The Dawn of Agent Based Models

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Abstract: Ever since the inception of Computers, the field has developed and has made huge strides. Since the past decade, Artificial Intelligence has taken the world by storm. AI is being commonly used around us from simple algorithms in Social Networking Sites to Self-Learning Bots. And today, when the use of computational devices is almost pervasive. It would come as a surprise if these devices don’t make a contribution towards better understanding and implementation related to real world problems. Modeling and Simulation help us deal with, study and even solve real world problems. Agent-Based Modeling and Simulation helps us deal with modeling systems which compromise of stochastic and interactive agents. Such systems are more complex as they change with time. In this paper, we will have a deeper look into various aspects of Agent-Based Models.

1. Introduction

Agent-Based Modeling came into picture to deal with expansion of processes with complex behavior even from simple activities. Agent-based modelling could be a procedural technique that permits researchers to form, analyze, associate degreeed experiments comprising of autonomous and heterogeneous agents that act inside a setting, so as to spot the mechanisms that achieve some larger interest [1]. It helps us look into properties of upcoming orders which may be born due to interactions with the environment within multiple components that may or may not depend on each other. This will in turn allow us to study these aspects in isolation and their effect on the model as a whole. It is planned that these systems typically organize themselves and make emerging order. ABMs additionally embrace models that reflect behavior and are accustomed to foresee the effects of agent behaviors and interactions [2]. When we model agents individually, as in this case, the diversity that exists among the agents and its effects can be observed. This diversity is one of the major driving forces behind the behavior of the system. When we begin from ‘ground up’, self-organization is clearly visible in the model and new patterns, structures and behaviors can be predicted or emerge that weren’t actually hard coded while developing the model. In ABM, a system is formed as a set of self-sufficient choice-making entities. Every agent separately assesses its situation and makes alternatives on the premise of a collection of rules. They might execute varied behaviors relevant for the machine they represent—as an instance, producing, ingesting, or promoting [3]. Complex behavior patterns might be showcased by even a very basic agent and may impart important knowledge about the real world model it is built to emulate. Agents may be capable of evolving with time as they observe the behavior of the surrounding environment and may predict unanticipated behavior. More Complex Models may involve Neural Networks, evolutionary algorithms which help them in realistic real time learning and adoption.

1.1 Basic Concepts Involved

A model can be termed as a representation of various aspect of the world around us. A simulation can be defined as the application of that model. They are utilized to make predictions as well as are capable enough to examine decisions that concern the real life situations. Modeling and Simulation is now being used for decades to simulate or predict real life events.

Simple Excel Sheets used by businesses to flight simulators, business planners etc. are all examples of Models and Simulators created for dealing with complex real life solutions and finding solutions.

Artificial Programs are often outlined as, programs that perform tasks that, if performed by an individual, would be thought of intelligent. They will be applied to a large set of tasks that convolutional programs are ill-suited: controlling robots, understanding natural language, process knowledge-based pictures so on [4]. They aren’t explicitly described using algorithms. The next steps are mostly determined using the previous steps and the interactions with the outside world. How can
1. **Artificial Intelligence be used in Simulation?**

AI can help deal with changing environment or where the behavior of the agent will change based on the interaction of the environment. Knowledge-Based Expert Systems are pc programs that interact with the environment and incorporate values like judgment, experience, rules of thumb, intuition, and alternative experience to supply knowledgeable recommendation to a few style of work [5]. They can help in three major ways: 1. Expert assistance to novice user. 2. Improved modeling representation of real world systems and 3. Reduction in Computational Burden of the simulation. It can also help in search reduction, problem reduction, providing adaptive search techniques and better usage of already existing domain knowledge.

1.2 **History of ABMS**

Agent Based Modeling can into picture around forty years ago. It is based on ideas about emergence of complex behavior from simple activities. With this technique we can study properties of emergent orders that arise from local interactions among a multitude of independent components. And we can understand the ways in which such emergent orders can influence or constrain the individual actions of those components. This process is known as ‘self-organization’ and is characterized by the concept of ‘bottom-up’ and ‘downward causation’ [1]. When compared to approaches using structural equations or system-based approaches using differential equations, ABM allows modelers to simulate the emergence of macroscopic regularities over time such as ant colonies, flock of birds, traffic jams, urban colonization etc. [6]. Agent Based Models comprise of mainly two main components called agents and environment.

1.3 **What is Agent?**

No universally accepted definition of agents exists at the moment. Some modelers define an agent to be any type of independent component [7] whose actions can vary from primitive reactive decision rules to maybe very complex and adaptive intelligence [8]. Some say that an agent must be adaptive and can learn from its surroundings and make changes in its behavior. One definition is that agents ought to contain each base-level rules for behavior furthermore as a higher-level set of “rules to change the rules” wherever where level rules offer responses to the surroundings whereas the “rules to change the rules” offer adaptation [9]. An agent should be capable enough that it can take its own decisions thus requiring it to be active rather than passive. Any agent should possess certain characteristics:

1. An agent must be identifiable and a discrete individual with rules that help govern its behavior and decision making powers. They must be self-contained so that it is easy to distinguish if something forms a part of the agent or not.

2. It is situated in a living environment which consists of other agents and all of them interact with each other. An agent can identify and categorize the functioning traits of different agents [8].

3. An agent must be concentrative of its final agenda and its main focus should be on achieving the goal that is assigned to it.

4. An agent must possess the know-how that allows it to learn and adapt its behaviors over time based on experience. Thus they might require some memory in that case.

5. It should be autonomous and self-directed and must have the capability to work independently in its environment.

1.4 **What is Environment?**

The environment is the surrounding virtual depiction of the actual world present around the agent. It is the surroundings in which the agent acts. It may have little to no effect on the agent, like in some cases of game theory. Or the environment may be as well planned and designed as the agent itself and in some cases may represent replicas of complex and vivid geographical spaces that might affect the agents’ behavior at a macroscopic level. An environment can be static or dynamic based on the fact that it changes with time or remains constant.

1.5 **The Need for Agent Based Modelling**

We exist in a world which is very difficult to understand, where every new discovery may add to the already existing complexity. Natural phenomenon like bird flocking, storms to fields like social interaction in humans, business planning, economic trading, urban planning, all these are very complex real world problems as changes take place with changes in the environment and as the agents interact with their environment. Thus, the systems we need to study or analyze are more complex and aren’t applicable in the same way as they were in the past. Hence, traditional modeling tools aren’t helpful anymore. Also, some systems have always been too complex for a model to be generated and simulations to be performed, for example, economic markets. ABM and Simulation give us a more realistic view to tackle such complex systems and even reach...
favorable outcomes. With the refinement of data into finer granularities taking place every minute, it is even more important to build systems that adapt themselves as the data provided to them changes. Agent-Based models have a very higher computational powers as compared to traditional models and can do computations in lesser time and by utilizing comparatively lesser resources.

2 When to use Agent Based Models
1. When we need to represent a natural world that will involve self-evolving agents.
2. When decisions and behaviors are possible to be defined in a discrete manner, with properly defined and fixed boundaries.
3. When agents are required to adapt and change based on their environment.
4. When it is agents need to learn as well as engage in the strategic behavior of the outside world which may or may not be strategic.
5. When agents need to have relations with other agents, ABM comes into play.
6. ABM allows to form organization of agents. At an organization level, Importance of learning and adaptation is unparalleled.
7. ABM allows the agents to possess special components to their respective actions as well as behavior that might arise through such actions.
8. When the past events may not certainly describe or have an effect on the future events.
9. ABM can be highly useful when arbitrary levels need to be scaled up.
10. ABMs have the capability to deal with structural changes in the model rather than changes in the model.

3. Principles of Agent Based Modelling
1. First of all, the evidence that needs to be explained by the study should be described precisely and in a clear way. A simplified and idealized set of properties should be mentioned for the system put under consideration.
2. The purpose of the simulation must be properly explained. What is the model supposed to do? To predict future values? To get accurate results than we have at the present date? To develop newer applications like traffic control?
3. Deciding on how to choose the agents in a particular model is equally important. Sometimes not all the agents involved need to be put under observation.
4. Formulating hypothesis or basic mechanisms resulting in the actual system behavior that has to be explained [10].
5. One mustn’t place into the model assumptions what one desires to clarify. The mechanisms on that the multi-agent simulations are primarily based ought to be (at least) one level additional elementary than the proof to be understood as an instance, the rich-gets-richer impact could also be used as an ingredient, if category formation shall be represented [11].

3.1 Potential of Agent-Based Models in Today’s World
Agent-Based Modeling and the use of Artificial Intelligence in designing models and running simulations has proved its worth with time. Agent-Based Models may be applied to:
1. Social influence and opinion formation [13, 14]
2. Coalition formation [15, 16]
3. Collective intelligence [17]
4. Social networks [18–20]
5. Group dynamics [21]
6. Social cooperation [22, 23]
7. Social norms [24, 25]
8. Social conflict [26, 27]
10. Competition and cooperation between firms [31, 32]
11. Micro-economic models [63, 34]
12. Macro-economic models [35, 36]
13. Organization and managerial decisions [37]
14. Migration [38]
15. Agglomeration and segregation [39, 40]
16. Urban and regional development [41–43]
17. Traffic dynamics [44, 45]
18. Crowd dynamics [46, 47]
19. Systemic risks in socio-economic systems [48, 49]

And more [50–54]

3.2 Agent-Based Models coupled with Super Computers

ABMs and Multi-Agent based simulations do well when made to work parallel with other systems. If used with super-computer, or systems with advanced super-computing power, it is very much possible to perform Agent-Based Simulations on real world scenarios with millions of agents and a larger set of data yielding a better and more efficient result. Some examples of such state-of-the-art models are:

A first prospering application space was large-scale traffic simulation. The TRANSIMS project of the Los Amacos National Institute (LANL), maybe, has created agent-based simulations of whole cities resembling Dallas or Portland. The approach has been recently extended to the simulation of the travel behavior of the 7.5 million inhabitants of Switzerland. These simulations area unit clearly supported parallel computing. They generate realistic individual activity patterns in step with elaborate applied math panel knowledge (“travel diaries”), that area unit these days complemented by GPS knowledge and public quality check out (e.g. from Greater London Area’s OYSTER Card). Different extensions Los Alamos interconnections between the traffic system and regional development. [52,53]

Recent applications square measure finding out contingency plans for large-scale evacuations of cities [44, 45]. The key side here is knowing the reciprocity of infrastructure systems [46, 47] and their vulnerabilities through natural dis-asters, terrorist attacks, accidents, and different incidents. As an example, the Los Alamos National Laboratories have already established a vital Infrastructure Protection call web [38]. Its advanced simulation capabilities have already been extensively used throughout past emergencies [56].

### 4. Other applications for ABMs

#### Table 1: ABM Applications

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<thead>
<tr>
<th>Business and Organization</th>
<th>Society and Culture</th>
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#### 4.1 An Electric Power Market ABMS Application

EMCAS (Electricity Market complex adaptive System) is an ABMS of electric power market created for work restructuring and deregulations of markets and to influence implications of competitive markets on the prevailing electricity costs, handiness and liableness of the businesses. The EMCAS model is rep-resented elsewhere from varied views together with the advantages of agent-based modeling for deregulated electrical power markets. Differing kinds of agents capture the heterogeneousness of restructured markets, together with generation corporations demand corporations, transmission corporations, distribution corporations, freelance system operators, consumers, and regulators. The agents perform various tasks exploitation specialized call rules. Agents study the market response to their price-quantity bids, infer the methods of their competitors, and adapt their actions consequently.

#### 4.2 Agent-Based Modeling and Simulation in Supply Chains

The supply chain consists of 4 stages: factories, distributors, wholesalers, and retailers who reply to customers’ demand. Varied simplifying assumptions are created such as: there’s only 1 artefact, no transformation of product is created and no assembly
of materials into products is needed. The flows of products and data within the kind of orders between stages (agents) similarly as physical shipments are enclosed within the model, however the flows of payments and also the extra complexities of pricing, negotiation, and money accounting that this could entail don’t seem to be enclosed. However, these aspects of supply chain agent behavior may simply be incorporated within the agent-based version of the supply chain model [8].

4.3 Agent-Based Modeling and Simulation in Supply Chains

The two best economic models widely used out there in the world are highly flawed and are almost obsolete. The first is an empirical statistical model. They fail when it comes to incorporating great changes and can only predict data of only up to a few upcoming quarters. The other one is called ‘dynamic stochastic general equilibrium’. They adopt the world to be perfect and rule out any crisis that might occur in the future or we can say, is occurring right now. Thus, policy makers have resorted to common sense and even anecdotal analogies for decision making. The better possibility to deal with such issues is Agent-Based Models. Such models don’t consider the belief that the economy can move towards a planned equilibrium state, as different models do. Instead, at any given time, every agent acts consistent with its current scenario, the state of the globe around it, and also the rules governing its behavior. Agent-based simulations will handle a way wider vary of nonlinear behavior than standard equilibrium models. Policy-makers will so simulate a man-made economy be-low completely different policy eventualities and quantitatively explore their consequences [12]. They display a ‘realistic behavior’ and provide a way to model financial economy into a complex system while keeping in mind or taking into consideration, human adaptation and learning. The displays yielded till now by Agent-Based Models that have been tested on small parts of the economy have been highly successful. They provide a holistic approach and since various key terms lead to economic crisis, these models can be used to model effects of tax reforms etc.

4.4 ABMs for Urban Cities

Thomas Schelling observed racial segregation in American Cities in 1971 and proposed a model for the same. It has helped understand the persistence of segregation not only in the United States but also in other urban centers [6]. Agent-Based Models are being used for replacing the square grids originally used by urban geographic to make the model meet the current demands such as affordability, houses feasible to move into, space allocation etc. ABMs have also been highly successful in distribution of resources such as water and electricity. They are being used to create plans for evacuation in cities in case of any disaster. Flow Management is one of the biggest application of ABMs. Traffic is an obvious application for flow management. They can estimate road blocks, jams, emission rates etc.

5. Challenges, Perspectives and Limitations of Agent Based Models

5.1. Empirical Validation of Agent-Based Models

There are six core issues when using empirical modelling with Agent-Based Models. The AB economists use various ways for validation through empirical methods. There are a group of core problems that require to be addressed by the AB social science community if it’s to proceed with success.

5.2. How is the modelling carried out?

For building an ABM, we have already talked about the principles that need to be kept in mind like the agents that need to be taken into consideration, Interaction rules among the agents and the agents and their environment. All these principles must be taken into account while building the model.

5.2. Acceptance of the model or simulation results

Agent-Based Models aren’t mainstream yet and with a huge number of people still having their doubts about Artificial Intelligence and whether to use them at the pace that we currently are, there is a standing issue about the acceptance and the understanding of such models. This might be motivational as many people might reject such models and it might be cognitive as most people don’t have enough knowledge related to ABMs. So even if the model put to use is extremely efficient and can produce the needed results, only a small portion of the society will receive it in the right way.

5.3. Who builds the Model?

Most of the empirical or conventional models had a mathematical formulation or hypothesis involved and thus majority of the modelers have a background in economics. However, in ABM, we
make use of algorithms and not formulas and symbols are used. Thus, it creates a mismatch.

5.4. Testing

The theory involved in the making of an Agent-Based Model can’t be at all time approved or made falsifiable with data. For example, in a field like finance and economic markets, finding any data that satisfies the group of agents will be very difficult. Furthermore, the agents change their behavior with the change in environment over time. They are then used to predict future or hypothetical events such as Evacuation plans in a disaster. Thus, there is no proper way of testing the outputs being generated by the Models and their Simulations.

6. Future Prospects and Paradigm Shifts

Multi-Agent Models, User-Friendly Simulation, Better Computational Power, Improvised Visualization, all this makes Agent-Based Models so productive. However ever, we expect a number a paradigm shifts in the future:

1. We are moving from a data-poor state to a data-rich state. More data will enable us to falsify models, calibrate parameters and make a shift to the data-driven approach. The level of details involved, accuracy of the outputs and the scale of the models will all increase by great orders. Thus the computational time for multi-agent simulations will come down by huge numbers.

2. We can move beyond descriptive model and rather switch to explanatory models. The inner relations can benefit from this.

3. Mining of real-time data is easier. Thus the estimates delay times in models can be reduced as we can accommodate more information from a large set of resources at a lower rate. Forecast timings can be increased to a larger periods. Reality Mining can help facilitate multi-agent models in much more better manner. Warnings can be detected earlier, leaving enough time to prepare and take necessary actions.

4. With the current boom in Artificial Intelligence, more and more people are getting interested in the field. This will create a major boost for ABMs as more people will be able to model, use and understand such models which aren’t very receptive at the current stage.

5. Multi-Agent Models within the close to future might be doable used and matched with science laboratory and net technologies. This can modify folks to require choices of agents in varied pc simulations. Serious multi-player online-games provides a probability to involve a bigger audience into the analysis of complicated knowledge and therefore the exploration of realistic decision-making eventualities in virtual worlds, that realistically map doable future worlds. During this means, agent-based simulation approaches could also be applied for crowd sourcing and e-Governance applications, to create use of the “wisdom of crowds” [55].

6. Confluence of the virtual and even the real world can yield results that might be highly useful. Augmented Reality tools can be used for translation or communication for people speaking different languages. People can share information using such systems. An already existing system such as Google Earth can be filled with virtual or real population to create bases for new models and theories.

7. Conclusion

Agent-Based Models have helped us learn about more complex real world problems. Agent Based Modeling and Simulations helps us get insight into simulations of events that weren’t possible to simulate earlier. Agent-Based Modeling has helped us in field like Economics, Manufacturing, Defense and even Urban Planning. With their progress being so productive in such a short span and with the future paradigms offering a helping hand to Multi-Agent Models, The productivity of Agent-Based Models is only set to increase with time.

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