k)$$

Although other probabilistic methods might be used to compute P(X), in case of objects comprising several components we may compute the probability of the whole object Obj_k computing the mean of the conditional probabilities of their n constituent parts, which are individually computed using the Bayes's formula (Shafer and Pearl, 1990) (notice that each one of those conditional probabilities individually gives the degree of unexpectedness of a specific piece of the object, given as evidence the rest of the object):

$$P(Obj_k) = \frac{\sum_{l=1}^{n} P(Obj_k^l \mid Obj_k^1, Obj_k^2, ..., Obj_k^{l-1}, Obj_k^{l+1}, ..., Obj_k^n)}{n}$$

2.3 Creative Reasoning/Decision-making

Partially inspired by psychological models such as the ones proposed by Wallas, Guilford, De Bono's, etc., and by computational models such as the one proposed by Ram et al., we have implemented a computational creative process rooted in ordinary mechanisms such as CBR. This process involves the following four steps: problem acquisition plus knowledge assimilation, search for a product (or solution), proposal of a product, and verification of the proposed product. More details about this process and its application to music composition may be found in (Macedo et al., 1996, 1997a, 1997b, 1998a, 1998c). In this paper we give more attention to the step concerned with the search for a product, because it differs slightly from the one presented in the above referred paper, mainly in that the function that drives the divergence of the process is not in this case the difference measure but instead the unexpectedness measure.

We assume that a new problem to be solved by the agent comprises a set of linked *knowledge pieces* (represented by nodes and edges in a graph-based representation). Thus a problem is represented by a subgraph. The agent has only to find the missing subgraph, i.e., the solution, not by chance but obeying to the Maximum Utility Principle as we will explain below, and recurring to the background knowledge stored in the episodic memory.

The step of searching for a product corresponds to the generation and formulation of a possible product (or solution to the problem), which corresponds, as we said above, to the synthesis of the missing subgraph of the new episode. Taking the combination theory of creativity as the basis (combining previously uncombined things), this is performed reusing and combining the *knowledge pieces* of past episodes (products) in the missing part of the current product. In the approach described in this paper this is performed iteratively, i.e., piece by piece until the product becomes complete (other methods may be followed such as reusing by analogy (Holyoak an Thagard, 1995) an entire past episode). In each iteration, the decision of what piece to add is not made by chance, but obeying to the Maximum Utility Principle (Russell and Norvig, 1995) which is explained as follows. Given a set of possible actions that the system might take, such as "add piece X" or "add piece Y", the system computes beforehand the states (in this case products or possibly partial products) resulting from each of those available actions, and then applies an Utility Function to each one of them. Considering that the goal is to produce creative solutions then such function should reflect the properties of creative solutions giving higher utility values to those actions leading to products or partial products with higher originality (higher unexpectedness - or surprise - and higher novelty) and, to avoid bizarreness, with higher appropriateness. At the current stage of development of the system, only surprise is taken into account in that Utility Function, as follows:

$$U(S) = U_{surprise}(S) = SURPRISE(Agt, S)$$

Notice that, in this context, a world state S is the product that is being produced.

Notice also that, after ranking the actions regarding to their utility value, during the process of building a product, the agent may select sometimes actions that lead to high surprising products and sometimes actions that lead to low surprising products.

Besides, the agent or other agents may use the same surprise function to evaluate products that have already been produced by itself (this may happen in the last step of the process - verification and validation of the proposed product) or by other agents.

3 Evaluation and Production of Creative Products: Examples

Let us present examples that show the role played by the intensity of surprise both on the production and on the evaluation of creative products.

3.1 Evaluation of Creative Products

The example presented below was taken from SC-EUNE, an artificial agent that Explores UNcertain and UNknown Environments guided by Surprise and Curiosity (in this case, the curiosity was not taken into account) (Macedo and Cardoso, 2001).

Consider the scene where the agent is in an environment with a few objects (depicted in Figure 3). Suppose that after a complete study of those objects, the agent obtained the information that they are all static houses. In what concerns to their structure the three objects are described as follows: *Obj1* has a triangular roof, a squared facade, a rectangular door, and a squared window; *Obj2* has a triangular roof, a squared facade, a rectangular door and a circular window; *Obj3* has a triangular roof, a triangular facade, a rectangular door, and a squared window. Suppose also that the agent has perceived before one hundred objects. These objects were stored in its episodic memory as four cases (listed in Figure 4).

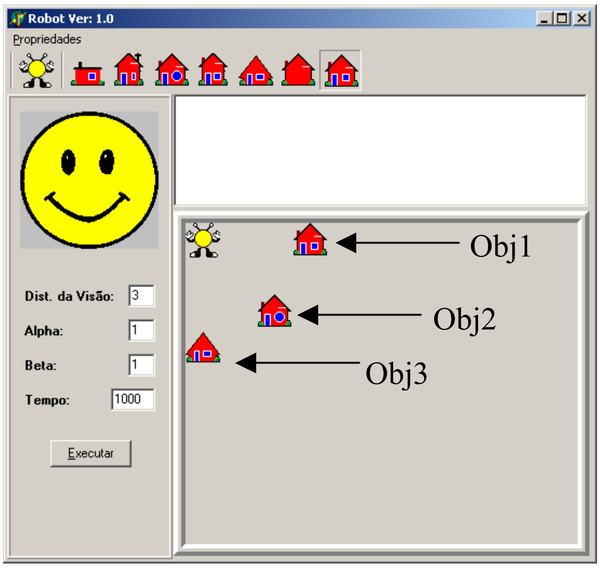

Figure 3: An autonomous agent acting in an environment comprising different types of buildings

Field / Case	C_1	C_2	C_3	C_4
Structure				
Function	House	House	Church	Hotel
Behavior	Static	Static	Static	Static
Abs. Freq.	50	40	5	5

Figure 4 - Descriptive example of the previous 100 perceptions of an agent

Applying the Utility Function described above to each one of the buildings present in the environment, comes:

$$U(Obj1) = U_{surprise}(Obj1) = 1 - P(Obj1) = 1 - 0.9026 = 0.0974 = 9.74\%$$

$$U(Obj2) = U_{surprise}(Obj2) = 1 - P(Obj2) = 1 - 0.8785 = 0.1215 = 12.15\%$$

$$U(Obj3) = U_{surprise}(Obj3) = 1 - P(Obj3) = 1 - 0.725 = 0.275 = 27.5\%$$

Thus, in what concerns to surprise, the objects are ranked as follows (from highest to lowest Utility): *Obj3*, followed by *Obj2*, and finally *Obj1*. Therefore, a possible behaviour of the agent may be to focus its attention on the building that has the highest utility value (*Obj3*), which in this case is the one that causes more surprise.

3.2 Production of Creative Products

Suppose the agent is required to design the shape of a house. If the agent wants to put some creativity on it, although making that house surprising is no enough, it is for sure fundamental. Thus, suppose the agent has designed a house equal to the one described in case C_1 (Figure 4), but where the window is missing. Suppose now the agent wants to design the window so that the house becomes more surprising. According to the knowledge level of the agent, it might chose among a rectangular, a circular, a squared window, or no window at all. Applying the Utility Function above, the agent will select the window that leads to the building with the highest utility value. Thus, the agent ranks the actions as follows (from the highest to the lowest utility): no window (95.67%), rectangular window (95.44%), circular window (59.5%), and finally the squared window (49.38%). The agent selects the no window choice. This makes the new building more surprising than any other window. However, if the agent wants to put a window then the rectangular one is selected.

4 Discussion and Further Work

Relying on several experimental evidences and theoretical works, the computational approach to creativity implemented in a software agent and presented in this paper involves two points of view: the creative process and the creative product. In both points of view surprise plays an essential role. Actually, on the one hand, the divergence of the process is guided by surprise, and on the other hand, the products are classified regarding to the surprise felt by the agent when perceiving them.

Taking into account the function of surprise in the process of producing products (for instance, in planning, problem solving, etc.), the agent becomes able to anticipate the degree of surprise of the hypothetical products it may produce. This means, its creative process is surprise-driven, i.e., every action the agent may take in the process of producing a product is previously evaluated so that it can select the best action (by the best action we mean the action that maximizes the surprise of the product and also - but not considered in this paper - other properties of a creative product such as novelty and appropriateness). If the agent's surprise function takes into account only the agent's knowledge base then the agent might create something that is surprising to it but not to other agents (this is related with Boden's concept of psychological-creativity (Boden, 1992). However, if the agent's surprise function takes into account not only the agent's knowledge base but also predictions of the knowledge bases of other agents, then it produces with more probability surprising products to those agents (this is related with Boden's concept of historical-creativity). Thus, surprise may play an important role to make the process of producing products as a divergent process (Guilford, 1968; Macedo et al., 1997b). Actually, a variety of products may be achieved repeating the process with different degrees of unexpectedness, i.e., using different degrees of divergence.

It is worth noticing that different agents may compute different surprise intensities for a given object since the surprise intensity depends on the contents of the agent's memory. Recent experiments with children and adults have provided evidence indicating that this is true in humans (see Schutzwohl and Reisenzein, 1999).

As we said above, since the goal is to produce creative solutions then the Utility Function should reflect the properties of creative solutions giving higher utility values to those solutions with higher originality (higher surprise and higher novelty) and, to avoid bizarreness, with higher appropriateness. Thus, in order to be loyal to these statements, a possible extension of the current Utility Function (currently depending only on surprise) may be as follows:

$U(S)=f_1[U_{orig}(S), U_{approp}(S)]$

where:

- $U_{approp}(S)$ computes the appropriateness of the product S, which may involve the computation of its rightness, valuable, aesthetic value and degree of satisfaction of constraints of the problem;

- $U_{orig}(S)=f_2[U_{novelty}(S), U_{surprise}(S)]$:

    - $U_{novelty}(S)=f_3[Difference(S)]$ measures the novelty or difference of the product S taking as reference the past products stored in memory;

    - $U_{surprise}(S)$ is the current Utility Function defined above in sections 2.2 and 2.3.

Possible examples of *f1*, *f2* and *f3* are listed below.

Utility:

- $U(S)=U_{orig}(S) \times U_{approp}(S)$ (cartesian product of originality and appropriateness)

- $U(S)=[U_{orig}(S) + U_{approp}(S)]/2$ (arithmetic mean of originality and appropriateness)

Originality:

- $U_{orig}(S)=U_{novelty}(S) \times U_{surprise}(S)$ (cartesian product of novelty and surprise)

- $U_{orig}(S)=[U_{novelty}(S) + U_{surprise}(S)]/2$ (arithmetic mean of novelty and surprise)

Novelty:

- $U_{novelty}(S)=Difference(S)$

The Utility Functions presented above allow us to model Vertical and Lateral Thinking as well as Convergent and Divergent Production. Selecting actions that contribute to highly original solutions, the system is following a highly divergent path to solve the problem. We may say that the agent is performing a kind of Lateral Thinking and consequently contributing to Divergent Production (in the light of the combination theory of creativity). The less the originality, the less the laterality, the less the divergence of the process. In the extreme, there is no laterality and hence an absolute verticality and convergence. Moreover, when the Utility Function takes into account the appropriateness function, it plays the role of providing some verticality to the process because it promotes actions that contribute to rightness.

In future work, we intend to implement these or similar functions and perform experiments with them in order to evaluate their influence in the creativity of the agent.

Furthermore, we plan to consider also semantic knowledge in addition to episodic knowledge (Tulving and Donaldson, 1972; Schank, 1982). The graph-based representation will be maintained because it provides a flexible knowledge representation, which is a prerequisite for knowledge restructuring and hence for creativity, as claimed by Spiro et al. (1987). Besides, it is an appropriate approach to deal with more complex domains (Macedo and Cardoso, 1998b).

Although in our opinion surprise is a fundamental part of the creativity phenomenon, we believe that it is not the only emotion involved, especially in artistic creativity. Therefore, we think that a model of creativity should include the influence of other emotions such as fear, anger, joy, love, etc. Actually, there is no doubt that stories, poems, music pieces, paintings are full of those emotions. In addition, as argued by psychologists such as Izard (1991), emotions are directly connected with creative activity. For instance, Izard emphasized the influence of interest on creativity.

To allow taking into account other emotions on the creativity model, other parameters should be included in the Utility Function corresponding to those emotions. This allows that, during the process of composing a music piece, painting, or writing a story, the agent may include situations (episodes, portions of the paint, etc.) in those products that may cause emotions to its viewers. In the particular case of stories and poems, we believe that it is somehow impossible to the author (human or artificial) to make the personages feel emotions such as love, without having experienced himself those emotions before. In that case, the author would behave like a blind, painting things of the real world that are only perceived through the eyes.

5 Conclusions

We have presented a computational model for creativity in which surprise plays a critical role. This role may be found both on the production and on the evaluation of creative products. We have illustrated this role by presenting examples with a simulated artificial agent acting in an environment of buildings. Although, in our opinion, surprise is a fundamental part of the creativity phenomenon, we believe that it is not the only emotion involved, especially in artistic creativity. Actually, there is no doubt that stories, poems, music pieces, paintings are full of emotions such as fear, love, anger, joy, etc.

Acknowledgements

We would like to thank Prof. Dr. Andrew Ortony and Prof. Dr. Rainer Reisenzein for their helpful comments.

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