Methodological Approach to Agent-Based Modeling of Social Networks

Olga Vasylieva[1], Borys Butvin[2] and Yuriy Shtyfurak[3]

[1] *Foreign Intelligence Service of Ukraine, 24/1, Nahirna Street, Kyiv, 04107, Ukraine*
[2] *Central Research Institute of the Armed Forces of Ukraine, 28b Povitroflotskyi Avenue, Kyiv, 03049, Ukraine*
[3] *National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37, Prosp. Peremohy, Kyiv, 03056, Ukraine*

Abstract

The article considers social networks as an environment with a complex structure, which is dynamically changing and difficult to analyze. Here is presented the basic methodological approaches for application in the theoretical analysis of social networks. Further, it is proposed to apply the method of agent-based modeling, which today, in the authors' opinion, can be the most adaptive for modeling internal processes of such dynamic social systems as social networks. The most popular software tools for building agent-based models are described and the software AnyLogic developed by XJTeknologies, which has a number of competitive advantages, is highlighted as the most versatile and multifunctional.

Keywords

Agent-based modeling, social networks, information influence

1. Introduction

Aim of the study. Modeling of social processes such as information influence in the social networks by applying agent-based modeling and selecting the most appropriate software tool.

Today, the information influence on human resource has a special place in the system of management decision-making, the political component, the development of business processes, etc. This has become possible due, firstly, to the rapid development of digital technologies, including those used for data dissemination and information exchange, the creation and development of new types of information resources, increased access to information for all segments of the population. Second, the large masses of information that circulates in cyberspace, is open, easily accessible and such that with the help of technology, linguistics, psychology and other knowledge can become a tool to manipulate human communities.

The most acceptable instrument for informational influence in terms of its own structure and the availability of appropriate target audiences are social networks today. The term "virtual (network) community" was firstly introduced in 1993 by G. Rheingold, who defined it this way: "Virtual communities are social associations, growing out of the Web, when a group of people maintain an open discussion long enough and humanly enough to form a network of personal relations in cyberspace" [1].

Social networks today are an important element of the structure of modern society, and their influence extends to various spheres of human activity: production, daily life, culture, politics, etc. They perform communication, informational, entertaining, socializing functions in the society; they provide opportunities for self-expression, exchange of information and experience, without any age, professional or any

ISIT 2021: II International Scientific and Practical Conference «Intellectual Systems and Information Technologies», September 13–19, 2021, Odesa, Ukraine

EMAIL: olga.vasiljeva37@gmail.com (A. 1); butvin_bl@ukr.net (A. 2); yura.shtyfurak@gmail.com (A. 3)
ORCID: 0000-0001-8263-782X (A. 1); 0000-0001-6086-6592 (A. 2); 0000-0001-7863-8862 (A. 3)

other restrictions [2]. The statistics are provided below demonstrate significant penetration of social networks in the life of modern human society.

For example, statistics of social networks in 2021 showed that 42% of the world population - that is a colossal 3.2 billion people - use social networks. The number of social network users has increased by more than 13% over the last year, with almost half a billion new users registered before 2021. On average, more than 1.3 million new accounts appeared every day in 2020, that's about 15.5 new users per second, according to the Digital Global 2021 report [3].

A social network is a set of agents (vertices) that can interact with each other, and the connections between them are social. From a formal point of view, such networks are dynamic social systems, it is convenient to present them in the form of graphs and apply the appropriate mathematical apparatus for their analysis.

This is what determines the relevance of applying methodological approaches for modeling such systems in order to further predict various social processes in networks, including information influence.

Since formalized models of information dissemination process in social networks are actually absent, taking into account their inherent subjective uncertainty, modeling the processes that occur in them, as well as modeling social network itself turns into a weakly formalized problem [4].

As a first step, we should consider the methodological approaches that are used to analyze social networks. They differ from traditional approaches in sociological sciences. The postulate that the attributes of individual actors are less important than the relationships and connections with other actors in the network comes to the fore. That is, the attributes of individual actors - friendliness or unfriendliness, level of intelligence - begin to play no major role [5].

Currently there are four main methodological approaches to the analysis of social networks:

1. Structural – emphasizes the geometric shape and intensity of interactions (weight of edges). All actors are viewed as vertices of a graph, which influence on the configuration of edges and other actors in the network. Special attention is paid to the mutual arrangement of vertices, centrality, and transitivity of interactions [6].
2. Dynamic – attention is focused on changes in the network structure over time. The reasons of disappearance and appearance of edges of a network; changes of structure of a network in case of external influences; stationary configurations of a social network are studied [6].
3. Normative – studies the level of trust between actors, as well as norms, rules and sanctions that affect the behavior of actors in the social network and the processes of their interaction. In this case, the social roles associated with a particular edge of the network are analyzed [6].
4. Resource – considers the actors' ability to attract individual and network resources to achieve certain goals and differentiates actors being in identical structural positions of the social network, according to their resources. Individual resources can be knowledge, prestige, wealth, ethnicity, gender (gender identity). Under network resources understand influence, status, information, capital [6].

In order to involve all four mentioned approaches of social network analysis, taking into account both the structure of dynamic system and its individual actors, defining their interaction, certain rules of the game, as well as giving them certain characteristics, the authors proposed to consider such method of simulation modeling as Agent-Based Modeling [7].

Agent-based modeling is a simulation method that examines the behavior of decentralized autonomous agents, their interaction (both individual agents and collective, such as organizations or groups) and how such behavior determines the behavior of the entire system as a whole. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming. It’s used in noncomputational scientific fields including biology, ecology, and social sciences.

Agent-based modeling is used to analyze decentralized systems that are quite large, have heterogeneous structures, and are dynamically changing: old connections die off and new ones appear. That is why this method is effective to study the process of spreading of information influence in social networks.

To create an agent-based model, all actors are viewed as separate agents. According to the structural approach, the social network can be viewed as vertices with certain connections between them. The network structure of the model is dynamic, it is a kind of system that is self-created, the elements of which appear and die. In such a system, the rules of behavior of each of the agents and their social roles are also defined. Finally, each of the agents is given a certain pool of personal characteristics, which determines the resource approach.

Considering the paradigms of system simulation modeling (Figure 1)

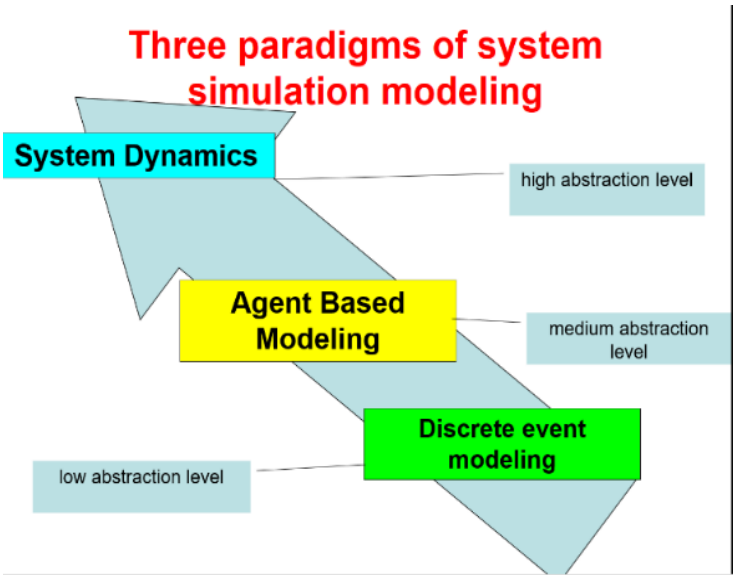

Figure 1: Three paradigms of system simulation modeling

it can be concluded that agent-based modeling is the most multiple-purpose one. In contrast to discrete event modeling, which is consonant with the low and medium abstraction level, and the system dynamics approach with a high abstraction level, agent-based models can be both very detailed, when agents represent physical objects, and extremely abstract, when competing companies or state governments are modeled using agents.

The main difference between the agent-based approach and the first two is the bottom-up construction of the model. Dependencies between aggregated quantities are not set on the basis of knowledge about the real world, but are obtained in the process of modeling individual behavior of tens, hundreds or thousands of agents, their interaction with each other and with objects, which are modeling the environment.

The advantages of the agent-based approach include: the absence of determinacy in the behavior of the system at the global level that can lead to new hypotheses about its functioning during model simulation; realism and flexibility in describing the system, the ability to model the most complex nonlinear feedbacks and to use any required level of detail and abstraction. In agent-based modeling, there are no restrictions on the heterogeneity of model elements; but there is possibility to simulate communication and information exchange [8].

During simulation experiments, computational complexities can arise because agent-based models on average require more hardware and software power to run simulations than system dynamics or discrete event simulations. Agent-based simulations can be implemented on small desktop computers, or using large clusters of computers, or any variation between the first two.

Desktop agent-based models can be simple and used mostly to teach how to model using agents, test agent-based model development concepts, and analyze the results. Desktop utilities include spreadsheets, particularly Excel, and mathematical computing systems such as Mathematica and MATLAB.

Large-scale agent-based models extends the capabilities of simple agent-based desktop models and allows a larger number of agents (thousands to millions) to participate in complex interactions. Large-scale agent-based modeling is usually performed using dedicated modeling environments that include a time-based scheduler, communication mechanisms, flexible agent interaction topologies, a wide variety of devices for storing and displaying agent state [9].

Due to the fact that the agent-based approach emerged in the 1990s in the U.S. university environment, so far most of the tools are intended for academic and educational purposes, and are not commercial products in full.

One of the most popular developments of this type is the Swarm environment. It’s a collection of C language libraries created at the Santa Fe Institute. The most famous commercial tools are RePast, AnyLogic, NetLogo and MASON.

MASO is a fast multi-agent modeling toolkit in Java that was developed as a framework for a wide range of multi-agent modeling tasks, from swarm robotics to machine learning and socially complex environments. MASON makes a careful distinction between models and visualization, allowing models to be dynamically separated from or attached to visualizers, and platforms to be changed at runtime. MASON is a collaborative effort between the Computer Science Department at George Mason University and the Center for Social Complexity at George Mason University. One of interest sources is social and biological models, particularly models of economics, land use, politics, and population dynamics [10].

The REcursive Porous Agent Simulation Toolkit (Repast) is the open and free source of libraries for large-scale agent-based modeling. Repast supports the development of extremely flexible agent-based models and is used in social process modeling. Users build their model by incorporating components from the Repast library into their programs or by using visual Repast for the Python Scripting environment.

Repast has a sophisticated built-in scheduler that supports discrete-event modeling and allows using a large set of communication mechanisms with a variety of interaction topologies and includes a full set of utilities for storing and displaying agent states. The system also includes utilities for automatic integration with both commercial and freely available geographic information systems (GIS). Integration with commercial GIS includes automatic connection to widely used geographic information systems such as ESRI and ArcGIS. Moreover, since Repast is based on the Java language, the Microsoft .NET platform and Python scripts, it is fully object-oriented [9].

Swarm was the first agent-based development environment. First launched in 1994 by Chris Langton at the Santa Fe Institute Swarm is an open source and free set of libraries and is currently maintained by the Swarm Development Group (SDG). The Swarm modeling system consists of two core components. The kernel components run simulation code written in general-purpose language Objective-C, Tcl/Tk, and Java. Unlike Repast, the Swarm scheduler only supports time progression at fixed intervals. Swarm supports a full set of communication mechanisms and can simulate all major topologies. Swarm includes a good set of utilities for storing and displaying agent states. Since Swarm is based on a combination of Java and Objective-C, it is object-oriented. But this mix of languages causes some difficulties with integration into some large-scale development environments, such as Eclipse [10].

NetLogo is another cross-platform agent-based simulation environment that is widely used and supported. Originally based on the StarLogo system, NetLogo adapts agent-based systems consisting of a combination of live and software agents. It is ideal for modeling complex systems containing hundreds or thousands of agents interacting simultaneously. It allows users to explore the relationship between micro-level agents and behavior at macro-level. The language has been developed heavily influenced by Logo and is intended for users from many disciplines - economists, anthropologists, physicists and many others. The interface allows users to interact with variables within a simulation and visualize results without having to look at the code itself. The language is similar to English, which makes it easy for a non-specialist to understand the functionality of each line of code. In addition, NetLogo contains an extensive library of models that includes example programs from a wide variety of disciplines, which is very useful for teaching and learning purposes [11].

AnyLogic is a development of XJTeknologies, which has found wide application among users.

The competitive advantage of AnyLogic is the support of all three simulation paradigms and the ability to use them within a single model. AnyLogic also features a powerful productive kernel that can simulate the behavior of millions of agents; rich animation and graphical model description capabilities; support for various types of experiments, including sensitivity analysis, Monte Carlo method, built-in OptQuest optimizer; integration capabilities with databases, ERP and CRM systems; a set of library objects from logistics, business processes, and pedestrian dynamics areas.

During developing an agent-based model in AnyLogic, the user inputs agent parameters (people, companies, assets, projects, vehicles, cities, animals etc.), defines their behavior, places them in an environment, establishes possible connections and then runs the simulation. The individual behavior of each agent forms the global behavior of the simulated system [12].

There are also some "templates" that simplify model creation and are included in AnyLogic:

- standard architecture;
- agent-based synchronization ("steps");
- state (continuous or discrete);
- mobility and animation;
- agent-based connections (networks, e.g., social networks) and communication;
- dynamic creation and destruction of agents.

AnyLogic provides a graphical language that greatly simplifies the creation of agent-based models:

- statecharts for specifying agent behavior;
- the action diagram for describing complex algorithms;
- the "Environment" element is used to describe the "world", in which agents "live" and to collect various statistics;
- the "Event" element is used to describe random or periodically occurring events.

It should be noted that this software was used in scientific studies regarding the prediction of the spread of Covid_19 infection in dynamic social groups, which are immanently identical to social networks. These studies showed high reliability of the obtained results: the experimental results coincided with the real ones. Fig.2 shows an example of the agent-based modeling application - model structure of the Covid_19 infection spread study on a local multiplicity (N = 10,000) of agents.

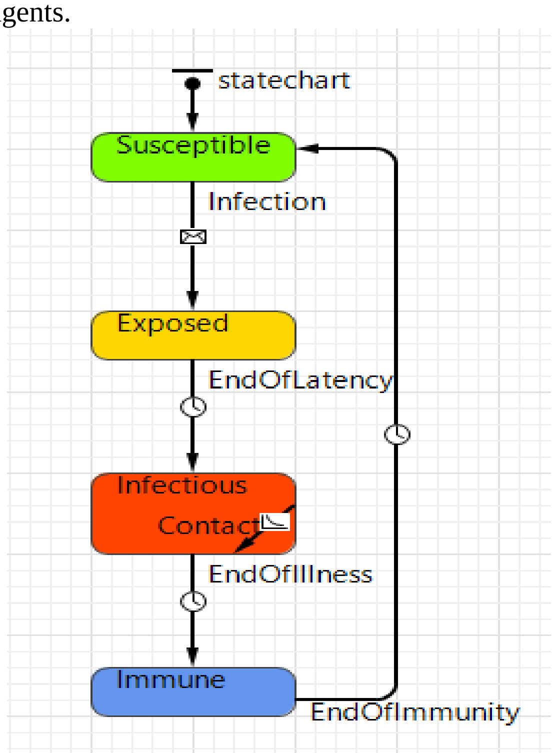

Figure 2: Structure of agent-based modeling the Covid_19 infection spread

Figure 3 shows the dynamics of epidemic spread over time.

Figure 3: The changing dynamics of epidemic spread results over time.

It should also be noted that these tools allow describing almost all behavioral features of agents. Moreover Java language allows simulating any special behavior or logic. Also the specific character of AnyLogic is possibility to combine agent-based models with discrete-event and system-dynamic models.

That is why the authors of the article propose to use AnyLogic software for modeling social networks.

2. Conclusions

Therefore, agent-based modeling allows creating a model of a social network, where, for example, social processes such as distribution of certain information take place, that is information influence is carried out, and all basic methodological approaches to the analysis of social networks are applied. Also, by analyzing the comparative characteristics of the most popular agent-based modeling platforms, it was determined that the most adaptive and multiple-purpose, as well as supporting a pool of platforms for optimization, is the AnyLogic platform, which among other things is designed to model such complex dynamic systems as social networks and their internal processes, such as the distribution of information influences.

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