Agent-Based Approaches for Behavioural Modelling in Military Simulations

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ABSTRACT

Behavioral modeling of combat entities in military simulations by creating synthetic agents in order to satisfy various battle scenarios is an important problem. The conventional modeling tools are not always sufficient to handle complex situations requiring adaptation. To deal with this Agent-Based Modeling (ABM) is employed, as the agents exhibit autonomous behavior by adapting and varying their behavior during the course of the simulation whilst achieving the goals. Synthetic agents created by means of Computer Generated Force (CGF) is a relatively recent approach to model behavior of combat entities for a more realistic training and effective military planning. CGFs, are also sometimes referred to as Semi-Automated Forces (SAF) and enables to create high-fidelity simulations. Agents are used to control and augment the behavior of CGF entities, hence converting them into Intelligent CGF (ICGF). The intelligent agents can be modeled to exhibit cognitive abilities.

For this review paper, extensive papers on state-of-the-art in agent-based modeling approaches and applications were surveyed. The paper assimilates issues involved in ABM with CGF as an important component of it. It reviews modeling aspects with respect to the inter-relationship between ABM and CGF, which is required to carry out behavioral modeling. Important CGFs have been examined and a list with their significant features is given. Another issue that has been reviewed is that how the synthetic agents having different capabilities are implemented at different battle levels. Brief mention of state-of-the-art integrated cognitive architectures and a list of significant cognitive applications based on them with their features is given. At the same time, the maturity of ABM in agent-based applications has also been considered.

Keywords: ABM, CGF, Behavior Modeling

1. INTRODUCTION

Agent-based modeling comprising of interacting autonomous agents have been used to develop models for a wide range of applications. Applications range from modeling agent behavior in voting during elections, to predicting price variations within stock market trading, from modeling the growth and decline of ancient civilizations to modeling the growth of bacterial colonies etc.

The human behavior has been modeled in a very basic manner in the synthetic battlefield environment. The latest technological advances made in the agent-based approaches, applied to military wargaming and simulation offers promising advantage in behavioral modeling while improving training effectiveness at the same time. This advantage is driven by emerging trends in learning using agent-based modeling and essentials from field of computer generated forces (CGF), artificial intelligence, game-theory etc. The agents are autonomous entities which observe through sensors and act upon the environment using actuators and direct their activity towards achieving goals. To be called intelligent, an agent also has to be reactive, proactive and social; meaning it must be able to react to changes in the environment, pursue goals and be able to communicate with other agents (Wooldridge 2004). Intelligent agents model
both individual human reasoning and team behavior, performing tasks without any human intervention as in constructive simulations.

An emergent phenomenon can have properties that are decoupled from the properties of the part. The emergent phenomena can be counter-intuitive and thus it can be difficult to understand and predict. E.g. In a traffic jam, taking place due to interactions between individual car drivers, a car may be moving in the direction opposite to that of the cars that cause it.

1.2 Issues in Military Modeling and Simulation

It is imperative to understand that the simulation leads to the output being a range of predictions, or a richer learning experience which is facilitated by ABM. Behavioral modeling of combat entities needs to be done adequately for the simulated battle scenarios.

- Simulation as a Predictive tool: Due to limited behavioral modeling, trainees learn the range of the simulated behaviors in a short period of time. Learning the simulated range of behavior results in learning to predict the training system's response.
- Simulation as a Learning tool: Using simulation so as to find out that how high-level properties and behaviors of a system emerge out of low-level rules applied to individual agents results in learning. Again, being able to study the emerging collective behavior of the group is important because it enables commanders and their subordinates to test a wide range of individual and collective behavioral rules and to observe if and how robustly the rules lead to the desired collective level outcome.

1.3 Military Modeling & Simulation Paradigms: A Comparison

The military modeling and simulation paradigms have been broadly classified into SDS (System Dynamics Simulation), DES (Discrete Event Simulation) and ABS (Agent-Based Simulation). The agent-based simulation can be further classified into Context based reasoning and BDI (Belief, Desire, Intention) reasoning. Some of the representative applications are: A system
dynamics simulation model for a four-rank military workforce [1], Application of RT-DEVS in military [2] and Military applications of agent-based simulations [3] respectively. Jay Forrester, the founder of SDS, defined it as the study of information feedback characteristic of industrial activity to show how organizational structure, amplification (in policies) and time delay (in decision and action) interact to influence the success of enterprise [4]. In other words, SDS is an approach used to understand the dynamic behaviour of complex systems over time at aggregate level. The modeling effort is usually a set of state equations. DES is a dynamic, stochastic and discrete simulation technique (Banks et al. 2005). In DES, simulation time plays an important role (dynamic model) and DES is a stochastic model as it consists of random input components. In addition, DES is discrete because it models a system in which the state of entities in the system change at a discrete time (Carson 2003). The DES model uses a top-down approach to model system behaviour. One of the advantages of using DES [5] compared to other simulation techniques such as SDS or ABS is it models a system in an ordered queue of events (Siebers et al. 2010). Another advantage of DES is that it has the ability to be combined with other simulation methods, such as continuous simulation (Zaigler et al. 2000) and agent-based simulation for studying complex systems (Parunak et al. 1998; Darley et al. 2004). Entities in DES are not autonomous. This issue of autonomy (Bakken 2006) which relies upon the capability to make independent decisions has made DES a less preferred choice to represent complex human behaviour such as proactive behaviour (Borshchev and Filippov 2004). In DES, people are usually implemented as resources or passive entities. Passive entities are unable to initiate events in order to perform proactive behaviour. Therefore, a proactive event that requires self-initiated behaviour by an individual entity is difficult to implement in DES (Borshchev and Filippov 2004). This is where agent-based simulations have a decisive edge in modeling proactive entities. These systems have many interacting entities and non-linear interactions among them. The corresponding computational technique is called multi-agent simulation (MAS). A MAS consists of a number of agents which interact with one another in the same environment (Wooldridge 2002); each of the agents has its own strategy in order to achieve its objective. Due to the MAS structure, ABS has the ability to be autonomous, responsive, proactive and social (Jennings et al. 1998). There are two approaches to ABS [6]: Context Based Reasoning (CxBR) and BDI reasoning. CxBR is a reasoning paradigm for representation of tactical behavior in agents (Gonzales and Ahlers 1998; Gallagher et al. 2000; Gonzales et al. 2008). The motivation behind CxBR is the realization that people only use a fraction of their knowledge at any given time. The idea is to divide the knowledge into contexts in order to limit the number of possibilities for the action selection process. For example, an agent representing a military platoon will require a different set of capabilities and knowledge when it is performing an attack versus when moving along a road. In BDI reasoning, set to work, the agent pursues its given goals, adopting the appropriate plans, according to its current beliefs of the state of the world, so as to perform the role it has been given.

<table>
<thead>
<tr>
<th>Top-Down/Bottom-Up</th>
<th>Discrete/Continuous</th>
<th>Reactive, Pro-Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDS Top-Down</td>
<td>Continuous</td>
<td>Reactive</td>
</tr>
<tr>
<td>DES Top-Down</td>
<td>Discrete</td>
<td>Note: Can be combined with Continuous and Agent-Based Simulations</td>
</tr>
<tr>
<td>ABS Bottom-Up</td>
<td>Discrete</td>
<td>Note: AnyLogic s/w package supports hybrid continuous/discrete logic</td>
</tr>
</tbody>
</table>

Table 1: Modeling and simulation paradigms comparison

Reactive behaviour is a response to the environment i.e. the employees respond to requests from their customers when they are available. Proactive behaviour relates to personal initiative in identifying and solving a problem. Many agent-based software and toolkits have been developed and are widely used. Packages such as Repast, SWARM,
NetLogo, SDML, Jade, MASON, and AnyLogic are quite extensive and have been well used by the agent-based modeling community for years.

2. TYPES OF SYNTHETIC AGENTS IN A BATTLEFIELD SIMULATION

The types of synthetic agents with different functional capabilities required in a battlefield simulation are as follows:

- Semi-automated forces (SAF) provide relatively simple computer-generated entity behaviors, and then depend on human operators to provide higher level guidance.
- Intelligent Forces (IFORs) attempt to provide intelligent autonomous entity behavior without human controllers.
- Command Forces (CFORs) attempt to automate the commanders that sit above the entity level providing automated models of command decision makers and automated tasking for entities.

SAF systems provide the simulation of individual platforms and small units. IFOR entities, though they do have deliberation capabilities, are more focused on reaction than planning. CFOR extends this to incorporate explicit, virtual representation of command nodes, command and control (C2) information exchange, and command decision-making. The responsibilities of a command entity (CE) differ markedly from those of lower echelon units [7]. In contrast to the issues faced by vehicle or platoon level units, CFORs must model the decision making from a broader perspective and over longer time scales. Whereas vehicle level decision making tends to be more reactive in nature, higher echelon units must deliberate about alternative courses of action and detect harmful (or beneficial) interactions between subordinate units and enemy forces.

Eg. Soar/CFOR [8] extends the Soar/IFOR capabilities to higher echelons and incorporates the communication and command functions necessary to operate at these levels. Reasoning about interactions and changes in the planning/replanning.

<table>
<thead>
<tr>
<th>Battle level</th>
<th>Synthetic Forces</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactical</td>
<td>IFOR</td>
<td>Efficient and responsive to dynamic changes</td>
</tr>
<tr>
<td>Strategic</td>
<td>CFOR</td>
<td>Extends the IFOR capabilities to higher echelons and incorporates the communication and command functions necessary to operate at these levels. Reasoning about interactions and changes in the planning/replanning.</td>
</tr>
</tbody>
</table>

Table 2: Battle Levels and Applicable Intelligent Agents

3. AGENT-BASED SIMULATION ENVIRONMENT WITH CGF COMPONENT

ABM provides a natural description of a system. It is flexible as it is easy to add more agents to an agent-based model. The CGF component provides the basic synthetic agents which interact among themselves to meet the desired goals while operating in the synthetic environment. The physical aspects [9] represent the movement and state of platforms (objects) in the simulation, including such aspects as maximum speed and the actions that can be performed in the world. The behavioral aspects of a synthetic force platform determine where, when and how it performs the physical actions, that is, its behavior (ritter et. al, 2002). There are lot of constructive simulation agent-based environments with a CGF component.

U.S. Department of Defense Modeling and Simulation defines CGF as "A generic term used to refer to computer representations of entities in simulations which attempts to model human behaviour sufficiently so that the forces will take some actions automatically (without requiring man-in-the-loop interaction)". Whereas a synthetic environment as given by Dompke (2001) [10] is "Internetted simulations that represent activities at an appropriate level of realism. These environments may be created by within a single computer or over a distributed network connected by local and wide area networks and augmented by realistic special effects and accurate behavioural models."

3.1 Modeling of CGFs

could be described as forming a new CGF entity from two or more existing CGF units all of whose numeric parameters are redefined by the Commander of the new CGF entity. Similarly, Force Deaggregating is described as forming two or more new CGF entities from a single one. The parameters of the new CGF entities should be defined by the old CGF Commander before the deaggregating takes place. In the case of Force Aggregating, the military hierarchy coherence is maintained by comparing the old CGF units Commanders level and assigning the command to the highest in rank; in case of deaggregating, the old CGF unit Commander chooses the new CGF unit Commanders assigning to each of them a Command position. The aggregation /deaggregation process enables to simulate the desired effects. Eg. The paper [12] describes the ABM approach used to simulate strategic effects at the operational level of war. CGFs have also been modeled in a Synthetic Theatre Of War (STOW) where CGFs and intelligent synthetic agents are brought to theater-level exercises [13]. STOW [14] is a program to construct synthetic environments for numerous defence functions. Its primary objective is to integrate virtual simulation (troops in simulators fighting on a synthetic battlefield), constructive simulation (war games), and live maneuvers to provide a training environment for various levels of exercise.

3.1.1 CGF as Battle Force Representation and Simulation Modeling

Current and planned CGF capabilities were evaluated [15] on the basis of two evaluation criteria: Battle Force representation and Simulation Modeling features. Battle force representation assesses the ability of the CGF to represent different types of weapon systems/military equipment for all services (Air Force, Army, Navy); levels of military organizations (platoon through Division); Command, Control, Communications, and Intelligence (C3I); behaviors of entities and units; tactics and doctrine. Simulation modeling features characterize simulation models and data bases used to represent system performance and the environment.

3.1.2 CGF as a Simulation and Wargame

The application Close Action ENvironment (CAEN) [16] can be run as either a simulation and wargame. It is both a means of simulation of weapons effects and an interactive wargame (operational analysis) between opposing forces of up to platoon level strength. It can operate either as an automatically replicated constructive simulation with no user intervention, or as an interactive game in which two or more independent players control the actions of their own forces. Thus a combination of wargame and simulation is more amenable to cater to the changing requirements for one-on-one to divisional and corps battles.

3.2 Examples of CGFs

Some of the significant CGFs developed so far, with their features have been listed in the following table.

<table>
<thead>
<tr>
<th>S. no</th>
<th>Architecture</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>JointSAF (JSAF)</td>
<td>U.S. Tri-service simulation system, including detailed modeling of air, land, and sea assets. JSAF lacks a comprehensive dismounted infantry model.</td>
</tr>
<tr>
<td>2.</td>
<td>MOD-SAF [17]</td>
<td>ModSAF simulates an extensive list of entities. For fixed wing aircraft, it simulates the F-14D, MIG-29, A-10 and SU-25. For rotary wing aircraft, it simulates the AH-64, OH-58D, Mi-24, and Mi-28. For its ground forces, ModSAF can simulate tanks (M-1 and T-72), infantry fighting vehicles (M-2 and BMP), ADA (ZSU-23/4), &amp; dismounted infantry. Enhancements could result in the support of additional physical models such as Cavalry, Howitzers, Mortars, Mine- fields, CSS, Scud Patriot.</td>
</tr>
<tr>
<td>3.</td>
<td>OTB-SAF [18]</td>
<td>OTB primarily caters for land-based behaviors and interactions, however it does include the representation of air and sea assets. In addition, OTB includes specialized Dismounted Infantry SAF (DISAF) extensions and behaviors developed to support US Army simulations.</td>
</tr>
<tr>
<td>4.</td>
<td>ONESAF [19]</td>
<td>A composable, next generation simulation architecture supporting both Computer Generated Forces (CGF) and SAF operations. Capable of replacing US Army legacy entity-based simulations: BBS, OTB/ ModSAF, CCTT /AVCATT SAF, Janus (A&amp;T), JCATS MOUT.</td>
</tr>
</tbody>
</table>
VR-Forces (COTS) is MAK's complete simulation solution, a powerful and flexible Computer Generated Forces (CGF) platform to fill your synthetic environments with urban, battlefield, maritime, and airspace activity. It can be used as a threat generator for training and mission rehearsal systems, a synthetic environment for experimentation, or an engine to stimulate C4I systems.

Table 3: Some of the notable CGFs

### 4. COGNITIVE ARCHITECTURE

This section talks briefly about the cognitive architecture, which is the blueprint for intelligent agents. A cognitive architecture proposes (artificial) computational processes that act like cognitive systems (human). It is an approach that attempts to model behavioral as well as structural properties of the modeled system. In military simulation, relatively little attention has been given to modeling human cognition, and how this affects human behavior and thereby affecting tactical decision making. Modeling cognitive behavior, includes variations like (timing, errors, physiological biases) of the human behavior.

A detailed account of the state of the art research in the field of integrated cognitive architectures [20] is given as a review of six cognitive architectures, namely Soar, ACT-R, ICARUS, BDI, the Subsumption architecture and CLARION. Another detailed chronology and evaluation for development of the cognitive architectures is given in [21] & [22] respectively.

#### 4.1 BDI Agents

Current research in behavior modeling is directed towards BDI (Belief, Desire, Intention) agents in command and control. The BDI intelligent agent as described here is an autonomous piece of software, which has explicit goals or desires to achieve, and is pre-programmed with plans or behaviours to achieve these goals under varying circumstances. Such an intelligent agent model is generally referred to as a BDI agent. Under the BDI model, agents may be given pre-compiled behaviours, or they may plan or learn new plans at execution time. The implementations of the BDI architecture include procedural reasoning system (PRS), dMARS, JACK, 3APL, Jason, JADE, JADEX, JAM, AgentSpeak(L), and UM-PRS. BDI is designed to be situated, goal directed, reactive, and social. This means a BDI agent is able to react to changes and communicate in their embedded environment, as it attempts to achieve its goals.

#### 4.2 Examples of Cognitive Architecture Based Applications

Some of the implementations based on the various architectures are listed in the table below:

<table>
<thead>
<tr>
<th>S. no</th>
<th>Architecture</th>
<th>Application</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>SOAR</td>
<td>Soar-RWA [23]: Planning, teamwork, and intelligent behavior for synthetic rotary wing aircraft</td>
<td>(1) Models pilot agents for a company of helicopters. (2) A command agent that makes decisions and plans for the helicopter company. (3) An approach to teamwork that enables the pilot agents to coordinate their activities in accomplishing the goals of the company.</td>
</tr>
<tr>
<td></td>
<td>TacAir-Soar System [24]: Automated Intelligent Pilots for Combat Flight Simulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Cognitive Architectures and Applications based on them.

More interesting applications of the BDI intelligent agent concept is given in [29] namely, the OASIS air traffic management system prototype [30], the SWARMM air mission simulation system [31], the IRTNMS network management system [32] etc.

5. AGENT-BASED MODELING: HOW MATURE IT IS?

Based on the survey paper [33] in the year 2009, the challenges with respect to ABM have been described as follows. Some important questions become immediately apparent.

- How much confidence we have about modeling people's behavior credibly?
- To what extent we know about modeling social interaction among people?

As compared to system dynamics modeling, Agent-based modeling does not as of yet have a mature set of standard formalisms or procedures for model development and agent representation. The absence due to the lack of models that were completely validated, the lack of references to the complete model and what can be accepted as publishable results. Despite use in many fields, agent-based simulations are criticised for having too many parameters. In other words, understanding of the scope and sensitivities of model outputs for varying parameter choices is limited. ABMS is more than having stochastic modeling elements only. Classical mathematical programming techniques such as linear and integer programming cannot be applied to optimize the settings for agent-based models, which are highly nonlinear and stochastic. It is a challenge that there is no data source against which the model can be calibrated. For this model simulations are run hundreds or thousands of times to generate a distribution of behavior, and behavior is compared with historical data to ensure that the model is correctly calibrated.

6 CONCLUSIONS

Intelligent CGFs helps in representation and simulation of realistic military tactical behaviour, without the requirement of involvement of life of humans. More importantly, representing aggregated entities using CGF inclusive agent-based technology enables modeling of the required behaviour at a fairly abstract level. At the time of execution, these abstract specifications map to quite complex behaviours which "emerge" during the running of the simulation.
REFERENCES


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Mr. Gaurav Chaudhary received his M.E. in Computer Science and Engineering from Indian Institute of Science, Bangalore. He is working as Scientist in Defence Research & Development Organisation (DRDO) and his current interests includes agent-based applications and rule-based systems.