Introduction to Multi-Agent Simulation

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INTRODUCTION

When designing systems that are complex, dynamic, and stochastic in nature, simulation is generally recognised as one of the best design support technologies, and a valuable aid in the strategic and tactical decision-making process. A simulation model consists of a set of rules that define how a system changes over time, given its current state. Unlike analytical models, a simulation model is not solved but is run and the changes of system states can be observed at any point in time. This provides an insight into system dynamics rather than just predicting the output of a system based on specific inputs. Simulation is not a decision making tool but a decision support tool, allowing better informed decisions to be made. Due to the complexity of the real world, a simulation model can only be an approximation of the target system. The essence of the art of simulation modelling is abstraction and simplification. Only those characteristics that are important for the study and analysis of the target system should be included in the simulation model.

The purpose of simulation is either to better understand the operation of a target system, or to make predictions about a target system's performance. It can be viewed as an artificial white-room which allows one to gain insight but also to test new theories and practices without disrupting the daily routine of the focal organisation. What you can expect to gain from a simulation study is very well summarised by FIRMA (2000). FIRMA's idea is that if the theory that has been framed about the target system holds, and if this theory has been adequately translated into a computer model this would allow you to answer some of the following questions:

- Which kind of behaviour can be expected under arbitrarily given parameter combinations and initial conditions?
- Which kind of behaviour will a given target system display in the future?
- Which state will the target system reach in the future?

The required accuracy of the simulation model very much depends on the type of question one is trying to answer. In order to be able to respond to the first question the simulation model needs to be an explanatory model. This requires less data accuracy. In comparison, the simulation model required to answer the latter two questions has to be predictive in nature and therefore needs highly accurate input data to achieve credible outputs. These predictions involve showing trends, rather than giving precise and absolute predictions of the target system performance.

The numerical results of a simulation experiment on their own are most often not very useful and need to be rigorously analysed with statistical methods. These results then need to be considered in the context of the real system and interpreted in a qualitative way to make meaningful recommendations or compile best practice guidelines. One needs a good working knowledge about the behaviour of the real system to be able to fully exploit the understanding gained from simulation experiments.

The goal of this article is to brace the newcomer to the topic of what we think is a valuable asset to the toolset of analysts and decision makers. We will give you a summary of information we have gathered from the literature and of the experiences that we have made first hand during the last five years, while obtaining a better understanding of this exciting technology. We hope that this will help you to avoid some pitfalls that we have unwittingly encountered. The second section is an introduction to the different types of simulation used in operational research and management science with a clear focus on agent-based simulation. In the third section we outline the theoretical background of multi-agent systems and their elements to prepare you for the fourth section where we discuss how to develop a multi-agent simulation model. The fifth section outlines a simple example of a multi-agent system. The sixth section provides a collection of resources for further studies and finally in the last section we will conclude the article with a short summary.

SIMULATION TECHNIQUES

Operational research usually employs three different types of simulation modelling to help understand the behaviour of organisational systems, each of which has its distinct application area: discrete event simulation (DES), system dynamics (SD), and agent-based simulation (ABS). DES models a system as a set of entities being processed and evolving over time according to the availability of resources and the triggering of events. The simulator maintains an ordered queue of events. DES is widely used for decision support in manufacturing (batch and process) and service industries. SD takes a top-down approach by modelling system changes over time. The analyst has to identify the key state variables that define the behaviour of the system and these are then related to each other through coupled, differential equations. SD is applied where individuals within the system do not have to be highly differentiated and knowledge on the aggregate level is available, for example, modelling population, ecological and economic systems. In an ABS model the researcher explicitly describes the decision processes of simulated actors at the micro level. Structures emerge at the macro level as a result of the actions of the agents, and their interactions with other agents and the environment. Whereas the first two simulation methods are well matured and established in academia as well as in industry, the latter is mainly used as a research tool in academia, for example in the social sciences, economics, ecology (where it is often referred to as individual-based modelling), and political science. Some example applications in these fields can be found in Table 1.

Although computer simulation has been used widely since the 1960s, ABS only became popular in the early 1990s (Epstein & Axtell, 1996). It is now a well-established simulation modelling tool in academia and on the way to achieving the same recognition in industry. The history of agent-based modelling is not well documented. This is most likely due to the fact that there is no general consensus about a definition of what deserves to be called an agent and hence opinions in the agent community about the beginnings of agent-based modelling differ. The technical methodology of computational models of multiple interacting agents was initially developed during the 1940s when John von Neumann started to work on cellular automata. A cellular automaton is a set of cells, where each cell can be in one of many predefined states, such as forest or farmland. Changes in the state of a cell occur based on the prior states of that cell and the history of its neighbouring cells. Other famous examples of theoretical and abstract early agent developments that show how simple rules can explain macro-level phenomena are Thomas Schelling's study of housing segregation pattern development and Robert Axelrod's prisoner's dilemma tournaments (Janssen & Ostrom, 2006).

Probably the earliest form of agent-type work that has been implemented dates back to the early 1960s when William McPhee published work on modelling voter behaviour (SIMSOC, 2004). In the 1970s

Table 1. Examples of ABS applications

Field	Application Examples
Social Science	Insect societies, group dynamics in fights, growth and decline of ancient societies, group learning, spread of epidemics, civil disobedience
Economics	Stock market, self organising markets, trade networks, consumer behaviour, deregulated electric power markets
Ecology	Population dynamics of salmon and trout, land use dynamics, flocking behaviour in fish and birds, rain forest growth
Political Sciences	Water rights in developing countries, party competition, origins and patterns of political violence, power sharing in multicultural states