Cognitive Computational Models of Emotions and Affective Behaviors

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ABSTRACT

Emotions are one of the important subconscious mechanisms that influence human behaviors, attentions, and decision making. The emotion process helps to determine how humans perceive their internal status and needs in order to form consciousness of an individual. Emotions have been studied from multidisciplinary perspectives and covered a wide range of empirical and psychological topics, such as understanding the emotional processes, creating cognitive and computational models of emotions, and applications in computational intelligence. This paper presents a comprehensive survey of cognitive and computational models of emotions resulted from multidisciplinary studies. It explores how cognitive models serve as the theoretical basis of computational models of emotions. The mechanisms underlying affective behaviors are examined as important elements in the design of these computational models. A comparative analysis of current approaches is elaborated based on recent advances towards a coherent cognitive computational model of emotions, which leads to the machine simulated emotions for cognitive robots and autonomous agent systems in cognitive informatics and cognitive computing.

Keywords: *Affective Computing, Artificial Intelligence (AI), Cognitive Computing, Cognitive Informatics, Cognitive Models, Cognitive Science, Computational Intelligence, Emotions*

1. INTRODUCTION

An emotion is a personal feeling derived from one's current internal status, mood, circumstances, historical context, and external stimuli (Wang, 2007a). Emotions are a set of states or results of perception that interprets the feelings of human beings on external stimuli or events in the binary categories of pleasant or unpleasant. In order to formally and rigorously describe a comprehensive and coherent set of mental processes and their relationship, a Layered Reference Model of the Brain (LRMB) has been developed by Wang and his colleagues (Wang et al.,

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2006; Wang & Wang, 2006; Wang, Kinsner, & Zhang, 2009). The LRMB model explains the functional mechanisms and cognitive processes of the brain and the natural intelligence. The main cognitive processes at the perception layer of LRMB are emotion, motivation, and attitude. It is recognized that a crucial component of the future generation of computers, known as cognitive computers (Wang, 2009), is a perceptual engine, which mimics the natural intelligence such as emotions and motivations (Wang, 2010; Wang et al., 2009).

It is observed that emotions influence human behavior in several ways. Emotions alter our processes of perception, attention, and decision making, enabling the development of emotionally driven responses (Damasio, 1994; Phelps, 2006; Wang, 2007a; Wang et al., 2006). Also, emotions help to determine the configuration of our facial expressions, body postures, and intonation of voice when interacting with others, revealing, via nonverbal behavior, our internal affective condition and attitudes towards situations, objects, and other individuals (LeDoux, 1989; Scherer, 2003).

Because of the multiple facets and components underlying the process of human emotions, it can be approached from a diversity of perspectives. Moreover, due to the nature of this process and its applications, emotions are currently the focus of study in multiple disciplines such as psychology, neuroscience, philosophy, computer science, cognitive sciences, and cognitive informatics (Fellous & Arbib, 2005; Phelps, 2006; LeDoux, 1989; Wang, 2007a, 2007b, 2007c, 2011, 2012a, 2012b; Wang & Wang, 2006; Wang et al., 2006, 2009, 2011). This multidisciplinary inquiry has provided evidence that shows the significance of emotions not only to the rational behavior of individuals, but to achieve more believable and human-like behaviors in intelligent systems. In particular, fields such as psychology and neuroscience have contributed a number of theories and models that explain the diversity of the emotion process. These theories are focused on revealing the mechanisms underlying the process by which humans transform external stimuli into emotional perspectives. Similarly, in fields such as computer science, cognitive informatics, computational intelligence, and artificial intelligence, researchers are interested in the design of formal and computational models of emotions that help improve artificial intelligent systems used for cognitive robots (Wang, 2010), autonomous agents (Wang et al., 2009), and human-computer interactions (Wang, 2007b). In this dual approach, computational modeling technologies are used for testing and refining psychological, biological, and cognitive models, which are further used to support the design of computational models of emotions.

The design of autonomous agents (AAs) aimed at embodying human-like behaviors has taken advantage of evidence from studies of human emotions. AAs have been endowed with mechanisms that simulate emotional processes in the architecture of Cognitive Computational Models of Emotions (C^2MEs), which are biologically inspired models intended to describe human emotional functions such as the evaluation of emotionally relevant stimuli, the elicitation of emotions, and the generation of fast and deliberated emotional responses. In some cases, C^2MEs focus on reproducing specific facets in this process, but in many others, they cover a more complete emotional cycle that goes from evaluation of stimuli to the generation of emotionally adjusted behaviors (Wang, 2007a).

Affective behaviors are thus induced in AAs through the embodiment of C^2MEs in their cognitive architectures. This type of behavior is an observable consequence of the verbal and non-verbal responses implemented by the agent, which reflect its internal condition, emotions, attitudes, and motivations. Moreover, the implementation of such affective behavior is what enables the attribution of particular emotion labels to the emotional state of the agent, such as happiness, anger, and embarrassment. In this context, the development of C^2MEs should be ultimately designed to allow AAs to implement affective behavior. In order to achieve such objective, various approaches have been considered which have their basis on emotion theories and models elaborated in cognitive and computational sciences.

In this paper, we review emotion theories and models originated in the fields of psychology and neuroscience that have extensively inspired the development of C^2MEs. Particular instances of C^2MEs are analyzed in order to investigate their internal architectures and cognitive functions. We explain how these computational models process perceived stimuli to translate them into cognitive and computational processes and explore the characteristics and mechanisms associated with the affective behavior induced by C^2MEs. This paper is structured as follows. The next section reviews theoretical models of emotions from a perspective that reflects their main contributions to the design of C^2MEs. Section 3 investigates the internal workings of some representative instances of C^2MEs. Then, Section 4 examines the nature of the affective behavior developed by AAs. A comparative analysis and discussion about C^2MEs is presented in Section 5. Finally, concluding remarks are given in Section 6.

2. COGNITIVE MODELS OF EMOTIONS

Given the nature of C^2MEs and their human-centered applications, the design of such models is not only based on computational technologies, but also on findings contributed by multiple disciplines concerned with the understanding of the human emotion processes. Most C^2MEs have been designed under the influence of theoretical models elaborated in fields such as psychology, cognitive science, neuroscience, and cognitive informatics (Gebhard, 2005; Marsella & Gratch, 2009; Velásquez, 1998; Wang, 2007b). The following subsections review some of the most influential theories applied in the design of C^2MEs, thus providing a deeper understanding of the nature and theoretical foundations of C^2MEs.

2.1. Hierarchical Theories of Emotions

In order to understand the domain of human emotions, many classifications have been proposed (Wang, 2007a). A widely accepted classification categorizes emotions as primary and secondary (or basic and non-basic), which derives from the assumption that there is only a small set of basic emotions (Lewis et al., 1989).

Emotions may be classified into the classes of primary and secondary ones. Primary emotions are supposed to be innate, instinctive, and with an evolutionary basis. Particular instances are fear, anger, and happiness. The eliciting conditions of some primary emotions have been identified and corresponding facial expressions are uniquely recognized across people in various cultures (Lewis et al., 1989; Ekman, 1999). On the other hand, secondary emotions are learned through experience. Instances of this class of emotions are embarrassment, guilt, shame, and pride. This type of emotions is often considered as derived from combinations of primary emotions. The eliciting patterns of secondary emotions and related facial expressions are dependent on individuals' culture and educational background (Lewis et al., 1989). Primary emotions induce reactions that are essential for the individual's survival, while the secondary ones induce appropriate reactions in social situations in which many environmental factors are involved.

Although there is not a commonly accepted list of primary and secondary emotions, Ekman (1999) proposes a set of six basic emotions known as anger, disgust, enjoyment, fear, sadness, and surprise. It has been suggested that other emotions may be considered as basic, such as contempt, shame, relief, and embarrassment. Damasio (2003) organizes emotions into three general categories: *background emotions*, *primary emotions*, and *social emotions*. The emotions in the first category are supposed to be generated by simple regulatory processes in terms of state of being, although these have not much influence on the behavior of the individual. Damasio (2003) identified a nesting principle to explain how complex emotions are composed of simpler ones. This principle essentially suggests that background emotions are the basic building blocks of primary emotions, and that primary emotions are basic building blocks of the social ones. In a recent study, a hierarchical model of emotions is developed by Wang (2007a). It is found that human emotions at the perceptual layer may be classified into two opposite categories: *pleasant* and *unpleasant*. Various emotions in the two categories can be categorized at five levels according to their strengths of subjective feelings as shown in Table 1, where each level encompasses a pair of positive/negative or pleasant/unpleasant emotions.

Table 1 indicates that the *human emotional system* is a binary system that interprets or perceives an external stimulus and/or internal status as pleasant or unpleasant (Wang, 2007). Although there are various emotional categories at different levels, the binary emotional system of the brain provides a set of pairwise universal solutions to express human feelings. For example, angry may be explained as a default solution or generic reaction for an emotional event when there is no better solution available; in opposite, delight is another default emotional reaction.

In cognitive computational models the aforementioned classifications of emotions have been often adopted. For instance, since autonomous agents are usually intended to interact with humans, secondary emotions provide them a mechanism for showing social abilities and generating and expressing learned emotions supposed to arise on diverse social situations and events. Also, the blend of basic emotions is a mechanism widely employed as the origin of these secondary emotions, and the behavior of autonomous agents is often in accordance with the pattern behaviors established for primary emotions (Becker-Asano & Wachsmuth, 2010; Velásquez, 1998).

2.2. Appraisal Theories of Emotions

Appraisal theories of emotions explain the elicitation and differentiation of emotions on the basis of the relationship between individuals and their environment (Frijda, Kuipers, & Schure, 1989; Ortony, Clore, & Collins, 1990; Scherer, 2001; Smith & Lazarus, 1990). Appraisal theories assume that emotions arise from the evaluation of situations, objects, and agents existing in the environment and which directly or indirectly impact the goals, plans, and beliefs of the individual. This evaluation of the *individual-environment relationship* is carried out using a

Table 1. The hierarchy of emotions (Wang, 2007a)

Level		Description	
0	No emotion	-	
1	Weak emotion	Comfort	Safeness, contentment, fulfillment, trust
		Fear	Worry, horror, jealousy, frightening, threatening
2	Moderate emotion	Joy	Delight, fun, interest, pride
		Sadness	Anxiety, loneliness, regret, guilt, grief, sorrow, agony
3	Strong emotion	Pleasure	Happiness, bliss, excitement, ecstasy
		Anger	Annoyance, hostility, contempt, infuriated, enraged
4	Strongest emotion	Love	Intimacy, passion, amorousness, fondness, infatuation
		Have	Disgust, detestation, abhorrence, bitterness

series of appraisal dimensions or variables, which vary in number and type among theories and models. The following is a list of dimensions proposed by Frijda et al. (1989):

- **Pleasantness:** Was the event, agent, or object in a pleasant or unpleasant situation?
- **Goal-conducive:** Was the situation conducive or obstructive to the agent's goals?
- **Suddenness:** Was it a situation that had already lasted for some time, or one that had developed all of a sudden?
- **Controllability:** Could the agent still affect the situation in any way?
- **Self responsible:** Were the agent responsible for what was happening or had happened?

In general, appraisal dimensions are measurement variables that capture information about the levels, quality, and types of influences between the agent and its environment (Reithinger, 2006; Smith & Kirby, 2001). Particularly, Scherer (2001) suggests that they should provide the following information:

- **Relevance:** How relevant is the event for me? Does it directly affect me or my social reference group?
- **Implications:** What are the implications or consequences of this event and how do these affect my well-being and my immediate or long-term goals?
- **Coping potential:** How well can I cope with or adjust to these consequences?
- **Normative significance:** What is the significance of this event with respect to my self-concept and to social norms and values?

After assessing its environment, an agent is able to determine how pleasant is a certain event to it, how well it can cope with that event, how well it can adjust to the consequences among other things (Smith & Kirby, 2001). According to the appraisal process, once this type of information is collected, proper emotions and their associated intensity can be derived. The particular type of emotion that is elicited depends on the specific configuration of values formed by the results in all appraisal dimensions.

There are several particular instances of the appraisal theory. The OCC appraisal model introduced by Ortony et al. (1990) is implemented in computational systems. This model proposes a taxonomy of emotions based on a systematic and structured hierarchy of their eliciting conditions. Ortony et al. (1990) consider emotions as valenced reactions (positives and negatives) elicited by the aspects of objects (likes and dislikes), the actions of agents (pleasure and displeasure), and the consequences of events (approval and disapproval). In this manner, their taxonomy encompasses 22 emotions that are triggered according to their eliciting conditions and their association with the agent, object, or situation that cause them.

In addition to contribute with explanations for the elicitation and differentiation of emotions, some appraisal theories have been extended to show how the assessment of the individual-environment relationship predisposes the individual to implement certain types of emotional responses. For example, Frijda et al. (1989) suggest that there are different states of action readiness (dispositions or indispositions to face the appraised situation) that are elicited by different events appraised as emotionally relevant, which take the form of approaching, protection, avoidance, attending, disinterest, apathy, and others. These emotional tendencies are capable of altering individuals' internal mechanisms in order to prepare them to deal with emotional contingences.

The appraisal theory is the psychological approach widely accepted and implemented in C^2MEs (Breazeal, 2003; El-Nasr, Yen, & Ioerger, 2000; Gebhard, 2005; Marsella & Gratch, 2009). The translation of the appraisal dimensions, appraisal evaluations, and the generation of responses based on the appraisal dimensions' outcomes is not a complex process for computer simulations. In addition, the appraisal processes constitute a cycle that covers the major requirements established for C^2MEs: *evaluation of emotionally relevant stimuli*, *elicitation of emotions*, and *generation of emotional behavior*.

2.3. Dimensional Theories of Emotion

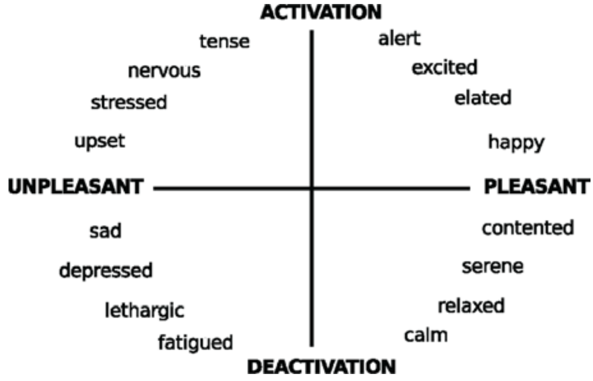
The main contribution of dimensional theories for C^2MEs is that they provide a suitable framework to represent emotions from a structural perspective. This psychological approach establishes that emotions can be differentiated on the basis of dimensional parameters. Two major approaches are reviewed in the following subsections.

2.3.1. The Russell's Two-Dimensional Model

Russell (2003) proposes a two-dimensional framework that considers pleasantness (pleasure/displeasure) and activation (arousal/non-arousal) to characterize a variety of affective phenomena such as emotions, mood, and feelings (Figure 1). In this framework, in order to generate emotions in an agent, emotionally charged events are first interpreted in terms of their relevance, causing a feeling of pleasure or displeasure and of activation or deactivation. Then, they are properly represented and situated within the two-dimensional space, where types of emotions identified are depicted in Figure 1. For example, an agent would experience happiness as the result of assessing an event as highly pleasant and with moderate activation.

In Russell's model, the notion of *Core Affect* is explained as the combination of pleasantness and activation and considered the essence of all affective experience (Barrett & Russell, 1999; Russell, 2009). The core affect is defined as a consciously accessible neurophysiological state which continuously represents a feeling generated by the assessment of the individual-environment relationship. The core affect of emotions is characterized as an unlabeled feeling. It is not tagged with common terms used to label emotions, such as fear, joy, and surprise. However, it may not be interpreted or attributed to any cause. Nevertheless, it is supposed that although a person has no direct access to the source of the feeling, one just can make attributions and interpretations of the core affect. In this sense, its subjective experience is simple, primitive, and irreducible to anything else psychological (Barrett & Russell, 1999; Russell, 2003). It is supposed

Figure 1. Core affects (adapted from Barrett & Russell, 1999)



that people always have core affect, which indeed falls within the two-dimensional space as shown in Figure 1.

Alterations in the core affect influence the cognitive functions of individuals (Russell, 2003, 2009). For example, in order to find the source that causes affective changes, perceptual and attentional processes are influenced. Similarly, the dynamics in the core affect is always providing appropriate information for the acquisition of preferences and attitudes to influence the decision making process. Russell (2003) proposes a set of attributes related to the core affect such as affect regulation (alteration or maintaining of core affect), affective quality (how stimuli are able to cause changes in core affect), mood (as prolonged core affect without a direct object as the cause), and attributed affect (the attribution of the core affect to an object). In this context, emotions are regarded as emotional episodes that consist of causative events, including the antecedent event, the core affect, attributions, psychological and expressive changes, subjective conscious experiences, and emotion regulation. All these attributes, concepts, and definitions become adequate for the computational modeling of emotions as they contribute to the explanation of varied affective phenomena and their relationship to emotions. However, although this psychological approach to emotions proposed by Russell seems plausible for the design and development of C^2MEs, it has barely been implemented (Becker-Asano & Wachsmuth, 2010).

2.3.2. The Mehrabian's PAD Space Model

Mehrabian (1996) proposes a three-dimensional space for describing emotional states. The PAD space considers the dimensions of pleasure/displeasure (positive and negative affective states), arousal/non-arousal (high-low stimulus activity), and dominance/submissiveness (stimulus potency resulting in control or lack of control) to characterize, represent, and measure individuals' all emotional states. For example, angry is related to high unpleasant, high arousal, and moderated dominance values. In this model, precise coordinates for this and other emotions are also provided. For example, while angry is located at [P = -.51, A = .59, D = .25], happiness is located at [P = .81, A = .51, D = .46].

Mehrabian (1996) suggests that temperaments can be derived by measuring and averaging emotional states characterized in the PAD space. In this context, temperament refers to individual's emotional predispositions that may last over a long period, and emotional states refer to rapidly changing individual conditions. The PAD space is therefore able to represent temperament scales based on emotional states. The derivation of personality measures is then possible by considering the points in the PAD temperament space as individual traits, regions as personality types, and lines drawn through the origin point of the three axes as personality dimensions. As an illustration of this, dividing each of the three dimensions in positive and negative, the resulting octants in the PAD space can be labeled with personality types as shown in Table 2. Besides these personality types, Mehrabian (1996) provides a set of personality scales and its corresponding values within the PAD temperament model. For example, extroversion is located at the coordinates [P = 0.21, A = 0.17, D = 0.50].

The Mehrabian's PAD space model is convenient for its implementation in computational simulations. In general, this model allows the generation of appropriate descriptions for emotions based on the assessment of objects, individuals or events in terms of the PAD dimensions (the process of evaluating the individual's environment is similar to that described in the previous section). Becker-Asano and Wachsmuth (2010) employ the PAD emotional space in the WASABI computational model of emotion to represent and elicit particular types of emotions in MAX, a virtual human. Further, the temperament approach has been adapted in AI models to produce long-lasting affective states. For instance, Gebhard (2005) implements the PAD tem-

Table 2. Personality types in the PAD space (Mehrabian, 1996)

Exuberant: [+P, +A, +D]	Bored: [-P, -A, -D]
Dependent: [+P, +A, -D]	Disdainful: [-P, -A, +D]
Relaxed: [+P, -A, +D]	Anxious: [-P, +A, -D]
Docile: [+P, -A. -D]	Hostile: [-P, +A, +D]

perament space in ALMA to simulate mood states in conversational agents, as is explained in Section 3.2.

3. COMPUTATIONAL MODELS OF EMOTIONS

A proper approach for constructing artificial intelligent systems has been the computational synthesis of natural intelligent processes observed in animals and humans. Studies of mechanisms underlying such processes have led to system designs based on the architectures and functions of biological components and brain structures. The development of C^2MEs is not the exception. Most of the C^2MEs have been developed based on the understanding of the functions and processes of human emotions. The following subsections introduce a number of representative C^2MEs. Their functions, architectures, underlying assumptions, main objectives, applications, and relationship with the studies described in Section 2 are elaborated.

3.1. EMA

EMotion and Adaptation (EMA) is a C^2ME whose design is based on appraisal theories (Marsella & Gratch, 2009). In particular, this model adopts the appraisal theory by Smith and Lazarus (1990). The computational model of EMA deals mainly with the elicitation of emotions and their impact on agent's behaviors and decision making. In this context, EMA tries to explain the rapid dynamics of some emotional reactions as well as the slower responses that follow deliberation.

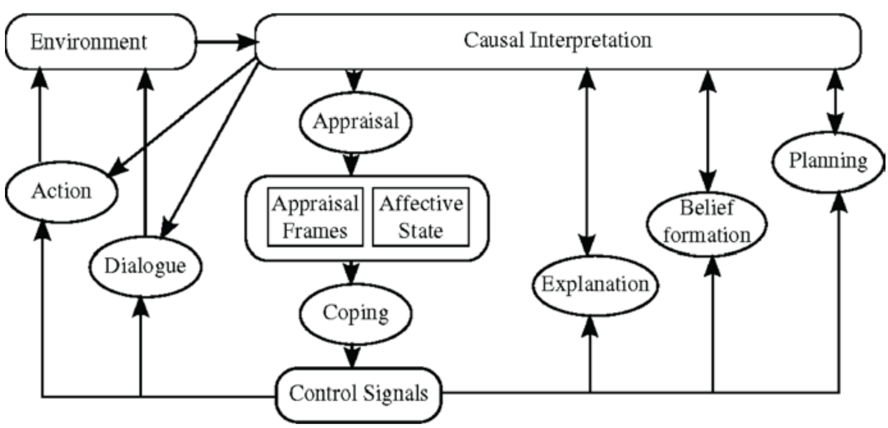
In EMA, the representation of the agent-environment relationship explained in appraisal theories is called the causal interpretation of the agent (Gratch & Marsella, 2004). At any point in time, it represents, among other things, the agent's current beliefs, desires, intentions, past events, current world state, and possible future outcomes. Furthermore, this causal interpretation encodes the inputs, intermediate results, and outputs of reasoning processes, which serve as mediators between the agent's goals and its physical and social environment. The causal interpretation is constructed and updated by a set of perceptual and inferential processes, where some of them are slow and deliberative and others are fast and autonomic. The causal interpretation is also used to perform the appraisal processes, which are fast, parallel, and automatic (Marsella & Gratch, 2009). This separation between the construction of the causal interpretation and the processing of appraisals evaluations clearly explains the nature of both rapid and slow responses. Moreover, this approach allows EMA to carry out a single-level appraisal process that acts over the outputs of cognitive processes.

In EMA, a set of feature detectors are continuously operating on the causal interpretation of the agent and mapping affective attributes into appraisal variables. These appraisal derivations are based on a decision-theoretic planning approach and augmented by the representations of agent's intentions and beliefs. Each significant feature appraised from the causal interpretation is represented in a data structure called the appraisal frame, which comprises a set of appraisal variables such as relevance, perspective, desirability, likelihood of outcomes, expectedness, causal attribution, controllability, and changeability (Marsella & Gratch, 2009). EMA maintains multiple appraisal frames at the same time, which are labeled with an emotion type as well as with their associated intensity. At some point, one of those frames will determine the agent's emotional state and response according to the values of their appraisal variables. Furthermore, in order to determine the next coping response, all appraisal frames associated with any data structure accessed or modified by a cognitive operator in each operating cycle are activated. Once activated, they are regulated by the agent's mood state (obtained from the combination of all the current appraisal frames). The frame resulting with the highest intensity will determine the agent's emotional state as well as the coping response. Figure 2 depicts the functional cycle of the EMA processes.

EMA relies on a set of coping strategies that identify the features in the causal interpretation that generate the current appraisal frame and then decides if they should be maintained or altered by enabling or inhibiting cognitive processes (Gratch & Marsella, 2004; Marsella & Gratch, 2009). These coping responses are supposed to change the individual-environment relationship, resulting in new evaluations by the agent and thus repeating the appraisal cycle again.

EMA has been employed in the development of virtual humans. In particular, this computational model has been included in the underlying architecture of the virtual humans of the Mission Rehearsal Exercise project (Swartout et al., 2006), a virtual reality based training program that serves to analyze how soldiers would act in some stressful situations. EMA has allowed these virtual entities to achieve more realistic and human-like behavior by influencing their decision making. The dynamics of the internal and external behavior in EMA has been also evaluated with respect to human data. The dynamical changes of its multiple variables (as responses to evolving events) have demonstrated to be consistent with subjective data collected from human subjects, which reported their feelings when imagining how they would respond in particular slowly evolving situations (Gratch & Marsella, 2005).

Figure 2. The EMA system (adapted from Gratch & Marsella, 2004)



3.2. ALMA

A Layered Model of Affect (ALMA) is a model aimed at endowing with emotions, mood, and personality to virtual humans (Gebhard, 2005). This model assumes that different affective aspects influence in different ways human's behavior. In order to associate affective states with the different types of emotional responses that an agent may implement, ALMA classifies agent's expressions, behaviors, and cognitive processes according to their temporal features. For example, while facial expressions and gestures are assumed to be influenced by the agent's emotional processing, cognitive processes such as decision-making are assumed to be emotionally adjusted by its mood state and personality traits.

The core module in charge of affect modeling in ALMA is the EmotionEngine. This component implements the OCC appraisal model for modeling emotions (Ortony, 1990), the Five Factor Model for modeling personality (McCrae & John, 1992), and the PAD space by Mehrabian (1996) for modeling moods states. The EmotionEngine is able to generate 24 emotions, which are associated to a set of specific emotion eliciting conditions (EECs) derived from dialogue act tags and appraisal tags that represent meta-information used for the production of emotions in ALMA. Because ALMA is mainly used in conversational agents, these tags are characterized and inserted behind the utterance where they refer to, and therefore they affectively characterize the dialogues among peer agents. The dialogue act tags indicate the underlying intention of an utterance, while the appraisal tags express how a character appraises an event, action, or object referred in the dialogs as explained in the following example (Gebhard, Klesen, & Rist, 2004):

- **Speaker1:** I didn't get the job for the MTV webpage. It went to a kid that looked like Britney Spears.
- **Speaker2:** Well, can you sing? [= attack Speaker1].
- **Speaker3:** The weather's getting better [= most_likely_future_event].

where [= attack Speaker1] represents a dialogue act tag, and [= most_likely_future_event] an appraisal tag.

To generate emotions, the EmotionEngine maps each appraisal and dialogue act tag into the following EEC variables: desirability of events, praiseworthines of actions, appealingness of objects, liking reflecting how one is attracted by another person, likelihood reflecting the degree of belief that an anticipated event will occur, and realization reflecting the degree of belief that an anticipated event has occurred (Gebhard et al., 2004). The intensity of active emotions is determined by the personality profile assigned to each character as well as by the current mood. Such personality profile is assigned by users before the simulation starts, and the initial mood is specified on the basis of the individual traits of this personality profile.

In ALMA, a mood is represented by a point in the PAD space and its intensity is defined as slightly, moderate or fully, which is determined by the distance from the point corresponding to a mood value to the zero point of the PAD mood space (Gebhard, 2005). In addition, the dynamics of mood is driven by all active emotions generated by the EmotionEngine, which are also mapped into the PAD mood space. An initial or default mood in ALMA is defined using the following formula based on the Five Factor Model:

- ***Pleasure*** = 0.21 • Extraversion + 0.59 • Agreeableness + 0.19 • Neuroticism.
- ***Arousal*** = 0.15 • Openness + 0.30 • Agreeableness - 0.57 • Neuroticism.
- ***Dominance*** = 0.25 • Openness + 0.17 • conscientiousness + 0.60 • Extraversion - 0.32 • Agreeableness.

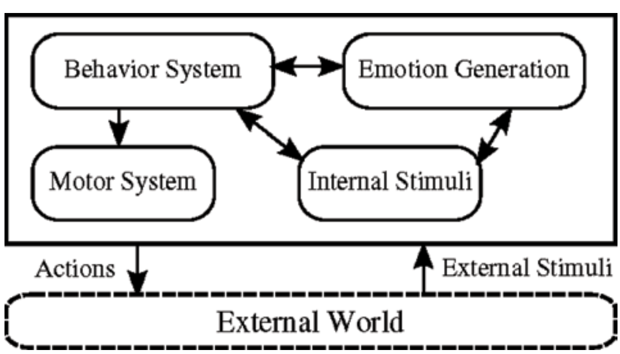
ALMA has been mainly used for modeling multi-agent conversations. This computational model has improved the interchange of information through verbal and non-verbal expressions. Particularly, Alma was implemented in the Virtual Human System (Reithinger, 2006), a knowledge-based framework aimed at creating 3D interactive applications for multi-user/agent settings. In these simulations, Alma allowed virtual humans to maintain affective conversations by implementing emotional reactions and expressions. In addition, in order to evaluate the plausibility of Alma, Gebhard, and Kipp (2006) carried out an experiment in which the emotional and mood states induced in virtual agents were evaluated. In this case, people were asked to evaluate the model based on textual representations of the affective states elicited. According to the authors, such evaluations validate Alma as a model that produces coherent affective states in virtual humans with respect to their human counterpart.

3.3. Cathexis

Cathexis is a C^2ME developed to process the dynamic nature of emotions, moods, and temperaments (Velásquez, 1997). Cathexis models a variety of aspects related to the generation of these affective phenomena and their influences on autonomous agents' behaviors. The architecture of this model consists of two main components, the Behavior System and the Emotion Generation component, as shown in Figure 3. In general, these two modules receive external and internal stimuli, which are used by the emotion module to update the internal motivations and emotions of the agent. Then, based on an updated agent's affective state, the behavior module selects a predefined behavior to perform the next action.

Emotions, mood, and temperaments are modeled using networks of emotional systems working in parallel (also called proto-specialists). Each of those systems represents a family of emotions that are elicited when a set of sensors that monitor external and internal events catch the appropriate conditions. These sensors are classified as neural, sensory-motor, motivational, and cognitive, where the first three categories are considered as Natural-Releasers and the other as Learned-Releaser. This allows Cathexis to characterize the cognitive and non-cognitive emotion elicitation systems of individuals (Velásquez, 1997, 1999). Each emotional system contains two thresholds. One controls the activation of the emotion and the other specifies the level of saturation or maximum intensity (Velásquez, 1997). Cathexis models the six basic emotions proposed by Ekman (1999), which are anger, fear, distress or sadness, happiness, disgust, and surprise, as well as other secondary emotions. The basic emotions are directly represented

Figure 3. The architecture of Cathexis (adapted from Velásquez, 1997)



by the emotional system, while the secondary ones arise as a mixture of parallel elicited basic emotions.

With regard to mood states, Cathexis differentiates this aspect from emotions in terms of levels of arousal. While a mood is handled as a low level arousal within the emotional system, emotions are explained as high level arousal in the same emotional system. Thus, the emotion activation is initialized or facilitated from the potential moods. Furthermore, temperament is considered as a factor that modulates the activation and saturation thresholds in each emotional system. This allows the simulation of diverse personalities by adjusting such thresholds.

In Cathexis, emotional systems may elicit physiological changes, which are modeled in the behavior system component. This module receives the current emotional state generated by the Emotion Generation component as well as the external and internal inputs in order to select the next appropriate behaviors to perform. This component is implemented as a distributed system composed of a network of behaviors and is constituted by two main components: the Expressive or Motor component and the Experiential component. The former alters facial expressions, body postures, and vocal expressions according to current emotions, and the latter simulates the modulation of emotions on actions and cognitions and alters motivation, action tendency, perceptual biases, and selective filtering in cognitive systems.

The Cathexis model has been included and evaluated in virtual and physical autonomous agents. Yuppy (Velásquez, 1997, 1999) is an emotional pet robot that has been situated in various controlled environments in order to evaluate the model of emotions provided by Cathexis. In different experiments, Yuppy was expected to display certain emotional behaviors such as approaching people, avoiding obstacles, and expressing emotions according to the particular situations in which the robot was involved. These experiments with Yuppy demonstrated that Cathexis is an appropriate model for the development of emotional agents whose expressions and behaviors developed in controlled situations are believable.

3.4. Other C^2MEs

In addition to the three models described previously, other C^2MEs have been proposed as reviewed in the following, which share similar architectures and functions.

- **Kismet:** It is an autonomous social robot designed to learn from humans by interacting with them (Breazeal & Scassellati, 2000). This robot is able to perceive affective cues through visual and auditory channels and respond with affective signals based on facial expressions, gaze direction, body posture, and vocal babbles. Its architecture includes a motivational system that implements an emotional process consisting of four phases: affective appraisal, emotion elicitor, emotion activation, and emotion arbitration. This robot has been mainly evaluated in environments in which the robot's emotional state plays a critical role in measuring and regulating the quality of learning (Breazeal, 2003).
- **FLAME (Fuzzy Logic Adaptive Model of Emotions):** It is a C^2ME that emphasizes on memory and experience mechanisms as the basis for emotion dynamics (El-Nasr et al., 2000). This model is inspired by appraisal theories (Ortony et al., 1990). In Flame, the emotional component receives and processes external data and information from a learning module in order to deliver emotional behavior. This component operates through a sequence of four processes: event evaluation, event appraisals, emotion filtering, and behavior selection. Flame has been implemented and evaluated in an interactive emotional pet called PETEEI (PET with Evolving Emotional Intelligence). Experiments demonstrated that flame is able

to improve the believability of this pet by improving its responses according to its internal affective state (El-Nasr et al. 2000).

- **MAMID (Methodology for Analysis and Modeling of Individual Differences):** It is a model that associates two concepts: a generic methodology for the modeling of the influences of emotion on cognitive processing, and an affective-cognitive architecture that implements it (Hudlicka, 2004, 2004b). On the one hand, the basic assumption of the methodology is that emotions and individual traits modulate cognitive processes through the adjustment of particular parameters. On the other, the key component of the architecture is the affect appraisal module which derives the affective state of the agent through the operation of three processes: automatic appraisal, expanded appraisal, and current state modulator. MAMID has been implemented in virtual humans for training and psychotherapy environments.
- **MADB (Motivation/Attitude-Driven Behavior):** It refers to a formal and rigorous model of emotion as a human perceptual process. This model associates emotions with motivations and attitudes in order to influence and control behavior. MADB models the functioning of emotion and other affective behaviors in a formal and rigorous way for quantification of the emotional processes. It demonstrates how brain processes can be explained through formal models and descriptions. In this model, emotions are supposed to arise from the interpretation of the current internal state, mood, experience, and external events (Wang, 2007a).
- **FAtiMA (FearNot! Affective Mind Architecture):** It refers to an affectively driven agent architecture aimed at guiding the construction of believable and empathic characters whose reasoning and behavior are influenced by emotional states and personality. This model is inspired by the work of traditional character animators, which are concerned with the creation of engaging and believable characters that are able to create the illusion of life. This architecture is focused in the modeling of fast and deliberative emotionally influenced reactions. In FAtiMA, each emotion is described based on the following attributes: type, valence (positive or negative), target, cause, intensity, and time-stamp (when the emotion was created or updated). The architecture of this model encompasses two layers known as those of reactive and deliberative for the appraisal and coping components (Dias & Paiva, 2005).

4. AFFECTIVE BEHAVIORS AND EMOTIONS

Affective behavior refers to behaviors implemented by individuals induced by their internal affective motivators such as needs, attitudes, emotions, and mood states. The study and understanding of this type of behaviors is essential to the development of C^2MEs, which have to synthesize the mechanisms underlying affective behaviors as well as the processes of the autonomic and deliberative reactions that accompany them. In this context, C^2MEs are designed to produce emotional signals appropriate to modulate the internal workings of intelligent systems so that they are capable of developing and reflecting an affective behavior. In this section, we analyze the nature of the mechanisms associated with this type of behavior. In particular, we focus on the affective behavior induced by emotions and discuss its significance to the design of autonomous agents.

4.1. The Mechanisms of Affective Behaviors of Humans and Autonomous Agents

Affective behavior is commonly realized in humans as motor reactions such as those of fighting or fleeing as well as non-verbal responses including facial expressions and body postures (Damasio, 1994; Fellous & Arbib, 2005). These are observable reactions that result from the cognitive perception and affective evaluation of internal and external stimuli presented to the individual. Furthermore, these reactions are able to reveal the individual's internal affective condition and its intentions, among other things.

It has been recognized that stimuli interpreted by individuals as emotionally significant always lead to the development of affective behaviors. Multidisciplinary evidence further demonstrates that an emotional experience is always followed by a diversity of psychophysiological responses (Damasio, 1994; Frijda, 1986; Frijda et al., 1989; Phelps, 2006). Moreover, it is known that according to the level of emotional significance recognized in the perceived stimuli, the affective reactions implemented by the individual vary in type and intensity (LeDoux, 1989; Lewis et al., 1989). For instance, a danger situation presented to the individual produces a series of bodily changes and subjective feelings, which are experiential elements of the emotional episode known as fear. As a consequence of these emotional experiences, the subsequent behavior of the individual is influenced by action tendencies also common to such fear episode. Particularly, its behavior is directed to implement the type of reactions that are appropriate to this particular situation, such as fighting or fleeing.

The development of affective behavior has a variety of implications for the individuals themselves and for those with whom they interact. For example, situations assessed as highly emotional always induce affective automatic reactions. According to experiments from diverse disciplines, these reactions are innate, instinctive, and designed to promote the survival of the individual (Ekman, 1999; LeDoux, 1989). However, the implementation of this type of reactions may not always be appropriate; their suitability depends on the context in which they are being developed. An illustrative example is the social environment, in which individuals are expected to have control of their affective feelings, desires, and impulses (especially when they contravene a social norm). Moreover, in interpersonal communication, non-verbal behavior induced by emotions opens a window to the internal state of the individual. For instance, emotional facial expressions reveal the feelings and attitudes towards specific elements in the environment, including the interlocutor's behavior (Ekman, 1999).

There is a large volume of empirical and theoretical evidence that demonstrates and explains the involvement of emotions in affective behavior. For example, experiments by Damasio (1994) and Loewenstein and Lerner (2003) have shown that emotions play a critical role in modulating the human process of decision making. In particular, their findings indicate that emotions are crucial in the development of appropriate decisions in social situations. Similarly, Phelps (2006) has explored the relations between emotions and cognitive functions underlying human behavior. Her investigations have revealed important aspects of their neural mechanisms, which explain how emotions are intertwined with processes such as learning, memory, attention, and perception. Additionally, as we mentioned earlier, research in psychology has led to the categorization of emotions as primary and secondary (Ekman, 1999; Lewis et al., 1989). In this context, while primary emotions have well defined behavior patterns, the behavior that follows to secondary emotions is more dependent on individuals' learned aspects.

For AAs intended to conduct human-like behavior, the inclusion of affective behavior mechanisms in their underlying architecture is a major requirement (Scheutz, 2004). As explained, the normal processing of cognitive functions underlying human behavior is modulated by the emotional significance of the internal and external stimuli perceived by the individual. Therefore, synthetic processes in agent architectures such as those of perception, attention, and memory must be implemented so that they operate on the basis of a cognitive and emotional evaluation of its internal and external environment. In this context, the development of C^{2}MEs becomes of great importance as they are designed to provide such affective behavior mechanisms. In another way, the theoretical foundations of human affective behaviors are also essential as they lay the basis for the synthesis of affective behavior mechanisms in C^{2}MEs.

5. ANALYSIS AND DISCUSSION

As seen in the preceding sections, there is a variety of emotion theories supporting the operational and architectural assumptions of C^2MEs. However, since these theories explain the process of human emotions from different perspectives and at different levels of abstraction, there is a variety of discrepancies between C^2MEs in terms of their architectural and operational designs. Similarly, diverse aspects such as the application domain of C^2MEs force developers to consider certain theories, approaches, and other specific elements during their development process. These decisions definitely result in very particular architectural and operational designs for each C^2ME. In the following, we discuss a number of similarities and dissimilarities among this type of computational models. Also, we analyze some of their most important properties and characteristics.

5.1. Comparative Analysis

In general, C^2MEs summarize the emotion process in three general phases: evaluation of stimuli, elicitation of emotions, and generation of emotional responses. In the first phase, C^2MEs evaluate the emotional significance of perceived stimuli on the basis of a series of appraisal dimensions. For example, MAMID (Hudlicka, 2004, 2004b) performs an assessment of stimuli in terms of their valence using appraisal variables such as expectation and novelty. In the second phase, this type of information is used to elicit particular emotions and determine their associated intensity. For instance, WASABI (Becker-Asano & Wachsmuth, 2010) uses a three-dimensional space to decide which emotions will be elicited. In the last phase, generated emotions may influence specific processes such as decision making (Hudlicka, 2004), conversational skills (Gebhard, 2005), and facial expressions (Becker-Asano & Wachsmuth, 2010). However, despite this general and well accepted abstract cycle, C^2MEs address each of these phases in very different ways. Moreover, regarding the last phase, C^2MEs are still unable to efficiently modulate all the processes that may be involved in a cognitive agent architecture.

One aspect that causes a marked variability between C^2MEs is the number and type of affective processes they take into account for the processing of emotions. As shown in Table 3, Marsella and Gratch (2009) consider mood as the unique affective modulator in the elicitation of emotions. Marinier, Laird, & Lewis (2009) implement a mechanism that includes emotions, mood, and feelings to determine the affective experience of AAs. Similarly, Gebhard (2005) integrates emotions, mood, and personality to achieve affective processing in conversational AAs. Nevertheless, the operational and architectural roles that such affective processes play in each computational model also differ, leading to very different models for the elicitation of emotions.

Regardless of how C^2MEs address the phases described previously and the number and type of affective processes they involve, their development process and architectural and operational design are mainly inspired by psychological evidence as shown in Table 3. The most implemented approach has been the appraisal theory. However, appraisal theories (and most other psychological approaches) do not provide the details needed to fully implement a computational model, forcing developers to include additional "working assumptions" in order to achieve a functional system. These working assumptions, however, may be theoretically validated by considering unaddressed biological evidence, which represents a key challenge in the contemporary development of C^2MEs.

Another important aspect which also varies among C^2MEs has to do with the process of labeling emotions. While some C^2MEs are not interested in providing specific models for this procedure (Marsella & Gratch, 2009; Marinier et al., 2009), others focus on the elicitation of categorical emotions (El-Nasr et al., 2000; Gebhard, 2005). The C^2MEs included in the first class

Table 3. Comparative analyses of main features of typical C²MEs

Model	Foundations	Affective Processes	Emotions Labels	Effects of Emotions	Case Studies
EMA (Marsella & Gratch, 2009)	Appraisal theory by Smith and Lazarus (1990)	Emotions and mood	Surprise, Hope, Joy, Fear, Sadness, Anger, and Guilt	Agent's expressions, attentional processes, beliefs, desires, and intentions	Decision-making in Virtual Humans developed for training purposes
Flame (El-Nasr, 2000)	Appraisal theory by Ortony et al. (1990) and Roseman, Spindel, and Jose (1990)	Emotions, motivational states, and mood	Joy, Sad, Disappointment, Relief, Hope, Fear, Pride, Shame, Reproach, and Admiration. Complex emotions: Anger (sad + reproach), Gratitude (joy + admiration), Gratification (joy + pride), and Remorse (sad + shame)	Action selection	Decision-making in virtual pets showing believable behavior
Mamid (Hudlicka, 2004)	Diverse appraisal theories (Smith & Lazarus, 1990; Smith & Kirby, 2001) and psychological personality models (McCrae & John, 1992)	Emotions and personality	Anxiety/fear, Anger/aggression, Negative affect (sadness, distress), and positive affect (joy, happiness)	Goal and action selection	Virtual humans for training and psychotherapy environments
Alma (Gebhard, 2005)	Appraisal model by Ortony et al. (1990), the Five Factor Model of personality (McCrae & John, 1992), and the PAD Temperament space by Mehrabian (1996)	Emotions, mood, and personality	Admiration, Anger, Disliking, Disappointment, Distress, Fear, Fears Confirmed, Gloating, Gratification, Gratitude, Happy For, Hate, Hope, Joy, Liking, Love, Pity, Pride, Relief, Remorse, Reproach, Resentment, Satisfaction, Shame	Verbal and Non-verbal Expressions such as wording, length of phrases, and facial expressions. Cognitive Processes such as Decision-Making	Embodied Conversational Agents
Cathexis (Velásquez, 1997)	Diverse psychological (Roseman et al., 1990) and neuropsychological theories (Damasio, 1994)	Emotions, drives, mood, and personality	Primary emotions: Anger, Fear, Sadness/Distress, Enjoyment/Happiness, Disgust, and Surprise. This model handles secondary emotions but does not provides an explicit model for the labeling of them	Agent's Expressivity such as facial expressions and body postures. Cognitive Processes such as perception, memory, and action selection	Decision-making in virtual and physical agents
PEACTIDM (Marinier et al., 2009)	Appraisal theory by Scherer (Scherer, 2001) and physiological concepts of feelings by Damasio (1994)	Emotions, mood, and feelings	This model implements the model by Scherer (Scherer, 2001) for the mapping of appraisal dimension values to specific modal emotions	General cognitive behavior	Goal-directed Autonomous Agents
WASABI (Becker-Asano & Wachsmuth, 2010)	Appraisal theory by Scherer (2001), PAD space by Mehrabian (1996), and physiological concepts by Damasio (1994)	Emotions and mood	Primary emotions: Angry, Annoyed, Bored, Concentrated, Depressed, Fearful, Happy, Sad, Surprised. Secondary emotions: Hope, Fears-confirmed, Relief	Facial expressions, involuntary behaviors such as breathing, and voluntary behaviors such as verbal expressions	Emotional expressions and responses in virtual players

argue that the labeling of emotions depends on factors such as culture and personality, which are aspects that may be or may not be considered in the development of C²MEs. Nonetheless, nearly all C²MEs consider the emotional labels included in the group of basic and non-basic emotions as illustrated in Table 3.

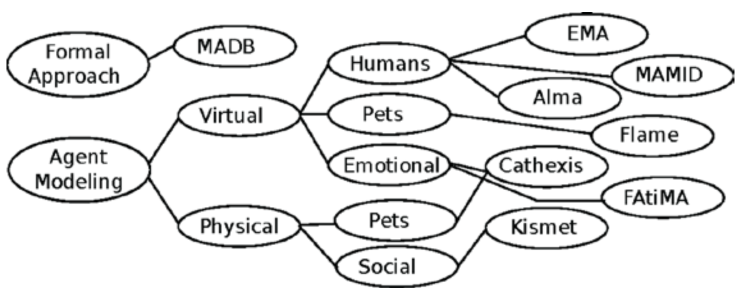
There are several case studies and application domains in which C²MEs have proven useful (Figure 4). As shown in Table 3, the main role of the affective information generated by C²MEs in most applications is to modulate the verbal and non-verbal behavior of AAs. However, although it has been recognized that such behaviors are ultimately developed and implemented on the basis of cognitive functions in humans, developers are not always interested in building convenient environments for integrating both affective and cognitive processing in C²MEs. In fact, C²MEs lack proper environments for the unification of pure affective processes. What's more, they lack scalable architectures able to consistently integrate new findings resulting from the research of human emotions.

According to the survey, the operational and architectural variability in C²MEs may be explained as follows. First, there is no universal and well-accepted theory explaining human emotions. Consequently, the underlying architecture and internal operations of C²MEs are designed on the basis of diverse theories of emotion which usually describe emotional processes from very different perspectives. Second, the development of C²MEs is largely based on psychological theories. As shown earlier, this type of theories lacks the detail needed to fully implement a computational system, leading to the formulation and inclusion of a variety of subjective assumptions in C²MEs in order to achieve a working system. Finally, since each C²MEs is designed for a specific purpose, C²MEs must meet different requirements that restrict the number, type, and nature of the elements that are included in their underlying design. Furthermore, the design of C²MEs has been restricted by mainly two conditions. First, because many of them have been constructed to be included in cognitive frameworks (Becker-Asano & Wachsmuth, 2010; Marinier et al., 2009), they are required to meet specific constraints imposed by these cognitive models. Second, although other stand-alone C²MEs have been proposed (El-Nasr et al., 2000; Gebhard, 2005); they have been developed to process affective information to modulate specific cognitive functions, limiting thus the development of more comprehensive models of emotion.

5.2. The Affective Computing Model of Emotions and Affective Behaviors

Typical C²MEs widely adopt both emotional and affective processes and models in computational intelligence. For example, primary and secondary emotions serve as the basis for understanding

Figure 4. Application domains of C²MEs



emotional states for autonomous agents (Velásquez, 1998), allowing an easy management of emotional labels and emotions elicitation. Furthermore, computational proposals for the emergence of secondary emotions are proposed for C^2MEs.

The relationship between an emotion, motivation, attitude, and behavior can be formally and quantitatively described by Wang's Emotion-Motivation-Attitude-Driven Behavior (EMADB) model as illustrated in Figure 5 (Wang, 2007a). It is noteworthy that, as shown in Figure 5, a motivation is triggered by an emotion or desire.

A behavior B driven by an emotion-triggered motivation M_r and an attitude A is a realized action initiated by a motivation M and supported by a positive attitude A and a positive decision D towards the action, i.e.:

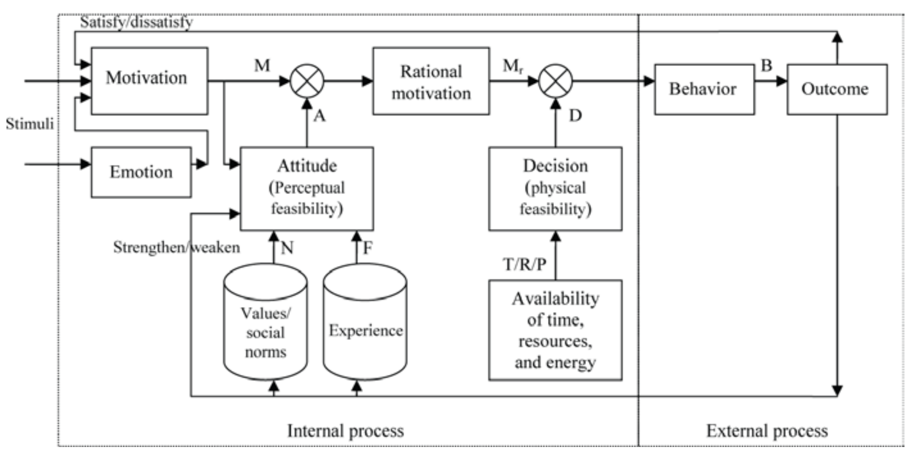
$$B = \begin{cases} \mathbf{T}, & M_r \bullet D = \dfrac{2.5 \bullet |E_m| \bullet (E\text{-}S)}{C} \bullet A \bullet D > 1 \\ \mathbf{F}, & otherwise \end{cases} \tag{1}$$

where detailed definitions of each cognitive variable may refer to Wang (2007a).

5.3. Findings and Discussion

The main purpose of C^2MEs is to simulate the processes of human emotions as well as their interactions with other cognitive processes such as motivations and affective behaviors. To accomplish this, psychological theories and models are intended to explain the process of how humans perceive emotionally relevant stimuli and how they respond to the empirical inputs. However, these theories have been mainly formulated from a functional perspective; they do not contribute to the explicit explanation of the mechanisms underlying human emotions or human cognitive processes. In addition, they do not commit to reveal the fundamental issues such as the source of emotions, detailed mechanisms of their processing, their interaction with other cognitive processes at lower and higher layers as identified in the LRMB reference model of the brain (Wang et al., 2006), and the related structures of emotions in the brain. Therefore, most

Figure 5. The Emotion-Motivation-Attitude-Driven behavior (EMADB) model (adapted from, Wang, 2007a)



of the psychologically inspired C^2MEs use hypotheses to fill these gaps, implementing fairly subjective interpretations or deductions of how a particular mechanism of emotions may work. Further, detailed and rigorous descriptions of cognitive processes of emotions are necessary in the implementation of C^2MEs; otherwise, it would be difficult to implement a functioning and reliable simulation system. For example, appraisal theories do not appear to explain essential characteristics of human emotions. They do not offer explanations for the fast reactions people perform driven by reflective survival processes rather than slow emotional reactions. As a cognitively inspired theory, the appraisal theories require conscious attentions in order to derive most responses, neglecting that the natural minds react by unconscious processes. As a result, although from a functional point of view psychological theories are helpful, they may not be very accurate and rigor to implement robust and rational cognitive C^2MEs.

The recent advances in disciplines such as neuroscience enable the understanding of human behavior by inquiring the underlying mechanisms of the brain (Damasio, 1994; LeDoux, 1989; Phelps, 2006). In the study of human emotions, subareas of neuroscience, neuropsychology, neurophysiology, and cognitive neuroscience provide new perspectives on the cognitive and affective processes involved in the processing of emotions and affects. More interestingly, the latest advances in the emerging fields of cognitive informatics, cognitive computing, neuroinformatics, abstract intelligence, and denotational mathematics (Wang, 2007b, 2010; Wang et al., 2009) are providing new perspectives on C^2ME design and implementation. All these new developments may eventually lead to a hierarchical and reductive explanation of all human unconscious behaviors, such as emotions and other perspective processes as well as those of conscious behaviors in computational intelligence.

6. CONCLUSION

This paper has presented a comprehensive survey and review of the cognitive and computational approaches to explain the human emotional processes in cognitive informatics and cognitive computing. Theories and models explaining the internal mechanisms underlying human emotions have been widely surveyed, which provide a foundation for developing a whole picture on how cognitive computational models of emotions (C^2MEs) may be designed and implemented. A number of psychological, cognitive, and computational models that inspire the development of C^2MEs have been described. Also, the mechanisms underlying affective behaviors and the reactions that accompany them were analyzed and emphasized as important elements in the design of C^2MEs. A comparative analysis of typical C^2MEs has been presented where the common characteristics and properties of C^2MEs are systematically described and elicited. Finally, a discussion was provided on the most essential challenges and issues to be addressed in the development of the cognitive computational models of emotions for autonomous agents and cognitive robots.

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