Introducing Emotions in an Analogy-making Model

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Abstract

Decades of research have shown that emotions are an essential component of human intelligence. However there are few attempts to model the interplay of emotions and other cognitive processes. In this article, we investigate the integration of emotion in a hybrid cognitive architecture on analogy-making. Two computer simulations are conducted to explore the effects of emotion on memory retrieval and analogical mapping. The results are consistent with empirical findings and show that emotions can lead to complex behavior which could be beneficial for the adaptability of an embodied cognitive agent to its environment.

Keywords: analogy-making; emotions; memory; arousal

Introduction

Nowadays there is little doubt that emotions play a crucial role in defining human behavior. A vast number of psychological studies have investigated how emotions relate to various physiological and cognitive functions. They found that experiencing emotions is an essential prerequisite for adaptive behavior. Moreover, contrary to some wide spread misconceptions, emotions constitute a very important component of intelligence. The impact of emotions on our cognitive abilities ranges from memory related processes to higher level reasoning. Some authors even claim that rationality stems from emotions and that an inability to feel emotions inevitably leads to an equal inability to make rational decisions (Damasio, 1994).

Considering the importance of emotions with regard of rational behavior it is no surprise that there are many attempts to model emotions computationally and to involve them in the development of intelligent agents (Breazeal & Brooks, 2005). There are also a few attempts to model the interplay between emotions and other cognitive abilities within integrated cognitive architectures. For example, Cochran, Lee & Chown (2006) explored the impact of arousal on memory using ACT-R and suggested that any general cognitive architecture should integrate emotions to some extent in order to be able to account for a number of psychological findings. We also follow this approach. The goal of this study is present some ideas and simulation results about how emotions can be employed into a cognitive model integrating memory, analogy-making, anticipatory behavior, active vision and action.

AMBR[1] (Kokinov & Petrov, 2001) is a model of analogy-making, based on the cognitive architecture DUAL (Kokinov, 1994). AMBR models analogy as emergent phenomena – it emerges from the local interactions of a large number of micro-agents. Each agent stands for an object, a relation, a property, a concept, a simple proposition, a procedural piece of knowledge. The connectionist's activation of the agent nodes represents their relevance to the current context. There are two special nodes that are the sources of activation – the INPUT and GOAL nodes – which are representations of the environment and the goals, respectively. Activation spreads from these two nodes to other nodes (typically instances of objects and relations from the target scene) then to their respective concepts and further upwards the concept hierarchy, then back to some of the concept instances and prototypes. The concept nodes are organized in a semantic network. Each instance node (representing a concrete token) emits a marker that spreads to the respective concept nodes (representing type) and then upward to the class hierarchy. When a marker from the target situation comes across a marker from a memorized situation, a hypothesis node between the two marker-origins is created. The hypothesis-nodes always connect two other nodes and stand for the inference that the entities represented by them are analogical. The consistent hypotheses support each other, whereas the inconsistent ones compete with each other. Thus, dynamically, a constraint satisfaction network of interconnected hypotheses emerges. After its relaxation, a set of winner-hypotheses, which represent the performed analogy, is formed.

Within the MindRACES project, in line with our belief that analogical reasoning lies in the heart of cognition, we developed an integrated robot architecture based on AMBR (Petkov et al, 2007; Kiryazov et al 2006). It addresses many

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[1] Associative Memory-Based Reasoning

aspects of intelligent behaviour: from visual perception through selective attention through high-level reasoning to physical actualization of the robot goals. The AMBR model is employed as a reasoning core and visual perception is handled by IKAROS (Balkenius & Moren, 2003; Balkenius, Moren & Johanson, 2007). A mediating module - AMBR2Robot - is used to link AMBR to the external world, providing it with perceptual information coming from IKAROS and executing action tasks.

In pursuit of implementing psychologically plausible and efficient robotic behaviour we had to reconsider and extend some of the underlying mechanisms of AMBR. One of the major contributions was to model the effect of emotions on analogy-making in order to make the robot performance susceptible to emotional states in a reasonable way. Before implementing emotions in a real robot we ran two simulation studies to investigate how emotions could be integrated within our cognitive architecture.

Simulations

Two well known cognitive phenomena related to emotions have been selected and modeled using AMBR in order to see whether the model can adequately reflect empirical data.

Simulation 1: Mood and memory

Probably the most extensively studied cognitive aspect of emotions is the relation between emotions and memory. Numerous studies have tried to show whether emotions enhance memory processes (Levine & Pizarro, 2004) As long as AMBR is also a memory model, it must be possible to demonstrate certain effects of emotional states on the process of analogy-making. We chose to model one particular psychological finding, the effect of mood on memory selectivity, usually referred to as 'mood state dependent retrieval'.

The mood state dependent retrieval account suggests that people are more likely to remember memory items which have been coded when in a mood that is congruent with their current emotional state. In an experiment conducted by Teasdale and Fogarty (Teasdale & Fogarty, 1979) subjects were induced to be in a certain mood and were asked to retrieve a real life experience brought to mind by a given stimulus word. The results showed that happy memories were more likely to be retrieved when subjects were induced to be in an elated mood while unhappy memories were more likely to be retrieved when subjects were induced to be in a depressed mood. In addition, the time it took subjects to retrieve a memory was longer if their induced mood and the affective connotations of the experience mismatched.

In order to test whether AMBR is suited to model such behavior we developed a simple simulation. Two memory episodes were manually encoded into AMBR long term memory and one has been used to represent perceptual input (Figure 1).

Episode-1 represents a situation in which the electronic dog AIBO is chasing a cat and feels joy (positive emotion). In Episode-2 a big dog is chasing AIBO and the latter feels scared (fear, negative emotion). In Episode-3 a fox is chasing a hare, AIBO is not participating, but it watches and experiences a combination of positive and negative emotions, enjoying the chase and sympathizing with the hare.

The objects and relations participating in the episodes were described in AMBR semantic memory (Figure 2). All the links in the semantic network were set to 1, except for the ISA links pointing to the abstract concepts 'Feeling' and 'Animal', which were set to 0. Each episode contained an instance of one of the four emotional states depicted in Figure 2. The emotional state was represented as a separate node connected by associative links to all the other nodes comprising the episode.

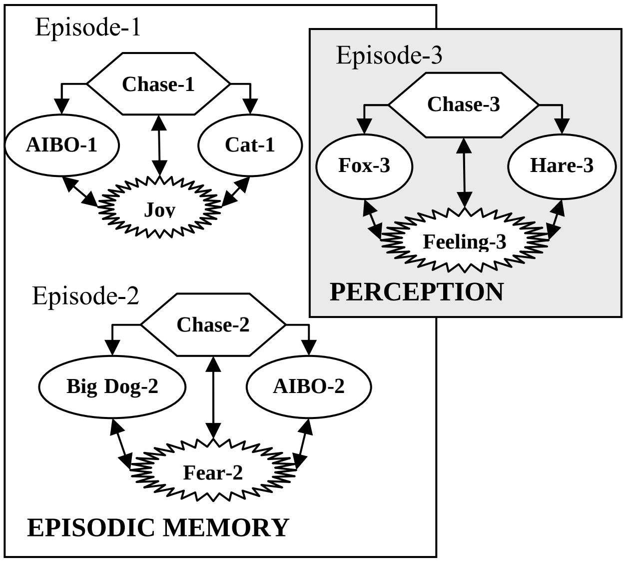

Figure 1: AMBR episodic memory in Simulation 1.

We wanted to show that if Episode-3 was used as a target situation, it would be mapped to either Episode-1 or Episode-2, depending on which of the emotions in the target situation dominated. To do that, Episode-3 was set as a target for the simulation and links from the 'Feeling-3' node to the 'Negative Emotion' and 'Positive Emotion' concept nodes were systematically manipulated to model how strong the positive (enjoyment of the chase) and negative (sympathizing with the prey) emotions were. In all the cases when one of the links to 'Negative Emotion' or 'Positive Emotion' concepts was stronger a mapping to the corresponding episode was formed.

To put it otherwise, whenever the sympathy to the prey dominated, the target situation was mapped to Episode-2 and the following object-to-object mappings were formed:

Fox-3 ↔ Big Dog-2
Hare-3 ↔ AIBO-2

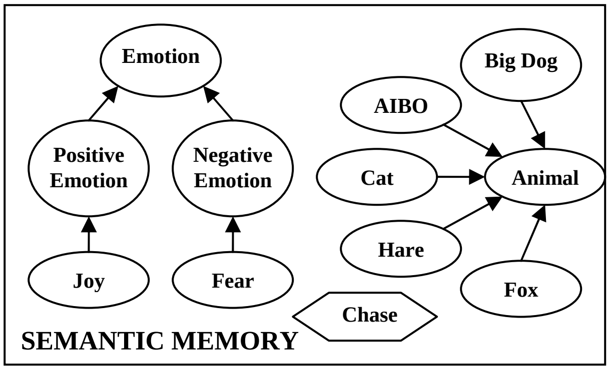

Figure 2: AMBR semantic memory in Simulation 1

On the contrary, when the positive emotion dominated, the mappings were:

Fox-3 ↔ AIBO-1
Hare-3 ↔ Cat-1

The results of the simulation show that emotional states can be used to enhance the retrieval and subsequent mapping of a relevant memory episode. We also investigated how strong the effect can be by measuring how much time (in terms of AMBR internal computation steps) was needed to establish a mapping, depending on the distinctness of the emotion encoded in the target episode. The emotional distinctness was modeled by varying the weight of the link of the 'feeling-3' node to the 'Negative Emotion' concept node. We did not model changing the distinctness of the positive emotion as this case was symmetric to the 'negative' one. Figure 3 shows the results of this simulation:

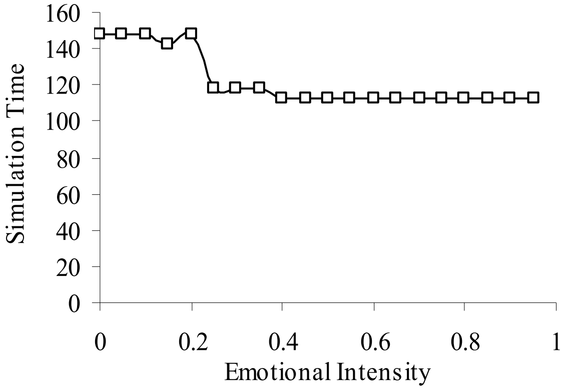

Figure 3: Simulation time, measured in AMBR computational time units, as a function emotional intensity.

It is observable from Figure 3 that the stronger the link to the emotional concept is, the faster the corresponding episode is retrieved and mapped. This result can be interpreted as evidence that the model is sensitive not only to the type of emotion being experienced, but also to its intensity and that it is consistent with the above mentioned findings by Teasdale et al.

Simulation 2: Arousal and analogy-making

In a series of software and robotic simulations (Petkov et al, 2006; Petkov et al, 2007; Kiryazov et al 2006) we used AMBR to guide the behavior of an AIBO robot. We showed that a variety of task can be solved by making analogies to pieces of past experience. However there is one particular problem with this approach that has been scarcely addressed so far. Analogy-making is a sophisticated and resource demanding process which sometimes takes a lot of time to complete. There are situations when immediate action is more important than a sophisticated solution. In such a case we would like our intelligent agent to make a decision in the quickest way, even if it is not the best one. One way to solve this problem is to introduce the notion of arousal in the model.

The effect of arousal on physical and cognitive performance has been known for years. Generally, it has been suggested that the relationship between arousal and performance resembles an inverted 'U' curve (Figure 4). That means that increasing the level of arousal up to a certain point enhances performance but beyond it performance deteriorates (Yerkes & Dodson, 1908). In order to model the effect of arousal on performance we developed a simulation in which arousal is caused by fear.

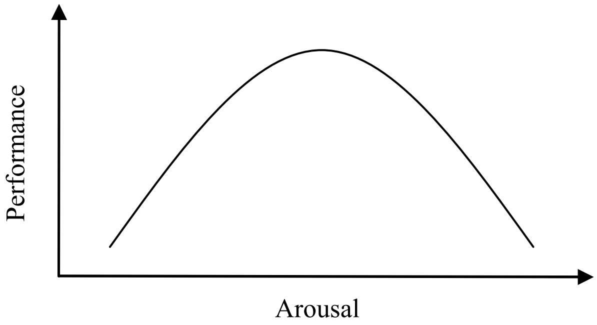

Figure 4: Dependence of performance on arousal

Imagine the following scenario. The intelligent agent – AIBO – is staying in a room with an open door and a closed window. Suddenly a danger appears – a big and nasty dog that AIBO is afraid of. AIBO manages to escape by running through the open door. The whole episode is remembered. Figure 5 depicts its representation in the long term memory of AMBR.

In the second episode AIBO is again in a room, but this time the window is open and the door is closed. The same danger pops out and AIBO has to escape. The situation is identical to the previous one, but this time AIBO is supposed to get out by the window and not the door. In order to make this decision AIBO has to make an analogy between the two situations, map the open door in the first episode to the open window in the second one and transfer the run-to relation (action) with the appropriate arguments. In this case the analogy that has to be made is not straight forward, because there is cross-mapping (Gentner & Toupin, 1986) – on the one hand it is naturally to map door to door and window to window, but on the other hand, single argument relations 'closed' and 'open' force their corresponding arguments to be mapped as well. In such a case AMBR will produce the structurally consistent mapping – it will map the relations and their corresponding arguments consistently: 'open-1' to 'open-2', 'closed-1' to 'closed-2', 'door-1' to 'window-2', 'window-1' to 'door-2'.

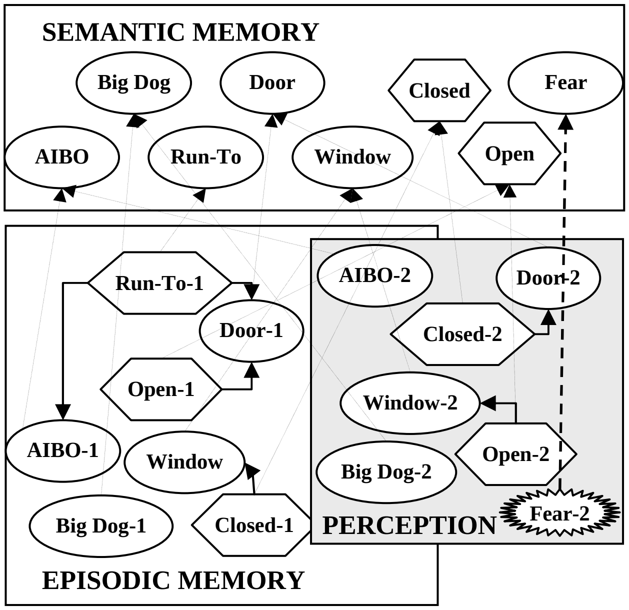

Figure 5: Episodic and semantic memory in Simulation 2

Although the situation is fairly simple, it will take AMBR significant time to resolve the cross-mapping. In real life, in face of an immediate danger, it is not acceptable to spend much time ruminating what to do. When a real animal is facing a danger, it starts to feel fear, which increases the level of arousal and forces it to act – the 'flight or fight' phenomenon. That is why we decided to relate the level of arousal, invoked by fear, to some internal parameter of the model, which will let it complete its work faster, though possibly not in the most precise way. A natural choice of such a parameter is the rating frequency.

The rating mechanism of AMBR is responsible for determining the winning hypothesis. It is invoked locally at each hypothesis at certain intervals (timed in AMBR time units). Each time the rating mechanism is invoked at a hypothesis it compares its activation to activations of the rival hypothesis and increases or decreases its rank. The hypothesis 'wins' when it reaches a certain rank and manages to keep it for a predefined amount of time. In general the rating mechanism corresponds to the constraint satisfaction going on in the hypothesis network, but unlike the latter it is locally defined. Under standard configuration, the rating mechanism makes all the hypotheses win approximately at the time when the constraint satisfaction network settles down. However by increasing the frequency of the rating mechanism, so that hypotheses ranks are evaluated more often than under the standard configuration, we can make the rating mechanism get ahead of the constraint satisfaction and come up with a solution before the constraint satisfaction network is settled down. The result of such a speeding up of the rating mechanism is that some deep structural constraints may not be taken into account. For example, in the case of cross-mapping, increasing the rating frequency will cause the superficial similarity mappings to win.

Relating the level of arousal to the rating frequency parameter may seem arbitrary, but there is some theoretical justification for it. Revelle and Loftus (Revelle & Loftus, 1992) have suggested that the effects of arousal on memory can be explained in terms of a 'tick rate hypothesis', according to which arousal increases the rate at which the environment is sampled. We believe that the metaphor of arousal as clock speed of a computer is meaningful when trying to explain the effect of arousal on other cognitive functions, such as analogy-making.

The effect of arousal was modeled by making the rating frequency dependent on the activation of the concept of fear by the following equation:

$$Rtp = Rtp_0 - 2Fear_{act}$$

where:

Rtp : The rating frequency parameter which determines how often the rating mechanism is invoked (measured in AMBR time units).

Rtp_0 : The value of the rating frequency parameter in the standard configuration;

$Fear_{act}$: The activation of the 'Fear' concept.

Then we encoded in the second episode an instance of 'Fear' and connected it to the AMBR input node. Finally we manipulated the ISA link of 'Fear-3' to the concept of 'Fear' (the dotted line on Figure 5) to model different levels of arousal and measured the time AMBR needed to come up a solution. A solution in this particular simulation was considered a transfer of the 'run-to' relation from the base to the target situation. The transfer of a relation is committed when its arguments are mapped and have won (the hypotheses of the argument mappings have won). Apart from writing down the time when the 'run-to' relation was transferred, we also recorded the arguments of the relation, which indicated whether AMBR instructs AIBO to run to the door or to the window. The results of the simulation are show in Figure 6.

The results clearly demonstrate that AMBR became sensitive to experiencing fear. Increasing the intensity of the emotion leads to a distinctive tendency to come up with a solution faster. Moreover, there is a critical moment when the high level of arousal causes the model to disregard the structural constraints and pay attention to the superficial similarity only, thus invoking a wrong action. These results are consistent with the U-shape hypothesis as long as they show that increasing arousal leads to better performance, but there is limit beyond which the effect is negative. The model predicts that in the case of a cross mapping situation there will be a sudden from jump from making the structurally consistent mapping to the superficial one, depending on the level of arousal.

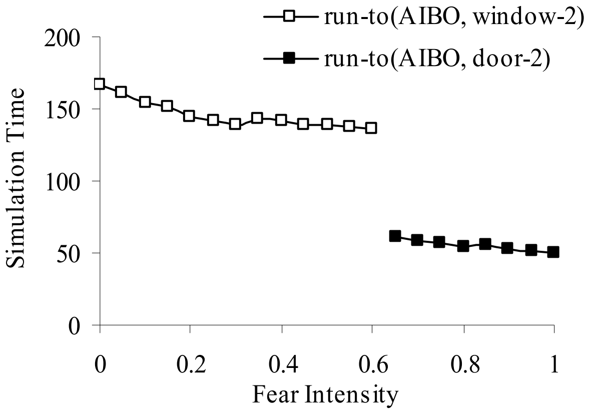

Figure 6: Mapping results and simulation time as a function of fear intensity. The second argument of the run-to relation show whether AMBR decided that AIBO should escape by the window or by the door.

There have been other attempts to investigate the relation between emotional intensity and solving a cross-mapping analogy task. Tohill and Holyoak (Tohil & Holoyak, 2000) conducted two psychological experiments, in which subjects were asked to make analogies involving cross-mapping under varying level of induced anxiety. Our simulation results are consistent with their empirical results – higher levels of arousal or anxiety lead to preferring the superficial similarity solution.

Implementation in a real robot

In the simulations described above the emotional type and intensity were manually encoded into the system. In order to have the robot acting in a real environment we needed mechanisms that automatically generate emotions in a psychologically plausible way. For that purpose integration with the FAtiMA emotional agent architecture (see Dias & Paiva, 2005) has been considered. FatiMA generates emotions from a subjective appraisal of events and is based on the OCC cognitive theory of emotions (Ortony, Clore & Collins, 1988). In the present work we use only part of the model related to reactive appraisal and coping.

During the appraisal process a model of an emotional state based on evaluation of the current environment state should be generated (see Figure 7). The robot perceives the environment though its sensors and the information is sent to the reactive appraisal module. The latter generates the base potential of various emotions. If the base potential is larger than a threshold specific for the given emotion type, then the emotion is added to the emotional state. Emotional state can hold from one to several emotions of different types. The hierarchy of emotions is based on the OCC structure and it is also presented in the AMBR's semantic web as described above. Different emotions can vary in intensity which doesn't stay constant through the life cycle of the robot but rather decays over time.

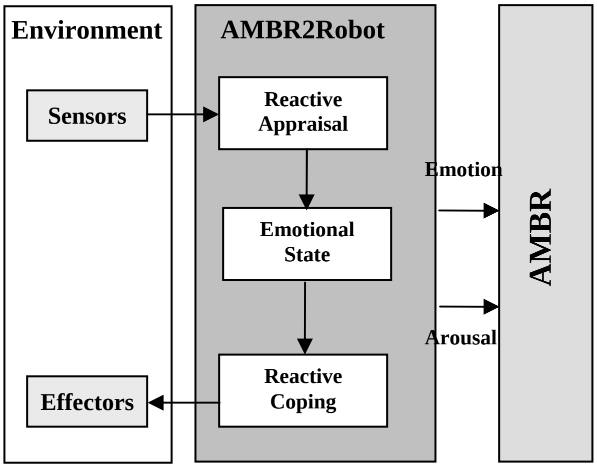

Figure 7: Implementation of emotion mechanisms in a real robot.

Arousal and mood are also included separately in the model (as in FatiMA). Arousal will increase when a high intensity emotion appears. At the same time, the agent will experience a higher intensity emotion if it is excited for some reason. The level of arousal will decay in time as well as the emotional intensity if nothing happens. That corresponds to the situation of the system calming down in the absence of external stimuli.

When the system is in a bad mood it will be more susceptible to negative emotions. This means that the base potential of emotions like fear, anger, etc. will be increased. On the other side emotion can also influence mood. Depending on the proportion and intensity of negative emotions in the emotional state the mood variable will decrease its value.

Next, the emotional state is reported to AMBR in order to be encoded as part of the episode perceived. The emotion node will be attached to the INPUT node of AMBR with a weight corresponding to the emotion intensity. On the other hand, the level of arousal is made available to AMBR in order to change the frequency of the rating mechanism.

The reactive coping module uses the emotional state to trigger appropriate action using the robot effectors. This includes the rapidly performed actions, dependent on the current emotional state, when a system has to react quickly to an event. For example, when frightened, the dog can lower its body and start waving its tail. This type of bahaviour occurs together with the high level actions based on the decision making processes in AMBR (not shown in Figure 7 in order to keep it clearer).

The integrated model described above is not tested yet in real robot settings. Sufficiently complex scenarios, based on the simulations presented in the article, are being currently developed in order to explore the advantages of the emotional mechanisms implemented. Additionally, the perception abilities of the model should be enhanced to handle the more complex objects and relations between them.

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Conclusion

This study is the first step in our attempts to build emotional cognitive robots, whose reasoning abilities are based on analogy-making. Based on simulations, two ways of incorporating emotions into the AMBR model have been investigated and found to be interesting and useful. These results open the door to implementing emotional sensitive behavior in embodied hybrid cognitive architectures.

The simulation results reported are relevant to any cognitive model based on activation spreading mechanisms and hybrid encoding of knowledge. Other models of analogy-making that have similar assumptions about the nature of analogy could exploit them as well. In particular, the idea that the effect of arousal on analogy-making, or any other reasoning process, is actuated in undertaking an action before a constraint satisfaction network has fully settled down can be applied in any relevant model that relies on constraint satisfaction or any other relaxation mechanism.

The emotional mechanisms explored in this study will be further developed and exploited in the design of a conversational agent based on the DUAL architecture. This agent is supposed to communicate with a user and help her find information in Internet. The emotional capabilities will augment considerably the adaptation capabilities of the agent and its believable behaviour with respect to its interaction with the user.

Acknowledgments

We would like to express our gratitude Ana Pavia and Joao Dias from Instituto Superior Tecnico (Lisbon) for the fruitful discussions and advises in using the FatiMA model.

This research was supported financially by the projects ANALOGY (NEST program, contract 29088) and RASCALLI (IST program, contract 27596), funded by the EC.

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