

# PLANNING THE IMPLEMENTATION OF SYNTHETIC AND INSTRUCTIONAL AGENTS IN VIRTUAL TECHNOLOGIES AND ENVIRONMENTS

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## ABSTRACT

The complex and dynamic environments encountered by our warfighters call for creative solutions to training challenges. The forward-deployed nature of amphibious forces, practical operational concerns, and perishable nature of complex cognitive skills and team process behaviors create the need to train our Marines and Sailors while at sea. Virtual Technologies and Environments (VIRTE), an advanced research initiative sponsored by the Office of Naval Research (ONR), aims to develop prototype simulation training systems for deployed amphibious forces. These training systems will provide the opportunity to refresh team skills and will include various environmental conditions that may impact the training exercises.

VIRTE will incorporate many technologies into the development of these amphibious forces training systems. This paper will be concerned with development and integration of Computer Generated Forces as teammates (Synthetic Agents) and an intelligent tutoring system (Instructional Agent). Synthetic Agents (SAs) provide the capability to replace individual crewmembers in training scenarios. Synther technology creates an atmosphere where the entire crew need not be present in order for one or more crewmembers to participate in meaningful training. Automated instruction, a key feature of the VIRTE program, is accomplished via intelligent tutoring. The Instructional Agent (IA) monitors trainee behavior and performance, assesses trainee actions, and provides after action review of trainee performance. VIRTE advances the current state of human behavior representation by integrating these powerful tools to emulate human operators and instructors with technology that uses artificial intelligence to simulate human reasoning.

Synthetic and Instructional Agents will be applied to virtual training platforms of the Navy's Landing Craft, Air Cushion (LCAC) vehicle and the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV). The model development process of the SA and IA will be discussed. This paper will discuss agent development, progress achieved, anticipated challenges, and plans for performance evaluations.

## BIOGRAPHIES

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**Stephanie Lackey** performs Human Behavior Representation and Intelligent Tutoring research tasks for the Human Behavior/Computer Generated Forces Laboratory. She is Research Engineer in the Science and Technology Division of the Naval Air Warfare Center Training Systems Division. She is currently active in the architecture development of the Virtual Environment Advanced Amphibious Assault Vehicle – Instructional Agent (VEAAAV-IA) as part of the Virtual Technologies and Environments (VIRTE) Demo I project. Stephanie earned a MS degree in Industrial Engineering – Simulation, Modeling, and Analysis from the University of Central Florida, and a BS degree in Mathematics with a double major in Secondary Education from Methodist College, in North Carolina.

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progress achieved, anticipated challenges, and plans for performance evaluations.

## INTRODUCTION

VIRTE is an advanced research initiative that focuses on the Expeditionary Warfare Domain. The full research effort is comprised of three technology demonstrations scheduled in FY 03, FY 06, and FY 07. The first, Demonstration I, focuses on weapons system training and human interactions with land, sea, and air vehicles; specifically, the LCAC, AAHV, and Tilt-rotor aircraft (MV-22 Osprey) (see Figure 1). Demonstration II concentrates on Military Operations in Urban Terrain (MOUT), and will culminate in a Close Quarter Battle (CQB) Scenario demonstration. Finally, Demonstration III includes a Full Spectrum Combat, Integrated Infantry System (IICS), Range Instrumentation System (RIS), and Virtual Environment (VE) marksmanship training (Worcester & Worcester, 2001). This paper focuses on the Human Behavior Representation (HBR) and Computer Generated Forces (CGFs) associated with Demonstration I.



Figure 1. VIRTE Demonstration I focuses on providing deployed training solutions to the Expeditionary Warfare community. This community includes air, land and sea elements. *Left:* Landing Craft, Air Cushion (LCAC); *Center:* Advanced Amphibious Assault Vehicle (AAAV); *Right:* The MV-22 (Osprey) is a tilt-rotor craft.

The deployable PC-based prototype simulators developed as part of VIRTE Demonstration I will be linked via High Level Architecture (HLA) networks. The simulators will interface with a Synthetic Natural Environment to replace the natural environment and will include wind, sea state, waves, rain, tide, fog, buildings, and terrain. Crafts, ships, and other vehicles that populate the synthetic battlespace will be represented by Joint Semi-Automated Forces (JSAF) entities. Additionally, the SA integrated into the Virtual Environment Landing Craft, Air Cushion (VELCAC) will replace a human teammate, and the IA

component of the Virtual Environment Advanced Amphibious Assault Vehicle (VEAAAV) will aid human instructors.

Ever increasing training challenges motivate extending Virtual Reality (VR) research beyond hardware and software technology. VIRTE's infusion of HBR and CGFs highlights a shift in VR research. Incorporating SAs and IAs allows VIRTE simulators to provide meaningful training to our most forward-deployed forces that addresses practical operational concerns such as the cost associated with live fire training and personnel availability. Plus, complex cognitive skills and team process behaviors are perishable in nature and require periodic refresher training or mission rehearsal. Due to the lack of resources with respect to instructional personnel and role player availability at-sea, a significant training challenge exists: how can timely, effective, and useful training be delivered to Marines and Sailors at-sea? VIRTE confronts these important training issues. VR training systems reduce the long-term cost of training while providing a safe environment within which to train. Personnel availability, instructor or role player, is no longer an issue. Deployed forces may train independently and still interact with teammates and receive feedback from an instructor. VIRTE simulators put training into the hands of our deployed warfighters, allowing them to train complex cognitive skills and team process behaviors, when they are available and wherever they are located.

## SYNTHETIC AGENTS

### BACKGROUND

Synthetic teammates, synthets, create an atmosphere where the entire crew need not be present in order for one or more crewmembers to participate in meaningful training. SAs provide the capability to replace individual crewmembers in training exercises by employing cognitive modeling techniques and artificial intelligence technology. The SAs developed for VIRTE's VELCAC are based upon the COGNITION as a NETWORK of Tasks (COGNET) architecture and instantiated through the associated cognitive modeling software toolkit iGEN. The main components of a COGNET/iGEN cognitive model include the *blackboard*, *tasks*, *perceptual demons*, and *actions*. The *blackboard* consists of the declarative knowledge about the given situation and mission. *Tasks* represent the procedural knowledge required to complete mission goals. *Perceptual demons* sense input from the external synthetic natural environment and JSAF entities, whereas *actions* respond to events and occurrences perceived from the external environment (Ryder,

Santarelli, Scolaro, Hicinbothom, & Zachary, 2000 and Zachary, Ryder, & Hicinbothom, 2000).

The benefits of this approach to constructing and programming synthetic agents are substantial. At its core, the concept of employing an SA gives VIRTE the opportunity to meet the critical training needs of deployed forces. Additionally, use of the COGNET architecture and iGEN toolkit leverages previous SA research programs sponsored by ONR and completed in conjunction with the Naval Air Warfare Center Training Systems Division (NAWCTSD): Virtual Environment and Training Technologies (VETT) (Martin, Sheldon, Kass, Mead, Jones, & Breaux, 1999) and Synthetic Cognition for Operational Team Training (SCOTT) (Weiland, Szczepkowski, Urban, Mitchell, Lyons, & Soles, 2002), and Conning Officer Virtual Environment (COVE) (Roberts, 2001). The VETT program developed a COGNET/iGEN expert observer model (Martin, et al., 1999) which serves as a basis for the synthetic Navigator role player (CHI Systems, Incorporated, 2001). SCOTT includes many of the technologies integrated into VIRTE. In SCOTT, a joint synthetic battlespace replaces the natural environment. Aircraft, ships, and other vehicles are represented by JSAF entities, and human teammates can be replaced by synthetic teammates and CGFs (Naval Air Warfare Center Training Systems Division, 2001; Weiland, et al., 2002). The focus here, of course, is the simulation of human teammates via CGF technologies.

Transitioning an existing cognitive model developed for SCOTT while integrating the expert model from VETT, the synthetic Navigator model in VIRTE proved to be advantageous due to this prior experience within similar simulation systems. Weiland et al. (2002) cite three specific advantages:

- 1) "a significant decrease in model development time over a de novo implementation of a model of similar scale,
- 2) a path to providing automation to augment this type of reuse, and
- 3) extending and standardizing geometric and navigational reasoning library ... permit[s] this component to be reused directly for future modeling efforts."

### APPLICATION

The LCAC (see Figure 2) supports Expeditionary Warfare by transporting critical personnel and materials. A LCAC's core crew consists of a Craftmaster, Navigator, and Engineer. The Craftmaster flies the LCAC. The Navigator develops the mission plan and provides direct guidance for modifying the

plan during the mission. The Engineer monitors and maintains LCAC system functionality throughout the mission. Together, these crewmembers, or teammates, accomplish mission tasks that focus on transporting troops, supplies, and vehicles from a ship to a previously secured beach landing site (Lyons, Schmorow, Cohn, & Lackey, 2002). Additionally, the LCAC is a multi-mission craft capable of mine countermeasure activity and mobile field hospital functionality (CHI Systems, Incorporated, 2001). However, due to the designed purpose of the LCAC, the craft possesses no offensive and significantly limited defensive capabilities (Lyons, et al., 2002).



Figure 2. *Left:* An LCAC transports cargo and troops to a secure beach site. *Right:* Two LCACs depart an Amphibious Transport Dock (LPD).

A SA Navigator model implemented in the VELCAC will perform major tasks identified through knowledge acquisition including: 1) making internal reports, 2) making external reports, 3) monitoring external communications, 4) monitoring ownship course and speed, and 5) monitoring contacts in an area of concern. The model receives input via a communication shell that alerts the COGNET/iGEN *perceptual demons* of an external event. That information is compared to the *blackboard's* declarative knowledge about the domain. Specialized model components (*tasks, goals, methods*) access and process the information to simulate the decision making processes of an expertly trained Navigator. The resulting decision is then output to the simulation system. Output from the Navigator to a live Craftmaster trainee takes two forms: synthesized speech and radar screen interface manipulation (CHI Systems, Incorporated, 2001). This approach allows for the trainee to participate in mission rehearsal in the same manner as he would with a live Navigator.

The VELCAC system represents a mission rehearsal system for highly trained Craftmasters, rather than a training system suited for skill levels ranging from novice to expert. Contact avoidance is a key element to mission success, and therefore mission rehearsal, and serves as an illustration. In order to safely proceed from ship to shore, obstructions and contacts must be appropriately identified and avoided. Specific procedures must be followed and particular communications must occur between the Navigator and Craftmaster in order to safely avoid contact with another vehicle or object. Within a VIRTE mission rehearsal scenario, crewmembers will communicate via

interaction using HLA networks. During the scenario, another craft may enter the pathway of the VELCAC. In this event, the live Craftmaster will interact with the synthetic Navigator in order to resolve the issue within previously defined parameters. Human and/or automated observers will collect data regarding the collision avoidance event and the performance of the Craftmaster trainee. The data can then be assessed accordingly to evaluate the live Craftmaster's performance (Lyons, et al., 2002).

## STATUS AND PERFORMANCE EVALUATIONS

Completion of the Navigator model is scheduled for December 2002. Iterative development of the synthetic Navigator's accuracy is ongoing and conducted by modelers at CHI Systems, Incorporated using modified testbed simulator components leveraged from the SCOTT testbed. Integration of the SA component into the VELCAC is scheduled for October - December, 2002. As previously stated, interim assessment of the model is ongoing, but verification and validation via Subject Matter Expert (SME) and Acceptability Criteria evaluation will be conducted during 2003.

## CHALLENGES

The sheer nature of cognitive modeling is, of course, challenging. Creating SAs that can dynamically act and react in real-time to input from an external environment, as well as a human operator, has proven to be an exciting, yet formidable task. One specific task, communications, posed significant challenges. No formal structure, nor training curriculum, exists for Navigator communications. Navigator trainees are expected to utilize standard Navy communications. However, a synthetic Navigator necessitates a formal structure in order to effectively communicate with human role players. Collaboration between the modelers and SMEs resulted in a documented and structured communication set which was implemented to facilitate on-board and off-board communications (Schmorow, Lyons, Cohn, Lackey, Allen, Norman, Szczepkowski, Urban, & Mitchell, in press).

## INSTRUCTIONAL AGENTS

### BACKGROUND

The purpose of an instructional agent (IA) is to provide a learning experience for a trainee that emulates one-on-one interaction with an instructor. An IA is a computer program application, which incorporates artificial intelligence techniques that monitor and evaluate a trainee's activities. In addition, an IA provides appropriate instructional feedback to ensure

the trainee is performing correct procedures in an accurate and timely manner. For the VEAAAV training system, an IA will be developed to monitor trainee performance during precision gunnery training exercises. IAs are effective training mechanisms when the preferred mode of instruction is “learning by performing”. Due to the nature of Marine Corps’ Combat Vehicles Gunnery skills, learning occurs when trainees are afforded the opportunity to practice those skills either in the real vehicle or through the use of simulation systems. Given the environmental expense considerations associated with live-fire training, simulation can provide additional training opportunities for AAV Gunners. However, simulation without an instructor is of little use because to improve, trainees must quickly obtain performance feedback. An IA can provide a trainee with immediate detailed feedback regarding the trainee’s performance. By reinforcing the correct actions performed by the trainee, procedural tasks become second nature. When tasks become automatic through practice, a trainee will be able to focus their attention on other cognitively demanding tasks. Enabling trainees to improve multi-tasking skills increases each trainee’s value to their team. In combat, chaos rules. Therefore, the more prepared our warfighters are to successfully handle challenging situations that require multiple tasking operations, the better their chances are of winning and surviving combat.

Conventional Intelligent Tutoring Systems (ITSs) are used to teach procedural skills with an end goal of mastering a predefined set of tasks. Traditional ITSs consist of four components: *expert model*, *student model*, *pedagogical model*, and *communication module* (Beck, Stern, & Haugsjaa, 2002). The *expert model* contains the domain knowledge to be presented and is a model of how someone skilled in a particular domain represents knowledge. The *student model* consists of specific information related to the individual trainee concerning their level of mastery in a particular domain. The *pedagogical model* is comprised of teaching strategies and how the presentation of instructional material should be handled. Lastly, the *communication module* controls the interactions between the trainee and the instructional system, and includes input with respect to appropriate dialogue and screen displays. Mechanisms which diagnose student performance and modify curricula/lessons typically characterize standard ITSs. Student diagnosis implies that the ITS must make inferences concerning the behavior exhibited by the trainee and then update the student model with the newly acquired information about the trainee’s knowledge state and skill level. The curriculum/lesson modification mechanism applies the updated information contained within the student model

to determine how to proceed with instruction (Lajoie, Azevedo, & Fleiszer, 1998).

While several ITSs in use today diagnose student performance, the proposed VEAAAV-IA will adhere to a non-diagnostic philosophy. The IA implemented will differ from diagnostic systems in that it will not generate inferences about the knowledge state and skill level underlying a trainee’s behavior. Therefore, the VEAAAV-IA will not adjust instruction based on systematic updates to the student model. The IA will simply record the trainee’s behavior. With this information, a trainee’s actions can be compared with that of an expert. The trainee can then be advised when and how their behavior differs from an expert’s performance of the same task given the same circumstances. Thus, the IA will simply point out the difference between expert’s and the trainee’s behavior.

The underlying reason for a non-diagnostic approach stems from the difficulty related to developing a tutor in a domain such as gunnery. The tutor must be able to 1) solve problems in the task domain at an expert level, 2) explain the reasoning processes used to obtain these solutions, 3) understand trainee misconceptions, and 4) sequence elements of instructions automatically so that one builds on another. Furthermore, a diagnostic tutoring system requires fundamental knowledge of various teaching strategies such as direct instruction and questions, hints, explanation, diagnosis and assessment techniques, and instructional management skills. Some of these teaching strategies are difficult to model because the process involves using student diagnosis to adjust teaching strategies in a highly interactive simulation environment. In addition, experts in the gunnery domain have different methods for performing the same gunnery skills. Some experts will spend more time on target acquisition and less on target engagement or vice versa. However, the main goal is still the same: put rounds on targets. The IA will evaluate the trainee’s ability to perform precision gunnery tasks with an emphasis on placing the correct type of rounds on appropriate targets. If trainees fail to correctly complete this task, the IA will be capable of tracking where in the scenario an error occurred. Corrective feedback can then provide insight into the reason incorrect actions were performed for that situation.

#### APPLICATION

The AAV (see Figure 3) is a vehicle currently under development that is envisioned as providing Marine infantry with the capability for high-speed water and land maneuver while carrying over a dozen infantry members. Unlike the LCAC, the AAV is meant to operate under hostile conditions, in both offensive and

defensive positions. Thus, the AAV crew consists of a Driver, who maneuvers the vehicle, a Gunner, who operates the weapons system, and a Commander, who performs command and control functions.



Figure 3. The AAV can quickly maneuver over land or water.

The focus of the AAV system will be training, rather than mission rehearsal. Initial analysis efforts revealed the need for VIRTE to develop a training system that will provide practice for trainees ranging from novice to expert levels. A key difference between the LCAC and AAV deliverables is the inclusion of an ITS for the AAV (Worcester, et al., 2001). Development of the IAs will be determined and directly impacted by the feedback needs indicated by the SMEs and ascertained through analysis of the AAV domain.

The VEAAAV system will be similar to the VELCAC system, but will include an important additional capability. In VIRTE, the VEAAAV platform simulators will communicate over the same type of HLA networks as the VELCAC and will also utilize JSAF to generate entities. However, the VEAAAV system is designed to serve the purpose of a trainer, rather than as a tool for deployed mission rehearsal. Within the VEAAAV, an IA will be available to replace and aid live instructors. The IA will provide the trainee with immediate feedback, when necessary, during the execution of the training exercise. Data collection duties, such as time and accuracy needed to identify a target, will also fall to the IA. The actions taken by the trainee(s) will be tracked through automated systems so that data may be gathered and performance measurement completed.

Translating knowledge into skill acquisition will be implemented through the following phases: *procedure-oriented knowledge*, *guided-example exercises*, *unguided-example exercises*, and *automated-example exercises* (Fink, 1991). *Procedural-oriented knowledge* involves learning each step required to perform a particular task. Each step of the task procedure will be represented in the sequential order required, and an explanation for performing each step at its specified time will be developed. Participating in the next phase, *guided-example exercises* will begin the actual skill acquisition process. A trainee will be presented with specific examples of the procedures to be performed, and will then be guided/coached through the examples. The goal is to provide not only experience through

physically performing previously defined procedures, but to provide sufficient experience to render acceptable results. In this phase, the IA must understand the procedures for a given task, and how to perform them correctly. The IA must also be able to determine when a trainee makes a mistake(s), categorize each mistake(s), and provide appropriate feedback so the trainee involved may correctly modify erroneous actions. To progress to the next phase, the results of the guided-example phase must indicate the trainee is capable of correctly performing a given exercise within accuracy and speed parameters. *Unguided-example exercises* allow the trainee to perform exercises without having the IA provide immediate feedback or coaching. This phase provides the trainee with opportunities to perform their tasks without interruption from the IA. Following the conclusion of an exercise, the accuracy and speed of the trainee's performance will be evaluated. At this point, in the progression from knowledge to skill acquisition, a trainee's skill performance is typically rated highly accurate but speed to perform these tasks may vary significantly. The strategy within this phase is "drill and practice". Trainees must be able to perform a given exercise with increased speed while maintaining accuracy, thus indicating that they have acquired a certain level of proficiency in performing their tasks. In the final phase, *automated-example exercises*, the trainee will be required to maintain accuracy and speed in their primary tasks while experiencing opportunities to perform different unrelated tasks during the exercises. The goal of this phase is to exercise the trainee so that they no longer think about performing the detailed steps involved in the primary tasks, but perform these tasks automatically.

For AAV gunnery, the following tasks/procedures will be researched, and strategies will be developed to address each task with the VEAAAV-IA:

- Visually scan for targets
- Monitor detection systems
- Identify target as friend or foe
- Determine whether to engage target
- Prioritize targets if multiple targets identified
- Select target to engage
- Acquire target
- Select weapon
- Select main gun ammunition
- Lase target to determine range
- Determine ballistic solution
- Lay weapon
- Aim
- Fire weapon
- Observe effects
- Terminate engagement
- Monitor ammo in ready rounds

The initial development effort will focus on gunner tasks using the weapon system's power control mode rather than the manual control mode for weapon engagements.

## STATUS

The VEAAAV-IA effort will consist of four phases: 1) Needs Assessment, 2) Cognitive Task Analysis, 3) IA Implementation, and 4) Evaluation Phase.

**Needs assessment.** This phase has been completed and the guidance given by the Marine Corps Direct Reporting Program Manager – Advance Amphibious Assault (DRPM-AAA) indicated that a requirement for this type of technology exists for both their embedded training system and schoolhouse training systems.

**Cognitive Task Analysis (CTA).** This phase has been planned for and is currently in progress. The CTA will drive the development of the VEAAAV-IA and will typically be performed to assess the concepts, principles, and procedures employed when performing specific gunnery related tasks. The CTA process is multi-stage, where the first step is to understand the aspects of the domain, followed by the differentiation between tasks requiring skilled and less skilled performance (Gugerty, 1997). Stages of the CTA process comprise:

1. Identify the tasks that constitute the target performance for the job, (i.e., what are the important and difficult tasks associated with the job?).
2. Determine the required skills involved in performing the target tasks, (i.e., what are the procedural skills and system knowledge required?).
3. Generate the mental model used by the expert(s) (i.e., what are the strategies and problem-solving techniques employed by experts?).
4. Identify the difficulties encountered by novice user(s) (i.e., what are common novice misconceptions and what knowledge, skills, and strategies do they lack?).
5. Focus the teaching concentration (i.e., which instruction components are most beneficial?).

**Instructional Agent Implementation.** This phase will consist of defining the simulation interface requirements and what information/data will be needed from the simulation system. In addition, the software coding for the instructional agent will be developed.

This phase has not yet started, but the planning process is ongoing.

**Evaluation.** The phase is scheduled to begin in the summer of 2003.

## CHALLENGES

One of the most challenging aspects of this development has been that the AAV program is in the Engineering, Manufacturing, & Development phase. Currently there exist three prototypes for this platform. With that said, there are not many AAV gunnery experts and limited training curricula are available to help define the standards and procedures needed to use this weapon system. However, the Marine Corps has other weapon system platforms that have similar armament systems and we plan to leverage those systems to help develop this IA. At first, the IA will be somewhat generic in nature for precision gunnery, and as we learn more about the AAV and have access to AAV experts/instructors, the models can then be tailored to comply with AAV precision gunnery standards.

## PERFORMANCE EVALUATIONS

As stated previously, performance evaluations will be performed. The development cycle dictates performance evaluations to be completed during FY03.

## CONCLUSIONS

By capitalizing on previous research conducted by NAWCTSD such as SCOTT (Weiland, et al., 2002), VETT (Martin, et al., 1999), COVE (Roberts, 2001), and Virtual Environment for Submarines (VESUB) (Hays, Vincenzi, Seamon, & Bradley, 1998 and Seamon, Bradley, Hays, & Vincenzi, 1999), and by pursuing creative solutions to increased training challenges, VIRTE advances the state of the art in HBRs and CGFs to the benefit of deployed Navy and Marine forces. One of the key components to serving the needs of the Fleet is to identify the appropriate strategies and technologies to implement. For example, the LCAC community required an easily deployable mission rehearsal system as opposed to a traditional training system. Due to the type of rehearsal specified for the Craftmaster position, VIRTE developed an SA to fill the role of the Navigator. Alternatively, the AAV community desires a training system to aid Gunnery instructors. To fulfill this need, VIRTE researchers developed an IA to monitor performance, give feedback, and provide information for an after action review. In this way, the HBR/CGF component of VIRTE Demonstration I strikes the delicate balance

of advancing the state of the art in research and meeting the needs of the Fleet.

Future lines of research could certainly include expansion of the existing VELCAC Navigator model, or the addition of a synthetic Craftmaster to support Navigator training. Likewise, further detail could be added to the current VEAAAV-IA, but a more interesting pursuit would be to adapt the IA to another platform such as the Light Armored Vehicle (LAV) or M1 Abrams Main Battle Tank (M1A1). The research accomplished in VIRTE provides tools to serve the needs of the Fleet and may be leveraged to a variety of platforms.

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