AGENT-BASED SIMULATION,
USEFUL MODELS?

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Introduction

"All models are wrong: some models are useful", George E. P. Box[1]

The range of tools and methods available to the military analyst for building and understanding models is ever expanding. Recently agent-based simulation has been included in this toolbox. The purpose of this paper is to provide direction regarding the future use and development of agent-based simulation for analysis.

The view espoused by above quote is central to many of the ideas presented in this paper. It is not argued that agent-based simulation models are any less wrong than other models. The primary thesis is that agent-based simulation models are useful. It is argued that in some cases analysis using agent-based simulation models has the potential to provide more useful insight than other approaches.

Agent–Based Simulation

Agreement on a precise definition of agent-based simulation is somewhat difficult to obtain. Many people use 'agents' to help them with their work, often with very different ideas of what their agents are. Computer scientist's talk of 'software agents'; chunks of code that are long-lived, semi-autonomous, proactive, and adaptive.[2] Others develop agents that are 'intelligent' to represent human behavior. The types of agents of interest for this paper are those constructed to represent entities in simulated military environments. In this context agents are representations of entities with intent.[3]

In agent-based simulation models an entity's behavior is generally modeled as a set of goals or actions. Agents control their own destiny, or in other words change their state, based on their knowledge of the environment in which they are placed. They do this in order to meet some goal, criteria, or intention. From a program architecture viewpoint agents are normally represented in an object-orientated way, where the object contains all of the program code that changes the state of the agent. The key to agent-based simulation is the representation of knowledge and behavior[4].

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[1] Professor Box stated that this was originally in *G. E. P. Box, "Robustness in the Strategy of Scientific Model Building" in "Robustness in Statistics", Eds. Launer R. L., and Wilkinson, G. N. Academic Press, New York. pp.202. 1979*

[2] See http://agents.media.mit.edu/index.html for example.

[3] The definition of agents as 'entities with intent' can be attributed to a course on agent design at the Naval Postgraduate School with Professor John Hiles.

[4] These terms are used with caution. The use of anthropomorphisms is discussed later in this paper.

The knowledge of an agent encompasses its awareness of the environment. This includes a representation of self, a representation of others that has been received via communication and other sensory channels, and perhaps some memory of past states. An agent's knowledge is also known as its inner environment. This is its representation of the outer environment (or real world). An important design consideration in the construction of agents is the encapsulation of information so that knowledge is controlled.[5]

Once an agent's knowledge has been constructed the behavioral mechanism then acts on its degrees of freedom. An agent's degrees of freedom are those state variables that it has the capability to affect. The agent's behavior is a function that takes knowledge as an input, and outputs changes to the agent's degrees of freedom. Agent behaviors may be extremely simple, or incredibly complex. At one end of this spectrum are simple reactive agents that have fixed behaviors. At the other end are complex adaptive agents that react to past behavior success and adapt to their environment.

Why Agent-Based Simulation?

"Pluralitas non est ponenda sine neccesitate", Ockham's razor[6]

When William of Ockham stated, "Entities should not be multiplied unnecessarily" in the 14th century he probably did not conceive that this principle would be so directly applicable to military simulations on computers in the 21st century. In general he meant, "Keep things simple!", which is a good principle for the construction of all models. Einstein was more specific when describing models, "*Everything should be made as simple as possible, but not simpler*". Simplicity is a basic principle that is used when constructing agent-based simulation models for analysis.

Agent-based simulation models are fairly small when compared to other military simulations. In general they are only designed to represent a small, focused, subset of entities and interactions than larger constructive simulation models. The representation of environmental considerations such as terrain and weather is usually much simpler than larger simulation models.[7]

The relative simplicity of current agent-based simulation models offers two key advantages. They are quick to set up, and they run very fast. From the time a simple scenario is conceived it may take less than a week for a single analyst to implement the scenario and conduct millions of simulation runs. This compares to more traditional constructive military simulations that may take many months to implement and produce

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[5] Encapsulation of information is one of the basic principles of object-oriented programming.
[6] A good summary of Ockham's razor and its relevance to the scientific process can be found at http://www.weburbia.com/physics/General/occam.html.
[7] There is nothing inherently small or simple about agent-based models. It just so happens that is they way many agent-based models used for analysis are at the moment. Other uses of agents have them incorporated in much larger models, for human behavior representation for example.

only a few runs that can be analyzed. Being quick to set up allows analysts to use agent-based simulations to provide insight to problems in a timelier manner.

The ability to produce millions of runs allows analysts using agent-based simulations models the ability to consider thousands of alternatives. A traditional analysis of alternatives using a large constructive simulation generally involves taking some scenario and varying the capabilities of a weapon system of interest, for example. In most cases only a few discrete alternatives are considered. With agent-based simulations many alternatives on some continuous scale, in many dimensions, may be considered.

Another advantage of small, simple models is in their interpretability. It is possible for a single human mind to conceive of every parameter and state variable in a simple model, and how they are related; this is not the case for large models. Large models may be as incomprehensible as the system they are modeling.

There are difficulties associated with using agent-based models that should be identified. Perhaps the most criticism from within the military simulation community concerns initialization data. In many cases agent-based models are trying to capture some intangible aspect of warfare such as aggression or morale. There is little data to support the values chosen for initialization parameters that relate to these intangible aspects; other than that the results pass a face validation test.

Arguments regarding such intangible aspect of an agent-based model can normally be avoided by a careful description of the model in terms of parameter and variable relationships, rather than just parameters. For it is only the relationship between parameters in a model that give them meaning. Without this relationship the parameters mean nothing. Ensuring that the sensitivity of the results to any assumptions made is tested is also important. The interpretability and fast run times of small agent-based models allow the careful modeler to achieve both of these.

Many analysts using agent-based modeling have endured healthy dose of criticism, often well deserved, from fellow modelers that use more established techniques. Having briefly defined and established the usefulness of agent-based simulation the remainder of this paper is concerned with identifying a path for future development, revealing myths, and describing potential pitfalls. This is aimed towards analysts that will use agent-based simulations to provide insight to military problems.

Developing a Methodology

The way ahead for using agent-based simulation models for analysis involves developing a problem solving methodology. This entails much more than just developing some agent-based modeling tool, in fact the development of a tool is perhaps the easiest part of this whole process as it has already been done many times. The parts of the process that are often lacking are the formulation of the question, the design of the experiment and the analysis of results.

Unfortunately there are plenty of examples where an analyst has developed an agent-based simulation with only a vague notion of the actual problem that needs addressing, and in many cases with little regard to the experimental design. Querying the modelers aim often discovers such work. If the answer is of the form, “Our aim is to model/simulate ………” then the lack of analytical rigor becomes evident. There are valid uses of agent-based simulation where the aim is something like, “To model human behavior”. From the military analysts viewpoint this may be important work, however it is not analysis per se.

Before we have an aim we start with a problem that we can address by answering a range of questions that will add valuable insight. The generation of these questions forms the first step in the formation of an agent-based simulation methodology. This is no different than for any other form of analysis. From these questions we get a number of aims, such as “To investigate the effect of ……”, etc. Note that the aims should directly address the questions.

Identification of a scenario that can help answer the questions comes next. At this stage we wish to describe the entities that are of interest and the interactions between them and any external environmental features. This stage should be characterized by trying to abstract and simplify until we have a scenario that only includes those aspects that are essential to gaining insight to the question at hand. The creation of the scenario may also be considered as the design of the conceptual model we are going to investigate.

Our well-defined scenario should then be implemented in an agent-based simulation modeling tool. Unfortunately the range of tools available tends to require us to modify the conceptual model somewhat to fit the tool. There is room for the development of more agent-based simulation tools however there is always a trade off between the flexibility of the tool and the time it takes to implement a scenario using it. The design of the tool may also control the design of the experiment. This is undesirable however as there is no agent-based simulation tool that allows for every experimental design we are bound by it.

In general for all scenarios we have a number of factors we wish to analyze. These factors may be discrete or continuous. Factors may represent something that is within our scope to change, or some assumption about our model that we wish to test the sensitivity of. In addition to factors there is a measure, metric or response that we are interested in. Often the question revolves around what values the factors should be set at in order to optimize the response.

At this stage we can think of our agent-based simulation model as a black box. At one end we feed in the factor levels (the values we set the factors at), and at the other end we get a response. If there is some randomness in our model the response will follow a distribution at each of these design points. The design of the experiment largely involves what to set the factor levels at in order to minimize the number of runs required to get a result of the desired statistical significance.

Another important part of experimental design is controlling randomness. The particular random number generator used, and the careful use of correlated random number streams between experimental runs can also significantly affect the number of runs required.

After conducting the designed experiment the data must be analyzed. There are many ways to do this effectively. Visualization of the multi-dimensional output is useful to get some ideas about which factors are important to the response and which are not. More rigorous statistical methods such as regression and classification trees may then be used to provide robust answers.

The steps outlined above as a methodology are not complex or new, nor have they been completely described. They have been presented independently however only the integration of the whole process will lead to a strong analysis. The steps should not occur in isolation. The development of a model must be made with foreknowledge of the design of potential experiments and the analytical methods to be used.

Old Wine, New Bottles

One common misunderstanding regarding agent-based simulation is that it is some new, fancy way of doing analysis. In the sense presented here this is not the case. The general procedure outlined above has been well understood in the simulation analysis community for some time.

What are new are the term agent and a few aspects of agent-based models. Specifically the representation of knowledge and behavior is new. Perhaps the most significant advance is due to the increased power of processors. With this comes the ability to perform millions of simulation runs and investigate much more complex scenarios.

The Right Questions

A potential pitfall of this entire process it trying to apply it to questions that it can not answer, or that some other method can answer more effectively. Agent-based simulations are good at investigating small areas of the battlespace, especially where a simple analytical model cannot provide enough insight, or a large traditional constructive model is too complex or time consuming.

There are many situations where larger, more traditional, modeling tools are more appropriate. One can imagine taking the large model that tries to represent everything and removing or abstracting parts of the model that the analyst thinks are not relevant to the result of interest. At the end of this process a significant proportion of the large model may have been removed and it will be similar in size, and perhaps operation, to an agent-based model. So why not use small agent based simulation models for everything? The problem is that in many cases there may be some unforeseen interaction between part of the large model that was removed and our measurement of interest. Only by running the large model can we discover these interactions.

Model Creep

Mission creep is a term that is widely recognized throughout the military, referring to the gradual expansion of a mission over time. Model creep refers to the gradual increase of the size of a model as a problem is investigated. A perpetual perceived problem with any model is that it is never modeling enough. There is always some new aspect of the universe that is not represented and 'should' be included in the model. This often means that it is included in some way and the model grows. This perception is not always correct. The proper definition of research questions, and the design of an experiment to answer them, helps to prevent model creep. The analyst should know when the questions have been answered and stop.

Model creep violates the simplicity principles described earlier. It is especially important that agent-models are kept simple. For by making them complex we loose our ability to investigate many factors by executing millions of runs. A model with more fidelity is no less wrong than a simpler model, and in many cases will not give any extra insight.

Time Marches On

Agent based simulations can be used to investigate the progress of a scenario over many domains; however we are most commonly interested in the change of state over time. Another potential pitfall with agent-based simulation is the unfettered use of time-step methods to advance time. It has been shown that the qualitative and quantitative results realized from simulations may be dependant on the size of time step used.

At the very least, analysts using agent-based simulations should be able to check the sensitivity of their results to the size of the time step used. A more robust approach is to use a discrete event modeling methodology; however the integration of a pure discrete event model, and a robust and flexible behavioral mechanism has yet to be achieved.

Playing With Words

"an·thro·po·mor·phism, *Attribution of human motivation, characteristics, or behavior to inanimate objects, animals, or natural phenomena."*

"re·i·fy, *To regard or treat (an abstraction) as if it had concrete or material existence."*

Analysts using and describing agent-based simulation models should be cognizant of the meaning of the words used to describe various aspects of their model. Anthropomorphisms often create more confusion and misunderstanding than a particular model deserves. Whenever anthropomorphic terms are used the analyst should qualify the terms with a definition of what is meant. This paper has used the terms knowledge and behavior to describe a generic construction for an agent. This was never meant to imply that the agents have knowledge or behavior on the same scale as humans, rather the terms are more convenient than 'the vector of state parameters that represents sensed information' and, 'the function that maps sensed information to degrees of freedom', respectively.

Another example of a typical anthropomorphism is giving an agent a property such as 'aggression' and assigning a number to it. It should be well understood by all involved exactly what effect the 'aggression' parameter has on the model. As stated earlier parameters mean nothing on their own; it is the relationship between parameters that give them meaning. In the case of our 'aggression' example it may actually mean 'the magnitude of movement towards a sensed enemy'.

The use of a term like aggression is also an example of the 'reification of behavior'. It can be argued that aggression, like other aspects of behavior in humans, is an abstract concept and is not actually measurable. To do so would be would be to treat aggression (a verb) as something that actually exists (a noun).[8] Analysts using agent-based simulations can avoid these arguments between social biologists and evolutionary biologists by being concrete about what is meant. This is achieved by describing that 'aggression' is, for example, the magnitude of movement towards a sensed enemy, and by acknowledging that such a relationship between parameters and variables in the model is itself an abstraction of reality.

Summary

Military modeling incorporating agent-based simulation models has the capability to answer a wide range of questions. Of particular importance to the development of agent-based simulations is the co-development of modeling methodologies incorporating experimental design and robust statistical analysis. In doing so we are not designing something new, rather we are applying a few new tools and concepts to well established procedures.

There are a number of pitfalls to be avoided in this process. We must make sure we only attempt to answer relevant questions using these procedures. We must avoid needlessly increasing the size of our model in the belief that more fidelity will actually produce more insightful results. We must be cognizant of the inaccuracies of the time step process. And lastly we must be careful when using anthropomorphisms and reifications such as referring to an agents 'aggression' or some other behavioral property, especially when communicating the results. Overriding all of this, every analyst, every day, must continue to realize that even if the model is useful, it is really wrong.

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[8] Lewontin, R.C., Rose, S., and Kamin, L. J., "Not in our genes", Pantheon, 1984 provides one side of this argument.

Further Reading

A thesis by the author regarding “Modeling Swarms of Robots Using Agent Based Simulation” can be found at http://diana.gl.nps.navy.mil/~ajdickie/marss/. This work presents a methodology for investigating robot behavior using an agent-based simulation model.

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