Artificial Economy and the usage of ACE

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Abstract
Nowadays, researchers all around the world are working to solve some of the complex problems that involve economy and artificial economy is becoming more and more popular among them. Artificial Economy is a new research field focused on the usage of Artificial Intelligence Algorithms to solve several complex economic problems. For many years, computer science researchers have been providing new tools to study, model and solve different problems. One of the tools commonly used in the field is agent-based modeling, which consists of modeling the problem and creating solutions under the assumptions of the problem. Agent-based modeling has been used in artificial intelligence (AI) for so many years and now under artificial economics is known as agent-based computational economics (ACE). This work discusses the usage of various ACE techniques to model, study and solve different, complex economical systems.

Keywords: *Artificial Economy, Artificial Intelligence, Agent-based Modeling, Computational Economics*

1. Introduction

From the beginning of economic studies, economists have tried to explain the economy by working with systems that they could easily define using equations in order to solve problems analytically. Economists have been ignoring the problems or systems that could not be solved by them, due to their complexity. Some of the economists have tried to use approximation models but most of the time this has led to misrepresentation of the economic system.
During the twentieth century, many of the researchers tried to find new ways mostly based on the mathematical analysis to explain these economic systems. Econometrics was a one of those fields who became very popular between the economic researchers [1]. The introduction of computers pushed the economists to use econometric analysis software, in order to study and explain the dynamics of economy and to try to solve its problems.
On the recent years, it became more evident that using just these economical tools were not enough. One major problem was the aggregation over individual economic agents, where these agents are in reality very heterogeneous and their composition is dynamically changing [2]. It is for this reason that nowadays, the Artificial Economy (AE) is emerging as a necessity to solve some of the complex problems that involve economy.
AE is a new research field focused on the usage of Artificial Intelligence (AI) algorithms to explain the complexity and dynamics of economic systems. Agent-based modeling is a tool that has been used in AI for so many years in order to model different aspects of intelligence. Therefore, under the AE field, the Agent-based Computational Economics (ACE) has been incorporated with the whole knowledge of the AI field to work and explain the economic problems.
In this paper, there will initially be an introduction of the Artificial Economy. Further, it will be continued with an explanation for the Agent-based Computational Economics. In the following part, there will be a detailed explanation for the ACE agent types. The other part consists in the explanation of the usages of ACE and to conclude some conclusions will be given at the end of this paper.

2. Artificial Economy

The concept of artificial economy is not new in the field of economics, where initially it was used to reproduce empirically plausible time series, which could numerically represent the theoretical model, as shown in Backus et al [3]. Even though time series could be used to analyse the economy from the transactional character of its interactions, there was a need to

represent the economy a wider and new perspective. The economy needs to be studied also from the dynamic and learning aspects of economical agents. A new approach of Artificial Economics was presented by Batten [4], where the principles of self-organization and co-evolution are taken into consideration. In this new approach, the challenge is to create a synthetic methodology where the behaviour of economical agents is examined. As shown also in an earlier paper [5], the synthetic approach would lead us to look beyond *economic life as we know it* and to look in the new concept of *economic life as it could be*. The synthetic approach became more evident after its usage on the predecessor field of Artificial Life, where the new concepts of AI like embodiement and environment were used as part of the intelligent behavior of agents [6].
The main focus in the beginning of AE was to create econometric models of the economy in order to understand it, later the main focus shifted into the understanding of the economic dynamics by simulating it. AE would deal more with multiple agents which would simulate the different economic behavious of the economic agents. In order to do so it would use the methodology of behaviour generators [7] of Artificial Life. This methodology gives us a notion of the self-organizing, growth, development, evolution, adaptation and many other features, that can be self generated by using the AI Algorithms.
One of the interesting features brought from Artificial life is the adaptation. Due to economic complexity, researchers will need to simulate adaptive agents that can learn and interact with the environment. In order to study these complex adaptive systems by simulating adaptive agents, it is needed to use an agent-based model which in AE is known as Agent-based Computational Economics.

3. Agent-based Computational Economics

The ACE stands in the very basis of the Artificial Economics. Its main role is to study the dynamics of economical systems with autonomous agents who interact with each other. The complexity that ACE research uses, cannot be explained by using any of the methods that we normally use to prove theorems or to introduce a new theory. In order to study this, ACE should simulate these systems who fall under the discipline of complex adaptive systems (CAS).
For this reason and in order to understand more clearly the need of ACE, it is needed to explain what these systems are. CAS are systems with very large number of units that interact and adapt [8], and economical problems are the most common problems of it.
In the paper of Batten [4], it is expressed that CAS systems have three attributes:

1. Large finite number of units
2. Adaptive and intelligent
3. Limited information

Taking into consideration these attributes, it can be seen that the economical systems have a large number of economical units who usually try to make decisions. At the same time, not all of these units have the complete information of what decisions all the other economical units are doing or make. The economical units try to be intelligent and adaptable to the changes of the market. This makes the economical systems very attractive to the researchers to simulate and model it and then to study the possible outcomes. From another view, the CAS systems should include 3 important features: *reactive*, *goal-directed* and *planner* units [9]. So the units should be reactive to the environmental changes by changing their behaviour to it, to be goal-directed so it can direct himself into the prefered goals that may evolve during the time and to be planner in order to facilitate the achivement of these goals by showing some control over the environment. The explanation of the CAS helps us to design better ACE models and with a higher focus on the design of the agents and their interactions.

4. Types of Agents in ACE

Agent-based simulation allows us to study these complex systems and to see the economy from a new perspective. The agents in an agent-based model are the economical units such as the individuals, groups, public or private institutions and other economic entities. For this reason these agents have different attributes and behaviour from each other. In order to represent these agents in the softwares, we need to code them with their attributes and use the AI algorithms to make them seem like the real economic units. There exist a huge set of algorithms in AI, most of which use different approaches from computer science, mathematics, neuroscience, psychology, social and natural sciences. These algorithms are the basis of building the agents in the ACE and this is why it is needed to properly define in a good manner these agents.

The main three agent paradigm as explained by Chen [10] are as follow:

- Simple Programmed Agents
- Autonomous Agents
- Human-like Agents

Simple Programmed Agents

In the simple programmed agents paradigm, the agents are programmed to follow simple rules. The focus in these simple programmed agents is not on the agent itself, but on the system behaviour by implementing a large number of these agents. The methods used for the agents in this paradigm may include the randomness of their behaviour. For example, a seller agent may simply pick a price in a random way from a certain range of prices from which he could earn more in his business. In such cases, a set of rules may be established by using simple economic formulas to calculate the benefits of agents. The main purpose here to study the interactions between the agents and their overall behaviour under certain policies that may be introduced in the system.

Under this agent paradigm there have been introduced several types of agents such as:

- Zero-intelligence agents
- Near Zero-intelligence agents
- Entropy-maximization agents
- Regime-switching agents

In the zero-intelligence agent, the agents don't have any knowledge of the environment and cannot learn from it. The agents are usually taking decisions only by their set of rules and constraints. Their usage is restricted to standard economic modeling where the real agents have no information about the economic environment, this usually is preferred when new rules are established and there is a need to simulate the economic behaviour of agents in the real economy. In the cases when these agents cannot be used for such kind of simulations, it is suggested to use the near zero-intelligence agents. The differences between the zero-intelligence agents and these agents is over the changes in parameters by using the previous state parameters, so a type of intelligence with short memory.

Another type of agents in the simple agents paradigm is the entropy maximization agent where the maximum entropy principle from information theory is used when designing the agents [11]. The last type of agents in this paradigm is the regime switching agents, where the agents choose between a set of behavioural regimes. The process of deciding about which regime to use, is done by using a stochastic method [10]. The above mentioned agents are sometimes called also as random behaving agents, as they are designed to behave in a random way over the changes of the environment or even to their agent to agent interactions.

Beside these types of agents, there exist also other versions of agents who fall under the simple programmed agents paradigm, but they are just modifications of these types of agents.

Autonomous Agents

The autonomous agents paradigm defines the agent to have a certain freedom by exploring the environment. Such agents would be very beneficial especially for modeling and studying the competitive environments such as the economy. Autonomous agents are different from simple programmed agents as the are able to create their own behavioural rules. The main concept here is that the agent should try to build the set of rules that it would follow later on. There are a lots of methods from AI that can be used to design such agents and the most distingueshed are the genetic algorithms. Genetic Algorithms are being used to represent learning in different economic models such as cobweb model, game theory and schedule optimization. A good description of the usage of genetic algorithms in economy has been given by Riechmann [12]. By using genetic algorithms, it may be possible to study the evolutionary and co-evolutionary processes of different economic units. For example it may be possible for the artificial economies to grow and evolve together with the agents in it without any outside intervention. The evolution of agent strategies by simulation may help on the discovering and exploiting of new economic opportunities [13].

Human-like Agents

The idea behind the human-like agents paradigm is to mimic the real human behaviour or even real economic behaviour by defining some of the attributes they have. There exist two main approaches to this paradigm:

- Calibrated Artificial agents
- Artificial agents with personal traits

In the calibrated artificial agents, the agents are calibrated by using real data that have been observed before from the real agents. In this approach the calibration is usually done by learning. There has been a lot of studies made AI about the learning algorithms, and most of these algorithms may be used on the artificial agents. From all these algorithms the most notable used one is the reinforcement learning, who is used to build or estimate the parametric artificial agents. In addition to the reinforcement learning which came directly from AI, under the ACE have been developed also the belief learning and experienced-weighted attraction (EWA) learning algorithms. The calibration by using these algorithms may be done in several ways, further more artificial agents may be calibrated by using different methods depending on their attributes.

Artificial agents with personal traits takes into consideration that the agents may rationalize by different behavioral variables such as emotion, intelligence, attitude and cognitive capacity. These agents take into consideration the studies made in different fields, such as psychology, cross-cultural studies and other, in order to design the agents [10].

5. Usage of ACE

ACE has two main divisions of its usage, descriptive and normative [9]. In the descriptive usage the focus is on explaining the how and why the economy or certain economic units work. From the normative usage, the main issue is the discovering of new patterns or even new economic designs that might increase the efficiency of it. This main divisions are also reflected in the explanation given above for the different types of agents in ACE. By knowing these types, any researcher may create his own technique of combining the different agents to model and study the economical problems. ACE is a very broad field of research and the main usages of it are depended on the combination of techniques used in the artificial agents.

Refering to the literature, there are eight research areas of ACE already classified [14] as:

1. Learning and the embodied mind
2. Evolution of behavioral norms
3. Bottom-up modeling of market processes

4. Formation of economic networks
5. Modeling of organizations
6. Design of computational agents for automated markets
7. Parallel experiments with real and computational agents
8. Building ACE computational laboratories

Each one of these research areas shows us the many ways of using the ACE models. The very first one explains to us the need of using learning algorithms in order to build human-like agents, as explained in the previous part.
The evolution of behavioral norms as the name itself suggests may be used to study the various collective behaviours that may show up from the interacting agents. In the bottom-up modeling of market processes, the idea is to model the market processes in a simulation where the agents may be able to provide explanations for it. The types of economic systems that may be taken into consi deration is enormous including here the financial, electricity, labor and lots of other economic systems. The relationships between the different economical units is studied under the formation of economic networks.
The last three research areas have a focus on the study of the different types of agents, and the necessity to study the economic problems by designing appropriate agents.
There already exist some authoring tools to use to build these agents, such as the NetLogo or the StarLogo who are the most used tools but who lack of proper control of agents properties. The best way to construct agent-based model economies are the usage of object-oriented programming languages whom do need very high programming skills.

6. Conclusions

For a long time, the economists and other researchers have tried to study and solve the difficult complex problems of the economic systems. Nowadays, with the rise of new computational capabilities and tools to solve such complex problems, a new interest has been shown from researchers to use these tools to model and study the complex economic systems. A set of conferences with the focus on solving and modeling such systems have been held during the last decade. In these conferences has been presented the concept of Artificial Economy as a new research area of study these systems.
This paper provides a literature review over the concept of Artificial Economy and usage of ACE methods. The importance of understanding the complex adaptive systems has been given in order for the researchers to build better ACE models. Several types of agents have been explained under the three main paradigms of agent design, simple, autonomous and human-like agent. The importance of understanding these paradigms is very crucial to the manner that the researcher will use them to study or solve by modeling their problems in ACE. The main usages of ACE have been explained where the eight research areas in ACE may be stressed as very important to understand when to properly use the ACE.
Taking into consideration the importance of dealing with the complex economic systems to prevent future economic crisis, finding new undiscovered paths of economy or even just studying the economy, the Artificial Economy and agent-based models should be taken into consideration from the future researchers.

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