TOWARD A HUMAN EMULATOR: A FRAMEWORK FOR THE COMPREHENSIVE COMPUTATIONAL REPRESENTATION OF HUMAN COGNITION

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In recent years, Sandia National Laboratories has undertaken a program of research and development with the goal to attain a realistic computational representation of human cognition, a "human emulator." Realism requires that the representation address cognitive, and organic factors (e.g., stress, arousal, fatigue). Near-term application is envisioned in training and evaluation with long-term potential for broad application across a spectrum of technologies. This paper describes the conceptual framework that has been developed and implemented in an initial prototype. Specifically, this framework emphasizes a computational instantiation of Naturalistic Decision Making with an underlying foundation based on human neurophysiology.

INTRODUCTION

To date, there has been limited application for human modeling and simulation technologies with military training and evaluation providing the primary driver for research and development. In general, attention to visual graphics and computational algorithms has dominated concern for behavioral realism. Nonetheless, various camps have made good progress in the computational representation of basic cognitive processes (Pew & Mavor, 1998). However, there has been marginal progress toward representations that incorporate the influence of organic factors on behavior (i.e., arousal, fatigue, etc.). It has been our goal at Sandia National Laboratories to develop a comprehensive framework that encompasses the requisite cognitive processes, but also incorporates organic factors that range from the microscopic (e.g., metabolic, pharmacological, etc.) to the macroscopic (i.e., culture). This paper describes the conceptual framework for a "human emulator," including illustrations from an initial prototype.

FOUNDATION

Two earlier projects at Sandia National Laboratories contributed to the initial conceptualizations for the human emulator. First, in developing the behavior model for a small unit combat simulator, we sought an instantiation of human naturalistic decision making theory within the context of an agent-based computer simulation. This instantiation utilized Klein's Recognition Primed Decision Making (RPD) model with emphasis on Level 1 decision making (Klein, 1997). According to RPD, an expert decision maker commits their resources to evaluating the situation and through this evaluation, patterns are detected that lead to recognition that the current situation is analogous to situations that are known from past experience. The appropriate course of action is implicit in recognition of the situation. As illustrated in Figure 1, the instantiation of this concept involved the representation of environmental cues and relevant knowledge in a manner that accommodates pattern recognition. Patterns are associated with known situations (i.e., tactics) and once there is a match between the ongoing situation and a known situation, generic scripts are employed to direct agent behavior.

Secondly, within a systems engineering/safety context, Forsythe and Wenner (2000) have advanced an organic model to account for human influences on engineered systems. This model challenges physical and computational science-based approaches through its emphasis on an organic systems perspective. Specifically, it is asserted that due to human influences, engineered systems are inherently organic and will exhibit properties of organic systems. These properties have been described and provide a basis for predicting aberrant behavior of engineered systems.

CONCEPTUAL MODEL FOR THE EMULATOR

Early in development, we realized that a purely psychological model, exemplified by Figure 1, would be inadequate for representing the influence of organic factors on cognitive behavior. There is enormous ambiguity in basic terminology (e.g., stress, arousal) and without a representation of underlying mechanisms, the scope and predictive capabilities would be severely limited. However, many facets of cognitive behavior (e.g., knowledge representation) are well described by psychological models (Goldsmith et.al., 1991). Consequently, we adopted a two-tiered approach in which knowledge is represented using a psychological model, however a separate physiology-based model serves as the engine that drives the psychological model (See Figure 2). The fact that knowledge is not directly represented in the neural (i.e., physiological) model distinguishes this design from neural net and connectionist approaches, yet facilitates representation of the vast quantities of knowledge essential to a realistic emulation.

The mapping of the psychological to the physiological model was critical. We retained the concepts embodied by our earlier instantiation of Recognition Primed Decision Making. This included a separate representation of individual situational elements, pattern recognition and activation of schema-like representation of known situations. Frame/Content theory provided an initial bridge. This theory asserts that the representation of individual elements of content within a structural or contextual frame is a basic organizing principle of the neural system (MacNeilage, 1998). Examples include figure/ground relationships in perception, syntax and semantics in linguistics, and differential motor specialization for stabilization and manipulation. Applying frame/content theory, individual elements of a situation represent content, whereas situation schema provide an interpretive frame.

Further extension involved mapping these ideas to the model of memory processes proposed by Wolfgang Klimesch and colleagues (Klimesch, 1996). Two phenomena have been described. First, in the absence of intrinsic or extrinsic stimulation, regions associated with semantic memory exhibit synchronous activation in the high alpha (10-13 Hz) bandwidth. Once stimulated, desynchronization occurs. It is suggested that semantic memory processes involve the activation of numerous localized neural assemblies. These assemblies oscillate in phase with pulses from a pacemaker until stimulated, at which time activation increases and assemblies begin to oscillate independent of the pacemaker. At this point, there is desynchronization. In contrast, episodic processes exhibit a completely different profile. Specifically, processing demands lead to increased synchronization in the theta (4-7 Hz) bandwidth. This pattern of activation is consistent with oscillation of a single distributed neural assembly.

These ideas are crucial to the current mapping of psychological to physiological processes. In particular, activation associated with individual elements of a situation is equated to the activation of numerous localized assemblies with oscillations in the 10-13 Hz bandwidth. Simultaneously, there is a separate pattern recognition process that monitors activation of assemblies associated with individual elements and responds when specified patterns of activation occur. This would be synonymous with matching current conditions to a known situation schema. The pattern recognition process is represented by a single neural assembly that oscillates in the 4-7 Hz bandwidth.

As illustrated in Figure 2, a knowledge network is used to represent semantic knowledge activated by individual elements of a situation. This network consists of nodes for individual concepts, and associative links between nodes that differ in their strength of association. Each concept is assigned a separate neural assembly. Neural assemblies contain a collection of individual neural units with the operation of individual units dictated by low-level neural processes (e.g., transmitter-receptor interactions, metabolic properties, etc.). The activation of concepts in the psychological model is a function of the activation of the neural assembly assigned to the concept.

Situation recognition is represented in the psychological model by a template matching process. Rows of the template represent known situation schema and columns correspond to concepts in the knowledge network. Currently, a simplified approach is utilized whereby binary numbers indicate the activation, or lack of activation, of individual concepts during a given time period. Recognition occurs incrementally and when a threshold is exceeded, there is activation of the situation schema.

INITIAL IMPLEMENTATION

A reverse engineering approach was adopted. Specifically, research was reviewed that reported findings concerning the relationships between human cognitive behavior and the electrophysiology of the brain. These findings provided the basis for a design specification emphasizing the relationship between input (i.e., cognitive task conditions) and output (i.e., electrophysiological response and cognitive performance) to the system. The objective was then to apply principles concerning the organization of neural systems to design a computer model that met these specifications.

One product of the emulation is a simulated EEG signal. In a series of tests, the emulation was presented conditions intended to mimic those described in published studies and the results compared to reported findings. This provided a means of calibrating parameters of the model and verifying the basic design. For example, the amplitude of response during cognitive task performance was shown to vary in accordance with the spreading activation attributed to stimulus concepts (Niedeggen & Rosler, 1999). Likewise, cognitive performance measures were assessed. For example, in one series of tests, anticipated relationships between arousal and cognitive performance were demonstrated.

With the emulation in an early stage of development, some factors could only be partially tested. For example, emotional associations must be specified by the user. The emulation does not automatically associate stimuli with emotional responses. However given an emotional association, the emulation responds appropriately. In particular, there is increased activation of associated concepts and active inhibition of unrelated concepts (LeDoux, 1998). Similarly, the initial implementation has an extremely sparse knowledge representation. Stress is modeled on the basis of ACTH heightening responsiveness to irrelevant stimuli (de Kloet et.al., 1999). Consequently, without a knowledge base that is well populated with both relevant and irrelevant knowledge, a meaningful emulation of the behavior of a stressed agent is not yet possible.

FUTURE DIRECTIONS

As noted in the previous section, a meaningful emulation of certain vital organic factors will require an extensive knowledge representation. Current work focuses on greatly expanding this feature. A second emphasis concerns computational requirements. The initial implementation operates at a speed that is on the outer margins of acceptable performance, using a top-of-the-line desktop computer. Thus, for the time being, practical application of the emulator may require that it be transitioned to a massively parallel computing environment. This will become particularly important as learning algorithms are incorporated into the emulation. Finally, whereas previous work has only sought to emulate the behavior of a single agent, we are now exploring simulations that involve multiple agents operating in cooperative and adversarial contexts.

ACKNOWLEDGEMENTS

This work was performed at Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

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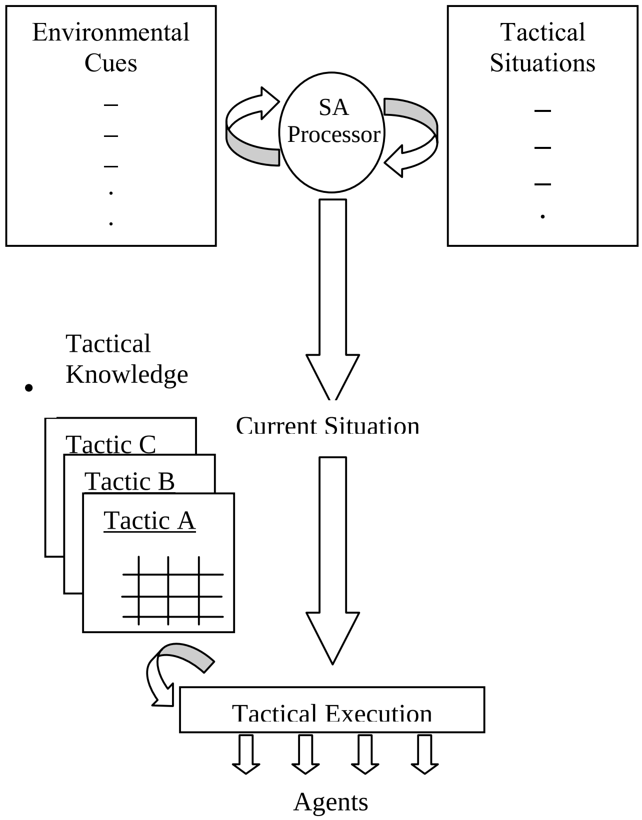

Figure 1. Conceptual Framework for Instantiation of Level 1 Recognition Primed Decision Making in a Computer Simulation

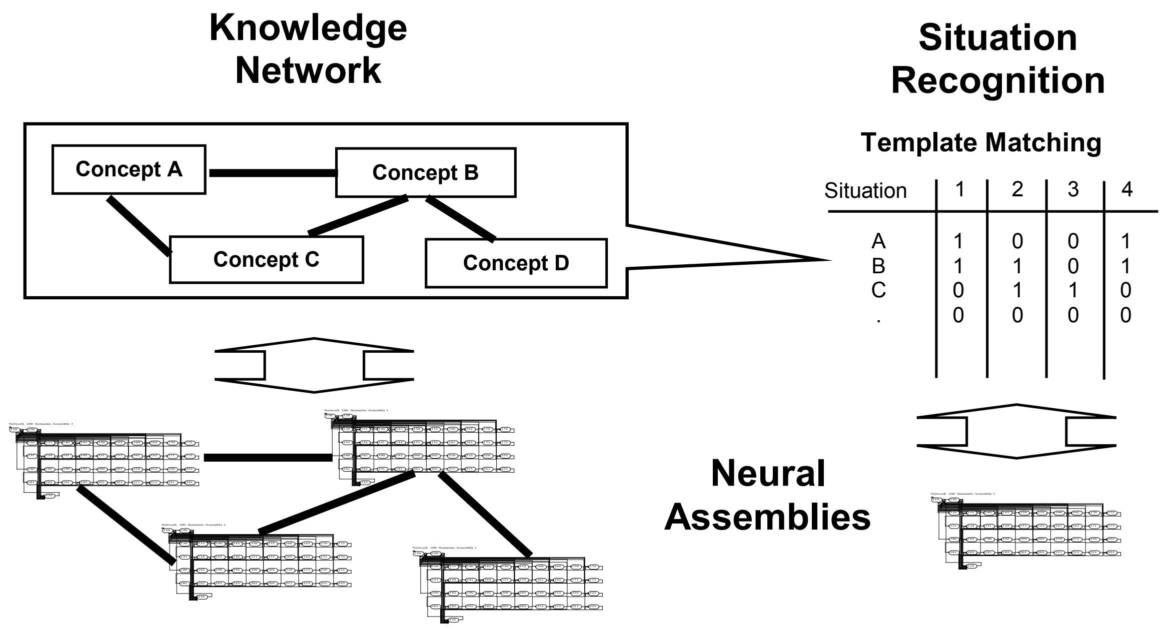

Figure 2. Framework for Emulator