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A Computational Model of Emotion and Personality: Applications to Psychotherapy Research and Practice

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Abstract: *VR applications in psychotherapy are gaining prominence in the research community and acceptance among practitioners, with particular successes in the area of phobia treatments. However, a promising technology remains unexplored: computational models of cognition and emotion. Cognitive models (also termed cognitive- or agent-architectures) aim to emulate cognitive processing such as attention, perception, and decision-making, and are used by cognitive scientists to advance understanding of the mechanisms and structures mediating cognition. These models are also used in applied settings to improve the realism of training and assessment environments, and to improve human-computer interaction and system design. Recently, architectures have been developed that explicitly represent emotions: both emotion appraisal processes, and effects of emotions on cognition. Such computational models of cognition and emotion have two types of applications in cybertherapy. First, they can enhance the realism of a synthetic agents used in VR assessment and treatment environments (e.g., avatars used in social phobia treatment). Second, they have the potential to advance our understanding of the etiology and treatment of a variety of affective disorders, by enabling the modeling of the mechanisms of cognitive-affective interactions that play central role in these disorders, and in their treatments. In this paper I first describe a cognitive-affective architecture capable of modeling the dynamic generation of emotions (affect appraisal), and selected effects of emotion on cognition. I then describe possible applications of this architecture to psychotherapy practice and research.*

INTRODUCTION

VR applications in psychotherapy are gaining prominence in the research community and acceptance among practitioners. Significant success has been achieved with VR therapies aimed at a variety of phobias and PTSD (e.g., http://www.virtuallybetter.com/).[1] However, a promising technology remains unexplored: computational models of cognition and emotion. Cognitive models (also termed cognitive- or agent-architectures) aim to emulate cognitive processing such as attention, perception, learning, problem-solving, planning and decision-making, and are used by cognitive scientists to advance understanding of the mechanisms and structures mediating cognition.[2] These models are also used in applied settings to improve training and human-system design.[3] Recently, architectures have been developed that explicitly represent emotions: both emotion appraisal processes, and effects of emotions on cognition.[4-9]

While a number of researchers are advocating the use of avatars in VR therapy environments,[10] and promising research efforts exist,[11] little work has been done in coupling synthetic avatars with cognitive-affective architectures. Thus, the potential of cognitive architectures, and associated computational modeling research methods, have not been explored in psychotherapy research and practice. The primary purpose of this paper is to introduce computational cognitive-affective architectures to the cybertherapy community, and describe examples of possible applications in psychotherapy research and practice. These include the enhancement of synthetic avatars in VR treatment and assessment environments (e.g., distinct avatars could be defined to support dynamic, adaptive interaction during social phobia treatment, each with different behavioral characteristics to practice particular situations), and the development of computational models aimed at advancing our understanding of the mechanisms that contribute to the development of emotional disorders (e.g., inappropriate coping strategies), and those involved in treatment (e.g., cognitive restructuring). The paper is organized as follows. First, I describe a cognitive-affective architecture capable of modeling the dynamic generation of emotions (affect appraisal), and some effects of emotions on cognition (section 2). I then discuss how this architecture could enhance psychotherapy practice (section 3.1) and how it could be used to advance research in the area of affective disorders, by enabling the modeling of the mechanisms of the cognitive-affective interactions mediating both the development and treatment of a range of affective disorders section 3.2).

MAMID COGNITIVE-AFFECTIVE ARCHITECTURE

The MAMID cognitive-affective architecture is an integrated symbolic architecture, aimed at emulating aspects of human information processing, with particular focus on the role of emotion in decision-making (see figure 1A). To this end, MAMID models the *cognitive appraisal* process to dynamically generate emotions in response to incoming stimuli, and then models the subsequent *effects of these emotions on distinct stages of decision-making*. Below we describe the MAMID architecture, the generic methodology for modeling effects of emotions (and other individual differences, including personality traits), and a preliminary evaluation.

MAMID ARCHITECTURE

MAMID implements a sequential see-think-do processing sequence (figure 1B), consisting of the following modules: *sensory pre-processing*, translating incoming data into task-relevant cues; *attention*, filtering incoming cues and selecting a subset for processing; *situation assessment*, integrating individual cues into an overall situation assessment; *expectation generation*, projecting current situation onto possible future states; *affect appraiser,* deriving the affective state (both valence and four of the basic emotions) from a variety of external and internal elicitors, both static and dynamic; *goal selection*, selecting critical goals for achievement; and *action selection,* selecting the best actions for goal achievement. These *modules* translate the incoming stimuli (cues) onto the visible behavior (actions), via a series of intermediate internal representational structures (situations, expectations, and goals), collectively termed *mental constructs*.

This "translation" is enabled by long-term memories (LTM) associated with each module, represented in terms of belief nets or rules. Belief nets resemble causal graphs and are well-suited for representing causal relationships among propositions, and at manipulating uncertainty. Rules represent 'IF-THEN' relationships, and are well-suited for representing simple inferences. (Figure 4 shows examples of rules.) *Mental constructs* are characterized in terms of a number of attributes (e.g., familiarity, novelty,

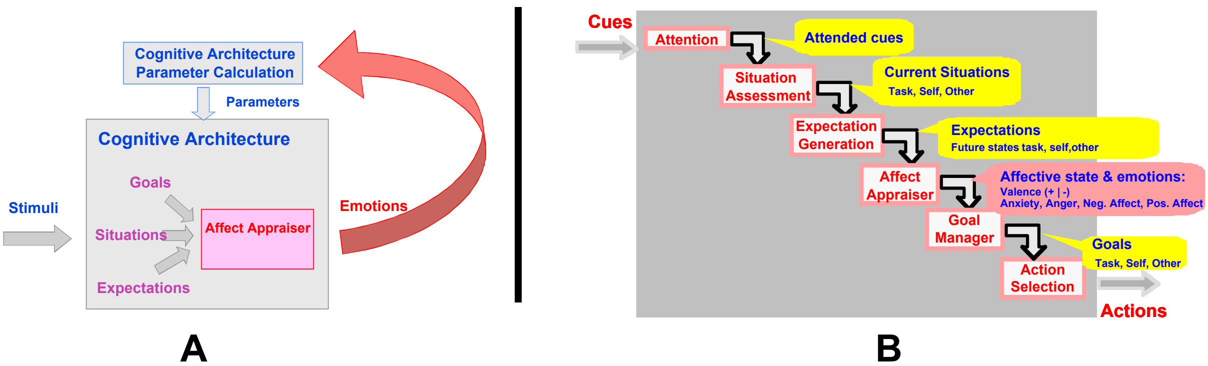

Figure 1. (A) Modeling Affect Appraisal and Emotion Effects within a Cognitive Architecture; (B) MAMID Cognitive Architecture: Modules & Mental Constructs

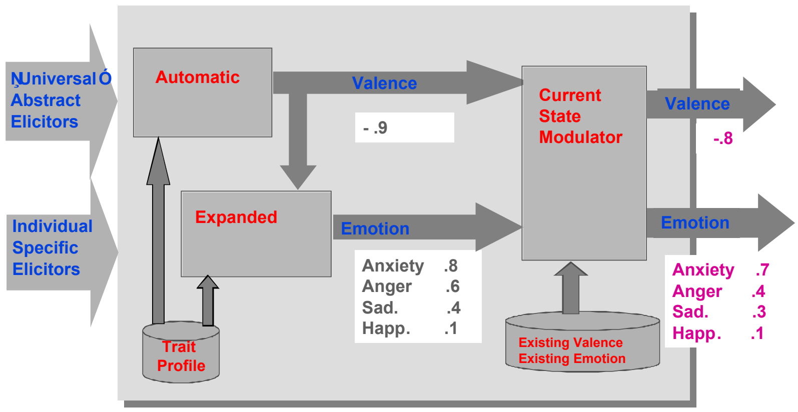

Figure 2. Affect Appraisal Model

salience, threat level, valence, etc.), which collectively determine their processing; that is, the likelihood of a cue will be attended, situation derived, goal or action selected, etc.

The Affect Appraisal module plays a central role in MAMID (see figure 2). It incorporates elements of several recent appraisal theories: *multiple*-levels[4,12,13] and *multiple stages*.[14] The *multi-level structure* generates both a *low-resolution assessment* of the current set of stimuli, in terms of a valence, and a *higher-resolution categorical assessment,* in terms of four of the basic emotions: anxiety/fear, anger, sadness, happiness. Its *multi-stage structure* uses both *universal elicitors* (e.g., novelty, threat level, pleasantness, unexpectedness), to generate the valence using an *automatic appraisal* (roughly corresponding to the largely 'hardwired', 'primitive' appraisal components), and more *cognitively-complex and idiosyncratic elicitors* (e.g., individual history, expectation- and goal-congruence), to generate a categorical assessment using an *expanded appraisal.*

The resulting affective states then influence processing in several ways: (1) they are used directly in the rules selecting the agent's goals and actions; (2) they influence the speed and capacity of the architecture modules; (3) they influence mental construct ranking, thus determining whether a specific cue or situation is processed, or specific goal selected. The last two effects have been a particular focus of this effort, and aim to emulate some of the empirically-identified mechanisms of emotion effects within the perceptual and cognitive apparatus, as outlined above.

GENERIC STATE AND TRAIT MODELING METHODOLOGY

MAMID uses a previously described methodology for modeling state and trait effects within a cognitive architecture,[5,15] which consists of mapping particular state / trait profiles (e.g., high trait and state anxious individual) onto specific architecture parameter values (figure 3). These parameters then control processing within individual architecture modules. Functions implementing these mappings were constructed on the basis of the available empirical data. For example, reduced attentional and working memory (WM) capacity, associated with anxiety and fear, are modeled by dynamically reducing the attentional and WM capacity of the architecture modules, which then reduces the number of constructs processed (fewer stimuli attended, situations derived, expectations generated, etc.). Attentional threat bias is modeled by higher ranking of threatening cues, thus increasing their likelihood of being attended, and by higher ranking of threatening situations and expectations, thus increasing the chances of a threatening situation / expectation being derived. Trait-linked structural differences in LTM are supported by allowing the flexible selection of alternative LTM clusters, reflecting distinct personality traits (e.g., selection of clusters with greater proportion of threat- and self-related schemas to represent individuals with high trait-anxiety (high neuroticism). Traits also influence the dynamic characteristics

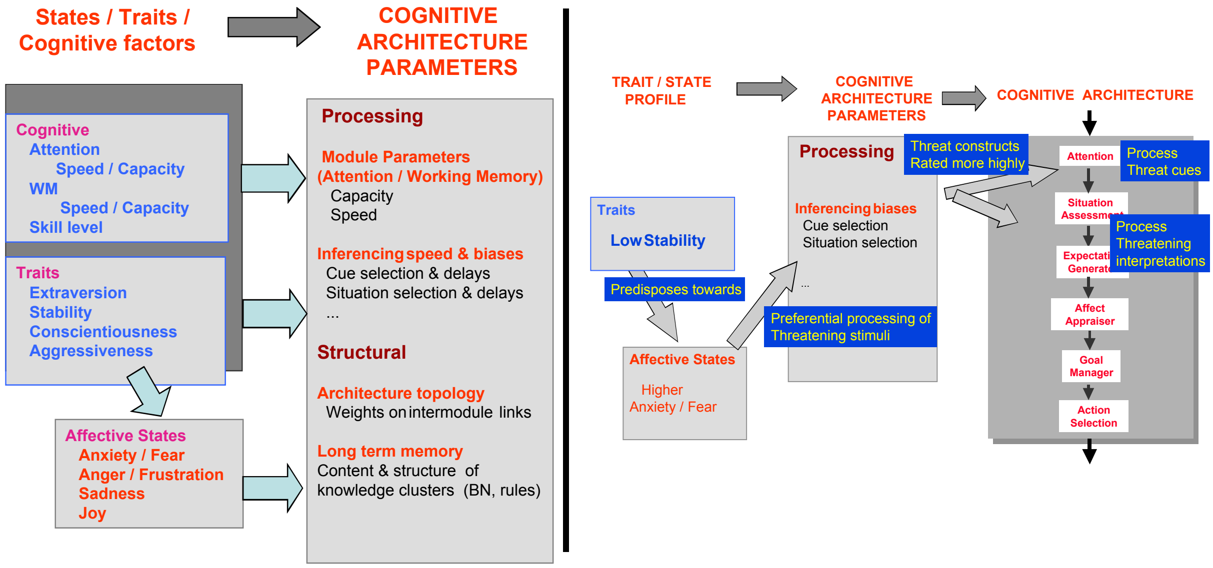

Figure 3. (A) Parametric State / Trait Modeling Methodology;
(B) Modeling Threat-Bias Effects Associated with Trait and State Anxiety

of the emotional responses (ramp up, decay, and maximum intensities).

There are several advantages of this methodology for state-trait effect modeling: *(1)* it facilitates rapid modeling of a broad range of distinct individual profiles; (2) the rich architecture parameterization allows the definition of additional high-level individual characteristics (e.g., obsessive-compulsive); (3) it provides a means of integrating the possibly conflicting effects of multiple, interacting traits and states, much as these influences interact in humans.

RESULTS

Feasibility of the model was demonstrated in the context of a simulated peacekeeping scenario, where separate instances of the architecture controlled the behavior of 'stereotypical' unit leaders ('anxious', 'aggressive', 'normal'). The same set of external stimuli triggered distinct emotions and emotional response patterns in the different stereotypes (e.g., higher anxiety levels in the 'high anxious' stereotype), and their effects on decision-making then caused differences in observable behaviors (e.g., slower movement and more communication behaviors in the anxious stereotype). The MAMID architecture is domain-independent, to facilitate transitions to other domains, including psychotherapy.

APPLICATIONS OF COGNITIVE-AFFECTIVE ARCHITECTURES IN PSYCHOTHERAPY

Below we describe how the MAMID cognitive-affective architecture could be used to enhance the effectiveness of therapeutic VR environments, as well as how it could advance our understanding of the etiology and treatment of a range of affective disorders, by supporting adaptive, dynamic interaction between patients and synthetic avatars.

Applications in Clinical Practice

MAMID's ability to represent a variety of distinct stereotypes (in terms of distinct state-trait profiles), and to control the behavior of synthetic avatars in virtual environments, enables it to generate a broad range of avatar stereotypes, characterized by distinct behavioral repertoires (e.g., 'aggressive audience member', 'angry friend', 'anxious spouse'). The ability to dynamically generate individual idiosyncratic behavior characteristic of these stereotypes then enhances the avatar believability, and effectiveness within therapeutic VR environments.

For example, to treat social phobia, or fear of public speaking, a virtual environment would be

ŅSupportiveÓAudience Member Avatar

Rule **Respond to Speaker**
IF (**Situation** = Speaker talking)

THEN
(**Action** = Facial expression: smile)
(**Action** = Head movement: nod)
(**Action** = Utterance: ŅThatÕs rightÓ))

Aggressive Audience Member Avatar

Rule **Respond to Speaker**
IF (**Situation** = Speaker talking)

THEN
(**Action** = Facial expression: frown)
(**Action** = Head movement: shake)
(**Action** = Utterance: ŅI donÕt think soÓ))

Figure 4. Examples of MAMID Rules Controlling Action Selection in Two Distinct Stereotypes, Controlling Avatars in a “Fear of Public Speaking” Application

populated by synthetic avatars displaying particular characteristics that trigger undesirable symptoms (e.g., aggressive individuals would be defined for patients exhibiting fear of public speaking symptoms when confronted with critical or aggressive remarks). The avatars would then generate aggressive or critical behaviors (e.g., frown while producing utterances critical of the speaker-patient). Figure 4 shows examples of two rules that would define distinct behavior sequences for distinct audience member avatars. The ‘optimal’ behaviors triggering the undesirable symptoms would be identified empirically, so that the avatar behavior could be customized to produce the desired level of anxiety in the patient. Once identified, the patient would be exposed to these behaviors to implement the desired therapeutic protocol (e.g., exposure therapy, systematic desensitization). The patient would be able to interact with the avatars (e.g., defend himself against a verbal attack, take time to implement a coping strategy), and the avatar’s ability to dynamically respond to these interactions (e.g., back off vs. persist) would then provide a degree of realism and customization that are not currently possible in VR treatment environments. The use of such avatars, embedded within simulated situations, would also enhance assessment.

ADVANCING PSYCHOTHERAPY RESEARCH THROUGH COGNITIVE-AFFECTIVE MODELING

By enabling the construction of computational causal models of cognitive-affective interactions, the MAMID architecture also provides a tool for modeling the etiology and treatment of a variety of disorders, as well as the systematic development of targeted assessment and treatment protocols. In this case MAMID would be used to model specific cognitive-affective processes characteristic of a particular disorder. For example, the positive feedback cycle among symptoms and behaviors characterizing generalized anxiety disorders and phobias could be modeled by representing the increasing predominance of anxiety-related schemas in the patient’s long-term memory, increased sensitivity to anxiety-producing stimuli, and generalization across previously neutral stimuli, as the disorder becomes established, all contributing to increasingly avoidant behaviors and withdrawal, characteristic of generalized anxiety. Results of therapeutic interventions could then be modeled by ‘exposing’ the MAMID architecture patient model to repeated simulated inputs, representing particular therapeutic interventions (e.g., cognitive restructuring, systematic desensitization), as well as changing social and environmental contexts. This would then result in the gradual emergence of more adaptive memory schemas and interpretations (in the case of cognitive restructuring aimed at teaching specific anxiety-coping strategies), and diminished sensitivity and reactiveness to previously anxiety-producing stimuli (in the case of systematic desensitization and exposure protocols). Improved understanding of these processes would provide opportunities for more finely-tuned assessment and treatment protocols. Computational models support the development of more refined theories and the generation of specific experimental hypotheses aimed at validating a particular theoretical model.

SUMMARY AND CONCLUSIONS

While much progress has been made in virtual reality treatment environments, the use of cognitive models to control synthetic avatar behavior has not been explored. In this paper I suggest that the incorporation of such models would greatly enhance the effectiveness of these environments, by enhancing the believability and effectiveness of synthetic avatars, and by supporting the development of customized treatment and assessment protocols.

I described a cognitive-affective computational architecture (MAMID), capable of controlling the behavior of such adaptive avatars. MAMID models affect appraisal processes and the effects of several emotions on distinct aspects of decision-making, thereby enabling the definition of a variety of 'stereotypes', capable of exhibiting distinct patterns of behavior within the VR environments. I provided examples of how the MAMID architecture could be used to enhance believability of synthetic avatars, and thereby enable the construction of customized VR treatment and assessment environments. I also discussed how a computational model of cognitive-affective interactions, and their role in perception and decision-making (including situation assessment, expectation generation and goal management), could be used to advance our understanding of the role of these mechanisms in the etiology, maintenance and treatment of a variety of affective disorders. To this end, I described an example of how MAMID could be used to model a patient suffering from a particular set of symptoms, and how specific interventions could be simulated and represented within the MAMID model.

The development of cognitive architecture in general, and cognitive-affective architectures in particular, is an active research area. Much progress has been made in modeling specific cognitive processing (e.g., acquisition of particular arithmetic skill, perception). While currently there is no validated architecture of cognition, the existing architectures are capable of producing a range of 'stereotypical' behaviors, which would resemble real humans and enhance VR treatment protocols requiring social interaction. The computational modeling methods are also well suited for advancing research in clinical psychology, by allowing the development of models of particular disorders, and exploring the different effects of alternative treatment protocols.

Research programs combining empirical studies with computational modeling are becoming more common in cognitive science. I believe that the modeling methods have matured to the point where similar applications in psychotherapy research can be of great benefit.

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