Agent-Based Modeling of Economic Systems: The EURACE Project Experience *

Mehmet Gençer, Bülent Özel
Istanbul Bilgi University, Department of Computer Science

Abstract

The EURACE project was one of the important research collaborations in the field of agent-based modeling of economic systems. Its target was to create an agent-based model and tools aimed at policy makers for use in macro-economic modelling and economic policy design at the European level. In this paper we report experiences and progress from the EURACE project, and summarize problems that needs to be addressed.

Keywords: Multi-Agent Systems, EURACE, Computational Economics, Simulation Tool Sets.

1 Introduction

Agent-based modeling recently emerged as a viable alternative to more traditional modeling approaches in various fields including biology, urban development, and economics. The essential element in this new approach is non-deterministic simulation of actors and their interactions in a complex system by means of running a high number of loosely synchronized computer processes, each of which represents a single agent. Recurring patterns of interactions or observed macro-level outcomes are then detected and analyzed. Such bottom-up approach to modeling and simulation seems to have an important advantage over most traditional approaches: it allows one to capture situated behavior of agents, rather than relying on identical behavior of clones of a representational agent (Jennings *et al.* , 1998). In this regard, agent-based approach allows one to study features of complex systems (such as biological or economic ones) that

*This work was carried out in conjunction with the EURACE project (EU IST FP6 STREP grant: 035086) which is a collaboration lead by S. Cincotti (Università di Genova), H Dawid (Universitaet Bielefeld), C. Deissenberg (Universitat de la Mediterrane), K. Erkan (TUBITAK-UEKAE National Research Institute of Electronics and Cryptology), M. Gallegati (Università Politecnica delle Marche), M. Holcombe (University of Sheffield), M. Marchesi (Universiti di Cagliari), C. Greenough (Science and Technology Facilities Council, Rutherford Appleton Laboratory).

emerge from behavior and interaction of many agents which are themselves simple. Application of the technique consists of generating simulated data in the manner described above, then inductively analyzing the data (Axelrod, 1997). The technique has been applied in various names besides *agent-based* modeling, such as *multi-agent* modeling.

The techniques which relies on combination of economics, behavioral sciences and computer science is seen to help to support decision taking and policy making (Conitzer, 2010), (Tesfatsion, 2006). Non-deterministic parallelism, borrowed from computer science, in agent-based simulations is an attractive property for modeling inherent autonomy of parts in biological or socio-economic systems. Work in agent-based approach is fueled by recent wide-scale availability of computational power and parallel processing technologies. Developments in agent-based simulation proved particularly attractive in fields such as biomedicine where researchers have limited means of experimenting on human subjects. The technique was successfully employed for studying biological phenomena such as in-stent restenosis in coronary artery disease (Sloot & Hoekstra, 2010) or skin tissue formation (Walker *et al.* , 2004). On the other hand, its application in simulation of complex economic or social systems is still in its infancy.

The EURACE project[1], which was concluded in October 2009 after three years of work, was one of the important research collaborations in this field. Its target was to create an agent-based model and tools aimed at policy makers for use in macro-economic modelling and economic policy design at the European level (Deissenberg *et al.* , 2008). In this paper, we report experiences and progress from the EURACE project, and summarize problems encountered by the agent-based simulation of economic systems which are likely to recur in future work in the field.

2 The EURACE Project Overview

The EURACE project states its goal as "the study and the development of multi-agent models that reproduce, at the aggregate economic level, the emergence of global features as a self-organized process from the complex pattern of interactions among heterogeneous individuals"(Cincotti, 2005). This approach should be contrasted with more familiar macro-economic forecasting models (see, for example, Fagan *et al.* 2005), which requires empirical features of the system to be known. Such models can differ substantially as they are concerned with different aspects of a complex system (Granger & Jeon, 2004). The approach in EURACE was to model heterogeneous agents in the European economic system (households, firms, banks, etc.) whose behavior is better understood than the features at system level. Once the emergent features of system can be shown to be consistent with the empirical data, such a model can be used to experiment with policy alternatives to understand their outcomes. Such an agent

[1] Project website: `http://ec.europa.eu/information_society/events/fet/2009/media_center/eurace/index_en.htm`

based method can, at least in theory, go far beyond approaches such as dynamic stochastic general equilibrium models in terms of forecasting a dynamic economic system.

The EURACE project has defined its technological objectives as: (1) "development of new software methodologies for implementing, designing and validating large-scale agent-based economic simulations.", and (2) "development of an agent-based software platform to perform simulation experiments on the macroeconomy with application to policy design for the European Union." (Cincotti, 2005). The resulting tools were expected to be employed by a mixed team of economists and computer scientists to perform the following steps:

1. Describe memory, behavior, and interaction of various types of agents in the economic system in the form of data structures, algorithms, and message exchanges (communication).

2. Describe specifications of system population to be used for running a simulation by specifying (i)geographical regions in the economic system, (ii)composition of regional populations containing different numbers of various agent types, (iii)state (e.g. assets) and relations (e.g. employment relations) of agents as stochastic events for initializing system state prior to simulation.

3. Create several concrete instances of population which has same stochastic and compositional features adhering to specifications.

4. Describe policy alternatives as global parameters (e.g. unemployment subsidies, central bank interest rates, etc.), and consequently by combining them with population instances, generate a set of experiments.

5. Run the set of experiments on a simulation engine with sufficient computational power (possibly using a parallel computing grid) for the desired time-span of simulation experiment.

6. Collect, summarize, and visualize final and intermediate states of the system to verify model, or examine outcomes of policy alternatives.

Although it was not the first example of agent-based modeling of economic behavior, the step 1 has involved a comprehensive modeling effort not attempted before. The modeling effort were divided into several parts corresponding to labor, goods, and credit markets. This division was done partly for practicality of both timely concluding them, using heterogeneous expertise among the economists in the project team, and more importantly for verifying that different parts of the model checks against observed data about those markets, before they can be combined to further verify the greater model. Various partner institutions participating in the EURACE project reported success in modeling different markets in the economy (Deissenberg *et al.* , 2008; van der Hoog *et al.* , 2008). However, verification of the combined model remains an unfinished target as of our writing.

The project required development of software components, whose use context roughly corresponds to steps of work described above. In the following section we summarize problems encountered and progress taken regarding most critical ones of those.

3 Technology created in the EURACE project

A key component in EURACE software platform was the simulation engine. From the beginning, project leadership has decided to adopt an existing software framework[2] for this purpose. The simulation engine was considerably improved during the EURACE project so that it allows breaking down a model into components for parallel development and partial verification, and it accommodates parallelization better. Rest of the software components are tied to data formats and interface of simulation engine to varying degrees. In particular an agent model editor component was developed to provide a graphical user interface for agent model designers which allowed them to browse and edit memory and behavior descriptions of various agents in a model, and message definitions for their communication, in a way which allows them to focus on their work while the program automates packaging of model components and their translation into simulation engine data formats.

A problem specific to the approach in EURACE project, in contrast to modeling efforts that use representative agents, has been the specification and initialization of the system population to be simulated, which consisted of heterogeneous regions in Europe containing various types of agents which have established relations with one another. A population design software module was designed for this purpose. This module allowed model designers to create geographic regions and their composition of varying numbers of different agent types. Population design module was also expected to solve the problem of initializing agent states and their relationships. A miniature computer language was specified and implemented to allow model designers describe agent states as stochastic or deterministic variables in a convenient way. In describing agent states, variables often depend on other state variables of same agent or different agents. In addition, initialization of an economic system required establishing relations between agents, which are often exclusive, such as in the case of employment relations where if an employee works for a firm he/she cannot work in another firm. The experience with population initialization in EURACE has shown that the population initialization can require long computations, which may reversely effect usability of the software system.

Another software component which was important for usability of the EURACE tool set was the module for summarizing and visualizing final state or changes of the simulated system. This visualization component was expected to be the tool that policy makers would be spending most time with. It was expected to be exploratory with built-in sets of analysis. The project team has

[2] For a description of agent-based simulation framework used in EURACE, see: `http://www.flame.ac.uk`

adopted the R Project [3] as the major vehicle of exploratory statistics in the EURACE visualization component.

The amount of data produced by very large number of agents at each iteration entails a challenging task of multi-agent systems, where efficient computational services are needed to store, extract, analyze, visualize and export useful data out of simulation. The EURACE visualization tool has provided a workspace environment where such multitude of tasks are implemented transparently from the end user point of view.

In addition, the experiment design tool of the EURACE tool set has fulfilled to overcome a set of pitfalls which are inherent to any simulation approaches. They are sensitivity of simulation results to population initialization, policy parameters and extremities that might be exposed as a result of very stochastic nature of a simulation approach (Kleijnen, 1998). In order to validate output of simulations a set of experimentation mechanisms has been designed. In experimenter is allowed to design and initiate different population distributions in order to observe the impact of different initial conditions on the final output. A second mechanism allows experimenter to set a range and a number of steps which would generate different values for policy parameters such as inflation rate or unemployment rate. This mechanism enables experimenter to observe sensitivity of designed markets to various policy parameters.

The data analysis and visualization workspace provides additional interfaces to conduct above sensitivity analysis before delving into rigorous work of making sense of simulation outputs.

4 Discussion: advantages and disadvantages of agent-based approach for modeling economic systems

The very computational power that enables us to envision agent-based simulations is also an inherent limit to their success. First of all it is impossible to simulate precisely the utterly complex behavior of humans in socio-economic settings. Particularly the intensity of communication between agents increases as the models becomes more realistic, and presents a problem for running simulations on a grid of computers. Despite these issues, however, the EURACE experience shows that simple algorithmic descriptions of economic actors' behavior produces promising results.

Most important advantage of agent-based approach to economic modeling and simulation lies in the fact that it produces complete states of an economic system, rather than predicting particular properties of the system as does the traditional methods. As a consequence, one can study desired aspects of the emergent system without the necessity of changing the behavioral model of agents for the particular system level aspect of interest. Furthermore, once agent behavior is described, it is possible to experiment with systems of different

[3] `http://www.r-project.org`

composition or structure. Additionally a grounded behavioral model for agents can be expected to be suitable for simulating a system's long term behavior and effects of a policy properly, as it does not require naive assumptions about system level interactions (Lucas, 1976).

Multi-agent systems are advancing to become a powerful paradigm for designing and developing complex social and economical systems. However, it is seen that to capture and to report robust, reliable, and recurring social phenomena out of simulation a set of realistic social properties need to be represented or modeled within artificial simulation environment of simulation platforms. These are rationally bounded decisions, opportunistic actions and interactionist behavior of social and real agents (Forno & Merlone, 2002), (Zuckerman *et al.* , 2007). Incorporations of dynamic network analysis with valid and contextualized network models are seen to contribute to multi-agent simulation in that direction (Carley, 2003), (Oflati-Saber *et al.* , 2007).

5 Conclusion

Agent-based modeling is a promising approach in modeling a variety of systems including economic systems. The EURACE project has been a considerable progress towards producing complete and valid agent-based models for economic systems. The EURACE experience shows that this approach is quite tolerant to model approximations; i.e. even crude models can produce emergent properties of an economic system which checks against empirical data. On the other hand the models created with the agent-based approach, no matter how simplified, leads to computationally intense simulations which challenge state-of-the-art systems available. Further progress in agent-based modeling of economic systems will require closer cooperation among computational economists and computer scientists to produce efficient modeling frameworks and tools to overcome these obstacles.

Recent research and advancement in agent-based modelling attempts to incorporate more realistic social actions within the simulation environments. A necessary future directions in the field of agent based modelling of economics that is recommended by EURACE is to incentivize agents to communicate their preferences. Incorporation of network models of interactions is deemed to be methodologically instrumental.

References

Axelrod, Robert. 1997. *The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration.* Princeton University Press.

Carley, Kathleen. 2003. Dynamic Network Analysis. *Committee on Human Factors. National Research Council*, 133–145.

Cincotti, Silvano. 2005. *Specific targeted research project IST call 5 FP6-2005-IST-5.* Tech. rept.

Conitzer, Vincent. 2010. Making decisions based on the preferences of multiple agents. *Communications of the ACM*, **53**(3), 84–94.

Deissenberg, Christophe, Vanderhoog, Sander, & Dawid, Herbert. 2008. EURACE: A massively parallel agent-based model of the European economy. *Applied Mathematics and Computation*, **204**(2), 541–552.

Fagan, Gabriel, Henry, Jerome, & Mestre, Ricardo. 2005. An area-wide model for the euro area. *Economic Modelling*, **22**, 39–59.

Forno, Arianna Dal, & Merlone, Ugo. 2002. A Multi-Agent Simulation Platform for Modeling Perfectly Rational and Bounded-Rational Agents in a Firm. *Journal of Artificial Societies and Social Simulation*, **5**.

Granger, Clive W.J., & Jeon, Yongil. 2004. Thick Modeling. *Economic Modeling*, **21**, 323–343.

Jennings, Nicholas R., Sycara, Katia, & Wooldridge, Michael. 1998. A Roadmap of Agent Research and Development. *Journal of Autonomous Agents and Multi-Agent Systems*, **1**(1), 7–38.

Kleijnen, Jack P.C. 1998. *Handbook of Simulation: Principles, Methodology, Advances, Applications and Practices.* John Wiley and Sons Inc. Chap. Experimental design for sensitivity analysis, optimization, and validation of simulation models.

Lucas, Robert E. 1976. Econometric policy evaluation: A critique. *Carnegie-Rochester Conference Series on Public Policy*, **1**, 19–46.

Oflati-Saber, Reza, Fax, Alex, & Murray, Richard, M. 2007. Consensus and cooperation in networked multi-agent systems. *Proceedings of the IEEE*, **95**(1).

Sloot, Peter M. A., & Hoekstra, Alfons G. 2010. Multi-scale modelling in computational biomedicine. *Brief Bioinform*, **11**(1), 142–152.

Tesfatsion, Leigh. 2006. Agent-Based Computational Economics: A Constructive Approach to Economic Theory. *Handbook of Computational Economics*, **2**, 831–880.

van der Hoog, Sander, Deissenberg, Christophe, & Dawid, Herbert. 2008. *Lecture Notes in Economics and Mathematical Systems.* Springer Berlin Heidelberg. Chap. Production and Finance in EURACE.

Walker, D.C., Hill, G., Wood, S.M., Smallwood, R.H., & Southgate, J. 2004. Agent-based computational modeling of wounded epithelial cell monolayers. *NanoBioscience, IEEE Transactions on*, **3**(3), 153–163.

Zuckerman, Inon, Kraus, Sarit, Rosenschein, Jeffrey S., & Kaminka, Gal. 2007. An adversarial environment model for bounded rational agents in zero-sum interactions. *Pages 1–8 of: AAMAS '07: Proceedings of the 6th international joint conference on Autonomous agents and multiagent systems*. New York, NY, USA: ACM.