Modeling the Mechanisms of Emotion Effects on Cognition

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Abstract

Emotions exert a profound influence on cognitive processes, both the fundamental processes mediating cognition, such as attention and memory, and higher-level processes including decision-making and learning. A number of emotion effects on cognition have been identified, but their mechanisms are not yet understood. In this paper I describe a methodology for modeling the effects of emotion on cognition, within a symbolic cognitive-affective architecture. The primary objective of the approach is to facilitate the construction of alternative mechanisms of observed emotion effects. The paper describes how the effects of anxiety are modeled and how alternative mechanisms of these effects can be explored.

Introduction

Emotions exert profound influences on cognition in biological agents. This is particularly evident in decision-making. All of the processes mediating decision-making are affected by emotion: attention, perception, situation assessment, goal-management and action selection, as well as the associated memory processes.

Emotion effects, and the associated affective decision biases and heuristics, can be adaptive or maladaptive, depending on their type, magnitude and context. For example, anxiety and fear are associated with preferential processing of high-threat stimuli. This is highly adaptive in situations where survival depends on quick detection of danger and appropriate reaction (e.g., avoid an approaching car that has swerved into your lane). The same bias can be maladaptive if neutral stimuli are judged to be threatening (e.g., a passing car is assumed to be on a collision course and causes you to swerve into a ditch.)

A range of emotion effects and biases has been identified: positive emotions induce a global focus and the use of heuristics, whereas negative emotions induce a more local focus and analytical thinking; anxiety reduces attentional and working memory capacities, biases attention towards the detection of threatening stimuli, and biases interpretive processes towards higher threat assessments, anxiety also induces a self-bias; mood induces mood-congruent biases in recall (Isen, 1993; Mineka et al., 2003).

However, the mechanisms mediating these effects are not yet understood. A better understanding of these mechanisms would enable us to make use of the adaptive aspects of emotion effects in agent architectures, and would enable the design of human-machine interfaces that could help counteract the maladaptive emotion effects.

This paper describes an approach to modeling emotion effects that focuses on identifying the associated alternative mechanisms. The approach is implemented within a symbolic cognitive-affective architecture, MAMID, that models high-level decision-making (Hudlicka, 2007; 2004; 1998). MAMID is a process-oriented model, focusing on emotion, and as such aims to explicitly represent the structures and processes mediating affective processing and emotion-cognition interactions.

Key aspects of MAMID that make it suitable for modeling alternative mechanisms of emotion effects are: (1) high degree of parameterization, enabling manipulation of architecture topology and data flow, and processing within the modules, and (2) testbed environment, within which MAMID is embedded. The testbed facilitates rapid model development and interactive model ‘tuning’, by providing the modeler access to a range of model parameters, and control of the functions that derive their values. By manipulating these parameters, alternative hypotheses regarding the mechanisms of an observed phenomenon can be rapidly implemented and their behavior evaluated within the context of a specific task.

MAMID is a domain-independent architecture, which has been evaluated in two domains: modeling members of a search-and-rescue team (Hudlicka, 2005), and modeling unit leaders in a peacekeeping scenario (Hudlicka, 2003; 2007). MAMID is currently undergoing validation in conjunction with a parallel set of empirical studies with human subjects, within the search-and-rescue task.

MAMID Cognitive-Affective Architecture

MAMID implements a sequential see-think-do processing sequence (figure 1), consisting of the following modules: Sensory Pre-processing (translates incoming data into task-relevant cues); Attention (filters incoming cues and selects a subset for processing); Situation Assessment (integrates individual cues into an overall situation assessment); Expectation Generation (projects current
situation onto possible future states); Affect Appraiser (derives a valence and four of the basic emotions from external and internal elicitors); Goal Management (identifies high-priority goals); and Behavior Selection (selects the best actions for goal achievement).

These modules map the incoming stimuli (cues) onto the outgoing behavior (actions), via a set of intermediate internal structures (situations, expectations, and goals), collectively termed mental constructs. This mapping is enabled by long-term memories (LTM) associated with each module, represented by belief nets. Mental constructs are characterized by their attributes (e.g., familiarity, novelty, salience, threat level, valence, etc.), which influence their processing; that is, their rank and the consequent likelihood of being processed by the associated module within a given execution cycle; (e.g., cue will be attended, situation derived, goal or action selected).

The availability of the mental constructs from previous execution cycles allows for dynamic feedback among constructs, and thus departs from a strictly sequential processing sequence. Note also that all constructs derived in a given execution cycle are available to subsequent modules for processing, within that cycle.

The Affect Appraiser module incorporates elements derived from the emotion-specific belief nets, reflecting the idiosyncratic contributions of specific elicitors. Emotion intensities are determined from four contributing factors: Trait bias factor – reflecting a tendency towards a particular emotion, as a function of the agent’s trait profile (e.g., high neuroticism/low extraversion individuals are predisposed toward negative emotions). Valence factor – reflecting a contribution of the current valence, where negative valence contributes to higher intensities of negative emotions and vice versa. Static context factor – reflecting the agent’s skill level and contributing to the anxiety level if skill level is low. Individual factor-weighted sum of the emotion intensities derived from the emotion-specific belief nets, reflecting the idiosyncratic contributions of specific elicitors.

The Affect Appraiser module incorporates elements from several appraisal theories: domain-independent appraisal dimensions, multiple-levels of resolution, and multiple stages (Leventhal & Scherer, 1987; Smith & Kirby, 2000).

MAMID models emotion effects using a generic methodology for modeling multiple, interacting individual differences, both stable traits and dynamic states (Hudlicka, 2007; 2003; 1998). A particular configuration of emotion intensities and trait values is mapped onto a corresponding set of architecture parameter values, which then control processing within the architecture modules, as well as the data flow among the modules (figure 3).
MAMID models all three of these effects, and provides reductions in both attention and working memory. Threat processing bias, self-processing bias, etc. (Matthews, 2008).

We illustrate the MAMID modeling methodology with an example demonstrating how multiple mechanisms of anxiety effects can be modeled within MAMID, for anxiety intensities ranging from low to extreme states, such as a panic attack. Anxiety was selected because of its direct relevance for decision-making and behavior, because robust empirical data regarding its effects are available, and because anxiety is emerging as the most significant effect in on-going empirical validation studies (Matthews, 2008).

Panic attack is an interesting state to explore because its extreme nature provides a useful context in which to model the effects of anxiety on cognition, and cognition-emotion interaction in general. Panic attack is a state where the confluence of multiple anxiety effects produces a type of ‘perfect storm’, frequently inducing behavioral paralysis. Three anxiety-linked effects are involved: threat processing bias, self-processing bias, and capacity reductions in both attention and working memory. MAMID models all three of these effects, and provides parameters that control their relative contributions to the overall effect on processing.

Recall that a given parameter value is the results of a linear combination of the weighted factors influencing the parameter. The same overall effect (e.g., reduced module capacity) can thus be obtained from multiple combinations of factor values and weights. These alternative configurations then provide the means of defining alternative mechanisms mediating specific effects. MAMID provides facilities that support the rapid construction of these alternative mechanisms, via interactive manipulation of the factors and weights, which allow the modeler to control the magnitude and contribution of each influencing factor.

Threat bias is modeled by first calculating the threat level of each cue, situation and expectation, from factors that include an a priori ‘fixed’ threat level (e.g., low level of resources is inherently more threatening than adequate resources), state and trait anxiety factors, and individual history. The threat level is then used as a weighted factor in the function calculating the overall construct rank, which determines the likelihood of its processing. In states of high-anxiety, high-threat constructs have a higher ranking, and are thus processed preferentially (cues attended, situations derived) (refer to figure 4).

Self bias is modeled by including a weighted factor reflecting the self vs. non-self origin of each construct in its rank calculating function. High levels of state or trait anxiety then induce a higher ranking for self-related constructs, contributing to their preferred processing.

The capacity reduction effects on attention and working memory are modeled by dynamically calculating the capacity values of all modules during each execution cycle, from weighted factors representing the emotion intensities, the four traits represented in MAMID, baseline capacity limits, and skill level.
MAMID’s ability to model alternative mechanisms of anxiety effects was demonstrated in the context of a specific task, within the search-and-rescue domain. Briefly, the agent’s task is to find a “lost party” in an inhospitable terrain, where “emergency situations” arise unexpectedly. The agent may need to obtain supplies from available “supply stations”, to maintain adequate resources (fuel, first aid kits). In the experiment described below, the agent approaches a difficult “emergency situation”, and lacks the required resources. The agent’s state of anxiety, dynamically calculated by the Affect Appraiser module, is high; in part because of a trait-induced tendency towards higher anxiety, and in part because of the difficult task ahead and lack of adequate resources.

Within this context, MAMID models a panic attack state as follows. Stimuli, both external and internal, arrive at the Attention Module, whose capacity is reduced. Because of the threat- and self-bias, self-related high-threat cues are processed preferentially, in this case resulting in the agent’s focus on a self-related anxiety cue (see figure 5, lower left). This cue, reflecting the agent’s anxious state, consumes the limited module capacity, leading to the neglect of external and non-threatening cues (e.g., proximity of a supply station). This results in a continued self- and threat-focus in the downstream modules (Situation Assessment and Expectation Generation). No useful goals or behaviors can be derived from these constructs, and the agent enters a positive feedback-induced vicious cycle (an endless self-reflection), where the reduced-capacity and biased processing excludes cues that could lower the anxiety level and trigger adaptive behavior. Figure 5 shows a diagram of the emotion intensities and module capacities,
both information seeking and behavior selection, within
with human subjects is demonstrating anxiety biases in
focus on anxiety and anger. The on-going empirical study
MAMID’s abilities to model alternative mechanisms of
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distinct patterns of neuromodulation, corresponding to
affective factors (states and traits), influence a broad
range of cognitive processes and structures (e.g.,
weights associated with trait and state anxiety intensity
factors), the baseline, ‘innate’ capacity limits (reflected in
the factors representing the minimum and maximum
attention and working memory capacities), and the
anxiety intensity itself. This factor can be further
manipulated via the set of parameters influencing the
affect appraisal processes, including the nature of the
affective dynamics (e.g., maximum intensity, and the
intensity ramp-up and decay functions).

Related Work

A number of researchers have independently proposed a
broader theory of mechanisms mediating emotion-
cognition interaction, where parameters encoding various
affective factors (states and traits), influence a broad
range of cognitive processes and structures (e.g.,
(Hudlicka, 1998; Matthews & Harley, 1993; Ortony et al.,
2005). These parameter-based theories are consistent with
recent neuroscience theories, which suggest that emotion
effects on cognition are implemented in terms of
systemic, global effects on multiple brain structures, via
distinct patterns of neuromodulation, corresponding to
distinct emotions (Fellous, 2004). Several recent models
of emotion effects use an approach that shares similarities
with the MAMID methodology described here, that is, the
use of processing parameters to encode emotion effects
(Belavkin & Ritter, 2004; Ritter & Avraamides, 2000;
Sehaba et al., 2007). The approaches vary in terms of
specific parameters represented, the functions used to
calculate their values, and whether or not the parameters
correspond to psychological functions and processes, or
serve a generic ‘noise’ parameters that globally degrade
architecture performance to simulate states such as stress.

Conclusions

MAMID’s abilities to model alternative mechanisms of
emotion effects are continuing to be evaluated, with a
focus on anxiety and anger. The on-going empirical study
with human subjects is demonstrating anxiety biases in
both information seeking and behavior selection, within
the search-and-rescue task context. The results are being
used to tune the MAMID parameters, as outlined above.
Since the parameters correspond to specific psychological
variables or functions, we hope that this parallel
empirical-computational approach will provide a useful
means for validating MAMID models of emotion effects
on cognition.

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