Human Capacity Development Through Simulations: Constructive Simulations as a Basis for Understanding Competency Requirements in Initiative Based Tactics

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ABSTRACT: This paper presents the state of development of a constructive simulation to better understand competency requirements in initiative based tactics in order to support training scenario design in a virtual training environment. The simulations of interest are cognitive models. The first section situates the development functions of understanding, training, and assisting human capabilities, in relationship to the traditional distinction of live, virtual and constructive simulations. The human development and their associated simulation types can also be laid out on a continuum of agent embedment in physical settings. The second section presents relevant cognitive modeling and simulated environment elements required by initiative based tactics; as well as some initial requirements for training scenario design. A conclusion summarizes the paper and indicates some future work possibilities.

1. Introduction

Agent-based modeling and simulation (Macal & North, 2007) is an important element for the development of the next generation of simulators. In particular, training simulations requiring human communication and interaction demand high cognitive fidelity, which must be measured not only by the avatars' physical appearance but also by their psychological and cognitive realisms from a trainee's point of view (Liu, Macchiarella, & Vincenzi, 2009), including natural language processing capabilities (Gluck, Ball, Gunzelmann, Krusmark, & Lyon, 2005).

There are many definitions of what an agent is but the following characteristics seem to describe adequately what being an agent means (Macal & North, 2007). An agent is an identifiable, discrete individual. It is autonomous and self-directed (goal driven); it is situated, living in an environment with which it interacts with other agents (having perceptual, motor, and communication capacities); and it is flexible, having the ability to learn and adapt its behaviors based on experience. Agent-based modeling is divided in two communities, one focused on large numbers of relatively simple and highly-interactive agents; and the other one focused on a smaller number of agents with more complex internal structures (Guerin, 2004). The current research falls into the second category, and uses the ACT-R cognitive architecture as a means to develop agents (Anderson, 2007; Anderson, et al., 2004).

This paper presents the state of progress of an agent-based modeling and simulation research and development activity as part of a larger project to build a virtual training environment for initiative-based tactics. This virtual training environment, the Immersive Reflexive Engagement Trainer (IRET), is developed as a collaborative research effort between the Canadian Department of National Defence and the National Research Council Canada (Institute for Information Technology). The purpose of IRET is to blend a number of existing technologies to allow soldiers to train simultaneously within virtual and real environments. The primary use of the system is to train personnel in the rapid application of judgment to include the application of rules of engagement and the use of force. The system will provide interactive enemy forces that react to the soldiers' actions and movements, challenging the soldiers' skills and judgment. A secondary purpose of the system is to allow personnel to practice engagement skills with primary and secondary weapons.

The agent-based modeling and simulation research activity within the IRET project has two principal objectives: a) develop high-fidelity cognitive models to be embedded as game agents in a room-size virtual environment; and b) develop detailed performance and learning models of the learners to support instructions. Both objectives are closely related, as realistic agents should have similar behavior to a range of novice to skilled soldiers. Theses objectives also require technological advancements in large-display interactive devices (Lapointe & Godin, 2005), speech processing, and the measurement of human performance in virtual environments. The cognitive modeling activity will contribute to the goal of applying cognitively realistic behavior representations to application environments (Dimperio, Gunzelmann, & Harris, 2008).

Through out the paper, cognitive models and agents will be considered synonymous. However, because the modeling approach is based on the ACT-R cognitive architecture (Anderson, 2007; Anderson, et al., 2004), when a reference is made to a cognitive model, the internal structure of the model is the point of interest, such as the perceptual and motor modules, or the declarative and procedural memory modules. On the other hand, when the point of interest is not the internal but the individual and discrete nature of an entity, then the term agent will be used.

The paper also focuses on the role of cognitive modeling and simulations can play in human capability development. The first section presents a conceptual framework to place this role in relationships to: 1) live, virtual, and constructive simulations; 2) human development functions such as understanding, training, and assisting human capacity; and 3) agent embedment in physical settings, from low-embedment in simulated environments, to medium-embedment in virtual environment, to high-embedment in field operations. Ideally, cognitive models could initially be developed as constructive simulations, then carried out and refined during development and deployment in virtual simulations, and eventually deployed as assistive agents to be part of the soldier's system.

The second section of the paper gives an overview of a constructive simulation composed of agents, and the simulated environment they live in. Finally, a conclusion summarizes the paper and indicates some future work possibilities.

2. Human Capability Development Through Simulations

The distinction between constructive, virtual and live simulations is sometimes a useful one even though the boundaries are often blurred, unique category assignment is not possible, and real systems controlled by artificial agents are not considered in the classification (Department_of_Defense, January 1998). The distinction is essentially based on the presence of real or simulated equipment with real or simulated human operators as outlined in Table 1.

Table 1. Simulation classifications and human capacity development functions.

	Real Human	**Simulated Human**
Real Equipment	Live Simulations	Autonomous Agents *[Assisting]*
Simulated Equipment	Virtual Simulations *[Training]*	Constructive Simulations *[Understanding]*

Live simulations are essential and key to many training operations, tactical exercises without troops within a local community (Burton, 2006), however a lot of attention is given to computer simulations as a means of reducing equipment and training cost, but mostly to save lives by providing efficient and progressive training (Hayward, 2006; Roman & Brown, 2007). When the focus is placed on information technology in simulations, the three relevant simulation types are constructive, virtual and autonomous. From the perspective of human capacity development, other categories also emerge to classify simulations such as simulations for understanding, training, and assisting. Table 1 associates these categories respectively to constructive simulations, virtual simulations and autonomous agents.

Understanding human capabilities is an important aspect of constructive simulations. Research and simulations using Integrated

Performance Modeling Environment (IPME) models (Armstrong, Belyavin, Cain, Gauthier, & Wang, 2007) as well as modeling human-computer interactions using cognitive architectures such as ACT-R (M. D. Byrne, 2001; Emond & West, 2004; Ritter & Young, 2001) are good examples of applications of modeling for understanding human capabilities. The purpose of the modeling effort in a constructive simulation context is to obtain accurate models of perceptual, motor, cognitive, and social skills. The main research trend in this respect consists of ensuring that cognitive models are validated against empirical data collected on human performance and that one can select amongst alternative models (Gluck, Bello, & Busemeyer, 2008). A constructive simulation environment might include not only the computational resources to build cognitive models but also resources to model the environment and collect data on human performance. A typical constructive simulation would have an application that either a human operator or a cognitive model can control. Data collected during human operations can then be modeled, or reproduced by the cognitive model.

Table 2. Cognitive model objects of perception and action, and human-in-the-loop by agent embedment levels

	Objects of perception and action	**Human-in-the-loop**
Constructive *Understanding cognitive processing* Low embedment	- Agents - Simulated environment	- Cognitive Modelers
Virtual *Training personnel* Medium embedment	- Agents - Trainees - Virtual environment	- Trainers - Trainees - Cognitive Modelers
Operational *Assisting personnel in the field* High embedment (soldier's system)	- Agents - Humans-in-the-field - Physical environment	- Humans-in-the-field

The evolution of models from understanding to assistance is also characterized by more cognitive model embodiment into human operations (Table 2). At the constructive (understanding) level, the objects of perception are restricted to other simulated agents and the simulated environment; the human-in-the-loop is essentially a cognitive modeler. At the virtual (training) level, the objects of perception and action are other simulated agents, trainees, and a virtual environment; humans-in-the-loop are people involved in training as well as cognitive modelers. A virtual environment is distinguished from a simulated environment because the main purpose of a virtual environment is to be perceived and acted upon by humans, while a simulated environment need only to be perceived and acted upon by cognitive models. Finally, at the operational level (assisting), objects of perception a actions are other simulated agents, humans-in-the-field and the physical environment; humans-in-the-loop are humans-in-the-field.

3. Understanding Competency Requirements for an Initiative Based Tactics Training Simulator

Simulators provide many advantages for training. One of the key features is their high fidelity to real-world operating environments. The main argument being that the closer the training environment is to the real world, the better will be the transfer of skills and knowledge acquired during training. However, it is now recognized that a simulator's fidelity must be measured not only by the physical appearance but also by its psychological and cognitive realisms from the trainee's perspective (Liu, et al., 2009). Simulators also offer instructors the capacity to select specific training conditions, as well as detailed recordings of a trainee's performance for the purpose of performance comparison, diagnostic, and evaluation (Moroney & Lilienthal, 2009). Another important aspect of simulators, when applied to skill acquisition, is the capability of going repetitively through a simulation scenario without the cost associated to live simulations. The availability of simulators is crucial to maintain readiness and avoid performance degradation (Gorman, 1990; Proctor & Gubler, 1998).

Constructive simulations are key elements in the development of training simulators. They can be used to help in the acquisition process (National_Research_Council, 2002), as a foundation for the development of synthetic adversaries (Wray, Laird, Nuxoll, Stokes, & Kerfoot, 2005), as a mean to detail the skills to be acquired in a training simulator, or even to study the transfer of agent skills (Gorski & Laird, 2007). A broader access to game engines as well as the emergence of new or improved cognitive architectures (M.D. Byrne & Anderson, 2001; Laird, 2008) has allowed the development of many simulation systems of military operations on urban terrain (Best & Lebiere, 2003a; Choi, Konik, Nejati, Park, & Langley, 2007; Cox & Fu, 2005; Evertsz, Ritter, Russell, & Shepherdson, 2007; Ting & Zhou, 2009; Wray & Chong, 2007; Youngblood, Nolen, Ross, & Holder, 2006).

There are very few empirical studies evaluating the knowledge transfer from game playing to effective room clearing operations. However, some results indicate (Proctor & Woodman, 2007) that games could be suitable for the transfer of planning, evaluation, and selection of small-unit tactical operations, but somewhat limited in supporting skill transfer to execution of well-honed techniques involving physical interaction with other people as well as the environment (Proctor & Woodman, 2007). Virtual training room environment have more potential in this respect, but they but be designed using scenario-based training, cognitive task analysis, adequate human-computer interaction strategies, training management systems, and intelligent tutoring systems (Schmorrow, et al., 2009).

Initiative based tactics are driven by the actions and initiative of the individual soldiers. Proper actions must conform to the doctrine and fundamentals of close quarter battle (CQB), but the actions success is highly dependent on the application of skills directed by the challenges of the immediate and specific conditions of a CQB situation. Communication and coordination with teammates, efficient body movements, as well as rapid threats assessment from environmental cues important building blocks of initiative-based tactics skills.

The following paragraphs aim at specifying the competencies to be learnt and the environment affordances to support the acquisition of initiative-based tactics skills in a room-size training simulator. The specification of the perceptual and motor skills as well as the environment affordances will take the form of a constructive simulation based on the ACT-R cognitive architecture.

As the Figure 1 suggests, a constructive simulation needs to identify the high-level primitive perceptual and motor representations essential for a cognitive model to interact with a simulated environment. These primitives constitute the first set of modeling requirements.

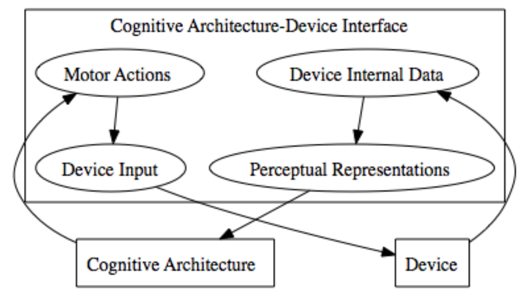


Figure 1. Information flow between a device and a cognitive architecture

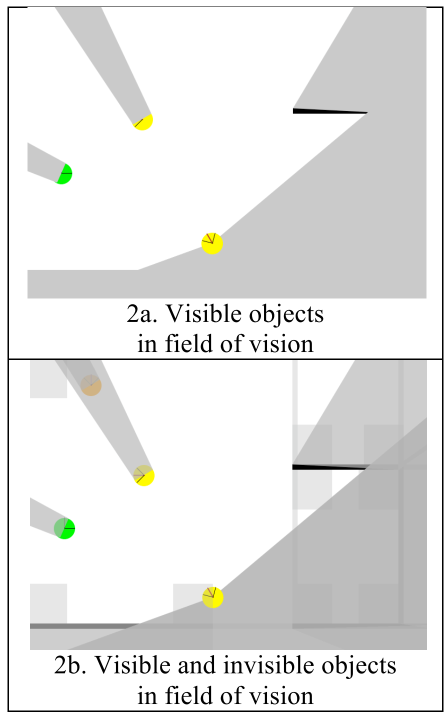
The intermediate layer (Best & Lebiere, 2009; Dawes & Hall, 2005) between a cognitive architecture and devices, such as a desktop application or a game engine, can be described by functions transforming internal device data into high-level perceptual constructs feeding in the cognitive model perceptual modules. In the same manner, motor actions get executed in the external device by translating high-level action representations in the cognitive model into device input.

Prior research in CQB tasks analysis and cognitive modeling applications (Best & Lebiere, 2003b; Templeman, Sibert, Page, & Denbrook, 2007; Wray, et al., 2005) provide an initial identification of key perceptual and motor primitives. Table 3 summarizes some of these primitives. The table is divided perceptual and motor modalities. Most of the categories and labels should be relatively easy to understand, such as location and end-points (defined in an egocentric spatial coordinate system), volume, and type. The people category however identifies environmental affordances that are crucial to the assessment of a threat level. Acquired-visual-object and weapon-target for example are the respective projections of the line of sight and weapon pointing direction onto agents in the room. Weapon readiness and potency are also other perceptual factors in threat assessment. A person can also exhibit composition of course and heading variations produce different kinds of body motion such as steering (aligned course and heading); canted (fix alignment offset between course and heading), oblique (constant heading position), and scanning (free heading movement from the course) (Templeman, et al., 2007).

Table 3. Perceptual and motor cognitive constructs required to operate in a CQB situation. [A] (Best & Lebiere, 2003b); [B] (Wray, et al., 2005); [C] (Templeman, et al., 2007).

Perception Audition	
Verbal messages	Location; Volume; Sender [A]; Content [A]
Weapon fire	Location [A]; Volume [A]; Type [A]
Ricochets	Location [A]; Volume [A]; Type [A]
Flash bang	Location; Volume
Footsteps	Location [A]; Volume [A]; Direction
Perception Visual	
Non-verbal messages	Sender; Content
Walls	End-points [A];
Corners	Location [A];
Pathways	End-points [A];
Doors	End-points; Hinges-location; Open-state;
Weapons	Location [A]; Type [A]
Objects	Location [A]; Type [A]
People	Location [A]; Type [A]; Speed [A, C]; Course [A, C]; Heading [C]; Acquired-visual-object; With-weapon; Weapon-potency; Weapon-orientation; Weapon-readiness; Weapon-target
Motor Communication	
Speech	Receiver; Content; Volume
Non-verbal messages	Receiver; Content
Motor Body	
Weapon handling	Type; Trigger-arm&hand; Readiness [B]; Orientation; Pull-Trigger; Throw [B];
Body displacement	Course [C]; Heading [C] Speed [C]; Modality
Body rotation	Heading [C]; Speed [C]

Screen shots of the current implementation of the constructive simulation are given in Figure 2. As Table 3 indicates, most properties can be mapped directly onto a 2D agent visualization representation, however the representation of the agents' prior knowledge and rules is not explicitly represented by the 2D model and could require more advanced visualization techniques (Guerin, 2004; Urbas, Nekrasova, & Leuchter, 2005). Both Figure 2a and 2b contain views of a scene perceived by one agent ACT-R (bottom yellow circle). All other circles are also ACT-R agents. Figure 2a shows what the agent sees, objects and other agents that are in the field of view and not hidden by other objects. Figure 2b shows the full scene, including hidden objects and spatial properties such as corners, end of walls, and pathways between walls (ex. doors). An agent encodes all objects in a scene as an egocentric set of parameters that support threats assessment, and plan execution. The user interface of Figure 2 is also used to drag agents around as initial physical. Initial agent knowledge and plans will also be accessed from the simulated environment user interface.



2a. Visible objects in field of vision

2b. Visible and invisible objects in field of vision

Figure 2. Agent's field of vision in a room with more that 4 walls

4. Conclusion

This paper presented the state of development of a constructive simulation to better understand competency requirements in initiative based tactics in order to support training scenario design in a virtual training environment. This cognitive modeling research activity is part of a larger project to build a virtual training environment, the Immersive Reflexive Engagement Trainer, a collaborative research effort between the Canadian Department of National Defence and the National Research

Council Canada (Institute for Information Technology).

The initial section of the paper presented a conceptual framework where constructive models can be carried out and refined through out development and deployment in virtual simulations and eventually as assistive agents to be part of the soldier's system. The framework situates the development functions of understanding, training, and assisting human capabilities, in relationship to the traditional distinction of live, virtual and constructive simulations. The human development and their associated simulation types can also be laid out on a continuum of agent embedment in physical settings.

The second section presented some primitive perceptual and motor elements as a set of requirements for a constructive simulation of initiative based tactics in close quarter battle. Cognitive models using these primitives in a simulated environment are currently under development.

There is a significant increase is technology complexity from a constructive to a virtual simulation. The main distinctive feature is the intention of the constructive simulation to represent all relevant cognitive and environment features at a high level of abstraction, focusing on requirements, with no immediate concern with providing a high-fidelity training environment. A virtual environment on the other hand aims at presenting objects of perceptual, motor and communication interaction as close as possible to the reality it represents. In this respect, a desktop application fails to provide the proper training environment, which requires trainees to move in space, handle real weapons, and toss flash bangs in a room size space. The coupling between perception and action must be as close as possible to its intended application context (Sanford & Hopper, 2009), using exertion interfaces (Pasch, Bianchi-Berthouze, van Dijk, & Nijholt, 2009), focused on physically moving around the real world and aiming freely at virtual and tangible objects (Zhou, Tedjokusumo, Winkler, & Ni, 2007).

Adversaries will also have to exhibits dynamic behavior with adaptive threats consistent with those increasingly encountered by the military (Jensen, Ludwig, Proctor, Patrick, & Wong, 2008), and ideally, adequate to the level of trainees' performance. Adversaries can be designed on the basis of the existing teammate model but most than likely adversaries are asymmetric. The training challenge is to present the trainees opponents that have unpredictable tactics, and alternative forms of behavior. These asymmetric and adaptive features are current limitation of virtual training environments (Jensen, et al., 2008).

Observation and analysis of close quarter battle live simulations is currently underway to identify cognitive modeling as well as training requirements. Future work will include cognitive model validation as part of an evaluation of the usability of the IRET system; and separate modeling of opponents' behavior.

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