Interdisciplinary Description of Complex Systems 2(1), 95-103, 2004

FIRST GENERATION MULTI-AGENT MODELS AND THEIR UPGRADES

András Vag*

World in Figures
Nagykovacsi, Hungary

SUMMARY

Multi-agent systems consist of interactive and independent agents of different kinds in a "world" of the computers. The key issue of multi-agent modelling is its ability to produce emergent phenomena at macro level from "micro-behaviour". For now this approach became a widely used methodology in socio-economics and ecology. This paper presents three famous first generation models and then drafts some of their upgrades, especially the agent-based computational economics, the spatial planning approach and the ecological models. Finally some conceptual developments are presented and discussed.

KEY WORDS

simulation, early multi-agent models

CLASSIFICATION

ACM Categories and descriptors: I.2.11 [Computer Applications]; Distributed Artificial Intelligence, Multiagent systems

APA: 4120

JEL: Z19

*Corresponding author, η: avag@worldinfigures.org; +36-309-985-884;
Park str 1/a, 2094 Nagykovacsi, Hungary

SOME FEATURES OF "FIRST GENERATION" MULTI AGENT MODELS

Multi-agent simulations of human or animal interactions show that simple agents and simple rules can generate aggregate effects, frequently identified as emergent phenomena. The first glorious period of this new methodology was a real breakthrough in the paralyzed social science methodology. Surprisingly the second wave was not as intensive as the first one, although the number of publications, Internet portals and conferences on top of multi-agent systems are steadily increasing.

Publications about multi-agent simulation of social phenomena have mainly dealt with conceptual or demonstrative issues and the usage of real data was rather seldom. In the last few years we could observe the increased popularity of multi-agent methodology for simulating real and complex problems. I present three famous "first generation" multi-agent models to illustrate the path which lead to the currently emerging questions. These models are Schelling's "Segregation" model, Epstein and Axtell's "Sugarscape" model, and the "Peppered Moths" model of Wilensky.

SCHELLING'S SEGREGATION MODEL

Segregation into different regional neighbourhoods was often considered to be a result of direct discrimination or of the effects of economic conditions. Schelling pointed out that if families (i.e. black and white) prefer to live in neighbourhoods, in which their own ethnic group is a majority, and they are able to move to the nearest location which satisfies this desire, complete segregation will inevitably emerge. The simulation models the behaviour of two types of agents in a small world. The "red" agents and "green" agents get along with one another, but each agent wants to make sure that it lives near some of "its own". The simulation shows how these individual preferences lead to large-scale patterns [1, 2]. Explanation of "macro" phenomena with "micromotivations" is extremely useful and became popular. *Schelling's model had an important role to demonstrate this, since relatively small individual preferences lead to significant overall segregation.*

EPSTEIN AND AXTELL'S "SUGARSCAPE" MODEL

This is an excellent illustration of a model which yields numerous interesting results about the emergence of evolution of social phenomena, although the agents are rather simple. In this artificial society the agents move within a grid, in which each cell has a changing quantity of 'sugar'[1]. Agents have to eat sugar to survive. The amount of sugar at each location varies spatially and according to the consumed quantity. If agents harvest more sugar than they need immediately, they can save it or trade it with other agents. Agents can see at a distance which varies randomly depending on their `genetic endowment', so that some of them can see many cells away while others can only see adjacent ones. Agents are goal-oriented and move by the rule: find an unoccupied cell, which has the highest available sugar level and move there. They also differ in their 'metabolic rate', that is the rate at which they use sugar. They die when their sugar level falls to zero and new agents replace the dead ones.

The model has demonstrated the 'survival of the fittest' mechanism successfully. Agents with poor vision, high metabolic rates and located in little sugar for harvesting area die quickly. The model also shows that even if agents start with an approximately symmetrical distribution of wealth, a strongly skewed wealth distribution soon develops. This is because a few, relatively well-endowed agents are able to accumulate more and more sugar, while the majority only barely survive or die [3].

WILENSKY'S "PEPPERED MOTHS" MODEL

That model simulates a classic example of natural selection through the example of the peppered moths of Manchester, England. The peppered moths use their coloration as camouflage from the birds that would eat them. Historically, light-coloured moths predominated because they blended in well against the white bark of the trees they rested on. However, due to the intense pollution caused by the Industrial Revolution, Manchester's trees became discoloured with soot, and the light-coloured moths began to stick out, while the dark-coloured moths blended in. Consequently, the darker moths began to predominate. Now, in the past few decades, pollution controls have helped clean up the environment, and the trees are returning to their original colour. Hence, the lighter moths are once again thriving at expense of their darker cousins. This model simulates these environmental changes, and how a population of moths, initially of all different colours, changes under the pressures of natural selection. *The most important thing is how the entire set of moths changes the colour over time.*

During the first few initial time-steps, the moth population booms, then the moth population fluctuates between different levels, some of which are quite large. The moths give birth to many offspring, but the world in which they live is finite - it has finite space and resources. If the population exceeds the available resources (carrying capacity), the moths tend to die a lot faster than they would otherwise. Under normal circumstances, the average population will tend to stay constant, at a level dependent on the speed and selection rates. In case of drastic change in the environment all of the moths are killed in a few time-steps [4].

Otherwise the too fast environmental change is frequently a subject of ecological simulations. *Most of these models analyse the adaptability of ecosystems to the accelerated changes, i.e. caused by the climate change or by some human activities.*

UPGRADES OF THE FIRST GENERATION MODELS

Needless to say that besides the above three simulations, many other first generation models were published. *I selected these to show, because the mainstream of agent-based modelling of socio-economic phenomena has integrated the approaches and concepts of the above models.* The “Sugarscape” model was a pioneer in simulating economic behaviour, while Schelling’s “Segregation” model and the “Peppered Moth” model can be evaluated as a reference for the later spatial simulations and ecological models.

AGENT-BASED COMPUTATIONAL ECONOMICS

Sugarscape was upgraded by Epstein and Axtell. They pointed out, that agents’ behavior becomes more complex when the model is extended to simulate inter-agent trade, thus `spice' is introduced as additional commodity. Similarly to sugar, spice is distributed over the landscape and is also necessary for the agents’ survival, while sugar and spice are independent from each other. Additionally, agents can barter sugar for spice, if they are short of one. *This upgrade of the model evolved interesting new rules.* For example agents need to have an algorithm to compare their needs for the two commodities to choose the possible cells they could move. Agents also need functions of comparing the commodities when making or receiving offers to barter, negotiating a price and determining the quantities of exchange. *In this way*

Sugarscape can be used for testing a number of scenarios of economic behavior, market descriptions, pricing, etc. Epstein and Axtell draw several conclusions from observing the trading in this extended model. All barters occur in a local context, negotiated between pairs of agents without any central authority or 'auctioneer'. Nevertheless, prices do converge to an equilibrium level as predicted by neo-classical economic theory, although this equilibrium is statistical rather than deterministic one, and some individual trades always occur at prices that deviate from the equilibrium price. Furthermore, the aggregate quantities traded are less than the market- clearing quantities predicted by economic theory. Another interesting consequence of introducing trade into the model is that the distribution of wealth among the agents becomes even more skewed and unequal [3, 5].

Fruitful and widely used extensions of Sugarscape are the so-called "Agent-based Computational Economics" (ACE) models. Of course ACE has other origins too, like computer science, cognitive science and evolutionary economics. (A symbolic triangle of the approach is presented in Figure 1.) As Tesfatsion argues: "agent-based computational economics is the computational study of economies modelled as evolving systems of autonomous interacting agents with learning capabilities. One principal concern of ACE researchers is to understand why certain global regularities have been observed to evolve and persist in decentralized market economies despite the absence of top-down planning and control. …The challenge is to demonstrate constructively how these global regularities might arise from the bottom up, through the repeated local interactions of autonomous agents. A second principal concern of ACE researchers is to use ACE frameworks normatively, as computational laboratories within which alternative institutions, market designs, and organizational structures in general can be studied and tested with regard to their effects on individual behaviour and social welfare" [6].

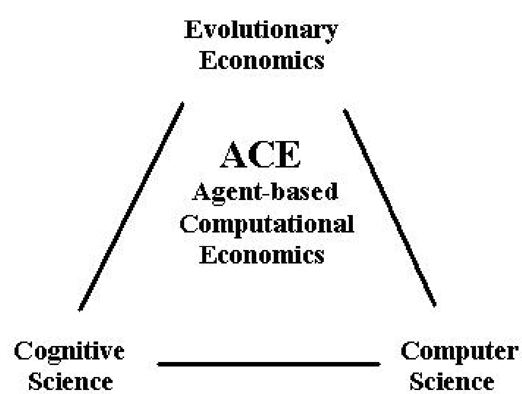

Figure 1. The ACE triangle [4].

This interaction between micro- and macrostructure has been recognized by economists for a long time from A. Smith to Hayek and Schelling. Tesfatsion distinguishes eight research areas to illustrate the usefulness of ACE methodology. These are the followings: (1) "Learning and the Embodied Mind" refers to the usage of learning algorithms in social sciences and economics; (2) "Evolution of Behavioral Norm" which can be best explained with the words of Axelrod "a norm exists in a given social setting to the extent that individuals usually act in a certain way and are often punished when seen not to be acting in this way." [7]. This approach examines the growth and decay of norms as an evolutionary process using agent-based computational experiments. Mutual cooperation among self-interested agents through reciprocity is analysed; (3) “Bottom-up Modeling of Market Process” is one of the most active areas of ACE. It deals with specific markets, like electricity, labor, financial, entertainment, Internet, etc.; (4) “Formation of Economic Networks” deals with transaction networks, partner selection and competitive markets; (5) “Modelling of Organizations” is the research area of constitution and functionality of organizations; (6) “Design of Computational Agents for Automated Markets” is a relatively new area of researches; (7) “Parallel Experiments with Real and Computational Agents” focuses on human-subject experimentation; and (8) “Building ACE Computational Laboratories” [8].

SPATIAL PLANNING AND ECOLOGICAL MODELS

Many papers were published to upgrade Schelling’s popular segregation model, either to test the concept on real data or to extend it with additional variables [9]. *But wider extensions and applications of the above presented original segregation and evolutionary models are “spatial planning” and “ecological models”.* Both represent a significant research area. In the present paper I can only draft these approaches.

Spatial planning is a complex method, regarding either its object (socio-economics, ecosystems, landscapes, etc.), or its process, (many actors, with different world's representation and different interests, individually attached to specific territories). Geographical Information Systems (GIS) is in the focus of spatial agent modelers from the second half of the nineteenths. As Ferrand says, “issues like exchange and coevolution of spatial representations between many distant actors, negotiation support and simulation, multi-actor multi-criteria decision support for continuous spatial planning, are usually not addressed by current GIS” [10]. He proposed to use Multi-Agents Systems (MAS) to enhance or develop such functionalities and presented two approaches: in the first he used Multi-REACTIVE-Agents Systems to solve the complex spatial optimization problems encountered in the search for least environmental impact area for infrastructures, where environmental sensitivities, structural constraints and different localized actors decision systems are used. In the second approach, he used Multi-COGNITIVE-Agents Systems to support and simulate the exchange and dynamics of spatial representations and policies, considering the general political values, the specific spatial constraints, and the socio-relational characteristics of embedded actors [10].

Ecological models simulate different layers of natural (and human) dynamics as complex and adaptive systems. In ecology MAS are known as individual-based models (IBM), which were first developed at the end of the 1980s. There were two reasons for introducing this approach: first, the need to take into account the individual behaviour, primary because of its genetic uniqueness and, secondly, the fact that each individual is situated and their interactions are local [11].

The problem of different layers triggers both theoretical and practical questions. In the context of the ecology “… it reflects the importance of the levels chosen for observing a given system. In ecology, there is no natural scale for observing all types of phenomena. Conventionally, the hierarchy of scales … refers to levels of organization: cell, organism, population, community, ecosystem, landscape, biome and biosphere”. One of the major challenges facing ecology is being able to take into account a multiplicity of scales of study in order to integrate - during a phase called “transfer of scale” - each of the phenomenon studied at their specific level [12].

A SPECIFIC NATURAL ENVIRONMENT – SOCIETY SIMULATION

One of the new generation MAS socio-ecological models is “Simulation of environment degradation caused social conflicts and cooperation” which is a model to demonstrate some interactions between society and environment and within society. The model focuses on “environment $\Rightarrow$ society” and “society $\Leftrightarrow$ society” impacts. “Society $\Rightarrow$ environment” interactions are modelled as embedded elements of the employed framework.

The key question of this research is: how environment degradation caused societal reactions, basically conflicts and cooperation can be modelled at general level. The model contains many important embedded functions, i.e. “technology development”. The curve of this function is adopted from different sources. Other functions are only partially set-in and some parameters of them can be calibrated on the graphical user interface of the program, i.e. “technology development caused pollution”. The rest of the model’s functions can be directly adjusted, i.e. “spreading of local pollution” and “vulnerabilities”. Thus, other important research question is: how to calibrate the functions and parameters of the model.

Besides the calibration-type research questions the model provides some contribution to others issues, like “when environmental changes become irreversible?”, “how and what kind of conflicts and cooperation are generated by environmental degradation?”, “how fast is the reaction of the humanity?” (what is its inertia?), “how fast is the environment degradation?”, “which one will happen first, irreversible environmental processes or fast-enough social reactions?”, “is adaptability enough?”, etc. This kind of research questions are frequently posed worldwide [13].

“The simulator program of “Simulation of environment degradation caused social conflicts and cooperation” was NetLogo, which is a programmable modelling environment for simulating natural and social phenomena. It is particularly well suited for modelling complex systems developing over time. Modellers can give instructions to hundreds or thousands of independent “agents” all operating in parallel. This makes possible “to explore the connection between the micro-level behaviour of individuals and the macro-level patterns that emerge from the interaction of many individuals.” [14].

Conclusion can be drawn from the simulation process both at general and specific levels. The simulation demonstrated that the general level outcomes are sensible to the initial parameters and to the shapes of the “built-in” function curves. Some runs resulted fluctuations or slow rise of the output curves, some others indicated dramatic changes for the near future. Consequently calibration and model verification seems equally important. The analysis of specific effects – for example when other variables were held constant – indicated the perfect functionality of the model and the necessity of further in-depth analysis of the problems.

Some of these models are built for demonstration purposes, while others are based on real-world data [15].

RECENT DEVELOPMENTS IN MODEL-BUILDING PRACTICE

The famous first generation multi-agent models demonstrate certain forms of evolution, 'survival of the fittest' mechanisms, segregation and market-like behaviour. Besides the development of new, advanced multi-agent based simulator programs, we can count on the wider usage the MAS models to solve multidisciplinary problems of real life. With some delay to the extension of research subjects, the researchers interest turned towards model-building strategies and knowledge base (i.e. ontologies) improvement. As Flores-Mendez argued “it is important that agents not only have ontologies to conceptualize a domain, but also that they have ontologies with similar constructions” [16].

Another interesting issue worth to mention is the problem of layers within the models. To deal with this practical problem, Sallach introduces a “hermeneutic” which intends to convey a multilevel interactive dialogue, capable of realizing controlled models of social complexity. He has developed a so called “Situated Social Ecology” (SSE) design framework for this purpose [17]. Sallach refers to Devlin and Rosenberg who have formalized their analyses have developed a technique called 'layered formalism and zooming' (LFZ analysis). LFZ analysis starts by making an initial non-mathematical analysis of the data, but which makes use of mathematical formalisms. This formalism, namely the “situation theory” is a branch of mathematics developed in the early 1980s, and discussed later by Devlin [18]. Then, that initial analysis is the subject to a process of stepwise refinement and increased formalism. Whenever a problem is encountered, the mathematical precision should be increased, as it applies to the problem area. That is to 'zoom in' and examine the problem in detail. When the problem has been resolved, one can 'zoom out' again. At each step of the refinement process, the minimal possible level of formalism and the minimal possible level of precision should be used, thereby minimizing the likelihood of any inadvertent alteration to the data under consideration. The analysis is checked against the data after each stage in the analysis refinement cycle. As a result the balance between the mathematical and the sociological aspects of the analysis is determined not by the analysts but by the data. In short, the process of formalization is used as an analytic technique. The aim is not to produce a formal theory. Indeed, there can be so many symbols floating around that denote decidedly 'soft' entities (such as contexts), that it would take a lifetime to come close to anything that might resemble a 'formal system' in the mathematician's usual sense [19].

SUMMARY AND CONCLUSIONS

This article have picked up some relevant, frequently quoted papers from the coloured palette of multi-agent applications bibliographies to illustrate the milestones from the first generation models to some of today’s new approaches. No doubt that this methodological challenge will further help researchers in studying socio-economic and ecological complexities of the real world.

REMARKS

[1]‘sugar’ is the symbol of the wealth.

ACKNOWLEDGMENT

The elaboration of this paper was funded by the “T 35070 sz. OTKA” research program.

References

[1] Schelling, T. C.: *Dynamic Models of Segregation*.
Journal of Mathematical Sociology **1**, 143, 1971,

[2] Schelling, T.C.: *Micromotives and Macrobehavior*.
W.W. Norton, New York, 1987,

[3] Epstein, J.M. and Axtell, R.: *Growing Artificial Societies: Social Science from the Bottom Up*.
MIT Press, Cambridge, 1996,

[4] Wilensky, U.: *NetLogo Peppered Moths model*.
http://ccl.northwestern.edu/netlogo/models/PepperedMoths, 1998,

[5] Plum, G.F.:
http://www.uni-koblenz.de/~kgt/Learn/Textbook/node100.html, 1998,

[6] Tesfatsion, L.:
http://www.econ.iastate.edu/tesfatsi/ace.htm, 2004,

[7] Axelrod, R.: *The Complexity of Cooperation: Agent-based Models of Competition and Collaboration*.
Princeton University Press, Princeton, 1997,

[8] Tesfatsion, L: *Agent-Based Computational Economics: Growing Economies from the Bottom Up*.
ISU Economics Working Paper No. 1, 2002,

[9] Sander, R.H.; Schreiber, D. and Doherty, J.: *Empirically Testing a Computational Model: The Example of Housing Segregation*.
http://www.econ.iastate.edu/classes/econ308x/tesfatsion/Schelling.Empirical.pdf, 1999,

[10] Ferrand, N.:
Conference on GIS and Environmental Modelling, National Center for Geographic Information end Analysis (NCGIA), Santa Barbara, 1996,
http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/ferrand_nils/santafe.html,

[11] Huston, M., et al.: *New computer models unify ecological theory*.
Bioscience **38**, 682-691, 1988,

[12] Bousquet, F.; Le Page, C. and Antona, M.: *Ecological scales and use rights: the use of multi-agent systems*.
http://cormas.cirad.fr/pdf/iufro.pdf, 2000,

[13] Vag, A.: *Environment degradation caused social conflicts and cooperations: a multi-agent model based simulation*.
http://www.worldinfigures.org, 2004,

[14] Wilensky, U.: *NetLogo User Manual 2.0.0*.
http://ccl.northwestern.edu/netlogo,

[15] Srbljinović, A. and Škunca, O.: *An introduction to Agent Based Modelling and Simulation of Social Processes*.
Interdisciplinary Description of Complex Systems **1**(1-2), 1-9, 2003,

[16] Flores-Mendez, R.A.: *Towards a Standardization of Multi-Agent System Frameworks*.
ACM Crossroads, Special Issue on Intelligent Agents **5.4**, 18-24, 1999,

[17] Sallach, D.L.: *Situated Social Ecology: An Integrated Design Hermeneutic*.
Macal, Ch. and Sallach, D., eds.: *Social Agents: Ecology, Exchange and Evolution*. Proceedings of the Agent 2002 Conference, University of Chicago and Argonne National Laboratory, 27-40, 2002,

[18] Devlin, K: *Logic and Information.*
Cambridge University Press, Cambridge, 1991,

[19] Devlin K. and Rosenberg, D.: *Language at Work: Analyzing Communication Breakdown in the Workplace to Inform Systems Design*.
CSLI Publications, Stanford, 1996,

Prva generacija modela agenata i njihove nadgradnje

A. Vag

Svijet u brojkama
Nagykovacsi, Madžarska

SAŽETAK

Modeli agenata sastoje se od interagirajućih i neovisnih agenata različite vrste u "svijetu" računala. Ključni element modeliranja pomoću agenata je njihova mogućnost reproduciranja izrastajućih pojava na makro-razini iz "mikro-ponašanja". Do sad je ovaj pristup prerastao u široko primijenjivanu metodologiju u socio-ekonomiji i ekologiji. Ovaj ra predstavlja tri poznata modela iz prve generacije i skicira njihove nadgradnje, posebno računalnu ekonomiju temeljenu na modeliranju pomoću agenata, pristup prostornog planiranja i ekološke modele. Naposljetku, koncepti daljnjeg razvoja su prikazani i diskutirani.

KLJUČNE RIJEČI

simulacija, rani modeli agenata