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AN APPROACH TO HUMAN BEHAVIOR MODELING IN AN AIR FORCE SIMULATION

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ABSTRACT

This paper presents a multi-level approach to incorporating more realistic human behavior models into military simulation environments. The Air Force is incorporating different levels of intelligent agents within the Enhanced Air-to-air Air-to-Ground Linked Environment Simulation (EAAGLES) to represent the human decision making processes required in military simulations. This will provide user's the ability to determine at what level of fidelity they need to represent human behavior to achieve their study objectives. EAAGLES is currently incorporating two mental models - Situational Assessment Model for Pilot in the Loop Evaluation (SAMPLE) and *Soar*. This paper will present an introduction to these mental models and discuss how they can be used in the EAAGLES environment. This paper will also introduce and discuss the difficulties associated with validating human behavior models that are used in military simulations.

1 INTRODUCTION

In today's world the military relies on modeling and simulation to support a wide range of development, analysis, acquisition, and training functions. One can only assume that the use of modeling and simulation will be even larger in the world of tomorrow. Human decision makers are often a key component in these simulations. To meet the demands of today, and to prepare for the demands of the future, it has become crucial to create a realistic representation of human decision makers that populate simulated environments. These representations of human decision makers can be referred to as intelligent agents. For the Air Force, intelligent agents often represent the mental tasks performed by a pilot, but the applications of intelligent agents should not be limited to pilots. Intelligent agents can be used to represent unmanned vehicle controllers, ground operators, decision makers in command and control centers, as well as pilots. The opportunity for the introduction of intelligent agents in our complex simulation environments is actually quite numerous; in fact, it is feasible for an intelligent agent to be used in any area of a simulation where a human is involved.

Developing high-fidelity human behavior representations (HBRs) is not easy, and the complexities of today's simulation environments further complicate the situation. The development of a high-fidelity HBR requires having a suitable HBR model. It also requires knowing the detailed cognitive functions of the human decision-makers to include in the simulation; this requirement is probably the most important. To satisfy these two requirements three types of people will have to work together as a team:

1. Subject Matter Experts (SMEs)
2. Cognitive Psychologists
3. Model Developers.

SMEs are individuals who are highly trained in the particular area being explored and are often the individuals who make the decisions in real life that are going to be modeled. For example, if one were going to create a HBR of a fighter pilot, the SMEs would be fighter pilots. If one were going to create a HBR of decision makers in a command and control center, the SMEs would be the generals who serve in that position. The cognitive psychologists on the team are individuals highly trained in knowledge elicitation (KE). Model developers on the team will need to be familiar with the software development environment, the HBR model architecture, and the underlying algorithms and processes. This team needs to understand the simulated mission and the roles of the decision makers, or in other words, the simulation goal. The cognitive psychologist will have to extract relevant knowledge from the SMEs by using KE. Simulation goals will then be translated into HBR requirements.

2 EAAGLES

The Enhanced Air-to-Air Air-to-Ground Linked Environment Simulation (EAAGLES) is government owned and managed, collaboratively developed software, maintained by the Simulation and Analysis Facility (SIMAF) at Wright Patterson Air Force Base (WPAFB) in Dayton, Ohio. The EAAGLES Toolkit (ETK) is designed to augment Developmental and Operational Testing with high fidelity modeling and simulation. ETK consists of configurable and extendable simulation components and applications that allow users to configure their EAAGLES simulation to meet their own unique requirements, which may include integration with other legacy models. ETK is written in C++ code and is designed specifically for improved real-time performance; however it can be used for either virtual (real-time, human-in-the-loop) or constructive applications. Scalable in both software and hardware fidelity, ETK enables a common Modeling and Simulation infrastructure for Acquisition, Test, and Training communities. Throughout developmental testing and operational assessment, ETK can be used to support requirements generation, CONOPS/Tactics development, and interoperability analysis. EAAGLES can be run as a single virtual or constructive program, but it is designed for distributed simulation environments across numerous low cost personal computers.

The EAAGLES toolkit, in general, has been developed to create military simulation scenarios, and it is developing a new approach to human behavior representation for military simulations. Within the EAAGLES toolkit there will be different available options for a user to create HBRs, or agents. For the Air Force, these agents have traditionally been pilots, but intelligent agents could also be used to represent Unmanned Air Vehicle (UAV) operators, ground station operators, or command and control decision makers. In theory, any human decision making that occurs in battle could be represented by an intelligent agent. EAAGLES will offer the user an option to develop an agent at varying levels of fidelity.

3 SAMPLE

Development of the Situation Awareness Model for Pilot-in-the-Loop Evaluation (SAMPLE) began in 1997. SAMPLE is written in Java was developed by Charles River Analytics Inc. for the USAF's SIMAF at WPAFB to model situation assessment (SA) in tactical aviation pilots. However, SAMPLE has been used in several projects across the Department of Defense (DoD), Nuclear Regulatory Commission (NRC), and National Aeronautics and Space Administration (NASA). SAMPLE is a staged, SA-centered cognitive architecture that decomposes human decision-making into three parts (Hanson et al. 2002):

1. Information processing
2. Situation Assessment
3. Procedure Execution.

Because SAMPLE is an SA-centered model designed particularly for cognitive congruence, it is an ideal model to represent human decision-making obtained through Cognitive Task Analysis (CTA).

The SAMPLE architecture consists of one or more human operator models and a system model. The system model includes system dynamics that can be modeled at any level of complexity. System dynamics are generally modeled by partial differential equations of motion (Pew 1998). In this situation the system dynamics will be modeled in the EAAGLES environment. SAMPLE will use outputs from EAAGLES to make decisions that human operators would make in real life. These decisions will then be used as inputs for EAAGLES. For example, if one were to use SAMPLE to model a pilot, the dynamics of the plane being flown would be modeled in EAAGLES, or another model connected to the EAAGLES environment. Based on outputs from the EAAGLES environment, SAMPLE will make decisions necessary to maneuver the aircraft, such as a requirement to evade an incoming missile. These evasion maneuvers would then be modeled in the EAAGLES environment. A HBR model may exist for each individual human operator participant that would be involved in the task in real life. It is important to note that the designer determines the fidelity of each of these human operator models depending on the focus of the study. One should also remember that since EAAGLES was designed as a virtual simulation environment some of the operators will be represented by humans participating as subjects in the study. As a result it will be necessary for SAMPLE players to interact with the virtual players.

SAMPLE consists of several processors and effector channels. Sensory channels are used to model visual and auditory sensing, both of which are based on an optimal control model with no perceptual delay. They model limitations due to stimulus energy and observation noise with respect to defined thresholds. Because an agent operator cannot process all sources of information concurrently, the model decides what to attend to, and in what order. For this purpose the attention allocator uses suboptimal attention allocation algorithms (Pew 1998). These algorithms are suboptimal to better represent a human's tendency to perform attention allocation suboptimally.

The development of a SAMPLE agent is based in knowledge engineering. Using knowledge engineering to develop computational cognitive models for HBRs is a two-stage process. The first stage consists of CTA. In this stage the relevant Situational Assessment (SA) information requirements, which are defined as the dynamic information needs associated with the major goals or sub-goals that the decision maker must perform, are extracted by using the Goal Directed Task Analysis (GDTA) method. The second stage involves the actual mapping between the GDTA results and the SAMPLE HBR. This can be accomplished in three steps that correlate with the three major elements of a sample model. These three steps are (Hanson et al. 2002):

1. Information Processing – transforms sensor data identified by the GDTA into important semantic variables that define the key events in the simulation.
2. Situation Assessment – generates a high-level interpretation of the situation as a function of situational memory and perceived events.
3. Decision-making and Procedure Execution – emulates a human's rule-based decision-making behavior to select a procedure to implement, feeding rules available in the decision rule memory with the overall assessed situation.

The GDTA structure is directly implemented within the SAMPLE Model. GDTA identified data forms the input, this input is fused together to yield assessments, and assessments are used to make decisions. Fuzzy logic is used primarily for information processing and event detection; this allows for contextual knowledge, which humans usually use from raw data. Bayesian Belief networks are used for situation assessment. Within SAMPLE, entire goal trees including decisions, assessments, and data can be implemented in a generic module. It is important to note that the development process of a SAMPLE agent should always be iterative and SMEs should view the model for accuracy and completeness. (Hanson et al. 2002)

A Graphical Agent Development Environment (GRADE) has also been developed to enhance SAMPLE. Charles River Analytics Inc. has developed GRADE for the Air Force Research Labs (AFRL) at Wright Patterson Air Force Base in Dayton, Ohio. GRADE is a development environment that allows for graphical agent construction, validation, and visualization. This user interface for SAMPLE is a great asset, increasing the usability of the software. Agent developers can use GRADE to more easily create SAMPLE agents. This allows agent developers to focus more on the task of developing the agent and less on the actual computer language used to write SAMPLE agents.

Charles River Analytics, Inc. is currently in the process of incorporating SAMPLE with EAAGLES. SAMPLE can be used to pilot digital players through a socket between the two simulations. SAMPLE agents will likely be used this fall at SIMAF to represent red-air threats and/or blue-air bombers in an Airborne Electronic Attack (AEA) event. However, one needs to keep in mind that SAMPLE agents could also be used to represent other types of players other than pilots.

4 SOAR

Soar is a general cognitive architecture for creating systems that model intelligent behavior. Currently, researchers all over the world are using Soar. It was first introduced as a computer model in 1983 (Newell 1990). Through the years Soar has evolved through many different versions. Soar 8.6 is the most current version (University of Michigan 2005). While Soar is written in its own language, the most current version of Soar is available for either a PC Windows or Linux platform.

The Soar architecture was originally developed to model learning and problem solving. It uses symbolic cognitive logic to implement goal-oriented behavior as a search through a problem space. The Soar architecture assumes that cognitive behavior has at least the following six characteristics (Newell 1990):

1. It requires a large amount of knowledge;
2. It is flexible, and a function of the environment;
3. It requires the use of symbols and abstractions;
4. It is goal-oriented;
5. It requires learning from the environment and experience; and
6. It reflects a rich, complex, detailed environment.

A cognitive architecture, such as Soar, is actually two things at once; it is a theory about commonalities in cognitive behaviors, and it is also a set of structures and mechanisms that process information to produce behavior.

The structure at the heart of the Soar architecture is the goal context. The following four slots and their associated values define the goal context (Lehman et al. 2005):

1. The goal;
2. The problem space;
3. The state; and
4. The operator.

The goal maintains goal-directed behavior, while the problem space organizes information in a goal-related way. The state is an internal picture of the situation and the operator maps from one state to another.

Soar working memory is used to contain the current situation. Working memory stores the current situation in the form of one or more goal contexts. Along with the current situation, working memory also stores past situations and hypothetical situations if they are important for reasoning. Results of perceptions as features and values in the Top state are also held in working memory. The Top state is the area in which all actions and perceptions occur. Associations in long-term memory and motor actions can be triggered by the contents of working memory. (Lehman et al. 2005)

Long-term memory is used within Soar as a repository for domain content processed by the architecture to create behavior. Associations are the formation of knowledge in the long-term memory. These associations map from the current goal context in working memory to a new goal context stored in long-term memory. A simple match process against working memory can trigger an association, because the mapping is from context to context. While Soar's long-term memory is associational, it is also impenetrable. This means that a Soar system cannot directly examine its own associations. A system within Soar only has one window into the long-term memory. This window is provided as a result of association firings that cause changes to working memory (Lehman et al. 2005).

The perception/motor interface is the mechanism used within Soar to define mappings from the external world to the internal representation in working memory. This mechanism also defines mappings from internal representations out to actions in the external world. This interface allows perception and action to occur at the same time, as well as in parallel with cognition (Lehman et al. 2005).

The basic architectural process within Soar that supports cognition is the decision cycle. The decision cycle is composed of the elaboration and decision phases. During elaboration, parallel access to the long-term memory changes the values and features that define the state and suggest new values for context slots. In the decision phase, preferences and suggestions are interpreted to make changes to the context. There are two possible results of the decision phase. There is either a single change to the goal context, or no change if none has been suggested. This application of a single operator per decision cycle can lead to what is referred to as a cognitive bottleneck in the architecture, or in other words, a limit as to how much cognitive work can be done in one cycle (Lehman et al. 2005).

Impasses within Soar signal a lack of knowledge. As a result, impasses lead to an opportunity for learning. Whenever the knowledge sought by the current context isn't enough, an impasse automatically occurs. The sought-after knowledge is insufficient when the decision procedure cannot resolve the preferences in working memory to a single change in the context. Like the language of preferences, the language of impasses is defined independently of the domain. If an impasse arises, the architecture automatically begins the formation of a new subgoal context. The goal of this new subgoal context is to resolve the impasse. By doing this, impasses create a goal/subgoal hierarchy in the contexts of the working memory (Lehman et al. 2005).

Chunking is the predominate architectural learning mechanism within Soar. Whenever a result is generated from an impasse, chunking creates new associations in long-term memory. These new associations map the pre-impasse working memory elements, which are relevant to the situation, into working memory changes. The working memory changes prevent that particular impasse form occurring in similar future situations. Chunking is basically a compositional or deductive mechanism that serves many purposes. Chunking can be used as the basis of analogical reasoning and inductive learning. Within Soar chunking can speed up behavior by using the pre-impasse problem space to compress many steps through many subspaces into a single step. Chunking is the only architectural mechanism for changing long-term memory. As a result, all types of learning in people are assumed to have a basis in chunking (Lehman et al. 2005).

SIMAF is currently in the process of incorporating Soar with EAAGLES. This is being accomplished through a custom interface that allows Soar to be used to pilot digital players within the EAAGLES environment. Soar agents should be used this fall at SIMAF in the Airborne Electronic Attack (AEA) event to represent blue-air bombers. However, one needs to keep in mind that it is possible for Soar agents to represent other types of players.

5 VALIDATION

Recent improvements to the fidelity of physics-based models have raised expectations for improved human behavior models. However, the well defined standards that are often used to validate physics-based models are not well suited for validating behavioral models. The human cognitive process itself is indeed at the root of this problem, due to the fact that cognition is nonlinear by nature. Inadequate metrics for validating human behavior representation models further complicate the validation process, and the large set of interdependent variables used by human behavior models may make it statistically impossible to account for all possible interactions (Goerger 2005).

However, in the realm of military simulations it is possible to validate human behavior models against operationally defined tactics. Since military personnel are trained with a set of defined tactics for their operational area of expertise, it is possible to validate human behavior models against these predefined tactics. That said, it should be remembered that not all humans follow these tactics in all situation. In real life it is possible for situations to arise that may not be covered by a predefined operational tactic. Even the validation of human behavior models against operational defined tactics can be looked at as a double edged sword, and there are those critics that will say this is not enough validation. Individuals that want a model to be validated using hard and fast numbers may not be satisfied with this approach. What one needs to remember is that the validation of a human behavior model is far different from that of a physics based model, and that validating against operationally defined tactics is a step in the right direction, but not necessarily the final step.

6 CONCLUSION

Human behavior modeling in the realm of military simulations covers a large area. There are those who want to specifically study human reactions and thus require a high level of fidelity in their HBR. There are those who require a much lower level of HBR fidelity for more of a quick-turn tool to get approximate answers to their questions. Mixed levels of fidelity may be required for allocations of player control in both constructive and virtual simulations. Many of the key players in virtual studies are manned by Air Force personnel, however, as a study scenario grows, it is no longer feasible for all players to be represented by humans. In this situation the need arises for some, if not most, of the players to be represented by HBR models. The EAAGLES toolkit has been designed specifically to build virtual distributed simulations with the ability to integrate HBR models of varying fidelity operating simultaneously. Thus, EAAGLES provides simulation developers with different options for the representation of these players. This will allow study designers and analysts to decide what level of fidelity is required for HBRs in their study. SAMPLE may be used for players that are of more importance and require a higher level of fidelity, and Soar can be used for players that require a lower level of fidelity.

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