AGENT-BASED MODELING AND SIMULATION OF AN ARTIFICIAL ECONOMY WITH REPAST

Igli Hakrama[1], Neki Frashëri[2]

[1]Epoka University, [2]Polytechnic University of Tirana
e-mails: ihakrama@epoka.edu.al, neki.frasheri@gmail.com
Albania

Abstract: This paper presents the approach used to implement a simulation model of an artificial economy by using agent-based modeling. The work starts by investigating the use of agent-based methods in economy and the different solutions given by other developers. Then it continues by describing the analysis and design of the artificial economy model, and later it shows the implementation steps taken to build this simulation on the Repast Framework.

Key words: agent-based modeling, multi-agent system, agent-based computational economics, simulation

1. INTRODUCTION

For quite a long time, economists have tried to study the economy by using mathematical models that they could easily define. Most of these models are based on some unrealistic assumptions of the economy supposing perfect conditions to be fulfilled. Many of the economic policy makers have made decisions based on these models, but most of them have failed in their assumptions. It is due to this reason that many researchers have tried to use unorthodox methods to study the economy, and many of those methods nowadays are based on the use of computer science. Agent-based modeling (ABM) is one of the methodologies that some economic researchers have been employing in their studies [1].

ABM has been used in understanding many complex problems in a variety of fields, and it is based on the notion of 'agent' [2]. This notion has its origin from the 'agent' word found from the early days of economic thought, and the same notion has been incorporated later in the field of artificial intelligence (AI), from which it won greater interest as a topic of study. It was this interest that pushed the researchers to coin the term multi-agent system (MAS), and many of them started to use it in different domains. ABM is basically a MAS, but with the difference that it is more concerned with the modeling of the agent. Nowadays, it is possible to find the same term in literature under different names depending on its usage, such as the agent-based computational methods, agent-based simulation, or even multi-agent simulation [3]. In economics, the term ABM is also found as agent-based computational economics (ACE), where its usage is to study the dynamics of interactive agents in an economic system [4]. The necessity to use these methodologies comes from the need for a better understanding of complex phenomena in various fields. It is for this reason that many researchers try to use ABM to study their respective fields.

This paper introduces a new approach used for the implementation of an artificial economy simulation by using agent-based modeling. The next section looks into the literature review of the agent based methodologies in economy, the research and development found in the literature and some remarks related to the construction of ABMs. In the following section, the conceptual model of the artificial economy is presented by describing the model and its analysis and design, followed by some important details on its implementation.

2. LITERATURE REVIEW

This section provides a literature review of the agent-based computational methods used in economics. The first subsection presents a discussion of the state of the art of ABM, followed by a subsection examining the some of the most relevant works for building artificial economies, and then finishing with a subsection highlighting useful recommendations from literature.

2.1. State of the art

The field of economics is the field that tries to understand human behavior in the allocation and use of resources; however, it has at times failed to predict or even prevent economic crises. This is due to misconceptions of economic theories based on some unrealistic conditions. Because of this, many researchers have been trying to use different computational methods to study economics. One of these methods is lately known as agent-based computational economics (ACE) [5], which is basically an ABM in nature but which tries to study the economic field from a broader perspective. The economy is considered as a complex adaptive system (CAS), due to its nature of having many units that interact and adapt. In principle a CAS is a system that has three main attributes [6]; a large but not infinite number of units, adaptable and intelligent units, and they have limited information. To study such systems, researchers have built simulation environments in which the agents have three basic features [7]: they should be reactive, goal-directed, and planners. In this context a MAS fulfills the criteria to build such systems, and it is for this reason that ABM does the same.

The ACE approach asks the developer to build an agent-based simulation model with economical units such as individuals, groups, institutions and other economic entities. In this context, the agents should have three main paradigms [8]: simple programmed agents, autonomous agents, and human-like agents. However, the difficulty arises in building such agents and in the need to create new techniques to build simulation systems that comply with all the mentioned requirements.

2.2. Relevant works

As a first attempt to build an ACE simulation model, a group of economists and computer scientists from different countries and research centers came together to work under the EURACE project. The project [9] was a three-year work and it aimed to build an economic model and simulator using ABM methodology. The model as described in the paper [10], was comprised of several markets in which the agents would take different attributes depending on the market in which they acted. The simulation tries to simulate the real economy of European Union, which includes several types of agents, such as firms, households, malls, banks, and governments. The framework that was used to build this simulation is the Flexible Large-scale Agent Modeling Environment (FLAME), which uses a specification language

for the agents and uses a C-like language for writing functions for these agents. For its implementation there was a need to use the fastest parallel supercomputers to achieve efficient communication between the agents. The project itself proposed an innovative approach to the macroeconomic modelling and to the economic policy design according to the field of ACE, and demonstrated that agent-based modeling of large-economic systems was possible and useful. A drawback of this project is that it is not very portable and it is very difficult to change parameters for a new model to analyze. It would take time and much effort to reimplement it on a new simulation model.

Another approach was taken into consideration with the creation of the Java Agent-based MacroEconomic Laboratory also known as Jamel, for the simulation and analysis of complex economies. The idea is that the mechanisms of the market are the ones who determine the behavior of the economic system itself [11]. The model tries to investigate the firms and how they change their strategies upon the changes of macroeconomic environment of the modeled system itself. As an ABM, Jamel gives economic researchers the possibility to create and use their models based upon some basic rules expressed in xml schema. The tool is created by using java, and even though it is open source it is hard to grasp and build new models by including new features beside the ones that this laboratory permits users to have. Another issue is that it cannot fully fulfill the three main paradigms mentioned above for the ACE approach to study the economy.

2.3. Remarks

Based upon different researches [12, 13] made in the context of building agent-based models, it is concluded that the use of object oriented programming (OOP) and of unified modeling language (UML) is necessary. ABMs are best represented graphically by using UML, where the developer may precisely plan and design their agents based upon their behaviors and features that they should be having. At the same time the agents are programmed easier by using OOP languages, as it provides a relation of the object and agent itself. In this case the agent may be considered as an object or as an object of objects, and this provides to the developer the possibility to inject heterogeneity to the agents.

In this context and as part of this paper, it is proposed a new approach for building an ABM based upon the use of Repast Simphony toolkit, which permits us to build large-scale agent based simulations [14]. Repast, also known as REcursive Porous Agent Simulation Toolkit, started as a project of the University of Chicago in 2000. It has been inspired by Swarm, a software toolkit developed to create simulation models in the field of Artificial Life. The language used to build the ABM is Relogo [15], a language that incorporates Groovy and Java languages in one. The use of this language with Repast Simphony will help to make use of OOP and other existing libraries.

3. CONCEPTUAL MODEL OF THE ARTIFICIAL ECONOMY

3.1. Model description

This work takes into consideration a classical economy with free trade and no government intervention. The economy has three main entities, namely; Person, Firm and Bank. The basic key concept that drives the simulation world is the person, who needs to consume goods as a basic need to survive every day. It is for this reason that the person as a basic economic entity needs to have money to buy goods from firms, and if he has more, it may give him insurance over his future existence in the simulation world. Based upon this realistic

approach, figure 1 shows a circular flow of interactions within the main entities of this simulation world.

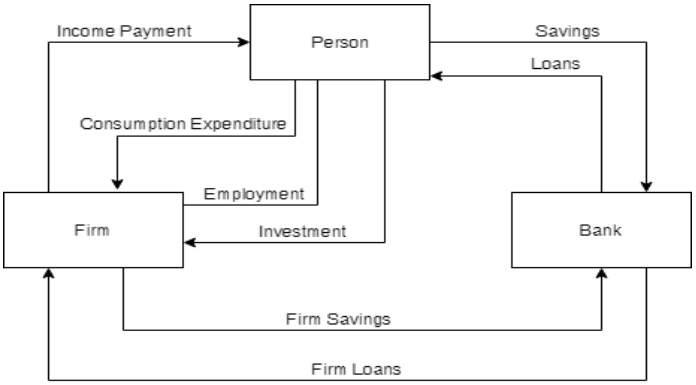

Fig. 1. Circular Flow of the model

The person agent in the model has an income, wealth, a specific experience and a defined employment status. There are three types of goods that the person can enjoy based on their needs and preferences. When the person income increase, he may decide to deposit in bank, buy luxury goods more frequently, or invest by buying stocks in firms. If the income is low and the person is in need for money, he may withdraw from deposits, or take a loan from bank which he will pay back after a certain time.

Based upon the given description, it is needed to properly define the agents with all the attributes and behaviors. In figure 2, it is shown the Use Case for the person agent where he is depicted with the important use cases of works, consumes and invests toward firm agent, meanwhile toward the bank agent he deposits or takes loans.

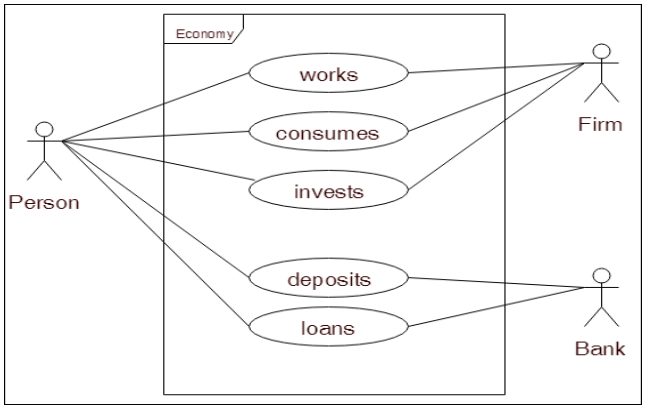

Fig. 2. Person Use Case

There are three types of firms that produce the goods for the persons. The first type of firm produces basic goods, the second type intermediary goods and the third one the luxury goods. The firm that produces basic good is concerned with the production of goods that are needed to survive. The intermediate firms are thought as the ones that produce goods and services which are needed but not on daily basis. The third type of firms are concerned with

the production of luxury goods that are required by middle and upper income persons. The firm agents start their business by having employees, cash, inventory, specific production, commodity price and a firm value. After determining the first factors they set up the share price. To analyze the working labor, the firm agents look at the labor product function based on number of employees and working capacity. In the case that the number of employees is lower than the production demand this leads to deficiency that requires extra labor and brings a demand for a higher number of employees in the firm. If the number of employees is higher than the production demand this leads to labor excess and the firm agent should make the decision to cut off the number of current employees.

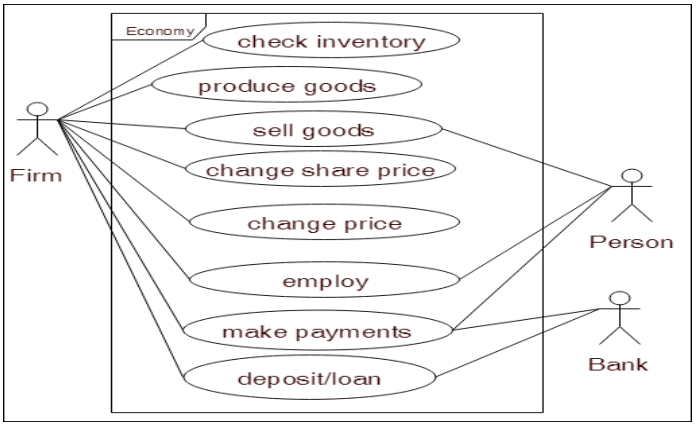

Fig. 3. Firm Use Case

In figure 3, it is shown the main use cases for the firm agent. Firm agent studies the daily demand; the current production levels, calculates the daily payroll and studies the labor market. It looks whether the persons have the adequate experience to have an appropriate working behavior. After hiring the new employees, the firm reviews the inventory and the production capacity. According to a certain period that may be a week or ten-days, the firm again checks the demand for its goods and it determines the commodity labor cost and the price. The company compares its prices with those of the competitors and finds a way to adjust its prices whether it is higher or lower compared to the other. In a monthly base, the firm makes a forecast based on the previous months' demand and it calculates the profit. After the entitled costs it pays the employees' wages. In the case that the supply is higher than the demand for the product, the firm can decide to cut off the number of employees. At the contrary, it can decide to search the market for new potential entrants. Taking the annual bases, the firms determine the overall profit and share the dividends to the shareholders. In the case that the cash plus the firm value is lower than zero, there could be the bankruptcy case or there would be a change in the owner. The firm can accept new investments by new shareholders or it can seek a loan from the bank.

The duty of a bank agent is to daily check the deposits or loans and at the end of each month to make a revaluation of the interests given on deposits and from loans. Bank agents aim to maximize the interest on loans given and to minimize the interest on the deposits taken, so they may make a profit from the operations. It is assumed that person wants to invest his money in the bank or in firm stocks. In case they invest more in the banks by lending the money as deposits, the bank will tend to decrease the interest rate, while in the

case more persons put their money on firms, the bank will try to attract them by increasing the interest rates.

3.2. Model analysis and design

Based on the model description given in the previous section, it is necessary to have an extended view of the methods, interactions, and relations the agents should have with each other. In figure 4, there are two sequence diagrams shown, both of which describe some of the daily methods agents apply toward each other as part of agent communication. The person agent on the right calls its method jobsearching() whenever he or she is not hired and is in need of a job. Meanwhile, on the left side is the firm that calls its method supplyOnLabor() to check the necessity to hire and then check if there are person agents who are searching for job. At this moment as part of the firm sequence logic, the firm calls a new method Employ() to start checking experience of each person searching for job, and then calls the hire method of the best person agents. When the firm has more person agents than needed the method UnEmploy() is called and the firm starts checking the work performance of the person and removes from work by calling the unhire() method of the person agents who had low performance.

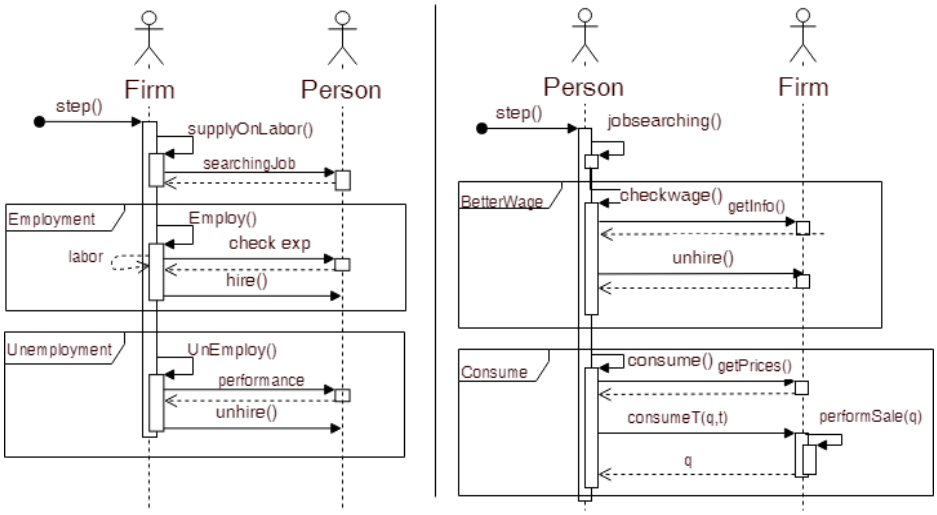

Fig. 4. Person-Firm Sequence Diagram

On the sequence diagram in the right of figure 4, the person agent calls the method checkwage() when he is employed on a firm and he checks for a better job by calling the getInfo() method of other firm agents. After getting the needed information, the agent makes a decision to keep the job or call the unhire() method to get unemployed from the firm agent.

A very important step that each person agent does daily is to consume. This part is shown in the sequence diagram on the right, and it shows the method calls that the person agent does to the firm agent. The first sequence of getPrices() method calls is directed to different firm agents, and after obtaining them the agent decides to consume by calling the respective method with the demanded quantity and type of product, then the firm processes the request and calls the performSale() method to make the transaction possible.

Figure 5 shows the person agent's wealth management by using sequence diagrams. The person agent checks his financial situation on every step call of the simulation, by calling the appropriate methods from his or her related firm and bank agents. Depending on the condition of money at hand the person agent has several options that are represented on the sequence diagram.

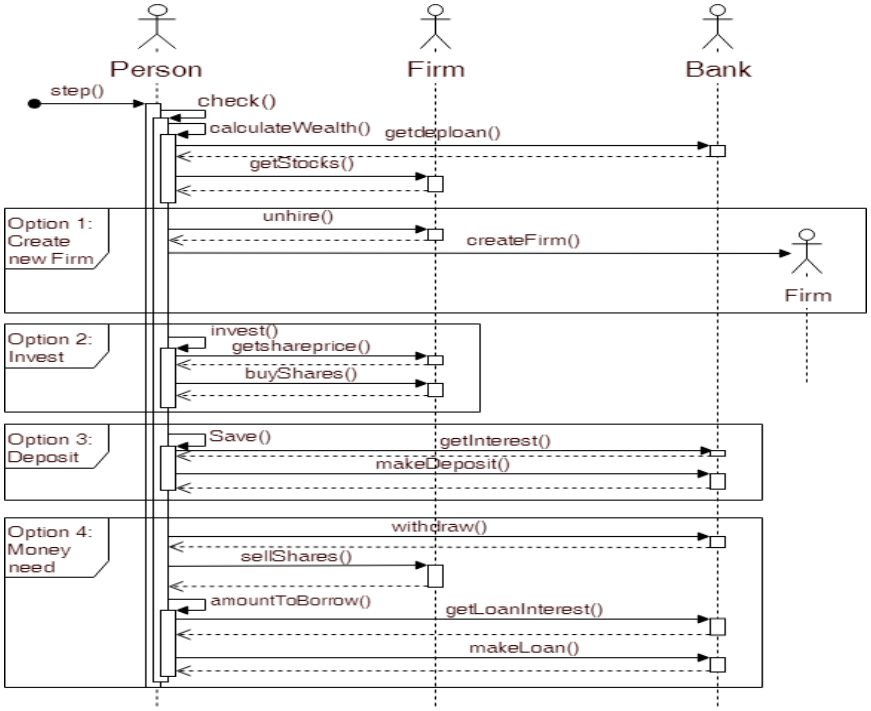

Fig. 5. Sequence Diagram for person wealth management

The first option is to create a new firm, on this moment the person agent may create a new firm agent with fixed initial values depending on the investment fund. The owner of all shares of the firm is the respective person agent who created it. Within this option, it is made possible that the person agent may evolve to a new state and be an owner of firm that was created. Other options related to money investment include investment in existing firms or depositing in banks. The last option is based on the money need that a person agent may have at a certain moment. In this case, the options are to withdraw from bank, sell shares, and taking a loan from bank.

4. IMPLEMENTATION

The implementation of the simulation is based on the main structure that Repast Relogo offers [16]. It is a structure that helps the modeler to define agents by creating a Groovy class for each type of agent. For these agent classes to be classified as agents in the simulation world, it is necessary to extend the ReLogoTurtle class. These agents are later created and initiated by the setup function of the UserObserver class. This class may be perceived as the environment where the agents behave and interact with each other. The structure of this class is shown in the listing 1.

```
1  class UserObserver extends BaseObserver {
2     def setup(){
3        //creates and initializes the simulation agents
4     }
5     def go(){
6        //calls the step plan methods of each agent for every tick
7     }
8  }
```

Listing 1. Part of structural code of UserObserver.groovy

The simulation in Repast is possible due to a tick mechanism that works as the clock of the simulation world. On every tick the go method of the UserObserver class is called, and in it are defined the step plan methods of each agent. These step plan methods are basically the activators of the daily behaviors that the agents should make. Each step plan method can be called in a specific order that is defined by the modeler and it can be different for each agent. The simulation framework offered by Repast provides a class for the developer to define the graphical components, which will later be used as inputs for the researcher.

In this work, the inputs taken into consideration for the researcher are the population number, number of banks and firms, worker producing capacity based on each product type and initial daily cost. The other necessary data are initialized based on some distribution function when the agents are created. The level of income for each person is initialized using a distribution based on real statistical data. These features are initialized on the setup method of the UserObserver class and integrated to agent classes. Another feature added to this work is the capability to create new person agents based on population growth models, and at the same time for the person to die based on a random illness distribution. This feature is included in the step plan and gives to the researcher a more realistic view of the simulated environments.

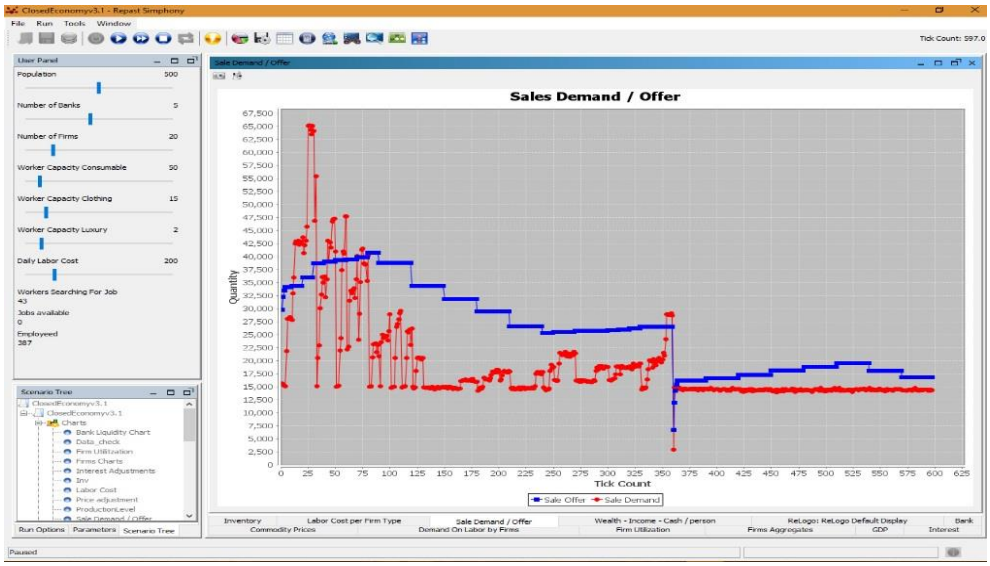

Fig. 6. Simulation of the artificial economy

The output of this model is a set of graphs of the aggregated economic data generated from the simulated artificial economy as shown in the figure 6. These data are generated within each agent at every time-step of the simulation. After the first generation the data are kept as part of each agent state and used for their future decision making in the simulation. Repast framework provides the necessary tools to export these data and use them with other tools for further research.

5. CONCLUSION

The paper presents the work done to implement a simulation of the artificial economy by using the most up to date agent-based methodologies and frameworks. In this context, it is presented a concise literature review of the state of the art where the most important definitions of agent-based methodologies have been studied and taken into consideration for a further analysis on their usage. It identified some of the research in the aspect of creating an artificial economy simulation by using these methodologies and has provided insights on the need to use OOP and UML graphical representation for building better ABMs.

Based on these findings, the conceptual model section gives a description of the model as a requirement used to build the simulation of the artificial economy. A more detailed view of the solution is provided in the next subsection where some of the important sequence diagrams of the artificial economy simulation are explained.

In the implementation section, it is explained in detail the structure used to build the simulator, and the important features that it includes. Based on these, it is concluded that agent-based modeling is an important methodology to build simulators for different domains of research. Due to this work, it is important to state that the use of UML and OOP techniques helps developers to build better models for simulation based on agent-based modeling.

REFERENCES

[1] Farmer, J. D., Foley, D., The economy needs agent-based modelling, *Nature,* (vol.460), 2009, pp. 685-686.

[2] Niazi, M., Hussain, A., Agent-based computing from multi-agent systems to agent-based Models: a visual survey, *Scientometrics,* **479** (vol. 89), 2011.

[3] Squazzoni, F., The impact of agent-based models in the social sciences after 15 years of incursions, *History of Economic Ideas,* **2** (vol. 18), 2010, pp. 197-234.

[4] Hakrama, I., Artificial Economy and the usage of ACE, in *Information Systems and Technology Innovations: Projecting trends to a New Economy*, Tirana, Albania, June 2014.

[5] Tesfatsion, L., Agent-based computational economics: growing economies from the bottom up, *Artificial Life,* (vol. 8), 2002, pp. 55-82.

[6] Holland, J. H., Studying Complex Adaptive Systems, *Journal of Systems Science and Complexity,* **1** (vol.19), 2006, pp. 1-8.

[7] Gevel, A. J. W. v. d., Noussair, C. N., *The Nexus between Artificial Intelligence and Economics*, Springer-Verlag, Berlin Heidelberg, 2013.

[8] Chen, S.-H., Varieties of agents in agent-based computational economics: A historical and an interdisciplinary perspective, *Journal of Economic Dynamics and Control,* **1** (vol. 36), 2012, pp. 1-25.

[9] Deissenberg, C., Hoog, S. v. d., Dawid, H., EURACE: A massively parallel agent-based model of the European economy, *Applied Mathematics and Computation*, **204**, 2008, pp. 541-552.

[10] Hoog, S. v. d., Deissenberg, C., Dawid H., Production and Finance in EURACE, *Complexity and Artificial Markets*, (vol. 614), 2008, pp. 147-158.

[11] Seppecher, P., Salle, I., Lang, D., Is the Market Really a Good Teacher?: Market selection, collective adaptation and financial instability, *Journal of Evolutionary Economics*, 2018, pp.1-37.

[12] Siebers, P.-O., Ongoo, B. S., Graphical representation of agent-based models in operational research and management science using UML, in *Proceedings of the Operational Research Society Simulation Workshop (SW14)*, 2014, pp.143-153.

[13] Vermeir, A., Bersini, H., Best practices in programming agent-based models in economics and finance, *Advances in Artificial Economics*, (vol. 676), 2015, pp. 57-68.

[14] North, M. J., Collier, et al., Complex adaptive systems modeling with Repast Simphony, *Complex Adaptive Systems Modeling*, **3** (vol. 1), 2013, pp. 362-376.

[15] Ozik, J., Collier, N. T., et al., The Relogo Agent-based Modeling Language, in *Proceedings of the 2013 Winter Simulation Conference (WSC)*, Washington, DC, 2013, pp. 1560-1568.

[16] Kielbasa, J., Agent-Based Modeling: An Introduction to RePast using ReLogo with Groovy, 2014. Retrieved on 22 January 2018 from https://sites.google.com/ site/jakubkielbasaau/p/agent-based-modeling/repast-using-groovy.

[17] Raberto, M., Teglio, A, Cincotti, S., Debt Deleveraging and Business Cycles. An Agent-Based Perspective, *Economics Discussion Paper No. 2011-31*, 2011.

[18] Tesfatsion, L., Agent-Based Computational Economics: A Constructive Approach to Economic Theory, *Handbook of Computational Economics*, (vol. 2), 2006, pp. 831-880.

[19] Judd, K. L., Computationally Intensive Analyses in Economics, *Handbook of Computational Economics*, (vol. 2), 2006, pp. 881-893.

[20] Collier, N., North, M., Repast HPC: A Platform for large-scale agent-based modeling, in *Large-Scale Computing*, chap 5, 2012, pp. 81-109.

Information about the authors:

Igli Hakrama - is a PhD Candidate at Department of Applied Informatics and Statistics, University of Tirana, he works as a lecturer and his research area covers artificial intelligence, agent oriented software engineering and agent-based modeling and simulation.

Prof. Dr. Neki Frashëri – is working as a lecturer at Faculty of Information Technology at UPT and a member of Academy of Sciences in Albania. From 2003 technical leader of local teams in European framework projects. His research area covers distributed systems, operating systems, parallel systems in geosciences, applied mathematics and informatics.

Manuscript received on 14 April 2018