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A multi-agent architecture for modelling and simulation of small military unit combat in asymmetric warfare ☆

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ABSTRACT

Today's armed forces, which have a new perspective of combat, are trying to use high-end technologies to improve their capabilities especially in combat and asymmetric warfare. Complexity is the real word to define the future war environment, which will need information about multi dimensional needs. With a continuous increase in the complexity and tempo on the modern battlefield; new demands are placed on rapid and precise information dissemination. The volume of information available to the user becomes larger while the time necessary for correctly interpreting and understanding this information becomes prohibitively smaller. Not only from an informational view but also from other perspectives land combat may be described – mathematically and physically – as a nonlinear dynamical system composed of many interacting semi autonomous and hierarchically organized agent continuously adapting to a changing environment. From this point of view agent based structures are good suited for modeling and simulating complex adaptive systems. This paper proposes a two layer hybrid agent architecture to match the needs of future multi-dimensional warfare. This architecture has an integrated simulation tool to simulate planning results from the cognitive layer via reactive agents. Our work showed us that results gained from this architecture are valid in small unit combat.

1. Introduction

Today's armed forces, which have a new perspective of combat, are trying to use high-end technologies to improve their capabilities especially in combat and asymmetric warfare. Command of military operations requires leaders who are able to make decisions and respond in an appropriate, timely manner even in highly uncertain situations. Complexity is the real word to define the future war environment, which will need information about multi-dimensional needs. With a continuous increase in the complexity and tempo on the modern battlefield; new demands are placed on rapid and precise information dissemination. The volume of information available to the user becomes larger while the time necessary for correctly interpreting and understanding this information becomes prohibitively smaller. This information must be reliable and rapid transmitted to the decision maker – the commander.

German military theorist Carl von Clausewitz noted that uncertainty is fundamental to warfare. To some greater or lesser degree, uncertainty might be lessened as a function of improved command and control and intelligence, but as events demonstrate in Afghanistan, Iraq and other crisis regions it cannot be eliminated.

Uncertainty, as a function of asymmetry, has increased with the spread of technology and the juxtaposition of conflicting aims, not only between nation-states, but also between non-state actors. As the potential for asymmetry increases, so do the level of uncertainty and the potential for tactical, operational, and strategic surprise. Asymmetry is really nothing more than taking the level of uncertainty, or surprise, to a new level that involves novel ways, means, or even ends.

The use of agent-based models to simulate behaviors in combat is gaining increasing recognition and interest across operational research community and the army. The goal of this paper is to give agent–based architecture to support military decision makers of small military units with an integrated simulation tool. We hope that more effective decision would be able to taken in this way comparing to human decision makers, which are under stress in combat situation.

From a military view the term combat is used for circumstances which at least one combatant (or weapon system) employs lethal means against at least one another. All other situations are preludes or postludes to combat, which either set the initial and boundary conditions for the next combat, or simply end the combat (Ancker, 1995). By extending this definition from a

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scientific view land combat may be described – mathematically and physically – as a nonlinear dynamical system composed of many interacting semi autonomous and hierarchically organized agent continuously adapting to a changing environment (Ilachinski, 2004). Therefore it is not hard to say that combat especially land combat posses nearly all-characteristic features of complex adaptive systems (CAS).

2. Background on CAS

The beginning of understanding warfare as a complex adaptive systems can be dated to the writings of Sun Tzu stated 2500 years ago (Tzu, 1963), but, recently a growing body of literature describes aspects of defence systems and operations in terms of complex systems science (Holt & Dent, 2001; Ilachinski, 1996; Moffat, 2002; Richardson, Mathieson, & Cilliers, 2000; Schneider, 1996).

CAS is defined as the study of many nonlinearly interacting components, where the interaction is governed by simple rules while the overall behavior of the system exhibits certain level of complexity.(Yang, Curtis, Abbas, & Sarker, 2008) In other words it is a complex system whose parts can also evolve and adapt to a changing environment.

The field of CAS was originally motivated by research about adaptation and emergence in biological systems. CAS have the ability to self-organize and dynamically reorganize their components in ways better suited to survive and excel in their environments, and this adaptive ability occurs, remarkably, over an enormous range of scales. John Holland, identifies properties and mechanisms common to all CAS. Properties of CAS are: (1) aggregation: allows groups to form, (2) nonlinearity: invalidates simple extrapolation, (3) flows: allow the transfer and transformation of resources and information, and (4) diversity: allows agents to behave differently from one another and often leads to the system property of robustness. CAS mechanisms are: (1) tagging: allows agents to be named and recognized, (2) internal models: allows agents to reason about their worlds, and (3) building blocks: allows components and whole systems to be composed of many levels of simpler components (Holland, 1995; Macal & Noth, 2005).

There are recently some difficulties faced by pure analytical methods in analyzing the high degree of nonlinear interactions between components within a CAS. To manage these difficulties agent based modeling has been widely adopted to model, simulate and study CAS. But there are some limitations in existing models. These are;

- Because these systems are representation free, validation of them is very difficult (Yang, Abbass, & Sarker, 2005).
- Reasoning during the simulation becomes more difficult by an increasing number of entities (Yang et al., 2005). For example cognitive agent systems (Barringer, Fisher, Gabbay, Gough, & Owens, 1989; Lesperance et al., 1996) are able to reason about actions but application of this in case of many agents it is hard. On the other hand, pure reactive agent systems (Wooldridge & Jennings, 1995; Sycara, 1998) cope with this problem well but it is hard to understand the behavior exhibited by the system or validate it because there is no reasoning.
- The lack of clarity between agent-centric or organizational-centric (Vázquez-Salceda, Dignum, & Dignum, 2005) methods. Most existing multi-agent systems (MAS) either focus on the model of individual agents with limited support on the interactions between agents such as GAIA (Wooldridge, Jennings, & Kinny, 2000), or concentrate on the model of the agent society by limiting the autonomous behaviors of a single agent, such as SODA (Omicini, 2001) and ISLANDER (Esteva, Padget, & Sierra, 2002; Yang et al., 2008).
- Lack of an explicit and auditable model of interaction. Existing systems always combine the agents and their interactions (relationships) in a single model. It is important to have an explicit model of interaction to understand the group behaviors of agents.

In order to address such kind of problem we propose a multi-agent architecture for modeling and simulation of small military unit combat with an integrated validated simulation tool. The architecture proposes a multi-agent system with all necessary needed dimensions of combat. Interactions are modeled by analyzing combat decision-making and agent capabilities are designed to fulfill these requirements.

3. Multi-agent systems (MAS)

MAS consist of a set of autonomous agents that interact among them and with their environment. The term autonomy here means that agents are active entities that can take their own decisions. This is not the same with objects, as they are predetermined to perform the operations that someone else requests them. An agent, however, will decide whether to perform or not a requested operation, taking into account its goals and priorities, as well as the context it knows.

MAS can be defined as the natural platform for studying CAS. Parts of the system are modeled as agents with a set of predefined characteristics. These agents adapt, evolve and co-evolve with their environment (Lauren, 2000; Schmitt, 1997). By modeling a part of a CAS as an agent, we are able to simulate a real world system by an artificial world. It is particularly effective to represent the real world systems which are composed of a number of nonlinear interacting parts that have a large space of complex decisions and/or behaviors to choose from such as those situations in combat (Ilachinski, 2000).

In other words, if a problem domain is particularly complex, large, or unpredictable, then the only way it can reasonably be addressed is to develop a number of functionally specific and (nearly) modular components (agents) that are specialized at solving a particular problem aspect. This decomposition allows each agent to use the most appropriate paradigm for solving its particular problem. When interdependent problems arise, the agents in the system must coordinate with one another to ensure that interdependencies are properly managed.

The characteristic of multi-agent systems is that; (1) each agent has incomplete information or capabilities for solving the problem and thus, has a limited viewpoint; (2) there is no system global control; (3) data are decentralized; and (4) computation is asynchronous (Sycara, 1998).

Agents traditionally are classified as (Wooldridge & Jennings, 1995);

- reactive,
- deliberative and
- hybrid

But there are many other approaches. For example Ferber describes agents in two main approaches: cognitive agents systems and reactive agent systems (Ferber, 1999). Simply the cognitive school represents systems of small number of intelligent agents whereas the reactive school does not believe that agents themselves must be intelligent for the system. Reactive agents reason at a sub-symbolic level. To fit our needs we will use in this paper a combination of these two approaches.

3.1. Cognitive agents

The cognitive agent can be seen as knowledge based system, which includes all the necessary data and knowledge to make