Biologically Inspired Cognitive Architectures (2016) 17, 57–70

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/bica

RESEARCH ARTICLE

Modeling the interaction of emotion and cognition in Autonomous Agents

Luis-Felipe Rodríguez [a,*], J. Octavio Gutierrez-Garcia [b], Félix Ramos [c]

[a] Instituto Tecnológico de Sonora, Cd. Obregón, Sonora, Mexico
[b] Instituto Tecnológico Autónomo de México, Mexico City, Mexico
[c] Cinvestav, Unidad Guadalajara, Guadalajara, Mexico

Received 7 June 2016; accepted 26 July 2016

KEYWORDS
Autonomous Agent;
Cognitive architecture;
Emotion and cognition;
Computational modeling

Abstract
A major goal in various fields has been the development of believable, intelligent, and social Autonomous Agents (AAs) whose behavior is influenced by affective signals. This endeavor has promoted the development of cognitive architectures for AAs that incorporate processes that imitate those of human cognition and emotions. However, there is still a need for appropriate environments in such agent architectures for the modeling of the interaction between emotional and cognitive components. In this paper, we address the following research question: *how to model the interaction of emotion and cognition in agent architectures so that AAs are capable of generating consistent emotional states and displaying believable emotional behaviors*. We address this problem from the perspective of the development of Computational Models of Emotions (CMEs). In particular, we propose an *integrative framework* for constructing CMEs whose design is focused on two main aspects: (1) the modeling of the underlying mechanisms of emotions, and (2) the incorporation of input and output interfaces that facilitate the interaction between affective processes implemented in CMEs and cognitive processes implemented in agent architectures.

Introduction

Emotions influence human behavior in several ways (Frijda, 1986; Lane & Nadel, 2002; LeDoux, 2000). Internally, the emotional significance of perceived stimuli modulates the normal operation of cognitive processes such as perception, attention, and decision-making (Damasio, 1994). Externally,

* Corresponding author.
E-mail addresses: luis.rodriguez@itson.edu.mx (L.-F. Rodríguez), octavio.gutierrez@itam.mx (J.O. Gutierrez-Garcia), framos@gdl.cinvestav.mx (F. Ramos).

http://dx.doi.org/10.1016/j.bica.2016.07.008
2212-683X/

the emotional state of individuals determines the configuration of their facial expressions, body postures, and intonation of voice when interacting with others, revealing, via non-verbal behavior, their internal affective condition and attitudes towards situations, objects, and people.

In fields such as artificial intelligence and human-computer interaction, a major goal has been the development of believable, intelligent, and social Autonomous Agents (AAs) whose behavior is influenced by affective signals (Scherer, Bänziger, & Roesch, 2010). For that reason, the architectures of AAs have incorporated processes that simulate those of human *cognition* and *emotions* such as action planning, situation appraisal, and perception (Becker-Asano & Wachsmuth, 2010; Hudlicka, 2011; Marsella & Gratch, 2009). It is expected that through the synthesis and interaction of cognitive and affective processes, AAs may be able to replicate the intelligent behavior observed in humans and thus improving the quality and believability of their expressions. However, there is still a need for appropriate environments in agent architectures for the modeling of the interaction between emotional and cognitive components.

In this paper, we address the following research question: *how to model the interaction of emotion and cognition in agent architectures so that AAs are capable of generating consistent emotional states and displaying believable emotional behaviors*. We address this problem from the perspective of the development of Computational Models of Emotions (CMEs), which are software systems designed to synthesize particular mechanisms of the human emotion process (Reisenzein et al., 2013; Rodríguez & Ramos, 2014, 2015). This type of computational model serves as a basic component of cognitive agent architectures, interacting with synthetic cognitive components to provide AAs with proper mechanisms for the processing of emotional information, the elicitation of emotions, the development of emotionally driven responses, among other tasks.

It is important to emphasize that CMEs are designed to be included in cognitive agent architectures and that (1) their internal mechanisms may depend on an extensive data exchange with *several* cognitive components such as perception and memory systems; and that (2) their outputs should be adequate to emotionally modulate cognitive components in order to exert an emotional bias in the agent's behavior. In this context, CMEs can be regarded as *integrative* or *non-integrative models* (Rodríguez & Ramos, 2015). We refer to non-integrative models as those that, for example, have been designed to emotionally modulate specific cognitive processes (as shown in the bottom part of Fig. 1). This type of CME is usually unable to provide data useful to emotionally influence cognitive functions in agent architectures that were not considered in their initial design (or to take into account cognitive information from not previously considered cognitive components). On the other hand, we refer to integrative CMEs to those designed to provide proper environments to communicate with diverse cognitive components of agent architectures, considering, for example, 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*" (see the top part of Fig. 1).

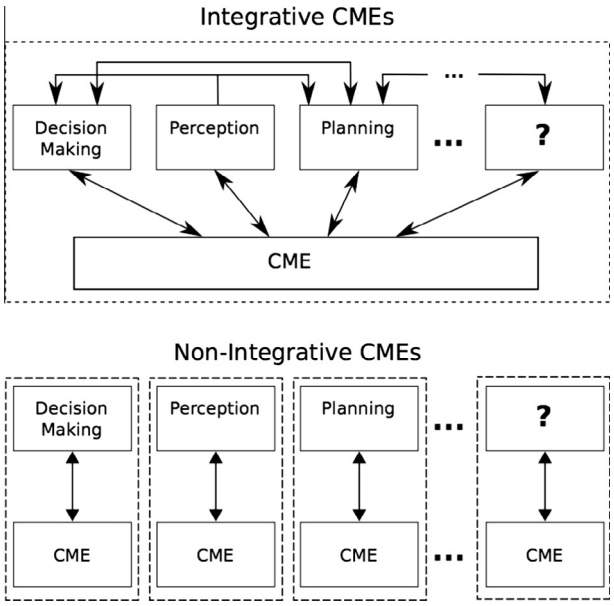

Fig. 1 Emotional modulation of cognitive processes in integrative and non-integrative CMEs. Boxes with solid lines represent cognitive or affective processes. Boxes with dashed lines define the architecture of a representative CME. The arrows between processes represent data flows.

In this context, we believe that in order to address the research question discussed in this paper, instead of focusing only on the design of new mechanisms for CMEs (e.g., for the dynamics of emotions or situation appraisal), we also have to focus on the structural aspects of the design of CMEs. In this paper, we propose an *integrative framework* designed to facilitate the development of such kind of integrative CME. The framework enables the construction of CMEs whose design is focused on two main aspects: (1) the modeling of the underlying mechanisms of affective processes such as the dynamics of emotions and mood, and (2) the incorporation of input and output interfaces that facilitate the data exchange between affective processes implemented in CMEs and cognitive processes implemented in agent architectures. This project contributes to the state of the art of computational modeling of emotions for AAs by promoting the development of social agents capable of meeting the increasing requirements of human-centered applications.

The paper is structured as follows. In Section ''Emotion and cognition interaction" we discuss the importance of modeling the interaction of emotion and cognition in AAs. Afterwards, in Sections ''Integrative framework" and ''Framework development" we present the proposed integrative framework (InFra) and provide details of its design and implementation, respectively. Finally, in Section ''Con clusion" we provide concluding remarks.

Emotion and cognition interaction

In this section, we discuss evidence about the interaction of emotion and cognition in humans and then emphasize the