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Review article

Agent Based Modelling and Simulation tools: A review of the state-of-art software

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ABSTRACT

The key intent of this work is to present a comprehensive comparative literature survey of the state-of-art in software agent-based computing technology and its incorporation within the modelling and simulation domain. The original contribution of this survey is two-fold: (1) Present a concise characterization of almost the entire spectrum of agent-based modelling and simulation tools, thereby highlighting the salient features, merits, and shortcomings of such multi-faceted application software; this article covers eighty five agent-based toolkits that may assist the system designers and developers with common tasks, such as constructing agent-based models and portraying the real-time simulation outputs in tabular/graphical formats and visual recordings. (2) Provide a usable reference that aids engineers, researchers, learners and academicians in readily selecting an appropriate agent-based modelling and simulation toolkit for designing and developing their system models and prototypes, cognizant of both their expertise and those requirements of their application domain. In a nutshell, a significant synthesis of Agent Based Modelling and Simulation (ABMS) resources has been performed in this review that stimulates further investigation into this topic.

Contents

1. Introduction

Computer modelling and simulation relates to the manipulation of a computational model in order to enhance the analysis of systems' behaviour and to assess strategies for its functioning in the descriptive or predictive modes. The term *model* is considered as "an abstract and simplified representation of a

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given reality, either already existing or just planned. Models are commonly defined in order to study and explain observed phenomena or to foresee future phenomena" [1]. A simulation is the discernible manifestation of a model, represented by a computer program that provides insights about the system or application under investigation. A simulation model refers to the computing algorithms, mathematical expressions and equations that encapsulate the behaviour and performance of a system in the real world scenarios.

An agent is simply regarded as an entity, notion or software abstraction similar to the well known programming specifications such as objects, methods, procedures and functions. An element or object abstraction wraps the methods and attributes of a software module. However, an agent presents a distinctly higher scale software abstraction that defines a complex software unit in an efficient and convenient way. Instead of being expressed in terms of attributes and logic-based methods, a software agent is primarily typified in terms of its intended actions. This is principally a matter of stating agents' responses instead of identifying classes, methods and properties. A suggestion to have a computer programmed agent that can undertake complicated charge on peoples' behalf, is naturally appealing [2]. There are a minimum set of fundamental traits that represent a software agent. "A software agent is autonomous; capable of operating as a standalone process and performing actions without user intervention" [3]. A software agent is responsive and able to converse; it inter-communicates with the user as well as to other software agents or processes. Additionally, an autonomous agent is inherently intuitive; it possesses the ability to perceive and respond to the changes within the surrounding domain [4]. A core characteristic of an agent is its potential to make independent deliberations during the problem-solving, conflict resolution and decision-making processes. An agent-based paradigm can be regarded as an intrinsic extension to object-orientation, whereby an agent represents an object having control on its execution [5]. However, agents are intrinsically more autonomous and proactive than objects. Agent-based methodologies permit the prototype designers to implement the system units with a number of specialized agents having sophisticated intellectual capabilities such as reasoning, learning and planning, thereby incorporating the resource knowledge of the underlying problem domain. Quoting [6], the "Agent metaphor fits perfectly well to the demands of complex and inherently distributed applications, where each agent is a coarse-grained computational system in its own right, as well as independently modifiable".

Agent Based Modelling and Simulation (ABMS) refers to a category of computational models invoking the dynamic actions, reactions and intercommunication protocols among the agents in a shared environment, in order to evaluate their design and performance and derive insights on their emerging behaviour and properties. From a simulation standpoint, an individual component's function can range from very basic 'if-then' reactive rules to a more sophisticated cognitively rich behavioural models. An influential paradigm is that of the BDI (Belief–Desire–Intention) framework for artificial intelligence based multiplexed models [7,8]. BDI terminology recognizes "an agent can be identified as having: a set of beliefs about its environment and about itself; a set of desires which are computational states which it wants to maintain, and a set of intentions which are computational states which the agent is trying to achieve" [9,10]. Valuable reviews of Agent-based programming tools and languages has been provided in the literature [11] and increasingly their application is becoming ever diverse challenging the capabilities of power constrained devices [12–14]. The philosophy of ABMS is to model complex systems adopting a bottom-up approach starting from the individual agents [15]. A concrete approach of ABMS is to model and simulate realistic scenarios with a group of self-governing agents either as simplistic entities inside the computing code-snippets or as considerably intelligent objects. This might possibly be considered synonymous to a human being's problem solving capabilities with infinite states, beliefs, trusts, decisions, actions and responses. Acquiring adequate know-how of the system in order to construct an appropriate conceptual and logical model is one of the most challenging task in the simulation tests.

Over the years, numerous agent-based modelling and simulation tools have been developed each with a somewhat unique motive for its presence. Every strategy marks a specific programming syntax and semantics for the agents and has a differing base concerning the generality, usability, modifiability, scalability and performance. The primary objective of this paper is to provide a comprehensive review of a wide range of agent-based modelling and simulation software packages. Due to differing factors, many of these tools are research artefacts that never transitioned from the academic sphere to the commercial world or have stopped receiving support. However their rich functionality and rich features form an important legacy for the future and therefore they are included in the survey presented within this paper. Web sites of the systems that are discussed in the paper have been archived in the Wayback Machine, a digital log of Internet's information that registers and maintains complete snapshots of all Web-links located under a single domain name [16].

The remainder of the paper is structured as follows. Section 2 reports some related past surveys. Section 3 outlines the implementation and application scope of different relevant platforms for ABMS with regard to modelling capacity or scalability. A comparison together with evaluation criteria, and salient features, merits, limitations of various state-of-art ABMS tools compiled in this review, are discussed in Section 4. Finally, in Section 5, the implications of this research and concluding remarks are presented.

2. Relevant surveys

The importance of the subject has attracted a number of surveys of ABMS tools in recent years focusing on the different aspects of Agent-based Systems (ABS) modelling and simulation. A number of review papers have addressed the specific domains of ABMS application. A survey reported in [17] has attempted to shed light on the landscape of agent designing, modelling and simulation toolkits available in the market focusing on their use in the post-secondary education. Data collection was based on the install and trial use of twenty agent toolkits. The paper concluded that no single consistent package fulfils the needs of entire agent-related curriculum. [7,18] surveyed agent-based simulation packages for the energy consumption markets. Based on this analysis, the papers investigated an agent-mediated simulation framework to facilitate the development of models for electricity markets. [19] portrayed previous online reviews on a number of ABMS packages and outlined challenges that should be met in order to realise ABMS a mainstream technology in the computational science domain. [20] evaluated how ABMS packages can offer any value-addition in the modelling/simulation of the highly complex peer-to-peer network systems. [21] discussed ABMS as a proven powerful tool for studying and analysing the dynamics of consumer market-place. [22] provided a survey pertaining to a selection of ABMS systems (Swarm, MASON, Repast, StarLogo, NetLogo, OBEUS, AgentSheets and AnyLogic) with particular reference to the development of geospatial simulations.[1] described the typical elements of an agent-based simulation model and included results of their investigation on a couple of accessible ABMS toolkits. In [23], the authors have categorized various characteristics of the agent development and simulation toolkits into user-friendly

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