New Challenges for AI in Military Simulation: Are Multilevel Heterogeneous Models the Solution?

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Abstract

As our nations military forces face new challenges in the field as the result of trying to defeat unconventional adversaries, so it goes with our military modeling and simulation (M&S) community, who are attempting to build decision-support tools for our command staff. This paper will address two extraordinarily large issues which the M&S community seeks to make progress on, and how multilevel heterogeneous models (MHM) may play a major part in moving forward.

Introduction

As our nations military forces face new challenges in the field as the result of trying to defeat unconventional adversaries, so it goes with our military modeling and simulation (M&S) community, who are attempting to build decision-support tools for our command staff. This paper will address two extraordinarily large issues which the M&S community seeks to make progress on, and how multilevel heterogeneous models (MHM) may play a major part in moving forward. The first of the issues concerns modeling our adversaries, who we conceive of as being an organization: from nation-states to terror cells, as systems with interdependent political, military, economic, social, infrastructural, and information-based components. Secondly, we face the more daunting problem of developing cognitive models of the human elements within these systems: from leaders of countries to the common citizen and everything in between. However, there seem to be parallels between these problems in that they both are readily able to be modeled by as multilevel heterogeneous systems. In this paper, I argue that while both problems are able to be modeled as MHMs, the real issue lies in providing strategies for integrating among the parts of the MHMs.

Introduction

Our most dangerous foes lurk in the shadows, blending in among the other citizens of the world, unrecognizable as members of paramilitary or terrorist organizations. To our credit, we have managed to adapt an incredibly potent conventional arsenal to the task of rooting out and destroying terrorists, wherever they are. But were still going through some growing pains, as should be clearly evidenced by the continuance of ill-sentiment for United States by various factions in the Mideast. While I do not contend that our military decision-makers have done a bad job, it seems as if we can use some improvement in planning full campaigns, especially in non-Western nations. The military modeling and simulation community is trying to adapt large-scale conventional simulations to the new type of conflict to which we are beginning to acclimate: the unconventional war. M&S is a crucial centerpiece in providing decision-quality information to the people who need it most: our commanders and policy-makers. Many of us in the M&S community see the pervasive nature of high-speed, intensive computation as being a key component in providing this information. Specifically, algorithmic byproducts of artificial intelligence research have been major enablers for our current M&S technologies. But new challenges have arisen, especially in providing the military commander with the ability to better anticipate what our adversaries will do, and develop strategies to nullify these actions. Of course, the enterprise of building a digital crystal ball seems to be the stuff of science-fiction, but so were stealth-bombers and unmanned arial vehicles (UAVs) at one point in time.

Two Major Challenges

As a community, we face two major challenges: the first challenge concerns the construction of an anticipatory system which will capture the nonlinear relationships between the different elements in the battlespace. We dub this the battlespace characterization problem (BCP). Particularly,we are interested in the interplay between political, military, economic, social, infrastructure, and information-oriented elements involved in the conflict. These can vary from the relationship between the condition of national infrastructure and the number of revolutionary movements within the country, to the relationship between social structures (such as the religious affiliation of a clan) to the local economy. This latter relationship may instantiate as a local cleric (of said religious affiliation) demanding a workers strike among his congregation as a result of a government policy which he feels is unfair. The second of our major challenges is to build cognitive models of the human elements of the battlespace. Again, this is a remarkably lofty goal: one which has been elusive since the inception of both AI and cognitive science as academic fields. I am not under the impression that any of us in the military M&S community are expecting a solution any time in the near future, but we are hoping at the minimum to isolate and analyze some of the more difficult aspects of the problem in light of both hardware, software, and theoretical advances. The problem of developing computational cognitive models capable of achieving human-level intelligence (at least in a somewhat rich domain) is the perfect opportunity for a renewed dialogue between AI researchers and cognitive scientists. I propose that multilevel heterogeneous models can be utilized in making progress on both of these daunting challenges, particularly in the development of *cognitive models of multi-agent systems* (CMMAS) which will be used to implement both single and multi-agent systems of human actors with an eye to fidelity of behavior. I view each challenge as an instance of an *integration problem* between system elements (either battlespace elements or specifically human elements) at a number of levels of abstraction (multilevel) and over a number of different representations (heterogeneity). The multilevel integration problem is endemic to the multi-agent systems community, often dubbed the "micro-macro" problem, and bidirectionally relates the behavior of atomic elements (individual agents) with aggregate elements (such as organizations, groups, cultures, societies, *et cetera*). In the battlespace characterization problem, the multilevel problem appears not only in differentiating individual human elements from groups, but also in relating the behavior of gubernatorial powers from the village-level to the national-level, or regional microeconomics to national macroeconomics among others. The heterogeneity problem arises in both challenges as well. In the case of the BCP, information regarding the political, military, economic, social, infrastructure, and informational (PMESII for short) aspects of the battlespace cannot usually be captured using a homogeneous computational representation (numbers or symbols) or dealt with in a methodologically pure way (a completely logic-based, or Bayesian solution, for example). Usually, each modeler develops his/her characterization of some aspect of the battlespace in a formalism of choice. How do we get all of these models, operating over multiple representations and using multiple computational methodologies to talk to one another? The heterogeneity problem also expresses itself at the level of developing CMMAS. Even at the level of developing computational cognitive models of single agents, the heterogeneity problem arises. For example, one of the dominant themes in Ron Suns CLARION architecture (Sun 2001) involves capturing the distinction between implicit and explicit learning processes. Implicit knowledge is usually characterized as distributed, not consciously accessible, and therefore unable to be verbalized; whereas explicit knowledge is has a localist representation, is consciously accessible, and therefore able to be verbalized. How do implicit and explicit learning processes interact with one another? This is a classic case of heterogeneity in the human cognitive architecture. Both CMMAS and the BCP are facing the same conundrum: they are both naturally modeled as multilevel heterogeneous systems, yet both face a serious problem of integration.

Integrating MHM's

As we have seen, both battlespaces can be roughly thought of as an extremely complex multilevel heterogeneous model. As of today, PMESII modeling is diffuse, with various experts developing proprietary models. In many cases, each type of information can be expressed compactly using multiple representations and different computational methodologies. Local laws (part of the political aspect of the BCP) may be best modeled using (defeasible) rule-based systems, whereas a neural network may be convenient for capturing financial dynamics due to oil exports (part of the economic aspect of BCP). It seems strikingly clear that political institutions (such as trade laws) may have a startling impact on oil exports, and thus the financial dynamics of the country which in turn may effect voter attitudes, and thus the fate of politicians. Recently, AFRL has embarked on a program to define both environments for developing PMESII models, and reasoning engines allowing these models to effectively communicate with one another. One promising approach has been offered in (Cassimatis 2005). The Polyscheme architecture was developed to reason across multiple representations in service of providing models of an infants reasoning about its physical environment. The claim is that infants use object recognition (implemented as neural networks), simple rule-based reasoning and temporal constraints (just to name a few) in a highly integrated ensemble in order to make inferences about their physical environs. Recently, it has also been used to develop computational cognitive models of "theory-of-mind" (ToM) mechanisms in children (Bello & Cassimatis submitted). ToM allows humans to predict and explain the behavior of other agents by appealing to the mental states of other agents: especially beliefs, desires, and intentions (Flavell, Miller, & Miller 2001). The Air Force Research Laboratory will be using the Polyscheme architecture to begin making progress on developing environments for PMESII modeling, and a reasoning engine with which to make inferences about the various PMESII effects associated with taking certain kinds of actions in a simulated battlespace. Polyscheme is a promising example of the kinds of integration engines needed to make progress on problems like the BCP and CMMAS: inspired by principles in cognitive science yet replete with the rich representational formalisms found in AI research; and thus a perfect opportunity for synergy between the two disciplines.

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