Agent-Based Modeling and Simulation: A Survey

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ABSTRACT

Agent-based models are simulations based on the global consequences of local interactions of members of a population. An agent is an autonomous, computational entity that can be viewed as perceiving and acting upon its environment and is autonomous in that its actions or behavior depend at least partially on its own experience. Since its origins in the 1940s, agent-based modeling has grown to be an interdisciplinary science with applications in a variety of areas such as Ecology, Biology and the Social Sciences. Considered by some as a third way of doing science, in addition to deduction and induction, simulation permits increased understanding of systems through controlled computational experiments. Agent-based modeling has the potential to improve the accuracy of complex system forecasting and to improve the insights into the factors and variables that are the primary drivers of emergent behaviors in multiple interdependent systems. This tutorial describes the foundations and applications of agent-based modeling and simulation and show how agent-based modeling can address questions common to many disciplines and facilitate interdisciplinary collaboration.

KEY WORDS: agent-based models, multi-agent systems, artificial intelligence

1. INTRODUCTION

Although there is no universal agreement in the definition of Agent-Based Modeling and Simulation (ABMS), it is commonly used to mean a simulation made up of agents, objects or entities that behave autonomously. Agent-based simulations are models where multiple entities sense and stochastically respond to conditions in their local environments, mimicking complex large-scale system behavior [19]. From all different definitions and opinions on what constitutes an agent the fundamental feature is the capability to make independent decisions. Therefore, agent-based systems should be capable of flexible autonomous action in dynamic, unpredictable domains [1]. Agents are aware of and interact with their local environment through simple internal rules for decision making, movement and action. ABMS has been proposed for and used in an increasingly wide variety of applications, ranging from comparatively small systems such as personalized email filters to large, complex, mission critical systems such as air traffic control.

This tutorial attempts to provide the reader with a definition of agents and Agent-Based Modeling and Simulation that although not accepted by every discipline will be just to the role played by agents in the different disciplines and provide an understanding of the agents capabilities. The second part of the tutorial will discuss the different applications agents have among a wide range of disciplines and the state of the art of the current technology for ABMS and what may be seen in the future.

2. AGENTS AND AGENT-BASED MODELING AND SIMULATION

2.1 What is an Agent?

The definition of an agent has been a theme of debate among the various disciplines ever since its conception. Some scientists consider any type of independent component (software, model, individual, etc.) to be an agent [4]; an independent component’s behavior can range from primitive reactive decision rules to complex adaptive intelligence. Others insist that a component’s behavior must be adaptive in order for it to be considered an agent [13]. Casti [5] argues that agents should contain both base-level rules for behavior as well as a higher-level set that provides for adaptation. In an attempt to provide a definition for agent that could be accepted by all, Jennings has identified some fundamental characteristics an agent must have; Macal and North later expanded on these characteristics:

- An agent must be situated: the agent receives sensory input from its environment and can perform actions which change the environment in some way.
- An agent must be autonomous, it should be able to act without the intervention of humans or other agents and have control over its own actions and inner state.
- An agent must be flexible, it should be responsive, proactive and social. Agents should perceive the environment and respond to changes that occur in it. Agents should exhibit goal-directed behavior and interact with other agents.
and humans in order to complete their own problem solving and help others with their activities.

- An agent is identifiable, with a set of characteristics and rules governing its behaviors and decision-making capability.

By an agent being identifiable it implies that it has boundaries and one can easily determine whether something is part of an agent, is not part of an agent, or is shared characteristic. Flexibility provides the agent with the capability to learn and adapt its behaviors over time.

2.1 Why use agents?

Humans have always felt the need to study and understand the world surrounding us. As we learn new things we realize that there are much more complicated questions to answer. Often the cost or the risks involved in studying a system makes it impossible to obtain the answers desired. This is where simulation comes into play, providing scientists with a new way of looking at the world. As the systems under study got more complex it became apparent that new methodologies capable of modeling the individual behaviors of the agents in the system would be needed and artificial intelligence (AI) was born. What is today known as AI began in the 1940’s with the Von Neumann machine, later called cellular automata. Von Neumann posed the question: Could a machine be programmed to make a copy of itself? This question was answered by Stanislaw Ulam, who demonstrated it was possible to develop a logical structure that was complex enough to completely contain all of the instructions for replicating itself. In 1970 J.H. Conway created the game of Life and with that the concept that life can exist as information led to some fascinating avenue of research. The use of artificial life to create bottom-up models of the real world followed from there.

Traditional modeling tools are not always adequate when dealing with complex systems, and some systems, such as economic markets have always relied on assumptions of homogenous agents and perfect markets in order to make them analytically and computationally tractable [13]. ABMS allows us to take a more realistic view of complex systems and with the advances on computational power it is now possible to compute large-scale simulation models that would not have been possible twenty years ago. Agent-based simulations are based on the idea that it is possible to represent in computerized form the behavior of entities which are active in the world, and that it is thus possible to represent an emergent collective behavior that results from the interactions of an assembly of autonomous agents [6]. Intelligent agent simulations allow for self-modifiability in an attempt to model natural or societal processes whose complexity would otherwise lead to exponentially increasing computational demands [23]. The chief difference is that agents change as the simulation progresses and adapt their behavior in order to meet general goals which are assigned by the simulation designer. ABMS has been particularly successful in modeling biological, bio-molecular and ecological phenomena. Even more surprising is the success these methods have had in modeling economic and financial processes such as commodity markets and currency exchanges [23].

3. APPLICATIONS

A major application for Multi-Agent Systems is constructing models of the real world. Such agent-based models offer a straightforward mapping to entities in the real-world domain and the interactions among those entities [16]. In applications of ABMS to social processes, agents represent people or groups of people, and agent relationships represent processes of social interaction [8]. The interest in agent-based and artificial life simulations continues to increase in a broad range of disciplines, following you will find a list of some of the major applications.

3.1 Military applications

Military combat has many of the key features of complex adaptive systems [9]. Combat forces are composed of large numbers of nonlinearity interacting parts that are organized in a command and control hierarchy. However, each soldier on the battlefield has some degree of autonomy and is continually making decisions to satisfy a variety of sometimes conflicting objectives. ABMS shifts the focus from finding a mathematical description of an entire system, as done by traditional modeling methods, to a low-level rule based specification of the behavior of individual agents making up that system [9].

One recent example of an application of an agent-based simulation to a military application would be the Unmanned Surface Vehicles study. The Navy is considering the use of unmanned surface vehicles (USVs) to reduce risk to personnel in maritime interdiction operations and to conduct intelligence, surveillance and reconnaissance and force protection missions. The study uses an agent-based simulating platform Pythagoras to model the performance of the USV with respect to current capabilities. The models are able to capture how the USVs act under a variety of circumstances. Some of the factors of interest include the environment (e.g. number of contacts, etc.), tactical employment (e.g. planned or dynamic control), and programming issues (e.g. number of USVs available). Findings provide program managers with information regarding USV speed and endurance, and number of USVs, as well as help focus future field test efforts.
3.2 ABMS in the Social Sciences

Agent-based modeling and simulation are natural tools for social science research and modeling real-world processes that involve individual and group behavior (Reed, 2004). In recent years ABMS has found applications in economics, sociology, anthropology, political science and game theory. The agents that populate an ABM can be based on individuals, groups, or institutions occurring in the natural system. The decision algorithms used in these agents can be based on knowledge and data available regarding the behavior of the associated individuals, groups, or institutions.

On a recent study it was desired to model the current system for web-based learning and find alternatives to solve the existing problem of coordination in this environment. The fast growth of the Internet has made online teaching a common phenomenon, but the outcome is still not comparable to that of a traditional classroom. The main reason being that the information exchange of the traditional classroom cannot be duplicated. There are propositions of solving the coordination problems of online teaching by using a student agent, a mediator agent and a teacher agent. These agents can provide a certain degree of interaction and coordination for students during their study.

Another common application of agent-based models is to simulate consumer behavior. Said et al. have created a virtual consumer population that can be used for simulating the effects of marketing strategies in a competing market context. They proposed a consumer behavioral model based on a set of behavioral primitives such as imitation and conditioning, which are founded on the new concept of behavioral attitude.

3.3 ABMS in the Biological Sciences

Researchers in bioinformatics and systems biology are increasingly using complex models and simulations to understand complex inter- and intra-cellular processes [22]. Alternatives to traditional representations, such as those offered by differential equations, have been looked into. The principles of Object Oriented analysis, design and implementation, as standardized in the Unified Modeling Language (UML) can be applied to the modeling and simulation of cells and other biological entities. CellAK, an agent-based approach, produces models that are similar in structure and functionality to existing tools in the biology community but it offers greater modeling flexibility and power. CellAK represents an agent-based cell modeling environment built on top of state of the art software modeling tools and practices.

4. CONCLUSIONS

We have discussed how agent simulation can be used to study how patterns and organizations emerge and to discover how system-level structures form that are not apparent from the behaviors of individual agents. Some examples have been reviewed and the applicability of ABMS to a wide variety of applications has been shown. Nevertheless, ABMS is not an universal solution and there is much room for improvement, such as adapting traditional designs derived from traditional Ordinary Differential Equations methods to Agent-Based models, and to resolve the issues of scalability and universality. The continuous growth in computer capabilities and the extensive research currently being done in the field of ABMS are expected to provide some of the improvements needed in the near future.

REFERENCES


