The Influence of the Size of the Episodic Memory on the Surprise-value of the Creative Agent's Products

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Abstract

In this paper we evaluate through an experiment the influence of the size of the episodic memory of a creative agent in the surprise-value of its products. We describe briefly the architecture of a creative agent which integrates a model of surprise. Within this architecture, surprise is used both to guide the agent's creative process and to evaluate products. Such a model of surprise depends heavily on the memory of the agent (in this paper restricted to the episodic memory), namely in that the surprise elicited by a given event (or object) is computed comparing it with the contents of the agent's memory.

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 and respective probabilities and then selects the action that maximizes a mathematical function, called Utility Function, that models its preferences.

In order to accomplish the task of building artificial agents that act and think like humans (Russel and Norvig 1995), we should be able to give an agent the capability of producing and evaluating creative products, in addition to other human features. Two main points of view, the creative process and the creative product (solution[1]), may be considered when modeling creativity in an artificial agent. Actually, creativity has been considered as a multifaceted phenomenon, and two more perspectives are commonly distinguished: the creative person and the creative environment (Mooney 1963; Sternberg 1988).

From the point of view of the creative process, several theoretical explanation models have been proposed in psychology and philosophy, like those from Dewey (1910), Poincaré (1913), Rossman (1931), Wallas (1926), Guilford (1968), Mansfield and Busse (1981) and De Bono (1986) (for a review see Glover, Ronning and Reynolds 1989). Most of them describe the process as a stepwise procedure that may be depicted, in a simplified way, 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 forward the problem of explanation to intangible things such as the unconscious or inspiration, giving evidence of the difficulty in 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 ones); hence there is no need to invoke such unsubstantial and obscure realities for them (Glover et al. 1989; Sternberg 1994; Smith, Ward and Finke 1995).

Taking his *Structure of Intellect* model as reference, Guilford has pointed out the significance of Divergent Production abilities to creative thinking, where the capacity to make broad searches through items in memory, to generate alternative ideas that satisfy a general requirement, is of prime importance (Guilford 1977). In contrast, he related Convergent Production abilities to

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

problems where searches must focus on finding the only correct answer satisfying a strict requirement.

De Bono (1986) proposed the concepts of Lateral and Vertical Thinking as two distinct but complementary ways of using the mind. The function of Vertical Thinking is to develop data models and combining them in a logical way, while Lateral Thinking, closely related to creativity, operates by restructuring existing models, freeing up information and stimulating the creation of new models.

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.

There are authors who argue that the creative process is in a continuum with ordinary processes (e.g.: Ram et al. 1994; Macedo et al. 1998). 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, they 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.

When taking the point of view of the creative product, originality (sometimes defined as unexpected novelty) and appropriateness (also 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. 1998).

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 evidence that creative products, by being unpredictable, unanticipated or unexpected, cause emotional states of surprise in their viewers (Lubart 1994; Boden 1992, 1995). Actually, both creative artistic products and creative scientific products seem to agree with this finding: surprise apparently plays an important role both in the production and in the evaluation of creative products. Thus, guiding a creative process by surprise seems to be a promising line. This kind of approach has similarities with the one taken in Lenat’s AM (1979), where the creative process is guided by interestingness. Schank (1986) also outlined the role of expectation failure (a closer concept to surprise) and CBR in creativity. Authors like Peters (1998), Williams (1996), Macedo and Cardoso (2001a), Ortony and Partridge (1987) and the research group of the Department of Psychology of the University of Bielefeld, in Germany, (e.g.: Meyer, Reisenzein and Schützwohl 1997) have addressed the subject of surprise in their works.

Recent research in neuroscience (Damásio 1994; LeDoux 1996) and in psychology (e.g.: Izard 1991) has provided evidence indicating that emotions play an important role in abilities and mechanisms usually associated with rational and intelligent behavior 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. Artificial Intelligence researchers have increasingly recognized the significant role of emotions on reasoning, and several models for emotions have been proposed in the past years (for a detailed review see Hudlicka and Fellous 1996; Picard 1997; Pfeifer 1998). Moreover, there seems to be evidence that emotions influence creativity (Picard 1997; Izard 1991; Macedo and Cardoso 2001b).

Within our approach to creativity in an artificial agent, surprise[2] plays an important role: we consider surprise as a feature of creative solutions. The points of view of the process and of the product are addressed. From the point of view of the creative process, we consider that it involves a sequence of steps (decisions) guided by surprise. Psychological models of creativity such as those proposed by Wallas, Dewey, Guilford, De Bono, etc., and computational models such as the one proposed by Ram et al. (1994) are the background of our model (e.g.: Macedo et al. 1997a, 1997b, 1998; Cardoso et al. 2000; Macedo and Cardoso 2001b). 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.

In this paper we evaluate the influence of the size of the episodic memory of a creative agent on the surprise-value of its products. As suggested by studies that compared the surprise reactions of adults with those of children (Schützwohl and Reisenzein 1999) surprise depends on the contents and developmental stage of memory. In this paper, the memory is of an episodic kind.

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[2] There is no consensus in the literature on whether surprise should be classified as an emotion. However, in the context of this work that classification is not an issue: we consider surprise simply as a psychological construct.

The next section introduces briefly the architecture that we have adopted for a creative agent. Section 2 describes an experimental test carried out to evaluate the influence of the size of an agent's episodic memory on the surprise-value of its products. In section 3 we discuss some key issues of our model, especially those related to its limitations and to future improvements.

Overview of the Agent's Architecture

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. Figure 2 presents an example of an environment in which the agent can act, exploring it and adding creative objects to it. The task of the agent is, in the example, building design.

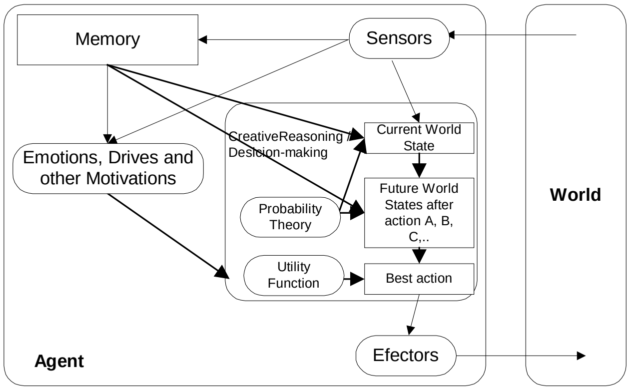

Fig. 1. Agent's architecture. The ovals represent processing modules while the rectangles represent information modules.

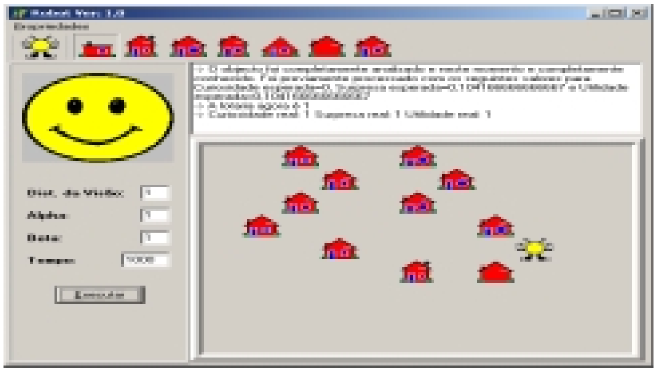

Fig. 2. An example of an environment.

The agent's memory is of an episodic kind: each different object (in this paper confined to buildings) is stored, in the form of a graph, as a separate case in the episodic memory. Each object comprises three distinct, fundamental components: *structure*, *function* and *behavior* (e.g.: Goel 1992). For the sake of simplicity, the *structure* (the visible part of the object), is restricted to the shape of the object (e.g., triangular, rectangular, etc.). The *function* of the object concerns its role in the environment (e.g., house, church, hotel, etc.). The *behavior* of the object concerns its activity (actions and reactions) in response to particular features of external or internal stimuli (e.g., static, mobile). This information related to the *structure*, the *function*, and the *behavior* of the objects, as well as the distance of the objects, is provided to the agent by two simulated sensors that form the perceptual system. We consider that the *function* of the objects is not accessible (i.e., cannot be inferred from visual information) unless the agent is at the same place as the object. In addition, each object representation is associated with a number that expresses its absolute frequency (Figure 3).

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

Fig. 3. Descriptive example of the previous 100 perceptions of an agent.

The agent is presented with *input propositions* concerning a particular event (in this case, a product or part(s) of a product), and is able to made *expectations* (*passive* or *active*) for it. When information from the environment is sampled, the *Emotions*, *Drives and other Motivations module*, in this paper confined to surprise, compares that information to the information stored in memory and outputs the intensity of the elicited surprise. A corresponding facial expression is also produced.

Surprise may result from three situations (Ortony and Partridge 1987):

(i) *active expectation failure*, resulting from a conflict or inconsistency 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 inconsistency 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 inconsistency between the *input proposition* and what, after the fact, may be judged to be normal or usual. Notice that in this 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, Reisenzein, and Schützwohl 1997; Reisenzein 2000a, 2000b) has defended similar ideas to those presented by Ortony and Partridge, namely that surprise consists on the appraisal of unexpectedness.

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 suggests that unexpectedness is the proximate cognitive cause of the surprise experience. On the basis of this evidence, we propose that the surprise felt by an agent *Agt* elicited by an object Obj_k is proportional to the degree of unexpectedness of Obj_k, considering the set of objects present in the memory of the agent. 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). Accordingly, the improbability of X, denoted by 1-P(X), defines the degree of not expecting X, and the intensity of surprise can, for simplicity, be equated with unexpectedness:

$$SURPRISE(Agt, Obj_k) = \\ = DegreeOfUnexpectedness(Obj_k, Agt(Memory)) = 1 - P(Obj_k)$$

where

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

Let us explain how the *reasoning/decision-making module* works in the context of creative activity. This module receives the information from the simulated external world and outputs the action that has been selected for execution. The outline of the process follows:

(i) Computation of the current world state. Taking the information of the world provided by the sensors (which may be incomplete) as input, the current state of the world (for instance, the shape of the object that is currently under construction) is computed.

(ii) Computation of future world states. Taking the current state of the world and the memory, and applying Probability Theory, possible future world states and respective probabilities are computed for the available actions that the agent can perform. For the particular case of creative activity, those available actions may be related to the addition of pieces to the product that is currently under construction (*AddPiece(X)*, *AddPiece(Y)*, etc.). The resulting new world states comprise the imaged or seen product (possibly partially constructed) resulting from those additions of pieces.

Usually, an action *A* may lead to one of a set of possible world states *W1*, *W2*, ..., *Wn*; it is not possible to know with complete certainty to which one, but it is possible to assign probabilities to them. This is represented by what is called within Utility Theory (Russell and Norvig 1995; Shafer and Pearl 1990) as a Lottery, which is represented by a list of elements, each one comprising a possible resulting state of the world and its probability:

$$Lottery(A) = [p_1, W1; p_2, W2; ...; p_n, Wn]$$

where p_i is the probability of the i^{th} possible resulting state W_i.

Notice that in the particular case of a single resulting state of the world for an action, the Lottery is as follows:

$$Lottery(A) = [1, W1]$$

(iii) Selection of the "best" action. Among the available actions, a single one (presumable the best one) is selected – the one with the highest Utility Value. Utility Values result from the application of the Utility Theory (Russell and Norvig 1995; Shafer and Pearl 1990) as follows. For each action, the following Expected Utility Function, denoted by *EU*, is applied to its lottery:

$$EU(p_1, W_1; p_2, W_2; ...; p_n, W_n) = \sum_i p_i \times U(W_i)$$

where *U(Wi)* denotes the Utility Function of state *Wi*:

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

The Utility Function relies heavily on the anticipated intensity of surprise elicited by the future state of the world. Thus, the preferences of the agent are reflections of its anticipated surprise. This Utility Function means that the utility of a world state *W* is given by the surprise that the state *W* causes the creative agent to "feel". In this article, a world state is defined as "being close to or seeing or imaging an object" (the object that is currently the focus of attention of the agent's sensors).

A variety of products may be achieved repeating the process with different degrees of surprise, resulting a Divergent Production of buildings (see Macedo 1998). Figure 4 illustrates this process.

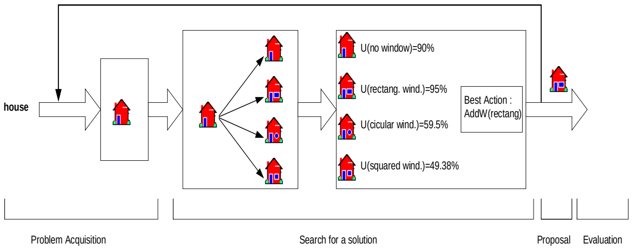

Fig. 4. Illustrative example of the decision-making process for generation of surprising products. We consider that the process involves the following steps: Preparation, Search for a solution (product), Proposal of a solution and Evaluation. Divergent Production may be achieved repeating the process, but with alternative decisions.

Experimental Test

We performed an experiment to evaluate the influence of the size of the agent's episodic memory on the surprisingness of the products created by that agent.

Notice that we have previously performed experiments to test mainly whether the intensity values rated by an artificial agent (with the model of surprise described above) match the ones rated by humans under similar circumstances (see Macedo and Cardoso 2001c). Those experiments were carried out in two domains: the domain of buildings (described in this paper) and in an abstract domain with hedonically neutral events. Best results were achieved with the hedonically neutral domain, in which an average difference of about 6% was obtained between the values given by the humans and by the artificial agent.

In the current experiment, an agent (called *author-agent*) was asked to produce the five most surprising products it could. This request was repeated eight times, each time with a larger episodic memory (see Figure 5), resulting in eight sets of buildings (denoted in Figures 5 and 6 by *A*, *B*, …, *H*), each one with five buildings. This means that the set of buildings *A* was produced using an episodic memory smaller than that used to produce the set of buildings *B*, and so on.

Subsequently, those buildings were provided to a set of fifteen agents (called *jury-agents)*, selected after exploring part of the environment. Since those agents have different ages, they have different knowledge levels, i.e., they have different episodic memories. These memories range from very small memories, with only 5 buildings, to large memories with 229 buildings, following an approximately linear distribution. For each set of objects produced by the *author-agent*, the average of the intensities of surprise elicited in the fifteen *jury-agents* was computed.

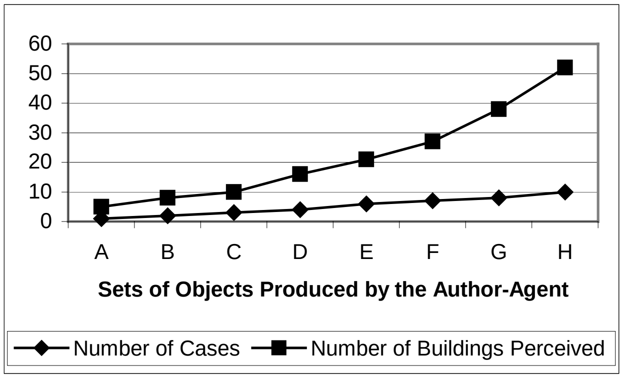

Fig. 5. Number of cases and number of perceived buildings stored in the *author-agent's* memory at each production process.

According to the results of the experiment (Figure 6), we may conclude that, on average, the larger the episodic memory of an *author-agent*, the higher the intensity of surprise elicited in the *jury-agents* by the products it creates. Since we consider surprise as a feature of creative solutions, we may infer that highly creative solutions are more likely achieved when the *author-agent* has a larger episodic memory.

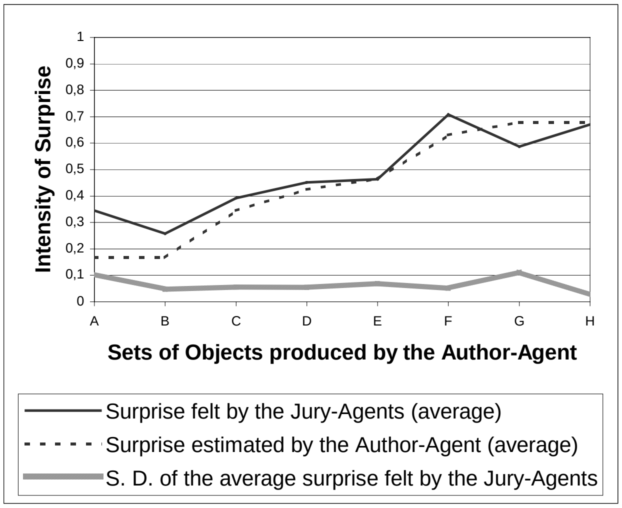

Fig. 6. Results of the experiment.

Discussion and Conclusions

The experiment described above allows us to take some conclusions concerning the influence of the size of an agent's episodic memory in the surprise-value of its creative products. However, there are a few key issues that we would like to discuss.

According to Smyth and McKenna (1999), the performance of a CBR system may be measured according to three criteria: efficiency, i.e., the average problem solving time; competence, i.e., the range of target problems that can be successfully solved; quality, i.e., the average quality of a proposed solution. Large episodic memories usually mean improved target problem coverage (competence) and better solution quality. However, the same cannot be said about efficiency. Actually, in what concerns to quality, as the episodic memory size grows, the typical behavior of a CBR system is characterized by a monotonic increase of solution quality, initially increasing rapidly until a specific episodic memory size (the knee point), after which the quality improvements are relatively insignificants (Smyth and Cunningham 1996). Regarding to competence, the behavior of a CBR system is quite similar. With respect to efficiency, there is an initial increase until a specific episodic memory size (the saturation point), followed by a significant decrease.

In this paper, solution quality is proportional to the degree of surprise it elicits. As indicated to some extent by the above experiment, the larger the episodic memory, the higher the quality of solutions. We may explain this by the fact that as the episodic memory grows there is an increase in the diversity of pieces of cases and therefore much more options when combining them in a new solution. However, we cannot take definite conclusions about this, because in the experiment the episodic memory of the *author-agent* is limited to 52 buildings. Additional experiments are required not only to take more accurate conclusions about this statement, but also to evaluate the influence of the distribution of cases in the episodic memory over the surprise-value of the creative agent's products.

Notice that equal size does not mean equal competence because, for instance, two episodic memories of the same size may have a different number of redundant cases. In the present circumstances, redundant cases may lead to a misleading measure of the frequency of some case-pieces, and consequently to the construction of solutions that the agent may incorrectly classify as surprising. This effect may be particularly significant for low frequency redundant cases. Also, a very high number of options for combination may disperse the focus of the construction process. Therefore, additional experiments are required for studying the influence of the competence degree of the *author-agent*'s episodic memory over the surprise-value of its products. Additionally, we may consider the use of case-base maintenance strategies (e.g.: Smyth and Keane 1995; Leake and Wilson 1998) to improve the efficiency of the process; however, their adequacy to surprise-guided creative systems must be verified.

The results of the experiments described in (Macedo and Cardoso 2001c) suggest that the described computational model is a possible model of surprise. However, alternative surprise functions are conceivable, such as

$$SURP(O) = \ln_2 (1/P(O))$$

as suggested by information theoretic accounts, or

$$SURP(O) = 1 - P(O) \Leftarrow P(O) < .5 \quad ; \; SURP(O) = 0 \Leftarrow P(O) \geq .5$$

as suggested by Rainer Reisenzein. We are currently exploring these and other alternatives.

The same is true for the function of surprise of an entire object. The current function adopts some simplifications that inhibit the distinction between an event such as "window is rectangular" from another event such as "window is missing". In addition, the representation for objects is also simplified, since it doesn't account for features like the sort of the material of the buildings, nor its color. This will be object of future work.

Since the goal is to produce creative solutions, the Utility Function described above should reflect the main properties of creative solutions, giving higher utility values to 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, the current Utility Function (currently depending only on surprise) should be extended to also consider a measure of appropriateness.

Another important issue worth of discussion is the connection between emotions and creativity. From the point of view of the product, the nature of the link between surprise and creativity is different from that of emotions such as fear, anger, joy, etc. and creativity. Whereas surprise is usually considered as a property of a creative product, i.e., almost every creative product causes surprise at least at the first time it is perceived, emotions such as fear, anger, etc., are not necessarily elicited by creative products. For instance, surprise seems to be elicited by both scientific and artistic creative products. In contrast, not all scientific or artistic creative products, and especialy scientific ones, need to elicit anger, fear, joy, etc.

Although the cognitive mechanisms of both creativity and emotions, as well as the nature of their connection, are not very well understood, there is evidence indicating that emotions influence the creative process (Picard 1997). Moreover, experiments performed by Isen and her colleagues (Isen, Daubman and Nowicki 1987; Isen et al. 1985) provided evidence indicating that emotions influence creativity not just in extraordinarily creative people, but also in ordinary folks. Actually, they have shown that positive mood have a significant impact on several aspects of creativity: recognizing relations between features of problems, giving unusual associations, etc. For instance, they asked subjects to respond the Duncker's candle task. In this task, subjects are given one of two situations: (i) a box of thumbtacks, a candle, and a book of matches; (ii) a box, a pile of thumbtacks,, a candle, and a book of matches. In both situations, the subjects were asked to affix the candle to a cork board on the wall in such a way as to keep it from dripping on the floor when it is lighted. The limit of time to find a solution was ten minutes. In the former situation, most subjects cannot find the solution, while in the latter situation most succeed. When subjects were put into a good mood before being presented with the first situation, a significantly higher proportion of them succeeded.

Thus, we are claiming that the creative performance of computers may be improved by providing them models of emotions. This is one of the goals of our ongoing work.

Acknowledgments

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