Cognitive Modulation of Appraisal Variables in the Emotion Process of Autonomous Agents

Sergio Castellanos, Luis-Felipe Rodríguez, and Luis A. Castro
Department of Computer and Design
Instituto Tecnológico de Sonora
Email: sergio.castellanos@hotmail.com, luis.rodriguez@itson.edu.mx, luis.castro@acm.org

Joaquín Pérez
Aragón Institute of Engineering Research (I3A)
Department of Computer Science and Systems Engineering (DIIS)
University of Zaragoza, Spain
Email:jpmarco@unizar.es

***Abstract*—In this paper, we present a scheme for modulating the results of evaluating emotional stimuli using appraisal dimensions. The level of modulation depends on cognitive information projected from components of a cognitive agent architecture. In particular, the proposed scheme models the influence of cognition on appraisal dimensions by modifying the limits of fuzzy membership functions associated to each appraisal dimensions in real time. The computational scheme proposed is designed in the context of an Integrative Framework designed to facilitate, through input and output interfaces, the development of computational models of emotion capable of interacting with cognitive components implemented in a given cognitive agent architecture. We also describe a possible scenario to show the functionality of the proposed scheme. This scheme is aimed at modeling in autonomous agents the interaction that occurs between cognitive and affective processes in humans.**

I. Introduction

Autonomous Agents (AAs) are software entities that carry out operations on behalf of users or other programs with certain degree of independence and autonomy. In doing so, AAs make use of knowledge about the environment and representations of desires and goals [1]. This type of intelligent system has been crucial for the advance of fields such as software engineering, human-computer interaction and artificial intelligence. In these fields, AAs have been designed to carry out tasks that require the imitation of human cognitive functions, including decision making, planning, and reasoning [2]–[4]. Moreover, evidence shows that emotions influence cognitive functions [5], [6]. The emotional significance of perceived stimuli influences the normal operation of processes such as attention, perception, and decision making. According to fields such as psychology and neuroscience, emotions result from the interaction of several cognitive and affective processes, including memory, perception, motivations, and attention [7]–[9].

A key objective of artificial intelligence is the development of software systems capable of doing complex tasks that produce intelligent responses, systems that act and reason similar to humans. In this context, the literature reports an increasing interest in the development of AAs with abilities to evaluate and respond to emotional stimuli [10]–[14]. Recent works have proposed the incorporation of affective processing in AAs by designing Computational Models of emotions (CMEs), which are software systems designed to synthesize the mechanisms of the human emotion process [15], [16]. These CMEs are designed to be included in cognitive agent architectures in order to provide AAs with mechanisms for the processing of affective information, generation of synthetic emotions, and generation of emotional behaviors.

However, despite of the importance of the relationship between cognitive and affective processes in humans, such interaction is not usually taken into account in the design of cognitive agent architectures [17] (Figure 1 shows an example of the types of components included in a representative cognitive agent architecture). Moreover, although the literature reports a variety of CMEs, most of them do not take into account the influence on the emotion function of aspects such as personality, culture, past experiences, social context, and physical context, among others, which are processes that may be implemented in cognitive agent architectures and which influence human emotions [14], [18]. In this context, although findings in psychology and neuroscience indicate that (1) the evaluation of emotional stimuli is influenced by the results of various cognitive functions and that (2) elicited emotions modulate cognitive processes (e.g., attention, perception, and decision-making), there are several challenges to be addressed in order to modeling in cognitive agent architectures this extensive interaction between mechanisms associated with cognitive and emotional functions.

The following are some of such challenges and issues involved in the modeling of interaction between cognition and emotion in cognitive agent architectures:

- A cognitive agent architecture may include a *variable number* of cognitive components.
- Each cognitive component in a cognitive agent architecture projects *very particular information* using different structure and formatting.
- The information provided by cognitive components *changes frequently* depending on the type of cognitive function these components implement. For example, the physical context changes very frequently but information regarding the agent's culture and personality change very slowly.

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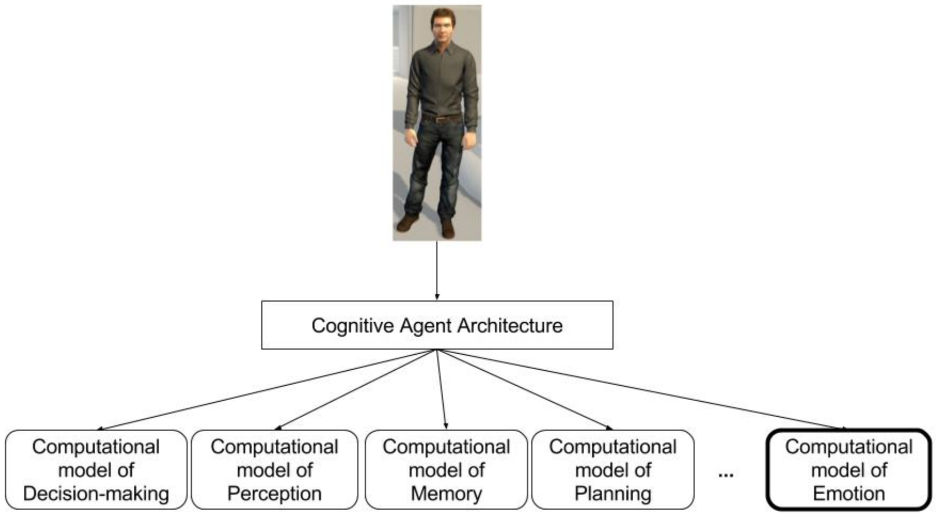

Fig. 1. A representative cognitive agent architecture

- The emotion component must *weight differently* the influence of each cognitive process on the emotion process.

In this paper, we present a computational scheme designed to model the influence of cognitive information on the emotional evaluation process in autonomous agents. The level of influence on such evaluation process depends on the cognitive information projected from components of a cognitive agent architecture. The evaluation process in a CME is responsible of assessing from an emotional perspective the stimuli perceived by an agent. The evaluation process is a crucial phase of the operating cycle of CMEs since the consistency of the results of other phases (e.g., emotion and behavior generation) depend on the consistency of such emotional assessment. In turn, the consistency of the evaluation process in a CME depends on the cognitive information taken into account. In particular, the computational scheme is designed in the context of the *Integrative Framework* proposed by Rodriguez et al. [17] (see Section III and [17] for further details), which is a framework designed to facilitate, through input and output interfaces, the development of CMEs capable of interacting with cognitive components implemented in a given cognitive agent architecture and which are involved in the emotion process (e.g., personality, culture, perception, motivations, and attention). Importantly, the proposed computational scheme is designed to promote the modeling of the interaction between cognitive and affective processes in autonomous agents, as occurs in humans.

II. Related Work

The literature reports a variety of CMEs designed to be included in agent architectures. These computational models take into account diverse cognitive information in their evaluation phase. In this section, we analyze some influential CMEs in order to understand the role of cognitive information in their evaluation process. In particular, we provide a detailed description of the role of Motivations and Internal Drives in Kismet [19] and the role of personality in Mamid [20], which are two CMEs that have proven useful in several application domains. Moreover, in Table I we present a summary of the role of cognitive functions in the emotion process of some CMEs reported in the literature.

TABLE I
Cognitive processes involved in the emotion process in some CMEs.

Model	**Cognitive Processes**
EMA [21]	Provides support for cognitive, perceptual, and motor operators. However, the model does not implement such processes directly
Kismet [19]	Perception and attention processes, learning mechanisms, behavior and expressive systems, and motor functions
Flame [13]	Decision-making process, memory and experiential systems, and learning and adaptability processes
Mamid [20]	Perceptual and attentional processes, memory systems, expectation and goal managers, and decision-making processes
Alma [14]	Dialog generation processes, decision-making and motivation functions, and behavior and expression generation systems
Cathexis [22]	Perceptual processes, memory systems, behavior systems, and motor processes
PEACTIDM [23]	Perceiving, Encoding, Attending, Comprehending, Tasking, Intending, Decoding, and Motor functions
WASABI [24]	Perception and reasoning processes, memory systems, and processes for the generation of expressions and voluntary and non-voluntary behaviors

Motivations and Internal Drives. Motivations refer to an internal phenomenon that results from the interpretation of the agent's internal and external condition [19], [25]. They regulate the agent's behavior in order to attain a certain state of affairs. Particular instances of motivations are drives, a factor that is often considered as participating in the processing of emotions in CMEs. In Kismet [19], a social robot designed to learn from humans by interacting with them, a motivational system is designed to carry out the processing of *drives* and its influence on *emotions*. The drives implemented in Kismet

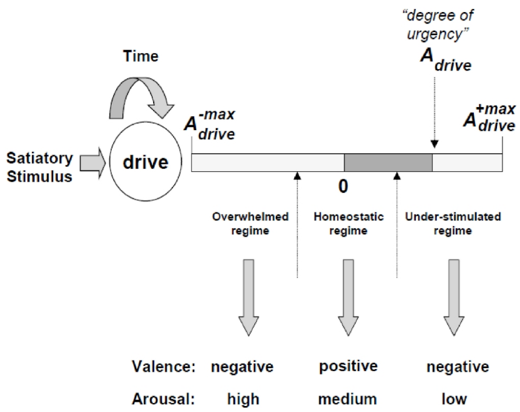

Fig. 2. The model of internal drives in Kismet [19].

are *social drive*, *stimulation drive*, and *fatigue drive*. They represent the robot's basic needs and always have an intensity level associated. The levels of intensity tend to increase in the absence of stimuli, and decrease when appropriate stimuli are being perceived. Furthermore, there is a bounded range called the "homeostatic regime," which establishes a desirable status for each drive as shown in figure 2. When the intensity of a particular drive is out of this range, the drive is into one of the following two states: under-stimulated (increased intensity) or overwhelmed (decreased intensity) [26]. In Kismet, drives influence the dynamics of emotions by contributing to their level of valence and arousal. As shown in figure 2, when the intensity of a drive is within the overwhelmed regime, the valence of emotions becomes negative and their arousal high; when the drive is within the homeostatic regime, the valence is positive and arousal medium; and when the drive is within the under-stimulated regime, the valence is negative and the arousal low [19]. In this manner, the intensity of emotions in Kismet depends on the status of its drives.

Personality. This term is seen in the domain of CMEs as the set of individual traits in which people differ from each other [27], [28]. These traits are considered consistent patterns of behavior that provide support to individual differences. In MAMID [20], a model that includes a methodology for modeling the effects of individual differences in cognitive-affective architectures, personality traits influence the agent's cognition and behavior. The personality traits modeled are *extraversion*, *introversion*, *aggressiveness*, and *conscientiousness*. They combine to form personality profiles which are characterized in terms of parameters that control the processing (e.g., speed), structure (e.g., long term memories), and content (e.g., beliefs) of architectural components. In particular, in the *affect appraiser* module, responsible for deriving the agent's affective state, personality contributes to the elicitation of emotions. For example, high neuroticism and low extraversion makes the agent susceptible to negative valenced emotions as well as negative and anxiety affect.

As seen in table Table I and the analyzed models, cognitive information play a key role in the emotion process. In particular, cognitive functions are highly involved in the process of evaluating stimuli from an emotional perspective in CMEs. Nevertheless, the complexity of such evaluation process has led to the design of CMEs whose architecture takes into account very specific types of cognitive information projected from components of a cognitive agent architecture. For example, Kismet [19] takes into account only Motivations and Internal Drives whereas Mamid [20] considers the influence of personality on the evaluation process. In this sense, most CMEs are not designed to take into account other type of cognitive information that may be available in a given cognitive agent architecture. This type of computational model is usually developed to work on very specific applications. In contrast, the complexity of the emotion process in humans involves an extensive interaction between cognitive and emotional components. The consistency of the emotional evaluation process in CMEs depends on projections from several cognitive processes. Therefore, CMEs should be designed considering that the more cognitive information taken into account in the emotion process, the more consistency and accuracy in the agent's affective states and emotional behaviors.

III. INTEGRATIVE FRAMEWORK

The *Integrative Framework* (InFra) proposed by Rodriguez et al. [17] follows the idea that instead of developing a CME that tries to unify cognitive and affective information in order to generate consistent emotional signals that allow AAs to implement believable behaviors, we can approach this problem by creating a framework that enable the development of CMEs whose architectures provide a convenient environment for the unification of cognitive and affective information. A basic assumption in the design of such InFra is that CMEs should comprise in their design only those mechanisms related to affective processing, leaving aside other mechanisms associated with cognitive processes and psychological constructs such as perception, action selection, motor action, culture, and personality. The design of the InFra considers that these latter processes are fundamental elements of cognitive agent architectures and that therefore these should be implemented there (see Figure 1). Nevertheless, this assumption does not mean that the internal processing and appropriate behaviors of CMEs are independent of those cognitive processes and psychological constructs. Instead, what the InFra suggest is that the design of a CME should be focused on two major aspects: (1) the modeling of mechanisms underlying affective processes such as emotions and mood states, and (2) the incorporation of input and output interfaces that facilitate the exchange of data between affective processes implemented in CMEs and cognitive processes implemented in agent architectures (see figure 3).

Based on this assumption, two main characteristics were considered for the InFra's design:

1) The framework should enable CMEs to take as input all information available from agent architectures in order to accurately evaluate the emotional stimuli perceived

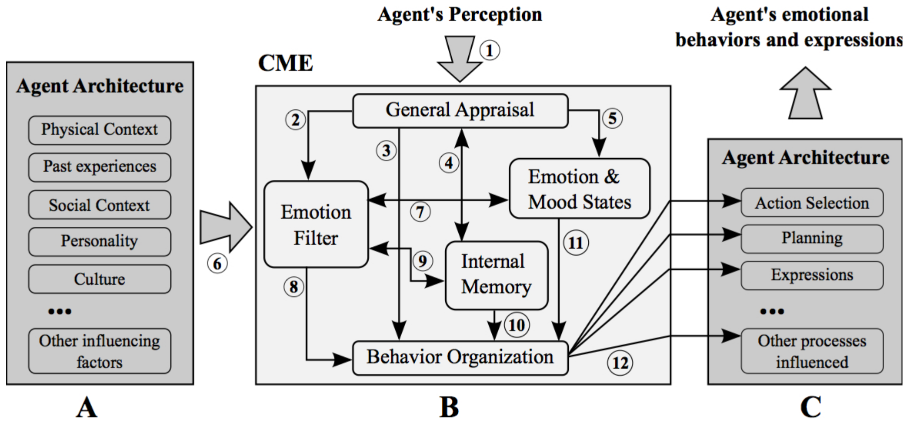

Fig. 3. Design of the integrative framework. It shows the relationships of a CME (part 'B') with cognitive agent architectures (part 'A' and 'C'). Note that numbers on the arrows are only for explanation purposes within the text, these do not explain the temporal relationships between the model's data flows.

by an agent and to generate more consistent emotional states and emotional behaviors.

2) The framework should enable CMEs to deliver appropriate emotional signals to those components in a cognitive agent architecture that are involved in the control of the agent's behaviors and expressions in order to exert an emotional bias.

In this context, among the requirements underlying the InFra's design, there are three related to this assumption, which recognize the need for more integrative designs in CMEs that facilitate the interactions between cognitive and emotional processes in cognitive agent architectures:

1) **Adaptable input interface**: the model should incorporate an input interface to handle all data that a cognitive agent architecture can communicate to contribute to the proper functioning of the CME.
2) **Reasoning with variable information**: the system should be able to reasoning about available information to generate coherent emotional signals. This information information is received from the CME and components of a cognitive agent architecture.
3) **Compatible output signals**: the model should be able to deliver appropriate emotional signals to all components of a cognitive agent architecture that are involved in the control of the agent's emotional behavior.

In this paper, the proposed computational scheme is designed to address the first and second requirement: *Adaptable input interface* and *Reasoning with variable information*. In the InFra, these requirements involve the components of the called *indirect route* (see Figure 3). This *indirect route* starts in the *General Appraisal* (GA) module, goes through the *Emotion Filter* (EF) module, and ends in the *Behavior Organization* (BO) module.

In general, this indirect route comprises processes that allow a CME to assign accurate emotional values (according to the agent's current internal and external condition) to the stimuli perceived by the agent and enable the agent to appropriately deal with social and emotional situations. In particular, there are two assessment phases in this route, one taking place in the GA and the other in the EF component. The main purpose of the evaluations performed by the GA is to determine the *inherent emotional significance* of incoming stimuli. The EF component conducts a second assessment of perceived stimuli. The main purpose of this evaluation is to re-appraise the initial emotional significance assigned by the GA. This evaluation process takes into account more information than that stored in the IM component (which provides the emotional significance of stimuli previously perceived and acquired by experience). Particularly, the operating cycle implemented by the EF is influenced by cognitive signals received from components in the agent architecture that are mainly involved in determining the agent's internal condition and interpreting its external environment (these signals are supposed to be crucial for the processing of emotional stimuli in humans). For instance, these components may handle information underlying the processing of the following cognitive functions and psychological constructs:

- the agent's culture,
- the agent's motivations,
- the agent's personality,
- the agent's social norms,
- the agent's beliefs,
- the agent's goals and desires,
- the agent's physiological signals,
- the agent's expectations,
- the agent's past experiences,
- the agent's physical context,
- the agent's social context, and
- the agent's current situation.

As mentioned above, the presented computational scheme is focused on addressing the first and second requirement of the InFra (*Adaptable input interface* and *Reasoning with variable information*), leaving aside any other process involved in the operating cycle and architecture of the InFra. In particular, the computational scheme is designed to provide mechanisms for the cognitive modulation of appraisal variables used in the emotion evaluation process of autonomous agents.

IV. Scheme for Modulating Appraisal Variables

As shown above, most CMEs have been designed to resolve a particular problem or application, reducing the complexity of modeling the human emotion process to an implementation of specific mechanisms according to specific design goals. A novel approach promotes the development of CMEs whose architecture integrates cognitive information in the emotion evaluation process. This involves designing scalable CMEs capable of taking into account information projected from cognitive components of agent architectures even when a CME was not initially designed to consider a particular type of cognitive information. In this section, we present a computational scheme designed to provide mechanisms for the cognitive modulation of appraisal variables used in the emotion evaluation process of autonomous agents.

As mentioned above, the proposed computational scheme addresses some of the design requirements of the integrative framework proposed by Rodriguez et al. [17]. In particular, in the InFra the evaluation of emotional stimuli takes place in the EF component (see Figure 3). This process of evaluating stimuli from an emotional perspective is based on the *Appraisal Theory*, a psychological theory that explains the elicitation of emotions on the basis of the relationship between individuals and their environment [29], [30]. This evaluation of the *individual-environment relationship* is carried out using a series of appraisal dimensions such as *pleasantness*, *goal-conduciveness*, *suddenness*, and *controllability*. In this context, in the proposed model emotions are characterized in terms of a set of values corresponding to appraisal dimensions. Moreover, cognitive components of agent architectures are assumed to send information that should be considered when evaluating such appraisal dimensions. In this sense, it is necessary to define a scheme to determine the level of influence of cognitive information on each appraisal dimension as shown in Figure 4. A computational schema to modeling the influence of cognition on appraisal dimensions, which characterize emotions, involves two main challenges: 1) considering that cognitive components vary in terms of relevance in the emotion process, it is necessary to define the particular influence that a cognitive function exerts on each appraisal dimension, and 2) the mapping of the information projected from cognitive components should be translated into dimensional values that characterize an emotional state and which are integrated into the evaluation process.

The proposed schema assumes that the GA module in the InFra assigns an initial value to each appraisal dimension according to the stimuli perceived by the agent. The modulation of these values is then determined according to what theories and models explain about the influence of cognition on the emotion process in humans. Although these theories and models are still scarce and limited, this information helps to define tendencies on the relationship between particular cognitive functions and appraisal dimensions. For example, in [31] a study concludes that individuals' culture (characterized

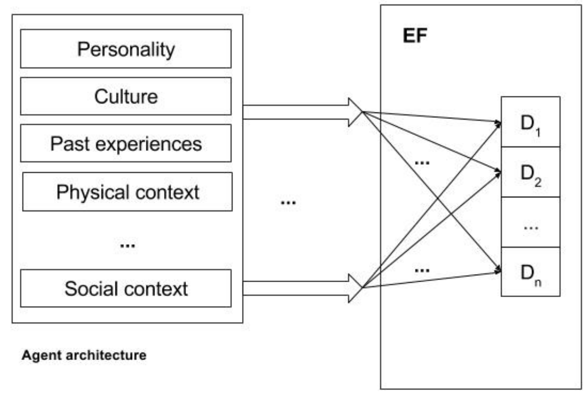

Fig. 4. Influence of cognitive components in agent architectures on appraisal dimensions.

as collectivist and individualist) influence the situation assessment. The study indicates that in collectivist individuals occurs a more intense assessment of negative situations (based on the goals and objectives of the individual) but a more tenuous assessment of positive situations. Considering this type of evidence from human studies, in the proposed schema logical relationships are defined to model the influence of cognitive information and psychological constructs (e.g., personality and culture) on appraisal dimensions. Moreover, the scheme takes advantage of similarities among some aspects of cognitive components in order to classify cognitive information and thus manage specific types of influence on appraisal dimensions.

An aspect of interest for the modeling of the influence of cognition on the evaluation process in CMEs has to do with the temporality of cognitive components. For example, components such as those modeling personality barely change over time. In contrast, components in charge of assessing the agent's social context change very frequently. In this case, both components influence the emotional evaluation of situations perceived by the agent and particularly both components may influence the evaluation of appraisal dimensions such as *suddenness*. This type of similarity suggests a grouping of cognitive components included in cognitive agent architectures. In particular, in the proposed computational scheme cognitive components are divided into two groups according to their temporality (see Figure 5): components that change slowly over time (e.g., personality and culture) and components that change very frequently (e.g., the agent's physical and social context). In this manner, regardless the number and type of cognitive components in agent architectures, they are included in one of these two classes according to their characteristics. In turn, each group will exert a consolidated cognitive influence in the appraisal dimensions underlying the emotion evaluation process.

The model associates a fuzzy membership function to each appraisal dimension so that the values generated by the GA component of the InFra are analyzed in terms of such membership functions. In this way, the influence of cognitive components (grouped in the two mentioned categories) is

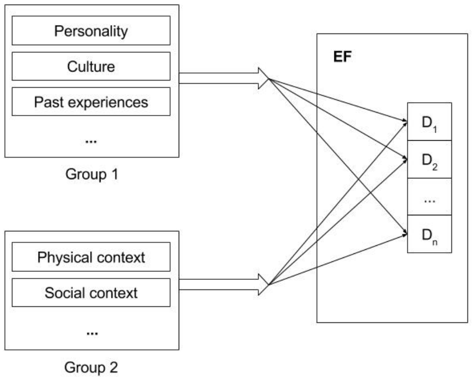

Fig. 5. Grouping of components.

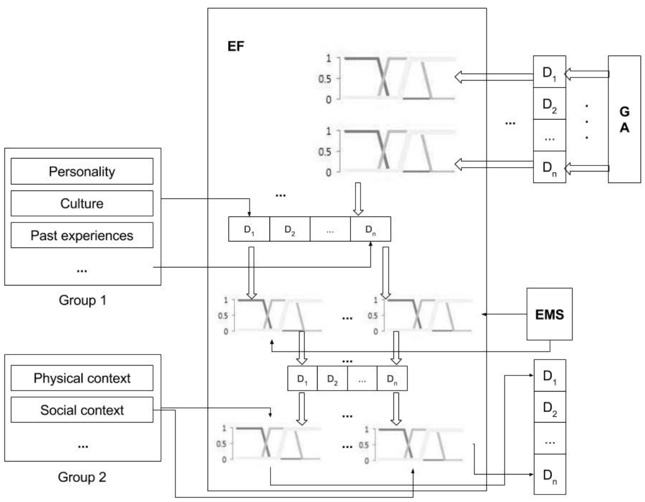

Fig. 6. Model of appraisal dimensions modulation.

represented by the alteration of the limits of membership functions. Figure 6 shows this computational scheme for the cognitive modulation of appraisal dimensions. The modulation in the evaluation process occurs as follows:

1) The General Appraisal (GA) component calculates an initial value to each appraisal dimension based on the event perceived by the agent and the internal mechanisms of the InFra.
2) These initial values are then fuzzified using the membership functions defined for each appraisal dimension. Initially, the limits of these membership functions are predefined.
3) Each component in the agent architecture that conform the first group of cognitive information (i.e., components that change slowly) is analyzed in terms of the structure and format of the information it sends. For example, the component of personality will send a type of personality such as neuroticism or extraversion. Information provided by all components of the group are consolidated and sent to the modulation component (i.e., the EF component in the InFra).

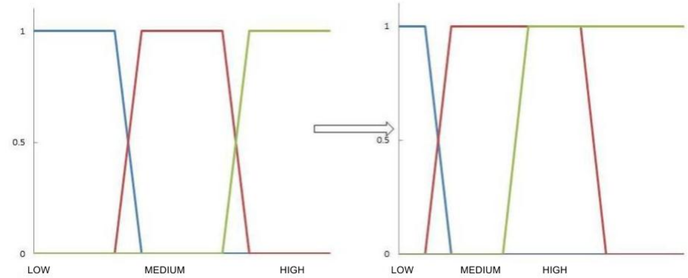

Fig. 7. A possible effect of the agent's personality on the membership functions associated to the relevance dimension.

4) The modulation component modulates the limits of the membership functions for each appraisal dimension according to the received information. Afterwards, this component analyze the initial values assigned by the GA to each appraisal dimension but considering the adjusted membership functions.
5) The third and fourth steps are repeated in order to consider the influence of cognitive information of the second group (i.e., components that change very frequently).
6) Finally, the modified values of each appraisal dimension are sent as the output to other components in the CME.

As mentioned above, the cognitive modulation on appraisal dimensions is reduced to the influence of two types of cognitive components (organized in two groups). However, there are still two key challenges: 1) the integration of individual outputs of cognitive components so that these are represented by a consolidated value that influences appraisal dimensions, and 2) the structure and format of the output information of each cognitive component. The first challenge may be addressed by performing the summation of the outputs of each cognitive components multiplied by an adjustment factor. Regarding the second challenge, although each cognitive component may represent the information in different ways, we consider that cognitive components deliver a limited number of outputs.

In order to illustrate the proposed schema to modulate appraisal variables, let's assume that the *relevance dimension* has associated the following three membership functions:

$$\mu_{BAJA} = \begin{cases} 1 & si\ x \leq 0.3 \\ \frac{0.4-x}{0.4-0.3} & si\ 0.3 < x \leq 0.4 \\ 0 & si\ x > 0.4 \end{cases}$$

$$\mu_{MEDIA} = \begin{cases} 0 & si\ y \leq 0.3 \\ \frac{y-0.3}{0.4-0.3} & si\ 0.3 < y \leq 0.4 \\ 1 & si\ 0.4 < y \leq 0.7 \\ \frac{1-y}{1-0.7} & si\ 0.7 < y \leq 1 \\ 0 & si\ y > 1 \end{cases}$$

$$\mu_{ALTA} = \begin{cases} 0 & si\ z \leq 0.6 \\ \frac{z-0.6}{0.7-0.6} & si\ 0.6 < z \leq 0.7 \\ 1 & si\ z > 0.7 \end{cases}$$

These functions are initially predefined and are then adjusted according to the cognitive modulation exerted by the two groups of cognitive components. Let's assume that the literature reports that the personality influences the emotion evaluation and particularly the *relevance dimension*. In this case, such influence is represented by the modification of the membership function limits. For example, a neurotic or euphoric personality increase the probability for the agent to perceive and assess an event as relevant. In this context, the limits of the membership function LOW would be reduced, the limits of the membership function HIGH will be increased, and possibly, the limits of the membership function MEDIUM will increase in one side (see Figure 7). The next pseudocode represents an example of the function for integrating the outputs of cognitive functions:

```
Response r.clearResponse();
while (group.isEmpty() != true)
for each Component c
    Output o <- c.getOutput();
    o.setTypeforOutput();
    r.integrateOutput(o.getTypedOutput());
```

V. Conclusion

In this paper we presented a scheme to modulate appraisal dimensions involved in the emotion evaluation process. The level of modulation depends on the cognitive information projected from components of agent architectures. The proposed scheme is designed as part of an integrative framework which was developed to address a key challenge of designing integrative CMEs. We are currently working on the computational implementation of the proposed scheme in order to validate the mechanisms presented to model the influence of cognition on the appraisal dimensions involved in the evaluation of emotional stimuli perceived by the agent. This work in progress presents a model that allows researchers to consider different appraisal theories by defining new influencing rules based on information reported in the literature about cognitive functions and their influence on the emotion process. In this sense, the current proposal promotes the design of CMEs whose underlying architecture includes mechanisms that consider those cognitive information available in cognitive architectures and are useful to achieve very consistent emotional states and emotional behaviors in autonomous agents.

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