ADAPTIVE SIMULATION: A COMPOSABLE AGENT TOOLKIT FOR WAR GAME ADJUDICATION

D. DUONG, * US Office of the Secretary of Defense

ABSTRACT

The Office of the Secretary of Defense/Program Analysis and Evaluation Simulation Analysis Center is exploring war games and war game adjudicators, to improve its ability to analyze irregular warfare. Adaptive simulation is a suggested technique of composing simulations of cause and synchronizing them through connections found in correlational studies. This toolkit of composable simulations will be a hybrid of agent based models and fuzzy rules, that may be used to adjudicate war games or play them without humans in the loop (HITL). It may be used in an adaptive, quick turnaround modeling process in which models are quickly assembled upon HITL moves that can adjudicate moves based on a consensus of social theories.

Keywords: Agent Toolkit, Agent Based Simulation, War game, Constraint Satisfaction, Social Simulation, Computer Adjudication, Irregular Warfare, Fuzzy Systems

INTRODUCTION

The factor that is most significant to the type of computer analysis used on a war game is the factor of how adjudication is performed. If the all of the moves of the game are expressed in the computer, and the computer adjudicates all of the moves, then the computer may be able to play the game on par or superior to human players using game trees. Such a game can be entirely automated and analyzed by computer, and needs no human play. On the other hand, if humans adjudicate, or the computer adjudications are ignored because of "psychological" moves that are not adjudicated by computer, then the computer can learn from the moves of the humans in the loop (HITL), but statistically significant analysis is more difficult to obtain. The X-game, the extended game played by in the office of the secretary of defense to test irregular warfare strategies in the global war on terror (Dunlap 2007), is more of the later case. This paper presents a methodology for using computer technology to make the X-game more like the former kind of game, thereby bringing it into the horizon of analysis

In a war game, someone or something has to make an educated guess on how groups of persons will behave in situations. Subject matter experts (SMEs) would use heuristics on classes of persons to make generalizations. SMEs are not able to walk out the individual choices that humans would make to the degree that a computer could, but are more flexible in interpreting the meanings of events and applying heuristics in context. A better computational ability to draw

* Corresponding author address: Deborah Duong, OSD/PA&E SAC1401 Wilson Blvd., Suite 300, Arlington, VA22209. email: Debbie.duong.ctr@osd.mil

a picture of the social environment by walking through the implications of social actions would enable a full automation of analysis, without the need for HITL. Full automation would allow a complete statistical analysis of the robustness of strategies, as well as support the discovery of new strategies through data farming and data mining the results. Short of improved technology, duel analysis can be done, on both human and computer adjudicated games.

Advantages that Computer Adjudication has over SME Adjudication

Besides the obvious advantage of saving human resources, being around when SMEs may not be able to, and achieving a statistically significant number of runs, computer simulation can do a number of things that SMEs find difficult. Agent based computer simulation gives the same advantage that war gaming itself gives to analysis: the ability to walk problems through. A SME will tend to use heuristics to generalize about the attitudes of citizens, rather than walk through their individual reasons, choices, and actions. Agent based simulations allow individual behaviors to be walked through, so that the higher order effects of those behaviors are calculated. Macro effects of micro actions are the forte of agent based simulation.

It has been said that we only have a tactical understanding of irregular warfare, making the macro effects of micro actions the central mystery of irregular warfare science. Studies have shown that SMEs have great difficulty in predicting how populations will react to events. This is because social science does not have good theories of micro macro integration. Agent based simulation can help develop theories of how micro actions effect macro level social phenomena in irregular warfare scenarios. If there is no reliable way to connect the micro actions of warfare to macro social attitudes, then walking out the micro actions of irregular warfare in the X-game becomes of questionable use.

Many adjudications of the X-game could have been more accurate and less frustrating if agent based simulation was used instead of a spreadsheet adjudicator. For example, participants could not adjudicate comprehensive effects across national boundaries well, and international effects were the purpose of including very many nations in the game. X-game participants divided their assignments into individual countries without sufficient crosstalk, because complexity at that level is hard for individuals to think about, and takes computer simulation to think out. The spreadsheet adjudicator did not compute higher order effects, and as a result, the macro effects of micro actions were not computed. For example, instead of computing out the effect of a terrorist action on the value of currency, the spreadsheet adjudicator asked X-game participants to figure this out. Being asked so many questions about the macro effects of micro actions that they did not know the answer to was a frustrating waste of gamer's time.

Further, participants had difficulty walking through information operations (IO) incidents. This bothered them, because they felt that IO and the politicized environment, as well as how it contributes to intelligence gathering, is essential to irregular warfare. Rather than walk through the social dynamics of IO, they would use heuristics to adjudicate how a population would react. The heuristics the SMEs used tended not to include details about how a population's mind could be changed, which was really the point of the game, and the source of frustration for players who tried to improve their public support levels. X-game participants thought it was useless to walk through individual IO scenarios when they did not know how to aggregate them to the strategic level. Since "walking through" is the whole point of a war game, an agent based program that could calculate the strategic effects of micro IO outcomes would encourage participants to walk through the events that are the most relevant to the problem of irregular warfare.

An agent based simulation that walks through the effects of micro level actions on the macro level economy would be a low risk replacement for the linear adjudicator of the first run of the X-game. It would surpass its algorithms with only a small amount of work, and would continue to improve and grow as more social phenomena is simulated.

Advantages that SME Adjudication has over Computer Adjudication

Xgame participants felt that the computer adjudication results were so separated from the verbal game that they tended to be ignored by players, and not looked at to trigger events. They were simply scorecards, and poor ones at that, that did not adequately reflect the verbal game. This separation has more to do with computer adjudication in general rather than the particular linear computer adjudicator of the first run of the X-game. Computer simulations are not good at addressing human contexts. For example, X-game participants asked a contractor to put "a kidnapping" in a simulation. But, the result of that kidnapping was not believable, because how a population reacts to any event depends on the context, which they could not put in the simulation. The world is too complex to put all possible contexts into simulations before the particular details about a scenario are known. If basic processes of the model do not address the cruxt of a situation, and if the important factors are not even entered into a model, then the result is not valid.

An approach to dealing with the problem of context is quick turnaround agent based modeling. That is, to have data and many relevant models and modeling practices ready at the beginning of the study, and to write important parts of the model after the scenario is known, with the help of an agent based simulation toolkit. There are some 200 computational social models in academia, along with papers that describe them. Ideas from them that reflect social theories relevant to the scenario may be put into an agent based simulation during the preparation phase of a war game. Since the X-game had week long turns for extended study of actions, some of this time in the game can be spent in putting the context of new actions that modelers did not think of in advance into the agent based model. Quick turnaround agent modeling will allow creative moves to be put into the computer adjudication, and will be available for more excursions in the post-game analysis phase. Models will be available for future use, even if that use is just the borrowing of design patterns, so that the turnaround time will be quicker as the toolkit grows.

A Toolkit of Composable Modules for Quick Turnaround Adjudication

The social world is so complex that we can not build a general model of it that will be valid in every situation at the present state of social science. This complexity, in the context of irregular warfare, makes the quick turnaround approach less risky in terms of verification, validation, and accreditation (VV&A) than the traditional approach of using a previously VV&A-ed model and only changing the data. The model must also be modified to the particular situation.

Composable models also enable the switching in and out of social theories. With composable modules, the modeling phase would mostly consist of combining models or sub-classed models together according to research done on the scenario. If the models come in modules that roughly correspond to different social theories, then relevant sides of issues related to the scenario may be assembled together into plausible alternative social environments to branch on. Both sides of controversial issues would be represented. This is an important capability, as the US government can not test strategies against only one social environment when social scientists have not come

to a consensus on what that environment is. Since the point of the game is to test the robustness of strategies, they should be tested against possible social environments as well as against possible enemy responses.

Agent based simulation should be used for this toolkit, not only because it can handle the micr-macro integration problems of irregular warfare better than SMEs can, but also because it is suited for recombination into new contexts. Agent based simulation is the most valid technique for quick turnaround causal modeling because it models with first principles, while other forms of adjudication tend to just model with correlated relations that do not apply outside of a particular context. When first principles or the root causes of phenomena are modeled rather than the appearance of phenomena, then a simulation becomes valid in new situations, and validity in new situations is an important requirement for a quick turnaround modeling toolkit. For example, X-game participants had difficulty with one of their computer models that simulated a "gravity point": a type of social homeostasis or healing, where the simulation goes back to the original state after a perturbation. However, because the model simulated the appearance of the homeostasis rather than the cause of the homeostasis, it occurred in every situation, even in situations where the point of the game was to find ways to prevent healing. If phenomena is simulated by assuming it is always true, then it can't be valid for exploring when it isn't true. In contrast, a good agent based simulation uses first principles and has fewer assumptions. Most phenomena in an agent based simulation is emergent from those few assumptions. Thus, agent based simulation is a technique that allows basic assumptions to be walked through in new contexts.

Combining Correlational Relations with Causal Models

In the first X-game, spreadsheets were used for computer adjudication because the agent based simulation was not ready. X-game participants put relations such as from the Fund for Peace's failed states index (Fund for Peace et al, 2007) into adjudication spreadsheets, combined with a random number generator to recognize that the relations were not always true. To put many relations from SMEs into a simulation so that they make sense together, modelers should no treat them as hard assumptions, as is done when relations are put into spreadsheet adjudicators. Modelers must take care to limit the number of assumptions in a simulation, and to understand the difference between correlational and causal models of social science, and how to apply both kinds of models to a simulation. Social science has thousands of studies of how one phenomenon correlates with another phenomenon. However, correlational relations can not be put into the assumptions of a simulation because they do not explain cause, and do not address why they are sometimes true and sometimes not. If they are put in as hard constraints, the model will not be able to explore anything outside of those relations, and the fact that the correlation coefficient is typically quite low in correlational studies of social phenomena makes it unrealistic to assume that many of them would be true at the same time. Moreover, correlational studies can not drive simulations : only causal models can do that.

Rather, correlational studies should be implemented as requirements to models of cause, or soft constraints on an answer that is determined by causal models. Observed correlations can and should be requirements for the higher order effects that result from theoretically based causes. Figure 1 illustrates composed causal models that are constrained in their outcome at designated points of correlation with events in other causal models.

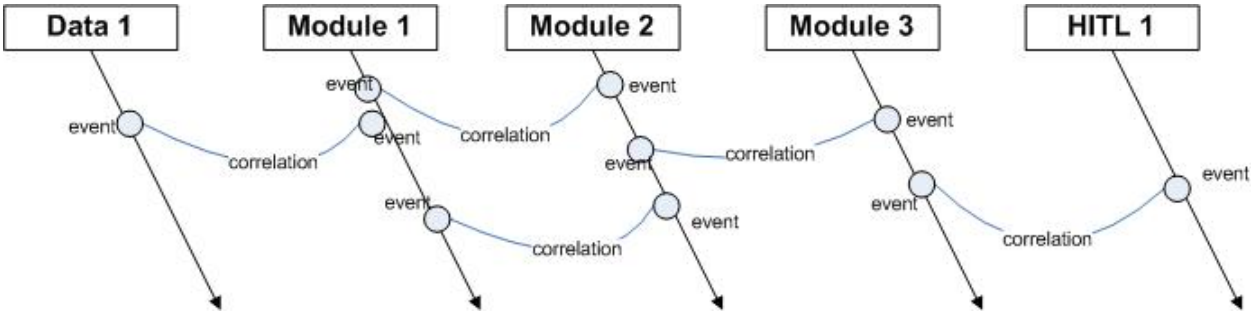

FIGURE 1 Correlational studies as soft constraints on models of cause, in a composition of models

A toolkit of composable models would cover both larger basic social theories of cause and smaller, more correlational studies. Causal theories would be expressed in simulation modules, while correlational studies would provide data upon which a designation of correlation between modules, or between modules and data, may be based. Designated correlations will place soft constraints on the consensus formed between sets of correlated modules at the places designated as correlated. Simulation modules would be synchronized at these places of correlation, so that they create a single picture of the social environment.

Fuzzy Rules to Implement Correlational Relations

Fuzzy rules are better implementations of soft constraining relations on simulation modules than spreadsheets are. Fuzzy rules work well with rich ontologies as distance metrics for simulation events. According to Weisel and Moya (2007), in order to be composed together, simulation events in different simulations must be related and described by a distance metric. Fuzzy rules can be used to decide whether a simulation event has come close enough to be designated as correlated with an event in another model, so that these models may be synchronized.

Fuzzy distance metrics can also represent gradient for use in data mining techniques and database retrieval of close cases, as is needed for case based reasoning. Fuzzy rules learned from HITL moves by data mining techniques such as the Center for Army Analysis' ACTOR program (O'Brian, 2003), can be added to hand-designed fuzzy rules from correlational studies, and put back into the composed model as soft constraints for post game runs without HITL. This would be useful for scaling, for example, to derive rules from war games of a few factions, and then test them on a more realistic simulation of 300 factions.

Adjudication rules in the form of fuzzy rules reflect the qualitative nature of social phenomena. As a method of soft computation, they are robust with respect to data, using the kind of verbal approximations that SMEs make. In a fuzzy system it does not matter if much of the data is approximate. Additionally, fuzzy systems can handle rules that contradict themselves, such as different SMEs or different correlational studies might make. Conflicting rules can just be added together.

Fuzzy cognitive maps can implement soft constraints leading modules to a consensus of the separate simulation models using constraint satisfaction methods. They can also implement the relations and feedback of systems dynamics models, another type of non-causal macro level model that can be used to put requirements on agent based simulations. With fuzzy rules, a quick turnaround toolkit can incorporate relations from spreadsheet and systems dynamics models, including feedback relations, into compositions of agent models.

Composing Simulation Models

The various simulations of major social theories, along with the designated points of correlation from correlational studies, will come to a consensus on a picture of the social environment, even though they may contradict each other. The phenomena in the different simulations will be made to correlate with each other at the correlation coefficients of published studies as much as possible. Individual simulations will have to adjust their states to the consensus state, and continue simulating from the point of consensus. This may involve iterative re-computations of simulation time until consensus is reached. Different simulations may be weighted differently in weighted voting schemes Since this is a constraint satisfaction problem, feedback such as in constraint satisfaction neural networks and fuzzy cognitive maps can help decide the consensus state. The National Science Foundation's Dynamic Data Driven Application System (DDDAS) program has developed techniques for feedback between data and simulations can also help.

The toolkit for composable models would have some qualities of a federation of independent models, and some qualities of a library of modules that need sub-classing in order to be instantiated to particular problems. As in federation composablity, modules would be viable without each other, for example, a model might use a draw from a distribution for phenomena it does not simulate, or if there is a designated correlation point it might use a draw that has been made to correlate with a draw from another simulation, or it might even replace the draw with an event from a trusted deterministic simulation. Since social phenomena are dependent on each other in the mathematical sense, theories can not switch in and out through neatly defined interfaces, as one might expect from a library. Figure 2 illustrates this point. Rather, there is functional overlap between theories, with different overlap depending on the theory. The same events, or correlated phenomena, in different simulations can be made to match up, synchronizing the simulations into one picture of the social environment at the designated points of correlation. Even replicated simulations, which are simulations of the same theories implemented differently, can benefit from coming to consensus through designated points of correlation, because artifacts of their implementation would be weeded out.

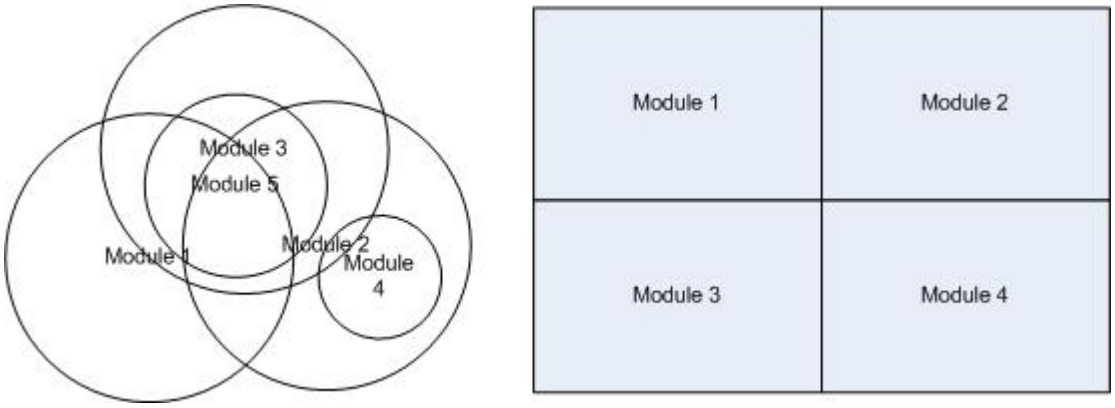

FIGURE 2 The modules of the toolkit will have functional overlap, on the left, as opposed to the traditional model of independent modules, on the right. Because social science theories look at the same phenomena in different ways, modules will be synchronized at their designated areas of overlap rather than through standardized interfaces.

Conclusion

Although SMEs have difficulty thinking about the macro effects of tactical moves in war games, they are still trusted more than computer simulation because they are better at understanding human contexts. A toolkit for composable models would give us many capabilities, including the ability to quickly adapt an agent model to the context of a move in the war game and the ability to switch different models of the social environment in an out. As more of the human context is put into a simulation, the simulation can replace the HITL game, so that irregular warfare strategies may be tested for robustness against many more scenarios than is practical for HITL games.

References

Dunlap, P., 2007, "Global War on Terror Analysis: An Extended Wargaming Approach," 75th MORSS Symposium.

The Fund for Peace and the Carnegie Endowment for International Peace 2007, "The Failed States Index 2007," *Foreign Policy*, August.

National Science Foundation, 2007, *Dynamic Data Driven Applications Systems* http://www.nsf.gov/cise/cns/dddas/

O'Brien, S. 2003, "Analyzing Complex Threats for Operations and Readiness (ACTOR)," 72cd MORSS Symposium.

Weisel, E. and L. Moya, 2007, "Towards an Architecture for Distributed Component Based Simulation," European *Simulation Interoperability Workshop.*