A Software Design Tool for the Modeling of Emotions in Autonomous Agents

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***Abstract*—Cognitive agent architectures implement a series of computational models of cognitive and affective functions to enable the emergence of behaviors in autonomous agents. The design phase of these computational models is usually based on findings about the information processing in the human brain and on principles and standards established for the development of software systems. Software tools and methodologies to assist in this design process are still limited and scarce. Moreover, although available software tools cover most phases of the software development cycle, these do not take advantage of theories and models formulated in fields that study the brain information processing and architecture. In this paper we propose a software design tool to assist in the specification and design of computational models of emotions for autonomous agents. We develop a preliminary case study in order to demonstrate the use of the proposed tool. This tool is intended to create consistent computational models of emotions that conform to theories and models that explain the process of human emotions.**

Keywords–Autonomous Agent; Computational Model of Emotion; Software Design.

I. Introduction

It has been recognized in fields such as psychology and neuroscience that human behavior is the result of the operation and interaction of brain processes such as perception, emotions, and decision-making [1]. In particular, a variety of brain structures and neural pathways have been identified as the architectural components of these cognitive and affective processes [2]. In the field of computer science, the underlying cognitive architectures (CA) of autonomous agents (AAs) are usually designed to include components that imitate the mechanisms of these cognitive and affective functions [3], [4]. The main assumption is that from the joint operation of these types of computational models of brain processes (CMB) will stem believable and human-like behavior.

Computational models included in CAs have a dual basis: 1) a theoretical support that validates the behaviors implemented, and 2) a computational basis that ensures the quality and adequacy of their development process. The design of these models is based on theories that explain human cognitive and affective functions [1], [2]. Moreover, their computational implementation have to follow principles and standards established to assist in the development cycle of software systems [5]. Although there is a considerable number of software tools and methodologies designed to assist in the development of conventional software systems (e.g., those for industry) [5], they do not seem totally appropriate to assist the construction of CMBs. These tools have been designed under the assumption that all system requirements are established by users. However, for computational models of cognitive and affective processes additional types of requirements must be considered. In this case, part of the requirements comes from user's observations of human behaviors, but the rest must be formulated from formal and well-founded evidence about the functioning of human processes. In this manner, nonsensical specifications can be prevented by considering theories and models developed in disciplines concerned with the understanding of the mechanisms and processes that underlie human behaviors. Unfortunately, few tools recognize these needs in the development of CMBs [6], [7].

In particular, the computational modeling of human emotions can lead to inconsistencies, complications, or even contradictions. This partly occurs because there is a wide variety of theories that study human emotions in very different ways. For example, the mechanisms assumed to be involved in the process of human emotions vary depending on the theory under consideration [8]. Nevertheless, despite these constraints posed by the dual nature of CMBs, several computational models of emotions (CMEs) have been proposed [9]. *EMotion and Adaptation* (EMA) is a model of emotions based on the appraisal theory and used in the development of virtual humans [10]. *A Layered Model of Affect* (ALMA) is a model that endows with emotions, mood, and personality to conversational agents [11]. *Methodology for Analysis and Modeling of Individual Differences* (MAMID) is a model that associates two concepts: a generic methodology to model the influences of emotion on cognitive processing and an affective-cognitive architecture that implements such methodology.

In this paper we propose a software design tool (CME-tool) for the construction of computational models of emotions. In particular, this CME-tool is designed to assists in the specification and design phases of the development of this type of computational model. The CME-tool acknowledges the dual nature of the computational modeling of emotions by providing a suitable framework to organize theories that explain human brain processes, which in turn guide development of CMEs.

II. Related Work

Research on understanding and facilitating the computational modeling of emotions has led to the creation of new tools and methodologies. The Emotion Markup Language (EmotionML) is a general purpose annotation language used for representing affective aspects in human-machine interactive systems [6]. It is proposed by the W3C Multimodal Interaction Working Group as an attempt to standardize the description of emotions in three main contexts: (1) manual annotation of texts, videos and anything that involves emotional data; (2) accurate representations of emotional aspects captured from user's expressions, postures, speech, etc.; and (3) for comprehensible generation of emotional responses from user interfaces. Although a specification of the syntax of EmotionML is still in progress, several elements may already be used.

Wang [12] proposed a set of denotational mathematics for the rigorous and formal description of cognitive processes and nature-inspired systems. These are expressive mathematical means that emerge in the framework of cognitive informatics, a discipline concerned with the internal information processing mechanisms of natural intelligence. Two particular instances of denotational mathematics are *concept algebra* and *real-time process algebra*. The former is appropriate to rigorously manipulate abstract concepts in a formal and coherent framework, which leads to the construction and treatment of more complex knowledge representations. The latter has been developed as a coherent notation system and formal methodology to algebraically denote and model the behaviors and architectures of systems and human cognitive and affective processes [12].

Cognitive Objects within a Graphical EnviroNmenT (COGENT) [7] is a software tool with a visual environment for the computational design and modeling of high-level cognitive processes. COGENT allows the creation and testing of cognitive models using box-arrow diagrams composed of functional components with their respective interactions. Conceptually, these components represent cognitive processes such as memory systems, knowledge networks, and decision procedures, which are embodied in computational structures such as memory buffers, knowledge bases, and connectionist networks. This tool provides an appropriate environment for executing and testing the developed models. The CME-tool proposed in this paper is also focused on the construction of this type of model, but at a lower level. Whereas COGENT deals with high-level cognitive functions, we are concerned with modeling their structural basis supported on theories and models from fields that study the brain functioning.

III. THE CME-TOOL

Computational models of emotions can be included in CAs using one of the following two schemas: as stand-alone models or as integrated models. The former refer to components that are separately developed and then included as extensions of existing cognitive architectures, extending their functionality by providing affective processing. The latter have to do with emotional models that are designed and implemented as part of these cognitive frameworks. They may not be implemented as a single architectural component.

The benefits and disadvantages of each approach vary. The use of stand-alone models allows the rapid and easy integration of emotional mechanisms in CAs using pre-tested components. Architectures use these components by sending them raw data and receiving back emotionally processed information. On the other hand, models of emotions designed and implemented within integrated environments such as CAs follow a more natural design. These models are not seen as individual architectural extensions, but as processes that emerge from the joint operation of multiple mechanisms. In this case, given that

TABLE I. Brain functions and structures used to create specification and design diagrams in the CME-tool.

Brain Function	Description	Related brain structures
Perception	Emotions influence perceptual processes to give a greater interpretation to novel emotional stimuli	Sensory System, Thalamus, Hippocampus, Sensory Cortex, Association Cortex
Learning	The emotional level of the perceived stimuli is used to provide a measure to learned knowledge	Amygdala, Hippocampus, Sensory Cortex, Association Cortex
Memory	Emotions influence the storing, retaining, and recalling of knowledge in AAs	Amygdala, Hippocampus, Dorsolateral Cortex, Sensory Cortex, Association Cortex, Ventromedial Cortex
Attention	Emotions facilitate AAs to concentrate on the salient elements of the environment and discard the irrelevant ones	Amygdala, Sensory Cortex, Association Cortex
Emotions	This process encodes stimuli in order to generate emotionally driven behaviors in AAs	Thalamus, Sensory Cortex, Association Cortex, Hippocampus, Amygdala
Planning	Emotions alter the creation of sequences of actions that will lead to an expected result	Orbitofrontal Cortex, Dorsolateral Cortex, Ventromedial Cortex, Sensory Cortex, Association Cortex, Amygdala, Hippocampus
Decision-Making	Emotions assist to this process to select the next action when a "rational" decision cannot be made	Orbitofrontal Cortex, Dorsolateral Cortex, Basal Ganglia, Ventromedial Cortex
Motor-Action	Fast and survival reactions are most of the time driven by emotions	Basal Ganglia, Motor Cortex, Association Cortex, Somatosensory Cortex

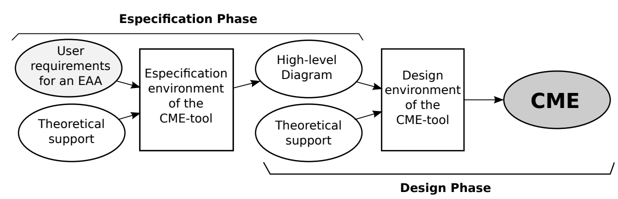

Figure 1. Design phases of the CME-tool.

multiple processes and their interactions must be understood to generate emotional data, their development becomes more complicated. However, although this approach is more error prone, many benefits can be gained. For example, because these models are built on the basis of the actual process of human emotions, they can conveniently be adapted to include other cognitive and affective processes.

The proposed CME-tool is developed to assist in the specification and design of integrative CMEs as part of CAs, which are additionally restricted by findings about the functioning and architecture of human brain processes. Table I shows the brain functions and brain structures currently included as functional and architectural components in the CME-tool for the generation of specification and design diagrams. They are well documented in the literature as processes that influence or are influenced by emotions [1], [2], [13].

From a high level perspective, the design process in the CME-tool begins with the definition of users' requirements for an emotional autonomous agent (EAA). This process ends with the architectural design of a CME to be included in the CA of this EAA. Figure 1 shows the steps of this design process, which are explained in the following subsections.

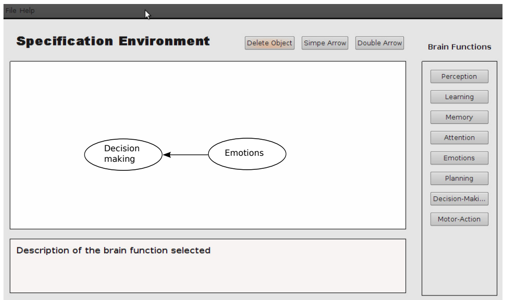

Figure 2. Specification environment of the CME-tool.

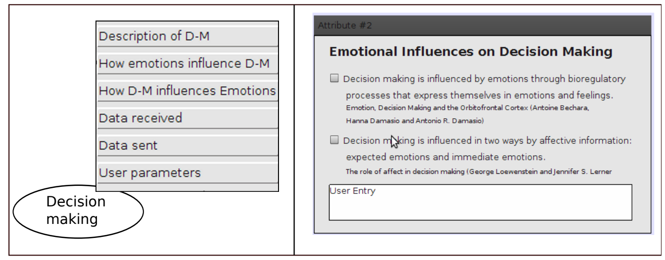

Figure 3. Left: attributes corresponding to the decision-making component. Right: Additional information about the decision-making process.

A. Specification Phase

In this phase, all requirements are translated into a high-level diagram composed of functional modules and their respective interactions. Two main steps are followed to accomplish this: (1) user requirements are grouped (or decomposed) so that they can be placed in predefined modules that represent affective and cognitive brain functions such as emotions, perception, and attention; (2) in order to completely meet the user's specifications, explicit operations, interactions, and other parameters should be defined for each of these modules.

The CME-tool automates this procedure by providing a series of pre-built functional modules representing specific brain functions (see table I). These functional modules are selected by users to form a functional diagram that meets the requirements of the CME defined. The parameters of each module are configured using available information provided by theories that explain the functioning and architecture of the brain process these modules represent. Figure 2 shows the *specification environment* of the CME-tool, which includes a work space designed to organize the high-level diagram and a series of ready-for-use icons that represent brain processes.

The following list shows the information provided to define each component, which appears when a component is selected in the work space (see left part of figure 3):

1) The role of this component: key aspects related to the functioning of the brain process it represents.
2) How emotions influence this component: roles that emotions play on the brain function it represents.
3) How this component influences emotions: how the results of this component influence emotion processing.
4) Data this component receives: information necessary for its functioning.
5) Data this component sends: information sent to communicate emotion-related aspects.
6) User parameters: open space for the user to introduce information.

At the moment the user selects one of these attributes, a window with more specific information is available. Given that there are diverse theories that formulate different hypotheses to explain the same phenomena, for each parameter the CME-tool may provide several explanations. The displayed information encourages the selection of theories that best fit the user' design goals. Thus, by following this procedure, all parameters of the entire diagram are defined.

To demonstrate how this procedure works in the CME-tool, we consider a single requirement from the specification of an EAA whose decision-making should be influenced by emotions: *the EAA should be able to make decisions that meet both emotional and rational rewards, thus maintaining a general emotional balance*. From this requirement an initial diagram with two components is drawn, see figure 2.

In this diagram when the user selects the decision-making component, its corresponding list of attributes appears (see left part of figure 3.) The right part of figure 3 presents the window that appears when the second parameter is selected; it presents information to define such attribute. The format that follows the data shown in this window has two fields for each entry. One contains the explanation of the attribute and the other the information of the referred theory.

Following this procedure, as the requirements in the specification of the EAA are analyzed, new components may be incorporated, or even, only new interactions or operations between the already considered modules may be necessary to meet the whole specification. In this manner, once the attributes of all components are defined, the specification of the EAA should be totally understood from the resulting diagram.

B. Design Phase

The CME-tool generates an architectural design by refining the functional diagram resulting in the specification phase. In the design phase, all components representing brain functions in the specification diagram are decomposed into brain-inspired structures that embody mechanisms to allow the emergence of specific behaviors.

The procedure to achieve the architectural design is similar to that carried out in the specification process. Once we have the functional diagram completed, we proceed to open it in the *design environment* included in the CME-tool (see figure 4.) This environment also provides pre-built modules that take the role of brain structures, such as the amygdala, hippocampus, and thalamus (see table I). In this manner, when a component of the functional diagram is chosen, related pre-built modules are shown, allowing the user to select those that meet its particular design goals and according to the parameters established in the previous stage.

Each structural component should be also fully defined. Needed information to do that is provided and classified in the same manner as with the functional components of the specification phase (see the list above and figure 3). This information is also based on theories, models, and concepts

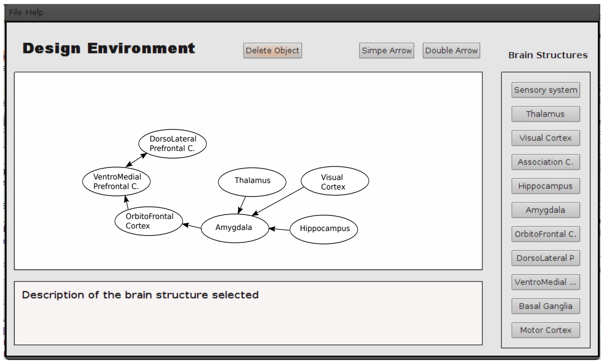

Figure 4. Design environment of the CME-tool.

addressing aspects related to the processing of human emotions. This guides the decomposition of the modules in the functional diagram in a coherent way.

To continuous with the example (figure 2), when the emotional module is selected, a number of components assuming the role of brain structures are shown. They are those supposed to be involved (directly or indirectly) in this particular process. After that, users are able to select those structures that are related to the processing of emotions in their particular design. Similarly, when we select the decision making component, structures involved with the functioning of this module appear, which allows the user to follow the same procedure (the work space in figure 4 shows a possible architectural design for this example).

The design process implemented by the CME-tool facilitates the construction of CMEs for AAs, which are based on the brain mechanisms underlying human emotions. The first phase of the CME-tool allows users to put together desirable characteristics and functions in EAAs in a simple and organized way. The second phase assists in the translation of these abilities to an architectural design, which enables the emergence of proper emotionally-driven behaviors in EAAs. This method promotes the design of AAs by modeling brain functions, which emerge from the interaction of a number of components that embody algorithms implementing mechanisms that imitate the brain functioning and architecture. Moreover, since most of the initial user requirements for the development of CMEs are not in terms of how emotions arise or what are the components of the emotional process, but in the form of emotions as influencing certain cognitive processes, the approach of the CME-tool is adequate.

IV. Future Work

The following list presents some future work:

1. Improvements for an accurate guidance in the composition of the functional and design diagrams are being considered. The CME-tool will provide clues to prioritize users' requirements and to translate desired behaviors in AAs to brain functions, as well as to assign precedence to components constituting its functional diagram when they are being decomposed into an architectural design.

2. We are considering to design a mechanism to extend the CME-tool with information about the processes in which emotions are not playing a main role. For example, the direct operation between planning and decision making. To do that, a more robust knowledge base may be implemented, which allows users to include additional theories in the CME-tool in a consistent and meaningful way, as well as to connect the CME-tool with other available knowledge bases.

3. To consider the implementation process in the CME-tool, architectural components in the design diagram may include additional information of computational techniques to appropriately implement the process they are embodying, as well as to include user's fields to precisely indicate data structures, functions, and other data useful for the implementation phase.

4. Finally, automatic generation of complementary documentation for an easier understanding of specifications and designs is also to be implemented.

V. Conclusions

In this paper we proposed a new software tool to assist in the specification and design of computational models of emotions as part of cognitive agent architectures. This tool was designed taking into account three basic assumptions: (1) it aims at developing integrated models, (2) it was inspired by the functioning and architecture of the mechanisms underlying human emotions, and (3) it was developed to address the specification and design phases of this type of computational models. This paper emphasizes on the importance of considering the study on human mechanisms to design computational models of brain processes, as well as on the significance of implementing adequate computational tools to assist in this complex task.

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