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Toward the Computational Representation of Individual Cultural, Cognitive, and Physiological State: The Sensor Shooter Simulation

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Toward the Computational Representation of Individual Cultural, Cognitive, and Physiological State: The Sensor Shooter Simulation

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Abstract

This report documents an exploratory FY 00 LDRD project that sought to demonstrate the first steps toward a realistic computational representation of the variability encountered in individual human behavior. Realism, as conceptualized in this project, required that the human representation address the underlying psychological, cultural, physiological, and environmental stressors.

The present report outlines the researchers' approach to representing cognitive, cultural, and physiological variability of an individual in an ambiguous situation while faced with a high-consequence decision that would greatly impact subsequent events. The present project was framed around a sensor-shooter scenario as a soldier interacts with an unexpected target (two young Iraqi girls).

A software model of the "Sensor Shooter" scenario from Desert Storm was developed in which the framework consisted of a computational instantiation of Recognition Primed Decision Making in the context of a Naturalistic Decision Making model [1]. Recognition Primed Decision Making was augmented with an underlying foundation based on our current understanding of human neurophysiology and its relationship to human cognitive processes. *While the Gulf War scenario that constitutes the framework for the Sensor Shooter prototype is highly specific, the human decision architecture and the subsequent simulation are applicable to other problems similar in concept, intensity, and degree of uncertainty*. The goal was to provide initial steps toward a computational representation of human variability in cultural, cognitive, and physiological state in order to attain a better understanding of the full depth of human decision-making processes in the context of ambiguity, novelty, and heightened arousal.

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1. Introduction

The present report covers the accomplishments of an exploratory LDRD project. The purpose of the undertaking of this research was to propose a plausible computational model based on current research methods and findings in social psychology, cognitive psychology, and neurophysiology. The present project utilizes a “brain-based” approach to better understanding the human variability in decision-making under stress (Figure 1). As shown in Figure 1, psychological models of recognition-primed decision-making in the naturalistic context were integrated with semantic (factual knowledge) and episodic (contextual knowledge) processes represented by independently oscillating neural assemblies and a single dispersed neural assembly respectively. These concepts are discussed in greater detail in subsequent sections of the present report.

Good progress has been made in the computational representation of basic cognitive processes [2]. However, a common problem that plagues the design of computer generated forces (CGFs) and computer generated actors (CGAs) for virtual or “synthetic” battlespaces used in training and assessment is the difficulty in computationally representing realistic and appropriate behaviors that reflect the full depth of human-like capabilities [3]. For instance, simulation used for assessment of high consequence applications (e.g. security, tactical effectiveness, operator response, etc.) requires confidence that CGAs are exhibiting behaviors *consistent* with those exhibited by humans under similar conditions. Additionally, in training military, law enforcement, and first responders for encountering ambiguous and human interaction-rich environments, CGAs should exhibit the *variability* of differing populations, cultures, individuals, or personalities. In other words, CGAs must reflect a level of unpredictability, not randomness, which is perceived to be both believable and valid by the human end user.

A successful approach to designing CGFs that exhibit more realistic, unpredictable human-like behaviors employed a Distributed Mission Training Integrated Threat Environment (DMTITE) combat psychology model [3]. The researchers based their decision-making model on a combination of relatively stable human traits with situationally derived transitory states. Based on these psychological principles and a multi-layered cognitive representation component incorporating critical, mid-term and long-term decision engines, a CGF could compute scaleable combat performance, and unpredictable behaviors emerging from a variety of combat situations [3]. The model is limited to functions relating to combat including leadership, command, communication, control, morale, and military skills performance. Individual variability such as hesitation, charging the enemy, and running amok, etc. is accounted for in the context of military performance. The cognitive representation component is responsible for simulating the *outcomes* of the decisions *enacted* by the CGF, not the decision-making process itself.

Note the reasons why the above approach was not taken in the present project. We did not seek to model the myriad of outcomes of decisions enacted by CGFs in virtual environments. We did not seek to model the behaviors or interactions of groups of CGFs. Instead, our intent was to model the cultural, cognitive, and physiological variability operating in an individual soldier as he interacts with an unexpected target (two young

Iraqi girls in this scenario) in an ambiguous situation while faced with a high-consequence decision. In effect, we sought to model a single decision point in order to illustrate the complexity of human decision-making at any given time, in any given situation, under any number of conditions. In particular it was our goal to bring to the forefront the importance of incorporating an individual's worldview, or culture, in decision-making models and simulations. Two elements drove our decisions. First, we wanted to know what hidden socio-cultural factors influence a decision to shoot or not shoot a *human* target. Second, we sought to that incorporate the influence of organic factors on decision behavior (i.e., arousal, fatigue, etc.) *in the context of the underlying socio-cultural factors operating when one is faced with a decision to harm another human being.*

2. Rationale for Choosing the Sensor Shooter Application

The Sensor Shooter scenario was chosen because (1) it represented a situation that was drawn from the "fog of war" reality faced by war fighters and peacekeepers [4], and (2) the scenario represented a highly ambiguous situation in which there was no universally correct or incorrect decision. In fact, it was surmised that one's propensity to shoot or not would have depended on a host of factors including but not limited to one's physical training, individual psychology, physiological state, emotional state, perception of the environment, and socio-cultural values. While not easily conducive to experimental assessment or empirical validation, the Sensor Shooter problem clearly satisfies the objectives of presenting an interesting array of interdependent factors that could potentially shape a life or death decision-making process. According to Schmitt & Klein [4], it is critical to understand the factors that contribute to uncertainty in decision-making because "uncertainty is a more fundamental, pervasive and dominant problem than is commonly recognized. Understanding it and learning how to deal with it are prerequisites to successful leadership." It is our hope that this LDRD project has contributed to understanding the effects of physiological stressors on the individual soldier as he is faced with a difficult, new decision that throws his training doctrine into question and hence draws significantly upon his cultural values and perceptions of the degree of threat associated with the target.

3. Background Work and Project History

Several concurrent efforts on the part of the present researchers led to the theoretical and methodological conceptualizations pursued by the researchers of the present project. A brief project history is provided below.

The principle investigator, Elaine Raybourn, was a member of the Advanced Concepts Group and had been tasked along with her team (Howard Hirano, Rich Pryor, and Stewart Cameron) in 1999 with spearheading new initiatives at Sandia National Laboratories. After much deliberation and analysis, the team concerned with proposing new initiatives for the laboratory in open conflicts (e.g. large-and small-scale wars, operations in urban environments, and defending the U.S. Homeland) focused on the area of human cognition (cognotech) and decision-making. In order to "personalize" the initiative for laboratory constituents, the Advanced Concepts Group team had focused on raising awareness of the challenges faced by the individual soldier—in the context of asymmetric warfare, ambiguity, and complications arising from "data explosion." Additionally, emphasis was placed on multi-national conflict reduction/resolution, peacekeeping/peacemaking, and intercultural negotiation. It was determined by the team that the increased deployment of Combined Forces operations had resulted in heightened complications in the areas of understanding cultures, intercultural communication, distributed decision-making, intelligence gathering, and interoperability. The challenge for the Advanced Concepts Group team was to choose a project that would serve to "kick off" the cognotech initiative and raise awareness throughout the laboratory about the importance of understanding human variability in decision-making. It was hypothesized that only by understanding human decision-making processes, could significant progress be made in helping the nation secure *decision superiority*, a major theme outlined in JV2010.

Raybourn has a history of exploring cultural dynamics in simulations and computer-based systems. Prior to the present project, Raybourn designed a simulation for virtual environments that explored to degree to which cultural dynamics were perceived by individuals to be threatening [5]. Through an individual's communication and interaction with others, a culture of negotiation was achieved in the simulated environment [6], [7]. In both her previous work [5], [6] and the present project reported here, the scenario of the simulation involved a circumstance where an individual significantly relied upon his cultural values and perceptions to aid in the determination of the degree of threat associated with another entity in the simulation.

Additionally, two earlier Sandia National Laboratories projects of which Chris Forsythe was a member, contributed to the incorporation of cognitive and physiological states into the implementation of the model. First, in developing the behavior model for a small unit combat simulator, Forsythe drew from his experience with a prior instantiation of human naturalistic decision-making theory within the context of an agent-based computer simulation [8]. This instantiation utilized Klein's Recognition Primed Decision Making (RPD) model with emphasis on Level 1 decision-making [1]. Secondly, within a systems engineering/safety context, an organic model was proposed to account for human influences on engineered systems [9]. By the term, organic, the researchers mean those biological-based properties exhibited by engineered systems that result from human involvement in said systems. Specifically, it is asserted that due to human influences, engineered systems are inherently "organic" and will exhibit properties of organic systems. These properties include biological organization, homeostasis, sensitivity to stimuli, metabolism, adaptation, reproduction and heredity, and life cycle maturation—which the researchers argue provide a basis for predicting behavior of engineered systems. Raybourn's background in culture and her participation on the present LDRD project extended Forsythe and Wenner's previous notions of the organic model and the affect of meta-systems on engineered systems [9] to include influences of individual national or ethnic cultural backgrounds, and salient group affiliations on the naturalistic decision-making process in contexts other than engineering systems.

Raybourn and Forsythe teamed together and pooled their expertise [15]. An appropriate scenario was required that could represent the complexity of the naturalistic decision-making process, and challenge the utility of existing decision models when the decision in question addresses dynamic, socio-cultural phenomena. The sensor shooter scenario, from a Gulf War encounter was chosen for the project. The present LDRD project explored the instantiation of the expertise brought forth by both researchers in a simulation prototype.

4. Decision Models Used in Sensor Shooter Cognitive Framework

Naturalistic Decision Making is a term that refers to decisions made in everyday circumstances, either on the job or in personal life. Naturalistic Decision-Making research is particularly relevant in military contexts because it focuses on diagnostic decision-making, or situation assessment. The following elements comprise the Naturalistic Decision Making Approach [10; p.17-18]:

1. Situation Assessment (in addition to option selection);
2. Single Option Construction and Modification (versus generating many options for comparison purposes);
3. Single Option Evaluation (versus comparing multiple options to themselves or to a standard);
4. Changing Conditions and Ambiguous Information (versus stable conditions and information within the decision event);
5. Shifting Goals (versus stable goals within the decision event);
6. Time Constraints (in deciding what to do);
7. Previous Experience (by the decision-maker in the decision event).

The Sensor Shooter prototype utilized Klein's Recognition Primed Decision Making (RPD) model [11]. In a RPD process (Figure 2), an expert decision maker commits her/his resources to evaluating the situation and through this diagnostic evaluation, patterns are detected that lead to recognition that the current situation is analogous to situations that are known from past experience, albeit for a slight variation. The appropriate course of action is implicit in recognition of the situation, diagnosis, and the subsequent mental simulation. According to Hutton & Klein [11],

> Experts' decision making is based on perceptual-recognition skill. This skill is built up through the accumulation of experiences with the task. Familiarity with the subtleties of a task allow the expert decision-maker to distinguish between typical and atypical, to make fine discriminations between similar situational factors, and to be able to generate expectancies about how a situation arose and it will evolve. Violations of these expectancies trigger the decision maker to re-evaluate the situation and update their current situation awareness.

Klein and others [10] have provided descriptive models of the process by which expert decision makers arrive at decisions in realistic settings. Currently, the Sensor Shooter simulation provides a very simplistic computational representation of Level 1 decision making from Klein's Recognition-Primed Decision (RPD) making model [1], [11]. Here, within ongoing events, the decision maker recognizes a pattern of cues associated with a known "situation." Once this recognition and anomaly detection occurs, there is a diagnosis of the appropriate course of action, as well as goals and expectations. The computational 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., existing mental models) and once there is a match between the ongoing situation and a known situation, generic scripts are employed to direct the CGA's behavior. We used this model because it is a model that addresses high consequence situations, and rapid decisions, even though in our scenario, some may argue that the shooter be considered a novice as he has never before encountered the situation at hand. In our conceptual design we perceived the shooter to be an experienced warfighter, since he was a sergeant in a Special Forces team. Figure 3 provides a screen shot of how RPD was represented computationally for the Sensor Shooter simulation. Note how it mirrors the RPD model illustrated in Figure 2.

The Sensor Shooter prototype focused on establishing the general NDM framework for a comprehensive simulation of human decision-making. The objective has been to identify the range of factors that influence decision-making and create a conceptual framework that accommodates these factors. This objective was undertaken within the context of a demonstration problem referred to as the "Sensor/Shooter Scenario" which is more completely described in the following section.

5. The Sensor Shooter Scenario

Image Provided Courtesy of Ken Miller, 2000

The Sensor Shooter scenario was based on an incident that occurred during Desert Storm. An eight-man Special Forces A-Team faced a human rights dilemma that would ultimately cost them their position, and compromise their mission. On February 23, 1991, a Special Forces A-Team was dropped 150 miles into Iraq before the ground war began.

Their mission was to establish a position, and covertly observe and report traffic on a major roadway. According to their sources at the Central Intelligence Agency (CIA), the area was unpopulated. However when the team arrived, they immediately heard dogs barking in the distance. The barking dogs indicated that they were “either in the wrong place, or something was seriously wrong.”

Before daybreak, the eight-man team dug a chest-deep hole in the sand in order to construct an underground bunker where they would live until the war officially started. However, the next morning they were faced with an unplanned encounter with the civilian populace. Two young girls came out to the farm fields along the road to play a few meters from the soldiers’ bunker. After a few minutes, the girls suddenly stopped playing. Helpless to prevent his discovery, the sergeant on watch observed as one of the girls turned and looked directly at him, making eye contact. The young girls started moving away. As the girls began to move, the sergeant observing the road, raised his 9mm Silencer, aimed at one of the children, and began to exit the bunker. Another soldier with an MP5 Silencer followed him out. The sergeant who had made eye contact with the child asked his A-Team leader, “What do we do, what do we do?” The chief instructed the sergeant to not fire.

In an interview for a special Discovery Channel “American Commandos” series, the chief and A-team leader reported, “Are we going to shoot the kids—that’s what they wanted to know. Had I said, ‘yes, shoot them,’ they would have shot the kids, there’s no doubt in my mind that they would have followed my orders. I’m a father, I have a Christian background, and these kids were unarmed. It was an instant decision, you know, there wasn’t a lot of time to think about it or ponder it and say, ‘no, I’m not going to shoot the kids.’” So they decided to let the little girls go away unharmed.

In the closing segment of the interview with the A-Team members, the sergeant mused, “We really didn’t know in our minds whether we would be looked on as failures, or uh, I don’t want to use the word heroes, but uh, you know, whether we did our mission or failed our mission. We were compromised because we made some mistakes. You know, all your training—it comes to a big head. And you’ve been challenged with it, you’ve faced life and death, and you passed.”

6. The Research: Expert Elicitation Methods

The purpose of an expert elicitation was to develop the key social-psychological, cognitive, and physiological concepts for the model of the Sensor Shooter simulation from the perspective of end users who have direct experience with the Sensor Shooter scenario. The utilization of the key concepts generated with subject matter experts (SMEs) is explained in subsequent sections. This section introduces the reader to knowledge elicitation methods. In order to understand why knowledge elicitation was chosen as a methodology in the present project, we must first identify the components representing the human mind (Table 1). Different communities of practice have studied each extensively and there are general understandings of the basic functions of each and some of the interactions between components.

Table 1: Several Components Representing the Human Mind

• Perception	• Attentional Processes	• Social Behavior
• Situation Awareness	• Physiological Arousal	• Group Interactions
• Decision Making	• Metabolic Functions	• Cultural Factors
• Mental Models	• Emotional Processes	• Learning
• Problem Solving	• Drive/Motivation	• Knowledge/Memory
• Linguistic Processes	• Communication	• Volitional Processes
* Overlaying each component, there are Individual Differences that encompass both normal variation and aberrations that appear with psychological disorders (e.g., obsessive-compulsive, paranoia, etc.)		

Situational Awareness requires the maintenance of an ongoing register of environmental cues from which a decision episode is derived. A change in environmental cues (e.g., suspicious noise) can cause a change in the current decision episode, provoking behavior appropriate for a new decision episode. The decision-making process is affected by psychological and physiological factors. For example, fatigue may result in environmental cues being neglected or misinterpreted leading to uncertainty or a failure to correctly recognize the current situation. The soldier may delay action until more information can be attained, or if the level of fear is sufficient, the soldier's instinctive fight-or-flight reflexes may take over invoking immediate self-preservation. This foundation describes the variability in human behavior through emphasis on the interplay of properties that were difficult to quantify within the scope of the present project. Therefore, a qualitative approach to data collection (expert knowledge elicitation) was employed.

The preliminary research in developing a prototype employed ethnographic and interview methodologies to better understand human decision processes and interpret the mental models at work in scenarios that involve the use of deadly force, unarmed civilians, ambiguity, emotional stress, and perceived threat. We conducted separate interviews with two Subject Matter Experts (SME) who each had direct experience with being in an ambiguous situation with unarmed civilians that could have led to a decision to use deadly force—as illustrated in the Sensor Shooter scenario. After describing the scenario in detail, interview questions focused on identifying the "key concepts" that would enter into the decision making process (Table 2).

Table 2. Sample SME Interview Questions (not necessarily asked in order below)

1. What factors would have played into seeing the little girl as a threat?
2. What comes to mind that would lead to the soldier or someone like the soldier, to shoot or not?
3. What are some of the psychological factors that go into shooting a target? A human?
4. Do you openly discuss (with your cohorts) what constitutes "reasonable" actions? In any scenario? In this scenario?
5. How much does exposure to other cultures influence the soldier?
6. Given the training the soldiers had before encountering the problem, what would have made them shoot or not?
7. Do you think it would have made a difference if the shooter had had previous, but different peacekeeping experience? What if it were the same experience?
8. How direct does the experience of the scenario have to be?
9. What characteristics would the commander of the shooter have had to have to make him want to shoot the little girl?
10. How did the incomplete intelligence affect the problem?
11. How does whether one has to make a decision on one's own vs. soliciting advice change the parameters of the process of decision making?
12. How does fatigue affect this situation?
13. Who else can we talk to?

The questions in the semi-structured interview were not asked in any particular order, but served as a guide to remind the researcher leading the interview of the areas we wanted to cover in the interview. Interview protocols loosely followed the procedures outlined in a cognitive task analysis, or critical decision method [12], [13]. Cognitive task analysis methods seek to describe cognitive demands of the task and situation, define task constraints, and provide a framework for the systematic interpretation of the qualitative results. Cognitive task analysis is concerned with *how* a task is carried out, not *what* steps are involved in carrying out the task [14]. Interviews generally lasted an hour or two, and opportunities to iterate with the SMEs were provided. Some of the factors identified by the SMEs that could influence a decision to shoot or not included the following listed in Table 3 (in no specific order):

Table 3. **Example of Data collected from SME: Factors Contributing to Shoot/no Shoot Scenario**

Trust	He has to react on a subconscious level
Not being prepared for the situation	The Fog of War
Hesitation--the longer he waits, the less likely he is to shoot	Religious convictions
	Moral convictions
Lack of explicit communication	Individualism
Social upbringing, the way we were raised	Surprise (buck fever)
Value for life	Legal issues—Will I be accountable?
Rights to life	Empathy with target
Kill transference: you think about target's family, wife, etc.	Special place in one's heart for children
	Work ethic
Sense of guilt	Whether your life is in jeopardy
Protection of team	He has a plan about going in--his mind is made up before the scenario is encountered
Not involved in total war	

Through a review of notes taken by the two interviewers, and several iterations of grouping concepts and themes, the key concepts listed in Table 4 were identified [15]. Additionally, we observed law enforcement training exercises in which personnel participated in real-time simulated scenarios involving the use of deadly force and civilians. These observations were accompanied by opportunities to witness debriefings and interview trainees. Finally, the researchers observed a debriefing in which Turkish law enforcement personnel described in detail the procedures and lessons learned of past operations that involved unarmed civilians, and the use of deadly force. We used every opportunity available to incorporate diverse cultural perspectives into the background research for the generation of the cognitive model used in the Sensor Shooter prototype.

Table 4. Key Concepts Identified through Expert Elicitation

• Covertly observe and report enemy movement	• Child's parents and family
• Prevent enemy knowledge of your presence	• My dying
• Killing may be punished	• Female
• Respect for life	• Hostile Territory
• Threat	• Commander
• Accountability to team	• Child as Asset
• Innocent child	• War

7. Conceptual Model for the Sensor Shooter Simulation

In this section we discuss how we employed the information garnered from the expert elicitations and developed the conceptual psychological model for the Sensor Shooter simulation. Additionally, we discuss how the physiological state was mapped to the cognitive model. In section 8 we provide a 'walk-through' of the Sensor Shooter simulation (as if the reader were a user interacting with the computer simulation). At this time, it is important to remind the reader what the Sensor Shooter simulation is, and is not. Recall that the Sensor Shooter simulation was designed to explore the cognitive processes of an individual soldier faced with a single decision, and although the user is able to ‘tweak’ variable weights and strengths among concept associations (explained in sections 7.1 and 7.2), this simulation should not be treated as a predictive tool. The simulation documents very exploratory steps taken to consider the complexity and nuances of creating such a predictive tool, or human emulator (discussed in Section 9). Nor was this simulation created to determine the best, or optimum decision. The Sensor Shooter simulation was created to illustrate the interconnectedness of the more qualitative, cultural concepts that work in concert with neural assemblies and one’s physiology (based on external stimuli) in decision-making under stress. Additionally, it should be noted that the cultural concepts, cognitive model, and neural frameworks underlying this approach were not validated with experimental data from human subject studies. Biological-based models involving human subjects are difficult to validate for a number of reasons. In light of all of these obstacles, the reader may ask, “Why, then, bother creating this simulation?” We would argue that before one can run, one must walk. And before walking, one must crawl. Creating Sensor Shooter simulation was an opportunity to embark on a research area where there are many unknowns. While the steps taken in this LDRD were not without limitation or critique, our goals were to explore human variability in the context of decision-making under stress, and provide a conceptual basis for future work in the development of realistic agents, and/or synthetic human actors. The desired outcome was human decision architecture and associated software program that would be applicable to other problems. It was intended that this FY 00 LDRD would serve to jumpstart Sandia National Laboratories’ initiative into the fields of human behavioral sciences and cognitive systems (i.e., systems based on human cognitive models). Lessons learned from the Sensor Shooter simulation are discussed in Section 9.

7.1 Cognitive Framework: Semantic Network Reflecting Cultural State and Cultural Differences

Figure 4 illustrates two examples of semantic networks identified by the researchers as the key concepts in Table 4 that provide the cognitive basis for cultural differences and states as expressed within the framework of the Sensor Shooter simulation [15]. Concepts such as “killing may be punished” and “respect for life” are represented as nodes in the semantic network. The semantic network represents the clustering of strengths of associations among various concepts, or nodes in the network. The differential representation of concepts, and especially, the differential associations between concepts within semantic networks is a primary means by which cultural differences may shape cognitive processes.

The diagram to the left in Figure 4 indicates a semantic network in which there was a propensity to Pardon, or let the child escape. The diagram to the right in Figure 4 illustrates a semantic network in which there was a propensity to strongly associate the child with concepts of threat and war and therefore capture the child. The tool Pathfinder [16] was employed to derive the proximity of concepts on the basis of conceptual relatedness. According to Goldsmith [17, p.89], the “Pathfinder scaling algorithm transforms a proximity matrix into a network structure in which each object is represented by a node in the network and the relatedness between objects is depicted by how closely they are linked." It is interesting and important to note that with a given semantic network, the Sensor Shooter simulation did not produce results distributed across several interpretations, but instead, a given semantic network favors a specific interpretation of whether to shoot (capture child), or let the child escape.

Klein, Pongonis, & Klein [18] have noted that national cultural differences may disrupt situational awareness, decision-making, coordination, and communication. Based on prior research they indicate that differences in power distance, dialectical reasoning, counterfactual thinking, risk assessment, uncertainty management, and activity coordination account for these disruptions. Another way of looking at this is that each of us perceives the world differently due in part to our cultural filter, or lens.

Nevertheless, although culture serves as a perceptual filter with which human beings view (make sense of) their world, the saliency of the variable culture is largely dependent on context, situation, task, prior knowledge, and individual differences, or personality, to name just a few [19]. Therefore, for demonstration purposes, one personality factor (extroversion/introversion) was incorporated to address the challenge of representing individual differences, or personality. "Personality" refers to a stable disposition to perceive and respond to the environment in certain ways. To demonstrate personality, the peacekeeping scenario simulation incorporated a capacity for the user to manually specify degrees of extroversion or introversion.

7.2 Mapping Physiological State to the Cognitive Model

In developing a cognitive architecture that mapped physiological state, an approach was taken that may be characterized as "reverse engineering." Specifically, literature was reviewed that reported findings concerning the relationships between human cognitive behavior and the electrophysiology of the brain [15]. 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.

There is enormous ambiguity in basic terminology of physiological phenomena (e.g., stress, arousal) and without a representation of underlying mechanisms; the scope and predictive capabilities are severely limited. Nevertheless, many facets of cognitive behavior (e.g., knowledge representation) are well described by psychological models [17]. Consequently, we adopted a two-tiered approach in which knowledge is represented using a psychological-based model, however a separate physiology-based model serves as the engine that drives the psychological model (See Figure 5 and explanation below). Since the concepts, or knowledge, is not directly represented in the neural (i.e., physiological) model, this design differs from neural net and connectionist approaches, yet facilitates representation of a realistic computational emulation of human behavior and cognitive processes.

We retained the key concepts embodied by our earlier instantiation of Recognition Primed Decision Making in mapping of the psychological to the physiological model (see Table 4). The mapping of the psychological model to the physiological model included representing individual situational elements, pattern recognition, and activation of the knowledge networks, or schema-like representation of known situations.
We used Frame/Content theory to provide 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 [20]. Applying frame/content theory, individual concepts of the Sensor Shooter situation represent content, whereas situation schemas provide an interpretive frame, or the context (see Figure 1).

Further extension involved mapping these ideas to the oscillating systems model of memory processes proposed by Klimesch and colleagues [21]. Initially, certain fundamentals were accepted. For example, a heavy emphasis has been placed on oscillating systems theory as an explanation for the mechanisms underlying semantic and episodic memory [21]. Given these fundamentals, published research with human subjects has provided the basis for creating a set of design specifications. These specifications tend to be of the form, "if input x is applied, output y should be observed." In generating specifications, attention has been focused on capturing the relationships between cognitive performance and electrophysiological phenomena.

For example, one output of the cognitive architecture is a simulated electroencephalograph 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, [22] reported increased amplitude of response in event-related potentials relative to the spreading activation generated by stimulus concepts. In testing the simulation, concepts producing low medium and high levels of spreading activation were presented and the expected difference in response amplitude demonstrated. Likewise, the researchers assessed cognitive performance measures. For example, in one series of tests, anticipated relationships between arousal and cognitive performance were demonstrated.

The next three paragraphs refer to the model in Figure 5. 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. In the Sensor Shooter simulation, 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.

It has been suggested that semantic memory processes involve the activation of numerous localized neural assemblies. 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. 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 above were crucial to the mapping of psychological to physiological processes for the Sensor Shooter simulation. In particular, activation associated with individual elements of a situation is equated to the activation of numerous localized assemblies with oscillations in the10-13 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. A single neural assembly that oscillates in the 4-7 Hz bandwidth represents the pattern recognition process.

With the Sensor Shooter simulation in an early stage of development, some factors could only be partially tested. For example, the user must specify emotional associations. The simulation does not automatically associate stimuli with emotional responses. However given an emotional association, the simulation responds appropriately. In particular, there is increased activation of associated concepts and active inhibition of unrelated concepts [23]. Similarly, the initial implementation has an extremely sparse knowledge representation. Stress is modeled on the basis of ACTH heightening responsiveness to irrelevant stimuli [24]. Consequently, without a knowledge base that is well populated with both relevant and irrelevant knowledge, a meaningful emulation of the behavior of a stressed CGA is not yet possible.

8. Implementation and Simulation Walk-Through

In developing the sensor shooter simulation, the Micro Analysis & Design simulation tool, MicroSaint, was employed as the simulation platform. MicroSaint is a commercially available product designed to facilitate cognitive modeling. In summary, by establishing the input/output relationships among human cognitive behavior and brain electrophysiology (as reported in the literature), a cognitive process model was developed. This method 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.

In addition to the semantic network models employed in the Sensor Shooter simulation, physiological and emotional factors were incorporated into the simulation. For example, arousal was manipulated by adjusting the pulse rate of the pacemaker. Concepts and situations were assigned emotional associations [23]. The recognition of an environmental stimulus triggers certain concepts, or nodes, to activate the frequency of underlying low-level oscillators, which subsequently activate certain emotions such as fear or surprise, and levels of arousal. The result is heightened activation of the initial concept, and related concepts, and active inhibition of unrelated concepts.

By manually varying the numeric values associated with variables in the simulation, the user can create scenarios in which the CGA has a propensity to pardon or capture. Therefore, if the reader were a user sitting in front of a computer on which the Sensor Shooter simulation were running, you could set (a priori) certain environmental (scenario parameters and duration of event), soldier (physiological state [emotions, fatigue, etc.] and strength of key cultural concepts in semantic network), and child characteristics (clothing, size, articles, and behavior) before running the simulation. After having set the variable values that correspond to aspects of your soldier's cultural semantic network, emotions, physiology, and perception of environmental factors—you could witness the activation (flashing) of key concepts of the semantic network map. For instance, Figure 4 illustrates the concepts (e.g. war, innocent child, etc.) that may be activated in a given simulation run and the strengths of their semantic associativity to other related concepts. In the case of pardoning the child, a salient concept such as 'innocent child' may be activated by the initiation of a perceptual event (e.g. child walks into the scene). Its underlying oscillator would then increase in amplitude, thus activating related concepts (child's parents and family) and spreading activation to subsequent oscillators.

Similarly, an emotion, such as fear, can be assigned (associated) with a particular concept or set of concepts. When the concepts are activated in the simulation at the appropriate level, then the emotional priming occurs.

Let's examine this in a bit more detail. First, at the beginning of the Sensor Shooter simulation, you would see a short duration immediately preceding appearance of the child during which the peacekeeper is engaged in reconnaissance activities and not "perceptually aware" of the child. The next event corresponds to the child entering the soldier's visual field. In the simulation, a binary variable represents the states, "Motion is absent" and "Motion is present." The soldier does not immediately detect the presence of the children; detection occurs through the operation of visual processes (perception). Modeling a true perception process could not be accomplished within the scope of this project. However we attempted to address critical timing considerations associated with the interplay among perceptual, cognitive, emotional, and other processes. The result was a very superficial representation of events visually perceived by the CGA.

Second, it is assumed in the simulation that there is a period of time after the child enters the soldier's visual field in which the child is unaware of the soldier's presence. By adjusting time, the peacekeeper is given differing durations to contemplate the child's presence prior to his learning that he has been detected by the child. Finally, the child looks in the direction of the soldier and detects his presence. At this point, the soldier's position has been compromised. In the simulation, there is a binary variable that represents the states, "No Compromise" and "Compromise."

Third, object recognition of environmental stimuli begins once the soldier has a visual fixation on the child. There is recognition that the object in the field of view is a child. Four features believed to be associated with object recognition for the concept of "child" are modeled. These include size of child, clothing, articles in hand, and behavior. By allowing values for each to be modified, the model allows manipulation of what might be considered the "child-likeness" of the child and consequently the time that transpires between recognition of a person and identification of the person as a child.

Following recognition that the person is a child, there is a period during which the soldier observes the behavior of the child, prior to the child detecting his presence. In actuality, perceptual processing would be involved in the soldier's recognition that the child has detected his presence. In the present simulation, it is assumed that this recognition occurs automatically. Salient concepts or nodes in the semantic network are activated for a period of time. Activation of a concept within the semantic network results in spreading activation with there being an increased likelihood of activation for neighboring concepts.

The user may manually enter values that adjust the activation thresholds of the semantic associativity, perceptual saliency (environmental objects that are associated with concepts, e.g. size of child associated with the concept 'innocent child'), context (relevance of concepts to situation), and priming (altering the base level of activation of a given concept, e.g. you assume the soldier has a heightened level of fear than normal). Depending on how the user sets the factors described above, the CGA executes a decision to "capture" or "pardon" (let child escape). As one might expect, we found that particular couplings of semantic associativity, priming, context, and perceptual saliency seemed to favor specific outcomes. That is, the specific mental model and physiological state (chosen a priori by the user) tended to yield the same decision almost every time. Occasionally the weak priming of certain concepts yielded a different outcome. These results should be regarded as preliminary, and anecdotal.

<u>8.1 Limitations of the Sensor Shooter Simulation</u>

Several limitations should be noted.

- The FY00 project did not seek to simulate all possible factors that shape the decision-making process. Several critical factors were demonstrated that included: cultural differences, arousal, emotion, priming, surprise and perceptual saliency. Nonetheless, other factors were considered and the model includes hooks to incorporate these factors.

- In FY00, we developed an “in principle” demonstration of stress to prove that the essential mechanisms were in place. However, to realistically model stress, it is necessary to have a model that includes an extensive representation of knowledge so as to address the intrusion of irrelevant thoughts on the decision process. With a very small, problem-specific representation of knowledge in the FY00 simulation, an attempt to simulate stress would be meaningless.

- Fatigue associated with different levels of arousal due to circadian processes may be simulated with the FY00 model. However, we could find no models of the effects on cognitive processes of extended physical or cognitive exertion that were sufficient for a meaningful representation of this factor. Thus, this form of fatigue remains an open issue.

- An additional limitation concerns the outcome of the simulation. While the underlying mechanisms for the simulation are based on faithful representations of current knowledge concerning human cognitive processes, there is need for human subject studies to mathematically characterize these mechanisms in a manner that allows a higher fidelity representation. For example, the mathematical relationship between the saliency of perceptual cues and semantic activation used in the simulation is entirely notional. As a result, the simulation does not enable precise predictions such as, Option A will be chosen 54% of the time and Option B 27% of the time. Nonetheless, we believe the model is sufficient for ordinal comparisons of the nature, Option A is a more likely choice than Option B. Yet, probably more importantly, we believe the model provides a good mechanism to understand the range of possible responses that might emerge, given certain conditions.

9. Future Directions and Lessons Learned

As described in the previous sections, a meaningful emulation of certain vital physiological and cognitive features will require an extensive knowledge representation. Validation and evaluation of the underlying cognitive models, and subsequent simulations is critical. A variety of methods may need to be explored to validate both the viability of the content (concepts, behaviors, etc.) and believability of the simulation—the ultimate test being extensive user evaluations [24]. Another 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 prototype may require that it be transitioned to a massively parallel computing environment. This will become particularly important as learning algorithms are incorporated into the modeling environment. Finally, whereas the present project has sought to emulate the behavior of a single CGA, in a single decision event, we are now exploring simulations that involve multiple agents operating in cooperative and adversarial contexts.

Generally, the knowledge endowed to synthetic entities has been restricted to that directly relevant to the application domain. For instance, a synthetic fighter pilot knows about air combat and nothing else. In reality, individuals have a collective life experience that may exert as strong, and sometimes stronger, influence on decisions than domain knowledge. Furthermore, differences in personal experience are a primary factor accounting for the individual variability observable in human behavior. For these reasons, we believe that a vital element in creating realistic synthetic entities will involve the ability to endow CGAs with a synthetic life history.

Future mechanisms for modeling cultural differences may lie within the episodic processes that contribute to one's life history. That is, cultural concepts may be represented by patterns of known situations. A process may be established that allows for the elicitation and modeling of episodic processes in a manner similar to the semantic processes (See figure 7). Conceptual graph analysis represents one approach [25]. Having its roots in discourse processing, conceptual graph analysis offers promise in that it resembles a semantic structure, however it provides a richer representation concerning linkages between concepts. This method of representation is believed to be important to modeling cultural differences since as Choi and Norenzayan [26] note, interpretive biases represent a primary factor differentiating cultures. Additionally, much caution should be observed when modeling cultures, or cultural factors. As in every software product, the biases of the designers and developers often influence the end result. Therefore, it will be very important to *fully* understand cultural dynamics and intercultural communication when purporting to computationally represent national, or ethnic cultures, or group affiliations.

Subsequent efforts have focused on developing a capability that allows synthetic entities to meaningfully represent their experiences, or stories [27]. In the following machine illustration, two robotic vehicles systematically search a building to locate a smoke source. Based on their sensors, communications and data processing capabilities, as they progress through the scenario, different concepts in their semantic networks are activated (See Figure 8a). The result is a time series of patterns of semantic activation. This time series may be statistically analyzed to identify recurrent schema (e.g., progressing down a hallway following a smoke gradient). This is illustrated in Figure 8b. Endowed with knowledge of these schemas, stories may be constructed that are based on the sequence of schema experienced during a given event (See Figure 8c). Given knowledge of these schemas, subsequent analyses allow identification of recurrent sequences of schemas (i.e., themes or storylines). Decision-making through the use of communication mechanisms such as stories, analogies, and metaphors is described in [28].

The capabilities described in the present report and the previous paragraphs are an initial step toward endowing synthetic entities with a life history. For instance, parallel efforts focus on mechanisms for generating unique life histories. It should be noted that these capabilities provide the basis for mental simulation, a key ingredient for expanding the model of RPD to levels 2 and 3 [1]. Furthermore, the episodic representations also provide a basis for synthetic entities to learn over the course of simulator runs and even develop knowledge based on shared experiences with individual trainees. Consequently, a synthetic entity might remind a trainee what happened in a similar scenario two months earlier or exhibit differential confidence based on the trainees' recent success or failure. In addition, the Advanced Concepts Group is concurrently pursuing a similar instantiation of personal awareness for both elderly and warfighters in the context of smart, wearable devices.

10. Conclusions

This FY 00 LDRD project sought to demonstrate the first steps toward a realistic computational representation of the variability encountered in individual human behavior. Realism, as conceptualized in this project, required that the human representation address the underlying psychological, cultural, physiological, and environmental stressors.

The present report outlined the authors' approach to computationally representing cognitive, cultural, and physiological variability in an individual soldier as he interacts with an unexpected target (two young Iraqi girls in this scenario) in an ambiguous situation while faced with a high-consequence decision that will greatly impact subsequent events.

The FY 00 LDRD accomplished its objective to develop a framework for a comprehensive model of human decision processes. This accomplishment included a simulation based on the Sensor Shooter demonstration problem. The simulation incorporated the essential elements for Klein's Level 1 Recognition Primed decision-making. Within the simulation, alternative cultural models may be introduced through use of differential knowledge, consistent with the cultural state being modeled. This provides a capability for developing customized models for individuals and/or cultural orientations.

Two forms of knowledge vital to the decision process were modeled. One involves semantic knowledge, or the knowledge of concepts and their associative relationships. This maps to the representation of environmental cues in the RPD model. Second, there is situational knowledge. This knowledge consists of contexts, and the behaviors that accompany different contexts, and maps to the "situations" discussed in the RPD model.

As a result of work conducted through the FY 00 LDRD, we now have the capability to develop simulations of human decision processes that enable cultural and certain organic factors to be addressed. The basic mechanism is generic in that it may be applied to a broad range of problems. However, with each application, a somewhat unique model must be developed to encompass knowledge that is specific to the application. This involves development of an application-specific semantic network, identification of situations and development of patterns for recognition of situations based on semantic activation. Currently such an application is being developed for a substantially more complex problem. This problem involves modeling Close Quarters Battle with complexity arising due to the numbers of concepts and situations, the hierarchical nesting of situations and the need to incorporate group interactions. Furthermore, and probably most importantly, the FY00 model has provided an approach that due to its innovation and comprehensiveness, in less then a year, has begun to open doors with government agencies interested in cognitive modeling (e.g., Office of Naval Research, Defense Intelligence Agency, Army Research Laboratory, and DARPA).

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Author Biographies

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CHRIS FORSYTHE, Ph.D. (Psychology) is a Principle Member of the Technical Staff in the Computational Initiatives organization at Sandia National Laboratories. Current projects focus on modeling and simulation of human cognition and behavior. Specific applications include small unit combat, insider threats and human performance in high consequence systems. This work also emphasizes the utilization of human cognitive models within the context of intelligent systems.

TO VIEW a power point presentation on the ideas discussed in the present LDRD report, refer to C. Forsythe & E. Raybourn, Computational Representations of Human Behavior: Naturalistic Decision Making, Organic factors, and Knowledge Representations. Presented to Department of Defense Human Factors Technical Advisory Group, El Paso, Texas, November 6-9, 2000. SAND 2000-2984 C, Sandia National Laboratories, Albuquerque. For more information about the Sensor Shooter Simulation, contact the authors.

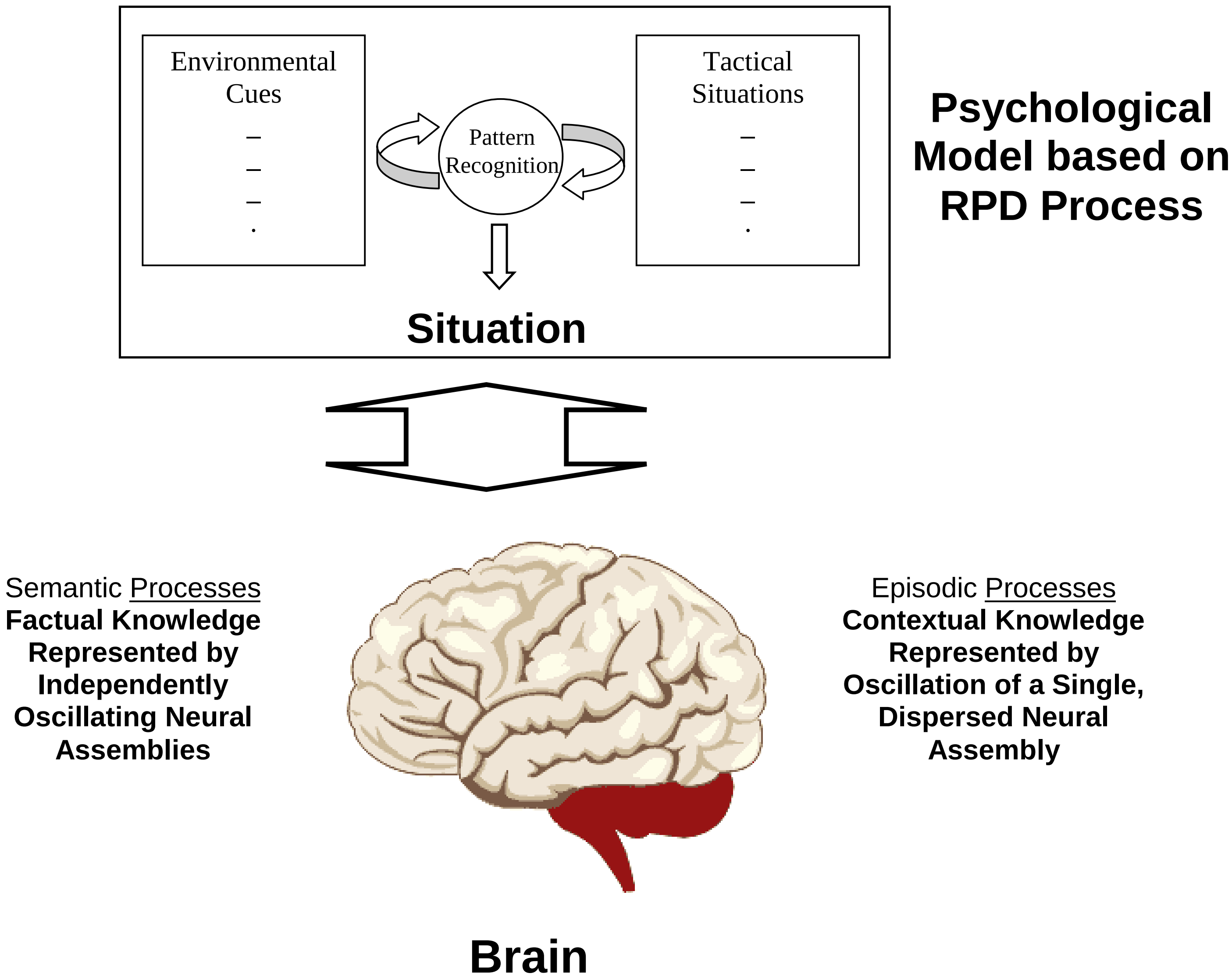


Figure 1. Mapping Psychological Model (knowledge network) to Brain Model (neural assemblies).

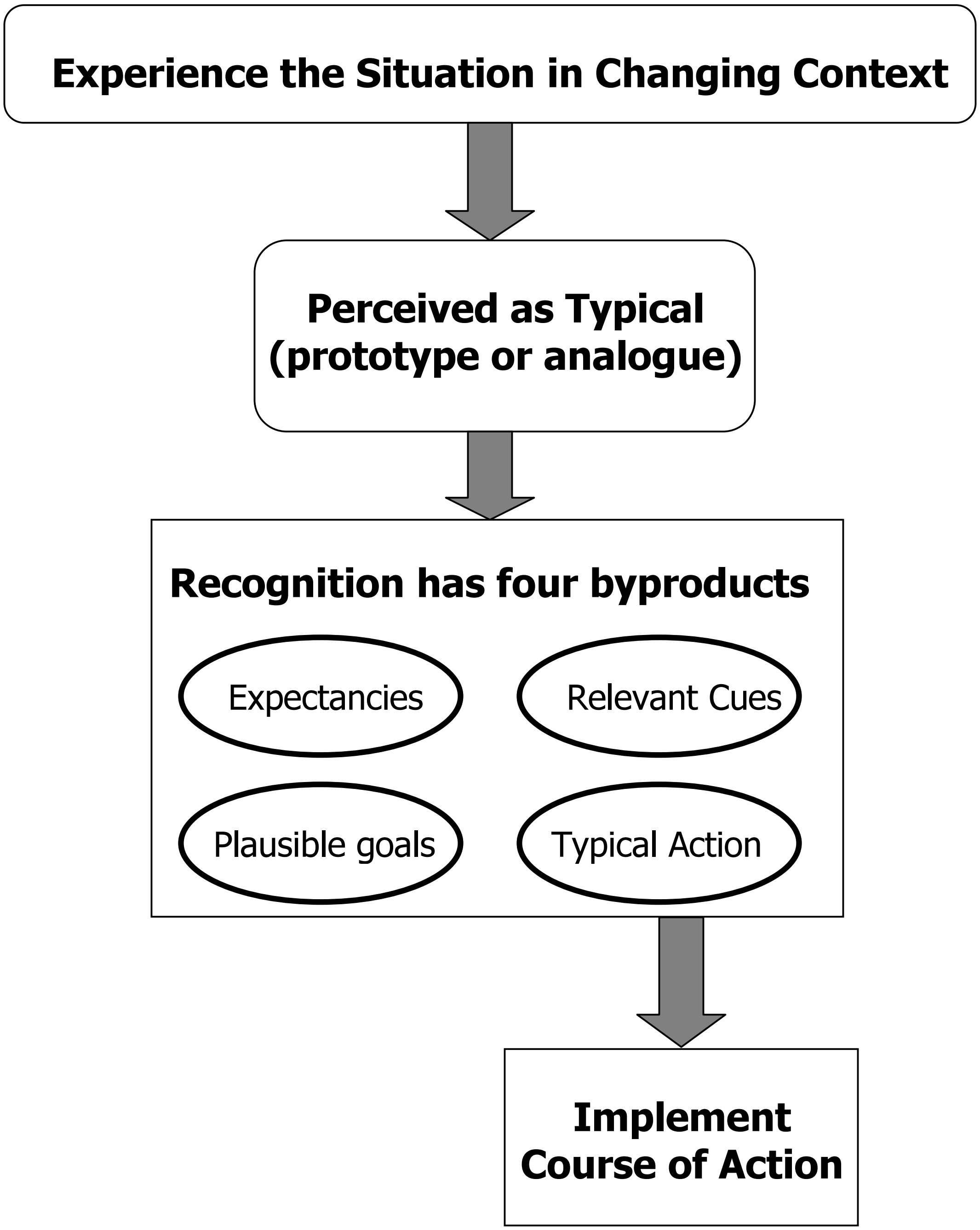


Figure 2. Level One (Simple Match) of the Recognition-Primed Decision making (RPD) Process [11].

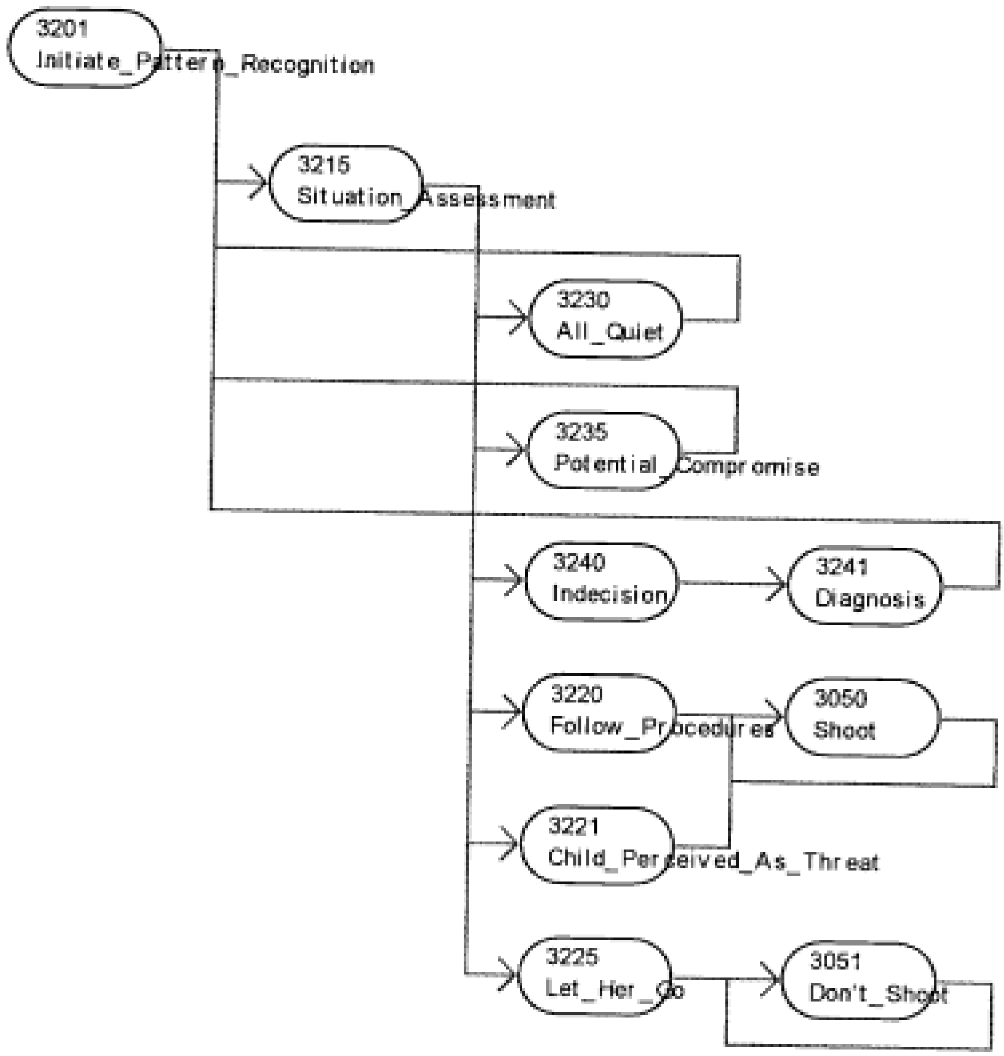
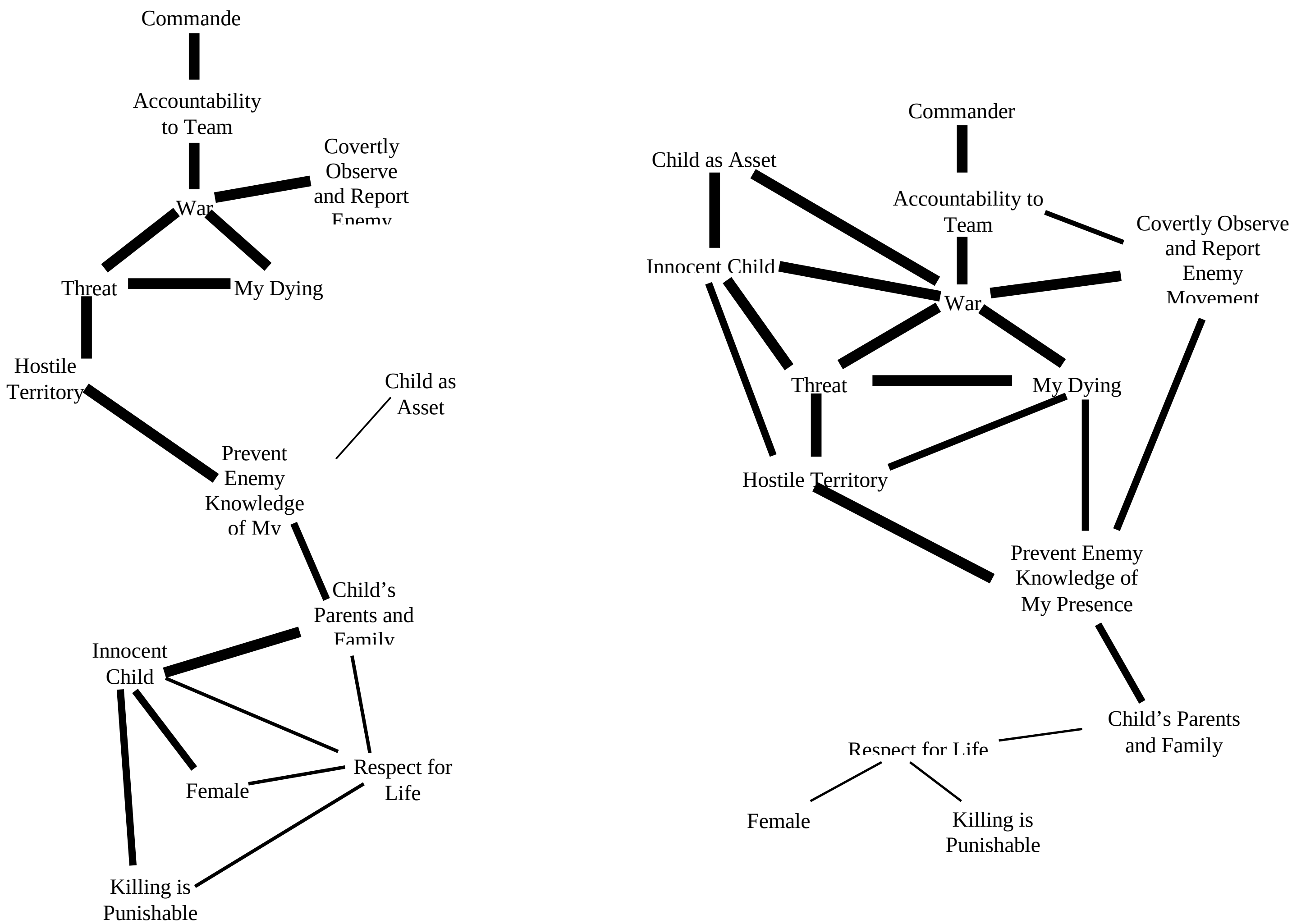


Figure 3. Framework for Instantiation of Level 1 Recognition Primed Decision Making in the Sensor Shooter Simulation (Situation Recognition Module).



Pardon　　　　　　　　　　　　　　　　　　Capture Child

Figure 4. Alternative Semantic Networks Providing the Cognitive Basis for Cultural Differences. Strengths of Associations Indicated by Thickness of Lines Connecting Concepts.

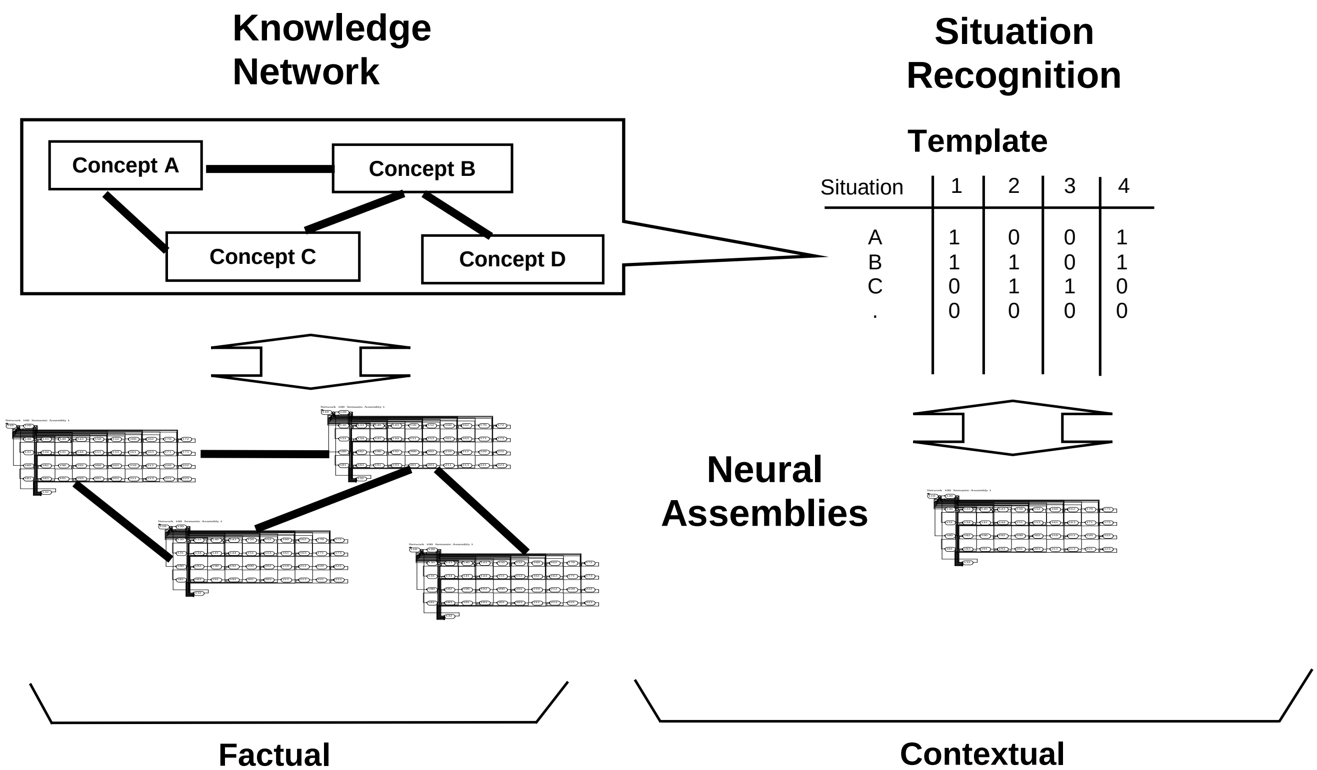
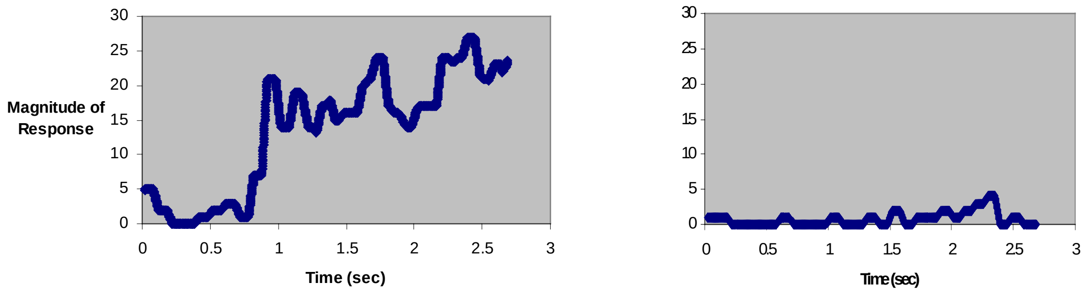


Figure 5. Framework for the physiology-based engine based on RPD Process and model of Memory Processes proposed by Klimesch.

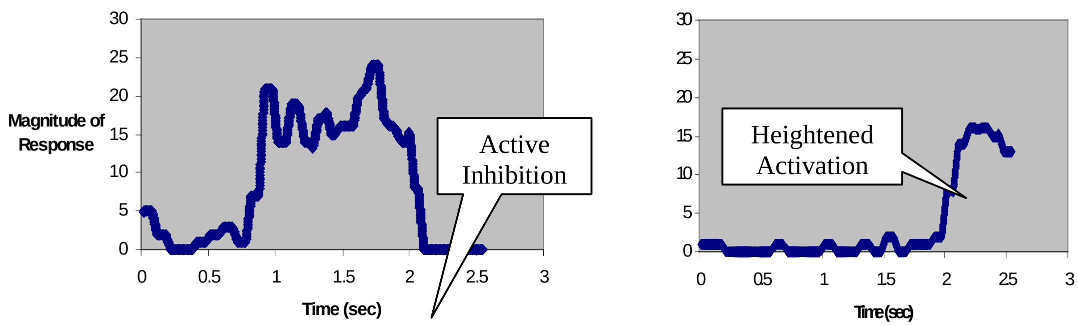
Emotion leads to increased activation of neural assemblies corresponding to the stimulus event or situation associated with emotional reaction (LeDoux 1998)



Concepts Not Associated with Fear Inducing Stimulus

Concepts Associated with Fear Inducing Stimulus

Activation in Context without Fear Inducing Stimulus*



Concepts Not Associated with Fear Inducing Stimulus

Concepts Associated with Fear Inducing Stimulus

Activation in Context with Fear Inducing Stimulus**

***Activation Observed in the Absence of Fear for Neural Assembles Associated with a Direct Threat Situation**

****Activation Observed with the same Neural Assembles Associated with a Direct Threat Situation Except that Fear Response is elicited at Approximately 2 Seconds.**

Figure 6. Differential Response to Direct Threat Situation with and without Fear Inducing Stimulus

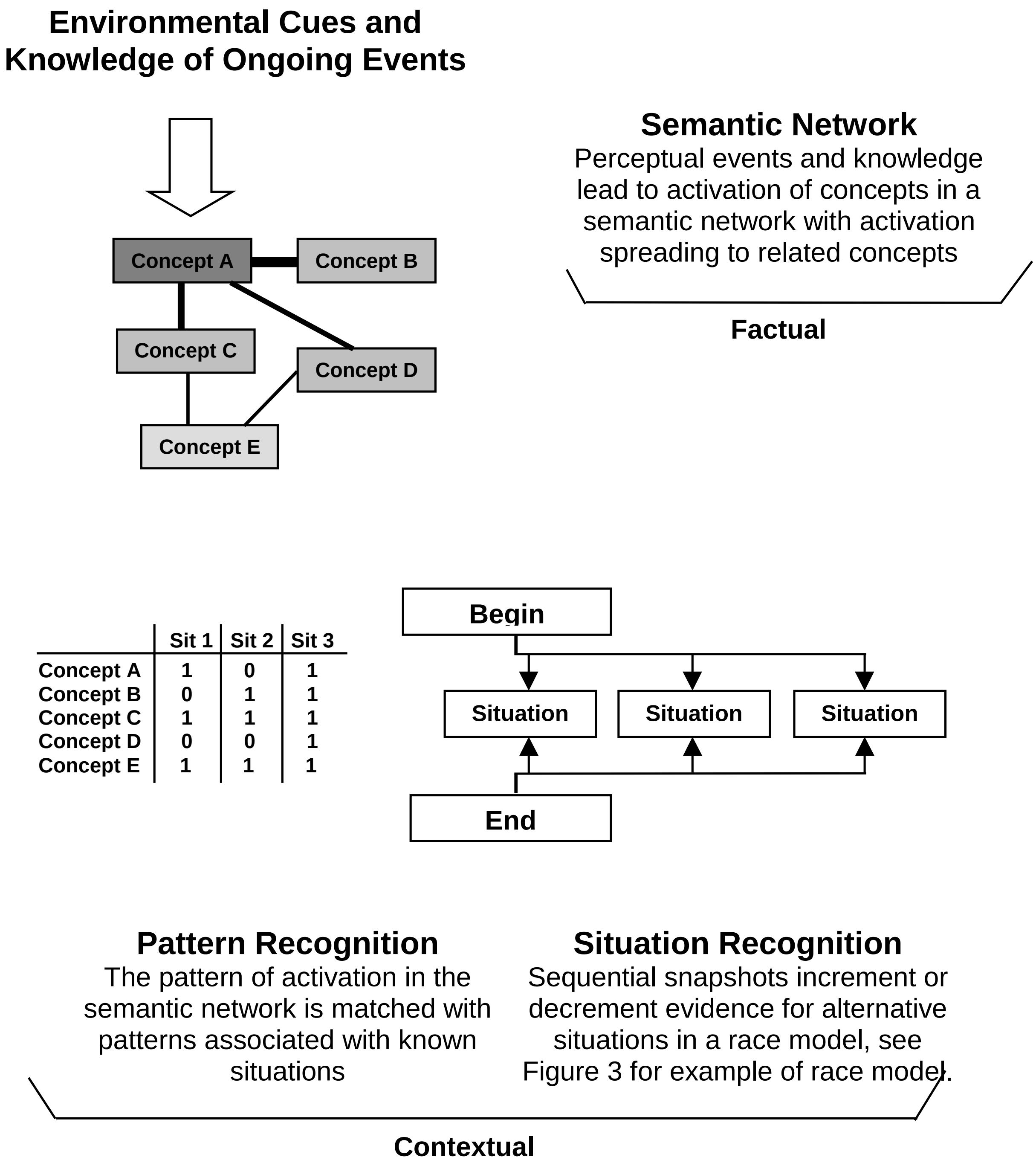


Figure 7. Cognitive Model: Differential Knowledge, Culture, etc.

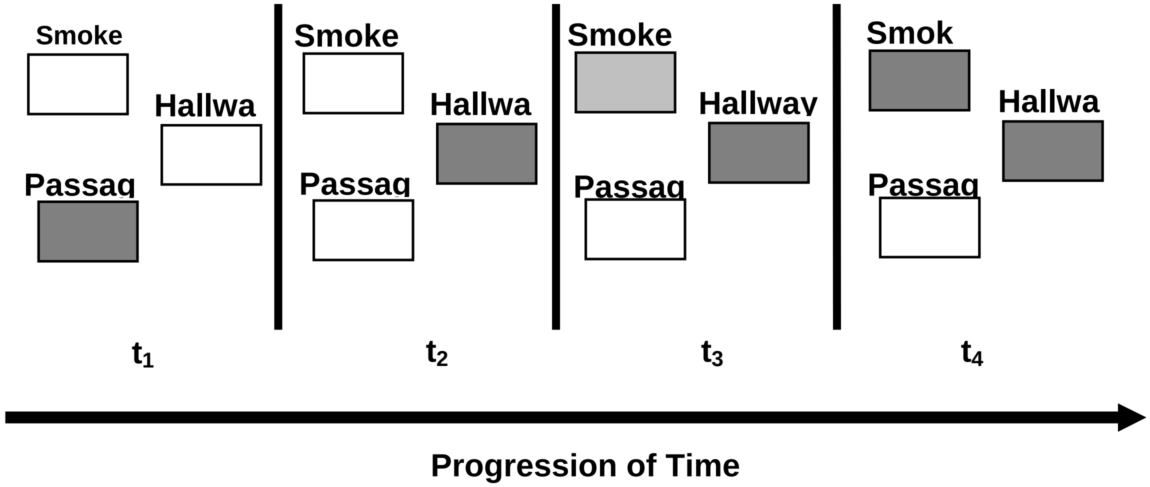


Figure 8a. Time Series of Patterns of Semantic Activation

R1 Goes Down Hallway with Increasing Smoke

	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
R1 Smoke	0	0	0	0	1	2	3	4	4	3	3	3	4	4	4	5
R1 Passage	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
R1 Hallway	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	1
R1 Intersection	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
R2 Alarm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
R2 Smoke	0	0	0	0	0	1	3	5	7	8	8	8	8	7	8	8
R2 Passage	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0
R2 Hallway	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	0
R2 Intersection	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1
R1–R2 Direction	1	1	0	1	1	1	1	1	1	1	0	0	0	1	0	0
R1-R2 Separation	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	4

Figure 8b. Derivation of Schema Based on Recurrent Patterns of Semantic Activation

1. Entered building
2. Searched for smoke, found no smoke
3. Selected path, passage into hallway
4. Followed path (search smoke)
5. Detected smoke
6. Followed path (smoke gradient), reached intersection
7. Sampled paths, found path with more smoke
8. Followed path (smoke gradient), reached intersection
9. Alerted (destination)
10. Followed path (destination)

Figure 8c. Story (Episodic) Generated Based on Sequential Ordering of Schema at the Conclusion of Simulation Run

Distribution

1 0129 Nigel Hey, 12600
1 0139 John Kelly, 9904
1 0157 Dorothy Stermer, 1322
1 0165 Chris Burroughs, 12640
1 0165 Neal Singer, 12640
1 0318 George Davidson, 9212
1 0449 Robert Hutchison, 6516
1 0449 David L. Harris, 6516
1 0451 Ron Trellue, 6501
1 0451 Tommy Woodall, 6502
1 0455 Michael Senglaub, 6517
1 0747Allen L. Camp, 6410
1 0748 Robert Waters, 6413
1 0748 John Forester, 6413
1 0759 Mark Snell, 5845
1 0780 Sabina Jordan, 5838
1 0806 Byron Dean, 9336
1 0830 Caren Wenner, 12335
1 0830 Bobby Baca, 12335
1 0839 Gerry Yonas, 16000
5 0839 Elaine M. Raybourn, 16000
1 0839 Robert Asher, 16000
1 0839 Frank Gerstle, 16000
1 0839 Louis Gritzo, 16000
20 0839 Advanced Concepts, 16000
1 0953 Jim Rice, 2500
1 1004 Ray Harrigan, 15221
1 1004 Eric Gottlieb, 15221
1 1004 Brian Rigdon, 15221
1 1004 Patrick Xavier, 15221
1 1004 Michael McDonald, 15221
1 1004 Jeff Trinkle, 15221
1 1010 Dan Small, 15222
1 1109 Rich Pryor, 9212
1 1110 William Hart, 9211
1 1125 Wendy Amai, 15252
1 1125 Keith Miller, 15252
1 1137 John Ganter, 6535
1 1137 Bill Stubblefield, 6534
1 1137 John Mitchiner, 6534
1 1137 John Linebarger, 6534
1 1140 Larry Ellis, 6502
1 1153 Stewart Cameron, 15336

1 1170 Russ Skocypec, 15310
1 1176 Robert Cranwell, 15312
1 1176 Dwight Miller, 15312
1 1176 Ruby Lathon, 15312
1 1176 Terri Calton, 15312
1 1188 John Wagner, 15311
1 1188 Eric Parker, 15311
5 1188 Chris Forsythe, 15311
1 1188 Steve Tucker, 15311
1 1165 William Guyton, 15300
1 1204 Craig Dean, 5902
1 9003 Ken Washington, 8900
1 9011 Nina Berry, 8920
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