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Agent-Based Model as a Research Tool

Oleksandr Kuzomin[1], Vyacheslav Lyashenko[2]

[1]Department of Informatics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
[2]Department of Media Systems and Technology, Kharkiv National University of Radio Electronics, Ukraine
e-mail: lyashenko.vyacheslav@gmail.com

Abstract*: The issues of analysis and research of applied issues based on multi-agent modeling are considered. The results of a literature review on the research topic are presented. The main features of existing solutions using multi-agent modeling are shown. An agent-based model for modeling and analyzing the dynamics of the infectious process is presented.*

Keywords—modeling, multi agents, multi environments, risk**.**

1. Introduction

Modeling is one of the tools for analysis and decision making. An important point is the construction of an adequate model. To do this, it is necessary to choose the model parameters correctly, use the necessary methods and approaches [1]-[10].

For example, the simulation environment can be divided into regions with specific purposes (e.g. commerce, educational, open public space), providing different constraints in social interactions, i.e. providing semantics to limit social contact – it overcomes the simplification of the "one agent may randomly contact all", since, in reality, it is most likely that an individual may not get in contact with just anyone. On the other hand, an individual is more prone to get a close contact with a co-worker, with someone who goes to the same store, or someone who lives in the same residence, etc. These interactions are delimited by environment regions and agent features.

In this case, the model should allow you to set restrictions or rules for agents and interactions.

For instance, it is able to model the conscious use of masks or the adoption of social distancing policies. Such works deal with binary solutions, i.e. lockdown or not, masks or not. They are not able to model targeted social distancing policies (e.g. stores may open, but educational facilities should close; some may use masks, while others may not). Therefore, we should talk about multi-agent models (MAS). In particular, such models can be used to diagnose and analyze disease processes. Some issues for such models are discussed below. This study also attempted to bring together the most effective modeling technologies.

2. Related Work

To address the above formulated problem, instrumental research has now been developed that uses so-called logical inference, based on precedent and ontological databases and knowledge. It is a decision-making method that reuses knowledge about previous emergencies.

According [11], an analytical model is primarily quantitative or computational in nature and represents the system in terms of a set of mathematical equations that specify parametric relationships and their associated parameter values as a function of time, space, and/or other system parameters. Equations that are defined in the model must provide a precise representation of the system and environment to meet the purpose of the model. This is done by modeling the underlying phenomena to predict or assess how well the system performs.

Several works ([12]-[14]) on modeling the COVID-19 epidemic dynamics use the Susceptible-Exposed-Infectious-Removed (SEIR) Model, but with limited scope.

The work in [15] makes several simplifications regarding the dynamics and the complexity of the relationships among individuals.

The work in [12] shows that restrictions to population mobility, including closing schools, cancelling presential meetings and embracing remote work should be considered to lower transmission rates. Their work analyzed the epidemic in Wuhan, China. The work in Ref.

In [13] analyzed the data available at the Tracking COVID-19 initiative of the Center for Systems Science and Engineering at Johns Hopkins University and their results show that the recovery time parameter is almost independent from the epidemic region/country, whereas the infection and mortality rates are more dependent on the region/country.

The work presented in [14] used the SEIR-HC model, an evolution of the SEIR model with two different social circles.

The work in [16] is based on the SIR model, and it tried to characterize the similarities and differences between the propagation behaviors of the COVID-19 pandemic in several countries, highlighting the heterogeneous character of the propagation of this pandemic in Brazil. The relevant contribution of that work consists in using the global average of the infection rates, recovery time and mortality rate of this pandemic.

To evaluate the spread dynamics of COVID-19 in a ship, the work in [17] made an adjustment to the data by applying a gamma probability distribution together with the earlyR package to estimate the reproductive number of the pandemic (R0) of its initial phase. However, that work presented some limitations due to the limited number of individuals in the population on board, the high transmissibility of COVID-19 and the rapid increase in the number of infected cases, which

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consequently contributed to a significant drop in the proportion of the susceptible population.

In [18], a Bats-Hosts-Reservoir-People (BHRP) transmission network model was developed to simulate the potential transmission from the source of infection (probably bats) to human infection. The research focused on the transmission of the Huanan Seafood Wholesale Market (reservoir), simplifying the Reservoir-People (RP) transmission network model. Thus, the study was very limited and the initial reproductive number of the pandemic (R0) was calculated based on the RP model to assess the transmissibility of SARS-CoV-2.

In general, the main disadvantages of analytical studies used to model are that: they assume population size is constant, meaning that those models do not consider the mobility of people; they assume individuals are homogeneous, which means that models neglect the heterogeneous social interaction, the mobility patterns and the different behavior of individuals. In this sense, agent-based models in which agents may be modeled as different individuals and may be mobile tend to be more adequate for representing disease processes.

3. Agent-based model studies

Agent-based models are composed of societies of software agents that are able to interact with each other. A software agent (or just agent) is a computer program which works toward goals (as opposed to discrete tasks) in a dynamic environment (where change is the norm), without continuous direct supervision or control, and exhibits a significant degree of flexibility [19].

According to [20], an agent is defined by the following properties:

(i) autonomy (agents perform most of their actions without direct interference from human agents or other computational agents, having total control over their actions and internal state);

(ii) social ability (ability to solve certain problems or for other convenience, interact with other agents, to complete the resolution of their problems, or to assist other agents);

(iii) reactivity (perceive and react to changes in the environment in which they are inserted), and;

(iv) proactivity (ability to deliberate instead of just reacting in response to changes in their environment(from [21]) illustrates how an agent interacts and reacts to the environment it is immersed in.

Some characteristics of an agent-based model include [22]:

each agent can act autonomously within the modeling environment;

there are no complex equations or formulations that control the global model;

they are capable of modeling complex systems in which they incorporate variables that are difficult to implement by analytical models, and; the data and results are decentralized.

Agent-based models have been used in several applications, such as urban traffic intensity [23], [24], simulation of anti-terrorism actions [25], evacuation simulations [26] and multi-criteria decisions in the financial market [27].

Agent-based models have also been used to model pandemic dynamics. The works in [28], [29] describe the state-of-the-art in epidemiological computing and state that agent-based systems can significantly contribute in applications in this area. They discuss some of the main problems in epidemiology, which can be solved using agent-based techniques and their challenges.

In [30], the authors define a database that seeks to quantify the risk of infection by COVID-19, according to the various attributes of professional activity, purchasing power, mobility (proximity among people) and other attributes. That work can be used as a methodological basis for the distribution of these attributes among agents and for the parametrization of infection, recovery time and death probabilities of the agents.

The work in [31] presents an agent-based model to simulate the spread of the influenza pandemic (new H1N1) in Egypt, in which agent interactions took place in a space-time context. The proposed model involves different types of parameters such as: attributes of the social agent, distribution of Egypt's population, and patterns of agent interaction. In addition, the proposed model was used to measure the effectiveness of different control strategies to intervene in the spread of the pandemic.

In [32], the authors present an agent-based model that demonstrates that geographic characteristics defined by the purchasing power can affect the health of individuals. The effects arise from complex interdependent processes in which individuals interact with each other and their environment and in which both individuals and environment adapt and change with time. However, traditional epidemiological studies and statistical regression approaches are unable to examine these dynamic processes.

The work in [33] developed an agent-based model to evaluate the spread dynamics of COVID-19 in a given population of agents. The behavior of each individual was characterized by a set of simple rules, which considered their basic interactions (their degree of autonomy). Each agent was configured with different mobility requirements and infection probability. Thus, several possible scenarios could be tested to obtain the behavior profile of the pandemic. However, this work does not include the recovery of agents in the model. In this sense, once an agent was infected, it could infect other agents indefinitely. It also lacks important individual parameters, such as age, economic conditions, profession and level of awareness. These parameters influence the actions (i.e. the mobility, interactions, etc.) of agents and they are important to provide more accurate scenarios of the pandemic spread. It also only considered just one environment in the model, which is far from the reality of the affected societies.

This work presents an agent-based model to analyze the spread processes of the COVID-19. It differs from the abovementioned studies since it considers the existence of different regions in the environment (e.g. home, work, commerce site, school) and some specific characteristics in the current scenario (e.g. social distancing, awareness).

4. AGENT AND ENVIRONMENTAL PARAMETERS

Consider the main initial parameters that should be set to define the distribution of the population, and include physiological and socioeconomic aspects. The parameters are described below:

Age: this parameter is important since most of the people who evolve to the acute form of the disease and, thus pass away, are of higher ages.

Physical health: this parameter is important since it models the existence of medical preconditions and comorbidities, which increase the probability of an agent to develop an acute form of the disease.

Mobility: this parameter is important since the disease is transmissible through proximity to contaminated agents, and the more mobile an agent is, the more likely it is to get infected.

Professional activity: this parameter indicates which type of regions the agent may be at (e.g. an agent who is a receptionist or a physician has a higher probability to go to a hospital or clinic - thus being more exposed to infection - instead of being an agent who is an architect, with lower probability to go to a more exposed region).

Purchasing power: this parameter is important since it defines if the agent is more likely to have access to prevention items (e.g. masks, running water to wash hands) or treatment in private medical facilities.

Awareness: the agent's degree of awareness may make it less susceptible to the infection. Agents with higher levels of awareness have more social empathy (e.g. wear masks, avoid crowds, and wash their hands). In the proposed model, an agent with 4 or less years of age inherits the value for this parameter from its parents, as it is not able to discern about this condition.

Type risk: this parameter is important since it is used to differentiate the risk of infection for each region (e.g. a hospital, a shopping, a factory plant may present more risk than a home or private office).

Crowd level: this parameter is important since it defines the allowed concentration of agents in a given region. The more crowded a region is, the higher its infection risk.

The set of the values used in the proposed model for the parameters presented above were based on the score and on the database presented in [34], [35].

5. THE PROPOSED MODEL

Step 1. The initial phase of developing an MAS to support the modeling and decision-making process for disaster prevention and management begins with a mission statement and terms of reference. Here, it is necessary to be able to pose questions to specialists or experts in order to define the main objective and the local objectives.

In the problem statement, the parameters of the environment (subject area) that are used in formulating the objectives of the Situation Centre (SC) to deal with COVID-19 must be set.

The new knowledge about the emergency, the quality of the SC development and the effectiveness of the proposed solutions are evaluated according to the risk criteria and the resources Σ required – the amount and means to prevent or eliminate the consequences of an emergency.

An assessment of the risk from a disaster is possible for the SC of the monitored area, for the environmental parameters $X = \{x_j, (j = \overline{1, m})\}$, it is possible to estimate the mathematical expectation of losses among the population according to the formula:

$$M(N) = \iint_{St} P(x_j)\, \psi(x, y)\, dx\, dy ,$$

where $P(x_j)$ − is the parametric law of infection of the population from the action of the virus, e.g. x_j−airborne virus; St − integration area; $\psi(x, y)$ − density of unprotected population within the elementary area; N − number of population.

Step 2. Execute a conceptual design or technical proposal. Development of tools for a specialized complex of information and management system of the SC.

6. CONCLUSION

In the current study, special attention was paid to the development of an adaptive principle of information technology that can ensure decision-making in emergencies with minimal risk . This approach is based on the use of a structuring concept that defines the description of the research object, its environment, natural phenomena and facts.

A multi-agent model was used to solve the tasks set. This model became the basis of agent-based modeling. A multi-agent system is an organization of autonomous agents interacting with each other in a common environment. Agents are heterogeneous objects used to model different people. An environment is a virtual representation of the spaces (or regions) in which agents reside. Interaction is the driving dynamics in a multi-agent system - it models the interaction between agents and between the agent and the environment.

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