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Emotion in the Common Model of Cognition

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Abstract

Emotions play an important role in human cognition and therefore need to be present in the Common Model of Cognition. In this paper, the emotion working group focuses on functional aspects of emotions and describes what we believe are the points of interactions with the Common Model of Cognition. The present paper should not be viewed as a consensus of the group but rather as a first attempt to extract common and divergent aspects of different models of emotions and how they relate to the Common Model of Cognition.

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Keywords: *Emotion, Motivation, Common model, Cognitive Architecture*

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1. Introduction

Modeling emotion is essential to the Common Model of Cognition [1] because emotion can't be divorced from cognition. Rational adaptive behavior, for example can't happen without emotion [2] .Emotions play an important functional role, with the purpose of helping us to survive and adapt in complex and potentially hazardous physical and social domains [3]. They aren't necessarily finely tuned but guide our behavior in directions evolution has taught us are wise. They operate more quickly than we can make conscious decisions. Below, we briefly describe the areas of research on emotion that we feel are important for the normal functioning of the Common Model, identify points of interaction with the Common Model of existing emotion models, and describe areas that still need clarifications.

2. Emotions and the four bands of cognition

Newell [4] classified levels of cognition into four bands: biological, cognitive, rational and social. Each band operates at a different time scale (from tens of milliseconds at the biological band to hours and months at the social band). Time scale is a direct result of the execution time of the type of operations implemented at each band. While cognitive architectures initially focused on the cognitive band (and part of the rational band), research in cognitive architectures has expanded to include the biological and social band. We believe emotions also act at four different levels: they emerge at a biological level, act on cognitive and rational control and are expressed and interpreted at the social level. Some emotions might be relatively more focused at the biological level, while some might gain a stronger emphasis at the social level. The balance of where an emotion sits over these levels will depend on the emotion in question and in the particular episode of that emotion. For example, momentary fear as a result of a loud noise is different from a more social emotion like embarrassment due to violation of social conventions

The biological band is concerned with processing at the neural level. We believe models need to be compatible with the neuroscience of emotions as it is a constraint to the structure of the architecture. ACT-R/Φ [5] is such a model, the primary-process affect theory is used as a layer between a physiological substrate and the ACT-R cognitive architecture.

The cognitive band includes memory-level operations (memory retrieval), decision operations (time required to manipulate knowledge), action, and the time required to build an action and execute an action (from 100 msec to 10 seconds). At this level, we believe emotional mechanisms need to blend in with cognitive mechanisms already present in the architecture. Past affective experiences can also influence cognitive processing as well as prospection of affectively loaded future episodes. Juvina et al.[6] 's core affect model, for example, integrates arousal and valuation terms to the general activation equation of ACT-R.

The rational band is goal-driven. It processes knowledge, in order to achieve an adaptive behavior and implements higher level cognition (goal-directed decision making, planning). In HCogAff [7] , a three-level architecture, the second and third levels of the architecture correspond to the rational band. Tertiary emotions can cause disruptions and modify the way the third level manages lower levels. Emotional mechanisms might also help decide whether or not we engage in further processing. In Larue et al.[8] 's model, the feeling of rightness (how good we feel about a first answer) is what will determine the length of processing in the architecture (if we engage in analytical thinking and to what extent). It is implemented using ACT-R's core affect mechanism.

The social band includes higher level cognition with functions such as Theory of Mind, representation of others and moral reasoning. Social aspects in cognitive architectures are increasingly being considered [9] .

3. Emotion: Theories and functions

3.1. Theories

3.1.1. Appraisal theories

Appraisal theories [10] [11] focus on the initial stage of emotional processing during which personal significance is attributed to situational factors through an evaluation process. During the evaluation phase, emotionally relevant information is captured by evaluating a set of factors.

Computational Models of appraisal have been developed (e.g EMA: [10]). In EMA, these factors are: relevance, desirability, likelihood, expectedness, causal attribution, controllability and changeability.

In Sigma ([12] [13]), low-level appraisals are modeled as architectural self-reflection. For example, expectedness, desirability and familiarity variables are added to respectively function as measures of surprise, the difference between the current state and the goal, and how often something has been experienced. These variables are then used, for example, to define attention and to guide search and exploration. Soar-Emote, uses emotional appraisals to frame information before it is processed by the cognitive system [14] . CLARION [15] also uses automatic appraisal (relying on implicit processes) and deliberative appraisal (slower and relying on explicit processes) to influence action-oriented behavior or reasoning (e.g. reevaluation).

3.1.2. Core affect theory

Core affect theory [16] proposes that phenomena attributed to emotions can be explained in simpler terms without the need for emotion labels. Core affect is a state that happens before the emotion is consciously identified that can be described along two dimensions: feeling good or bad and feeling lethargic or energized. Core affect can be seen as a type of appraisal and linked to appraisal theory.

Core affect has been modeled in ACT-R as the weighted accumulation of valuation and arousal values for memory elements [6] . The existing reward mechanism of the architecture and usage information are used to compute valuation and arousal, which are added to the general activation equation and influence the probability of retrieving a chunk. This model was used to explain the impact of affective valuation and arousal on memory and memory decay using participant's memory of negative and positive emotion words after different time periods [6]. It has also been used to model decision-making [17] and deliberative thinking, specifically what triggers deliberation [8] .

3.1.3. Somatic markers

Somatic markers [2] can be thought of as emotional tags attached to a piece of information in declarative memory. The key point about somatic markers is that they enable emotional learning, as they are updated whenever retrieval is associated with good or bad outcomes. ACT-R has been adapted in multiple ways to model effects that can be attributed to somatic markers ([18]-[22]). The representation of appraisals in Sigma also can be viewed in this manner, and more broadly the use of the quantitative metadata that is associated with memory structures in the Common Model of Cognition also maps into this model.

3.1.4. Primary-process affect

Primary-process affect theory [3] posits primary affective processes that are implemented in evolutionarily older neural structures. These lower-level processes combine with secondary-level (e.g., memory) processes to result in secondary-level affect. Tertiary affective processes are also described in yet another (higher) level that is the result of the combination of secondary-process affect with higher-level functioning (e.g, meta-processes like those involved in self-reflection). Key in this formulation is that there are distinct systems that are defined by neurophysiological structure and function and that make up affect; this affect, when combined with other processes, results in higher-level emotional experience.

3.2. Functions

3.2.1. Alarm and interruption

One function of emotion is to generate alarms and interruptions. In HCogAff [7] , emotions are seen as interrupts to ongoing processing following Simon [23]. As West and Young [24] point out, responding intelligently to unexpected interruptions presents a computational problem for production system architectures that is difficult to resolve without the use of external, parallel modules.

In the HCogAff architecture, interruptions and the loss of control can be caused by primary and secondary emotions. Being frightened for example can be implemented as an interruption of processing in the lower reactive level. Secondary emotion can be caused by interruptions in higher level cognitive process (in the deliberative layer). For example, being anxious or being relieved as a consequence of deliberating about what may occur. Additionally, interruptions/disruptions in the third level, which manages processes occurring at the lower levels, result in tertiary emotions. Impairment such as lapses in attentional control are a result of disruption but also more "positive" results such as redirection or acceleration. Tertiary emotions include grief, love, and any emotion where meta-management of other cognitive processes is perturbed. Similarly, in CLARION [15] , interruption (more specifically suppression) allows to carry out emotion regulation: by suppressing some actions at the action-oriented level, by suppressing the perception of certain stimuli or changing priorities at the motivational level. Kennedy and Thompson [25]also see interruption as a potential solution to implement emotional influence on rational processing through interferences with memory retrievals (memory and goal attributes loss in high stress situations) and rules sequences (allowing to skip procedural steps in order to act faster in high stress situations).

3.2.2. Procedural reward

Reward and punishment is essential for learning within the procedural module. The valuation of rewards and punishments is essentially emotional. A theory of emotion would help determine what rewards and punishments for achieving different goals should be. Work has been done in the ACT-R architecture to determine the impact of time (moment in the task), magnitude and purpose (influence performance time or performance itself) of rewards on reinforcement learning [26] .

3.2.3. Social emotionality.

Appraisals and feelings are important for interaction, including competition, collaboration, and assistance demonstrated in several social cognition tasks. Appraisal theory accounts for this to some extent, but, may not be sufficient, as a cognitive-architecture-based empirical study using moral schemas representing relations of trust, subordination, and competition showed[9]. To be believable, an agent needs to rely on virtual constructs – in this example, moral schemas ([9], [27]), representing relations of trust, subordination, competition, or elements of narratives.

3.2.4. Neurophysiological plausibility

While we focused here on functional aspect of emotions, we think models need to be compatible with the neuroscience of emotions. ACT-R/Φ [5] combines a model of a physiological substrate and the primary-process affect theory to augment the ACT-R cognitive architecture. The primary-process affect theory acts as a functional layer between physiology and the architecture. It allows simulating the effect of homeostasis on the architecture, including how these changes in physiology may cause downstream changes in affect and behavior [28]. Similar to previously mentioned work, ACT-R/Φ has these affective changes functionally represented as sub-symbolic changes to modulate behavior, for example, decision-making behavior [29]. While ACT-R/Φ contains functional systems, it may also be beneficial to represent these systems using a system that more closely emulates processing in neural systems [30].

4. Emotions in the Common Model: Potential points of interaction

While the group has not yet reached a consensus in the domain, in the following section, we review points of interaction with the Common Model of Cognition [1] that appear in current models of the emotion-cognition dynamic developed by members of the group. Section numbers in parenthesis refer to Laird, Lebiere & Rosenbloom's original paper.

4.1. Structure and processing (A)

4.1.1. Support of bounded rationality, not optimality (A. 1)

Emotions are a powerful heuristic in bounded rationality that are considered in some theories as designed to solve adaptive problems [30]. They are primordial to prioritize information when our limited bounded capacities can't process all of the information. An ACT-R model [8] reproduces human results by using core affect to show how one prioritizes information using emotional valuation. This strategy proves more efficient than the more optimal strategy of memorizing all elements when there is more information than what one can fully memorize. An affective modulation of memory allows for more adequate decisions in complex tasks that exceed human's limited cognitive capacities. Similarly, Sigma uses surprise and desirability to provide the bottom-up and top-down inputs to attention that determine the level of abstraction during memory retrieval[13] .

4.1.2. A small number of task-independent modules (A.2)

Emotion needs to be integrated into the existing common model of cognition to provide evaluation that participates in actions or decisions but doesn't realize action "on its own". There are currently different approaches. In most models presented in this paper, emotions affect cognitive processing, not as an independent module. West and Young [24] propose to describe emotional processes at a biological level adjusting sub-symbolic processing; but also in response to symbolic information (rewards for example). In Juvina et al. [6] , this dual dynamic can be seen: valuation and arousal are two terms added to the general activation equation which are learned using the existing (positive and negative) reward system of the architecture. In Sigma [13] , low-level appraisals are interoceptors, with low-level sub-symbolic aspects of emotion and high-level symbolic aspects both supported by the existing hybrid (discrete and continuous) mixed (symbolic and probabilistic) nature of the architecture. ACT-R/Φ while adding a physiological module to ACT-R, uses an affect theory as a layer between the two causing dynamic change in subsymbolic values associated with symbolic memory elements. Thus these affective processes influence cognitive processing as through influence of information elements used by functional modules in ACT-R.

4.2. Memory and content (B)

4.2.1. Symbol structures and associated quantitative metadata in declarative and procedural long-term memories (B.1)

Affects are specified as quantitative metadata affecting memory elements. As described in the previous section, somatic markers map directly on to this, and in ACT-R core affect models [6] , declarative memory includes both symbolic structures (i.e., memory chunks) and sub-symbolic quantities that control the operation of the symbolic structures in the equations. The valuation and arousal values, which help to define the core affect, are sub-symbolic quantities. The metadata is the valuation and arousal value associated to chunks in the declarative memory which are additional terms to the activation equation. In ACT-R/Φ, the metadata is the offset added to the ACT-R utility function. In [9] , evaluations are emotional states, understood as an attribute (an appraisal) of a mental state, based on the current situation perceived by the agent in this state. In Sigma, predicates exist into which appraisals can be perceived, with the quantitative metadata defining functions over them.

4.3. Learning (C)

4.3.1. Memory content (symbol structures or quantitative metadata) is learnable (C.1)

As with other memory contents, emotional structures and metadata should be learnable. Eventually, initial values need to be learned. It is theorized that those values (in regard to emotions) are provided to us by society and possibly evolution [31]. In Juvina et al. [6] , the model gradually learns the emotional valuation and arousal associated to different memory elements. In a paired-associates experiment, learning also affects the retrieval of those memory elements, as they are retrieved, reinforced and forgotten. In Sigma, learning over appraisal predicates provides a form of hysteresis akin to moods.

4.3.2. Learning occurs online and incrementally, as a side effect of performance (C.2)

Research shows that the mechanism for the valuation of rewards involves the amygdala (e.g.[32]). To model this we need to know what the evaluation is based on.

In Juvina et al. [6] , learning valuation and arousal metadata for memory chunks is achieved gradually through the existing reward mechanism of the ACT-R architecture. West and Young [24] raise the question of the rewards/awards origins. Indeed, the reward is not necessarily external and can be based on internal values. In Larue et al. [8] , the reward value is based on an internal value of estimated time processing by the architecture obtained through the temporal module.

4.4. Perception and motor capacities (D)

Sigma's work shows impact of appraisals variables (expectedness and desirability) on visual attention.

5. Work in progress

While we pointed to the necessity for emotions to be integral parts of architectures, work still needs to be done on reaching a consensus on what should be the necessary points of interactions between Emotion models and the Common Model of Cognition. We believe however that the review presented in the previous section already emphasizes key divergences between the approaches. Models presented in this paper vary in their implementation choices. In ACT-R/Φ, a separate module allows for affect-associations due to existing evidence that affective association happens in distinct circuits ([33, 34]). In Juvina et al.'s core affect, valuation and arousal values are directly integrated in the existing modules.

Which architectural elements are affected by emotions also needs to be clarified. The core affect approach mainly acts on declarative memory through arousal and valuation variables integrated to the activation equation. ACT-R/Φ proposes action on both procedural and declarative memory. The affect-associations module allows the two different ACT-R memory systems (procedural and declarative memory) to be associated with different affects. In Sigma, affect currently modulates attention in memory retrieval and decision making.

As the different models evolve and address more issues, we expect these questions to be answered. For example, ACT-R/Φ and the core-affect approach address different types of cognitive functions. ACT-R/Φ describes how emotion affects behavior, adding a functional layer between physiology and the architecture, while Juvina's core affect approach was more focused on memory and decision making. We anticipate being able to address the differences between approaches as more models are developed and more efforts are made in the domain of Emotion research to unify existing theories.

6. Summary

In several instances, emotions allow for a decision to emerge faster than one produced through conscious processing. They often act as an efficient heuristic to select relevant information from a flow too large to be completely parsed by our bounded capacities. By adding arousal and valuation values to our declarative memory, by acting as alarms and interruptions or providing fast measures of the desirability of a goal, they can adapt ongoing processing ecologically. In procedural learning, which is an important aspect of the Common Model, the valuation of rewards and punishments is essentially emotional and further study of such processes can inform our use of rewards (specification and effects) in a cognitively plausible way. We also recognized the necessity of developing models that are compatible with neurophysiologically plausible models of cognition. While we have not reached a consensus yet, this paper lists the current points of interaction with the current version of the Common model: structural and processing aspects, emotions as a quantitative metadata in memory, and learning. Finally, we identify the numerous areas the group still needs to work on.

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