Simulation of evacuation with multi-agents on georeferenced layers with GAMA

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***Abstract*—This work deals with agent-based modeling within a geographical environment, it reviews concepts on Multi-agents and Geographic Information Systems (GIS). It is oriented to perform a simulation that considers aspects of human behavior (through agents) during an evacuation, considering real restrictions of the environment in which they are developed (GIS layers). This simulation is done in the GAMA[1] platform, which allows us to easily implement models based on agents and geographic layers. It allows us to work with the attributes of the layers and to define constraints based on them.**

***Index Terms*—GAMA, Agents, Multi-Agents, GIS, Complex Systems.**

I. Introduction

Today the growth of geographic information management is evident. The management of spatially referenced information and their topological relationships, is undoubtedly the main feature that defines Geographic Information Systems (GIS) [1]. Thanks to the type of data they manage, we can represent reality in a simplified way to perform different types of analysis.

On the other hand, we find Complex Systems, whose main characteristic is to be unpredictable, because they are composed of different elements that interact with each other, they also evolve dynamically [2].

GAMA is a solution that allows modeling or constructing simulations based on spatially referenced multiagent systems; the model or simulation considers the different elements that make up the complex system and whose medium in which they develop are georeferenced thematic layers containing information to be integrated into the model and to be able to perform calculations or establish restrictions [3].

GIS are currently used in different areas [4] as well as complex systems [5], both techniques are generally used separately. This project intends to use the two techniques and experimentally prove the benefits obtained by using these two techniques simultaneously. Modeling or constructing simulations based on spatially referenced multi-agent systems is an alternative that tries to give realism to the environment in which agents operate to obtain results as close to reality as possible.

The methodology used in this work complements the traditional studies allowing to analyze data in a more dynamic way, modeling the behavior of complex systems on spatial layers that allow visualizing their behavior in an environment with real characteristics and obtain results closer to reality.

It is intended to clearly define the relationships between the different elements that make up the complex system to be modeled and what effects they have if some component is altered or external elements are introduced.

This document is organized as follows. Section II introduces aspects on simulations based on multi-space agents. Section III presents an application model in the GAMA platform. Finally, in section IV some conclusions and opportunities for future work are presented.

II. Georeferenced Multiagents Simulations

In this section we review simulations with spatial multiagents and describe the two systems used to create them.

Computer models are gaining ground in various areas and sectors, being able to represent phenomena through models is a real challenge today. Integrating multi-agents systems with geographic information systems allows better simulation of phenomena or specific activities whose behavior is complex. In a simulation, to be able to consider spatiotemporal restrictions with multi-agents, potentiates any proposed application [6]. To be able to implement simultaneous strategies using simulations based on spatial agents in a study, allow to face challenges to model complex systems that include specific characteristics like the real form of terrain, slopes, sense of mobilization of vehicles, alleys, among others. In this model, the agents consider the distances to the so-called safe places depending on their current location and the access to roads through which they will be mobilized.

Among the studies analyzed, we find simulations to model the traffic flow in evacuations [7], socio-ecological models [8], models of human behavior due to climate change [9].

Several studies propose simulations that consider complex systems, but the biggest limitation they have found has been the absence of tools that integrate environments with real characteristics, that allows them to create dynamic and realistic environments [10]. Typically, most platforms solve modeling with multi-agent systems separately to solve the complex problems that arise and those involving spatial information, and it is not usual to find a platform that integrates a complete solution that allows to execute both tasks simultaneously.

The open source GAMA platform (GIS and Agent-based Modeling Architecture) is oriented to the modeling and simulation of multi-agent systems with complex environments [11].

A. Geographic Information Systems

Today the search for facilitating the visualization of factors that intervene in a study, and to include in the study the spatial positioning, has allowed the improvement and popularity of tools oriented to the management of space information [12]. Being able to evaluate more accurately any study that can be

[1]GIS and Agent-based Modeling Architecture

represented with its spatial location is more relevant. Every study related to spatial information tries to project from the point of view of the geographic information systems, all the elements that constitute a particular problem and to be able to obtain efficient and safe designs [13].

The use of geographic information systems based on open source software, proprietary or mixed, in the applications gives us advantages such as the discretization of the information that is stored in geographic databases [14], which contain, on the one hand, information concerning the geographical location of the elements involved in the study and, on the other hand, the descriptive information of them. The first would be the geometry that represents the object, georeferenced geometric form, and the second attributes associated with the object of various types.

B. Multi-agents Systems

Currently, multi-agent systems are an expanding area with applications in various areas such as artificial intelligence, numerical simulations and distributed systems, among others, making important contributions in solving problems, where traditional methods have not provided sufficient satisfactory solutions, thanks to the natural form of distributed problem solving [15].

Multi-agent Systems (MAS) are composed of multiple agents that are able to meet goals, whether they are intelligent or not. The design of a MAS must aim to coordinate, through some procedure, the behavior of autonomous agents that, with their beliefs, desires and intentions, are able to construct the sequences of actions that they must take to solve the problem, which can be an individual problem (that is, specific to each agent) or global (common to the whole set of agents) [16].

C. GAMA Platform

This platform[2] allows the representation of features associated with complex systems and environments based on GIS layers. It has its own development language, called GAML, that allows the construction, coupling and reuse of complex models with different agent architectures, real environments and abstraction levels [17].

This platform is oriented not only to professionals with solid programming knowledge, its graphical interface allows to build models through wizards that automatically create the code associated with the generated graphic model. Agents in the GAML language are defined as species (those that provide a set of attributes, actions, behaviors and properties), while the grid is the medium where they develop (this may be spatial layers) [18]. It is possible to generate species of generic type, parent or child that inherit properties or qualities of another species, very similar to what happens in the object oriented design paradigm. GAMA allows us to work with vectorial layers, be these polylines, polygons or points. Not only allows you to visualize the vector layers, but also allows you to interact with the attributes of each one.

[2]http://gama-platform.org/

III. Evacuation Model

Today there are many studies that are based on current techniques to optimize the results obtained by simulations of various kinds [19]. Traditional modeling techniques have become increasingly imprecise because they do not contemplate within their calculations the changing factor of Complex Systems or the special features of their environment. The studies related to evacuations in case of seismic risks at urban level are very common, however in most of them the predominant factor in reality is not taken into account: human behavior [20].

Humans, for modeling purposes, should be considered within the Complex Systems field because of their changing characteristics according to the environment, external factors and how they interact with each other. There are few studies oriented to the simulation of evacuations taking into account people and mobility according to the location at the time of an emergency [8].

In this work a model of evacuation to safe sites is generated that verifies the routes of evacuation and the time of response to an emergency, using the GAMA tool. The model consists of three important parts:

- Agents Modeling.
- Environment analysis and definition.
- Agents and environment interactions.

A. Agents modeling

The relevant factor to take into account within the model are people, so at this stage we design the different types of agents to create and their specific parameters. First, we create a global species that has common characteristics to all agents that represent people and who can inherit these characteristics to specific species such as:

- Pedestrians: People whose environment at the general level are streets and do not have a defined location schedule. Its basic characteristics are: mobility without fixed schedules, minimum and maximum speed.
- Employees: People who at fixed hours move to buildings considered workplaces and stay in those places during well-defined days. They have characteristics such as: mobility with schedules defined by ranges, job location, minimum and maximum speed.

B. Environment analysis and definition

People can occupy different types of environments within the model which are represented by spatial layers, which can be of three types:

- Streets: Vector layer that contains streets with spatial reference and own characteristics like: length, positioning, orientation, connectivity, among others. It represents the environment where people move and thanks to the characteristics of the spatial layer, you can calculate the maximum capacity, limitations to access certain places. Thus you can also perform calculations to find the best alternative route or routes to get from any location to destinations points.

- Buildings: Polygonal vector layer that are associated with the environment, represent workplaces or educational establishments. Here people will be accommodated in certain days.
- Safe places: Layer depicting safe environments for people in emergencies.

Buildings and safe places are defined by the attribute of the vectorial layer. In the GAML language the vectorial layers are also declared as another kind of species allowing to work with their attributes.

C. Agents and environment interactions

Simulations are now considered an effective method to prevent further complications in the event of natural disasters or terrorist attacks [21]. In case of emergencies, the evacuation is the first step to follow, either in an orderly way or by simple human reflection. For this reason, it is important to consider how the agents interact with each other and with the environment in case of an emergency. The characteristics and functions of agents must be clearly defined under certain restrictions. Performing simulations that according to defined schedules reflect urban problems such as traffic, are of vital importance to obtain optimal results in the simulation.

We define two agents types:

- The ”employee” agent type that moves to the buildings for the time set in their restrictions.
- The ”pedestrian” agent type that moves over the streets with a minimum speed for certain time ranges.

After defining the agents and the environment in which they operate, it remains to introduce the functions of relationship between agents and the environment. Some function examples are:

- Location: Allows to define the location of the agents on the vectorial layers.
- Displacement: Functionality that allows people to move through the street layers.
- Emergency: In case of activating this functionality, people move only to safe places. Carry out a search for the best route to the nearest point of safe places.
- Restrictions: Restrictions are defined both at the level of people and of vectorial layers, such as streets without pedestrian access (simulates the presence of meshes, doors that limit access), dead ends (owned by the vector layer).

When running the model, the agents move to their places of permanence (it depends on the agent type).

When the emergency is activated, all the agents move to safe places using the maximum speed defined in their restrictions. The safe place to which each agent is mobilized depends on the value of the distance calculated using the *simple_clustering_by_distance*[3] function. Also, the estimated time for this displacement is defined within the model. With this, we can define the percentage of people who can reach a safe place.

[3]https://gama-platform.github.io/wiki/Operators

Figure 1. Initial status

The initial status is shown in Figure 1. Red buildings represent workplaces or educational establishments, while green buildings are safe places. Pedestrians can be seen on the streets and employees inside buildings.

In the Figure 2 we can see the final state of the simulation. It shows the people who reach a safe site, the accommodation capacity of safe places and people who by the estimated time for evacuation failed to reach or worse still did not come out of buildings.

The simulation environment has the fallowing layers (maps):

- Buildings *Redificacion.shp*
- Streets *Rcalles.shp*
- Zones *Rzona.shp*

These layers allow us to have different levels of interaction of the environment within the model, each of them represents a geographical vector data with their respective attributes.

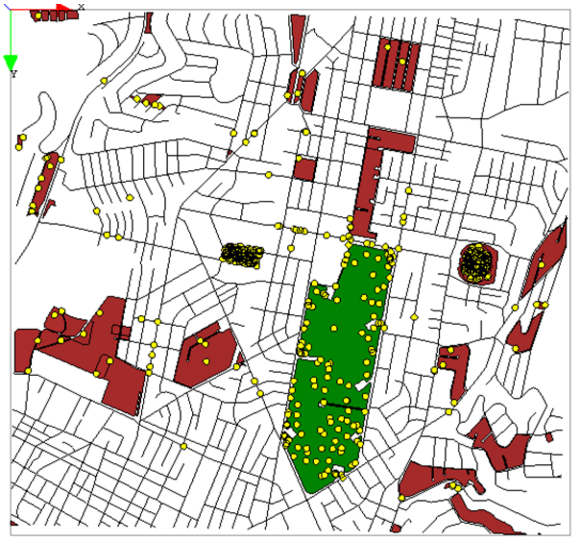
For the location of the agents within the simulation, the *use_building* attribute is used, this attribute belongs to the building layer (buildings or safe places). If the agent type is *employee*, its initial location will be inside a building.

Pedestrian agents are located on the streets layer and are mobilized at random. As a restriction in the model, it is necessary that all the agents will move to the safe places only in case of emergency.

The initial parameters of the simulation are:

- Number of employees: 500
- Number of pedestrians: 100
- Minimum speed: 1.0
- Maximum speed: 5.0

Figure 2. Final status



In order to choose the safe place to which the agents will move in the model, the closest distance from the current location of each agent to the safe-type constructions is sought through the *simple_clustering_by_distance* function. At the end of the simulation, the percentage of employees and pedestrians who managed to evacuate in in a given time range is calculated.

IV. Conclusions

Among the conclusions that we could draw from this work we have:

The ability to implement a simulation with MAS and GIS allows you to visualize specific problems with real restrictions: take a dead end, not be able to find an optimal route to arrive at a defined time to safe places, the ability to evacuate buildings through the doors access, among others.

When making models or simulations related with geographical characteristics, it is more appropriate to use properties of the geographic data. Therefore, we obtain better results by decomposing the environment into different levels that allow a better interaction with its attributes.

GAMA represents a useful tool when making models that implement the two systems (MAS and GIS). It allows exploiting the full potential of both systems to solve problems related to the modeling and simulation of spatially referenced complex systems.

Simulations of this type should be considered as an aid in decision making in the urban part in case of emergencies.

As future work is intended to carry out a deeper simulation contemplating vehicular traffic and rescue personnel in order to have a complete idea of what happened in case of an evacuation: the response time of the rescue groups, the problem caused by traffic jams and other .

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References

[1] A. Carrara and F. Guzzetti, *Geographical information systems in assessing natural hazards*. Springer Science & Business Media, 2013, vol. 5.

[2] H. Yu, Z. Shen, C. Leung, C. Miao, and V. R. Lesser, "A survey of multi-agent trust management systems," *IEEE Access*, vol. 1, pp. 35–50, 2013.

[3] E. Macatulad and A. Blanco, "3dgis-based multi-agent geosimulation and visualization of building evacuation using gama platform," *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 40, no. 2, p. 87, 2014.

[4] M. Tahri, M. Hakdaoui, and M. Maanan, "The evaluation of solar farm locations applying geographic information system and multi-criteria decision-making methods: Case study in southern morocco," *Renewable and Sustainable Energy Reviews*, vol. 51, pp. 1354–1362, 2015.

[5] S. Li and W. A. Mackaness, "A multi-agent-based, semantic-driven system for decision support in epidemic management," *Health informatics journal*, vol. 21, no. 3, pp. 195–208, 2015.

[6] J. Izquierdo, I. Montalvo, R. Pérez-García, and D. Ayala-Cabrera, "Multi-agent simulation of hydraulic transient equations in pressurized systems," *Journal of Computing in Civil Engineering*, vol. 30, no. 4, p. 04015071, 2015.

[7] X. Chen and F. Zhan, "Agent-based modeling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies," in *Agent-Based Modeling and Simulation*. Springer, 2014, pp. 78–96.

[8] T. Filatova, P. H. Verburg, D. C. Parker, and C. A. Stannard, "Spatial agent-based models for socio-ecological systems: challenges and prospects," *Environmental modelling & software*, vol. 45, pp. 1–7, 2013.

[9] M. Pons, P. A. Johnson, M. Rosas, and E. Jover, "A georeferenced agent-based model to analyze the climate change impacts on ski tourism at a regional scale," *International Journal of Geographical Information Science*, vol. 28, no. 12, pp. 2474–2494, 2014.

[10] A. Drogoul, E. Amouroux, P. Caillou, B. Gaudou, A. Grignard, N. Marilleau, P. Taillandier, M. Vavasseur, D.-A. Vo, and J.-D. Zucker, "Gama: multi-level and complex environment for agent-based models and simulations," in *Proceedings of the 2013 international conference on Autonomous agents and multi-agent systems*. International Foundation for Autonomous Agents and Multiagent Systems, 2013, pp. 1361–1362.

[11] D.-A. Vo, A. Drogoul, J.-D. Zucker, and T.-V. Ho, "A modelling language to represent and specify emerging structures in agent-based model," *Principles and Practice of Multi-Agent Systems*, pp. 212–227, 2012.

[12] R. Debnath and A. N. Amin, "A geographic information system-based logical urban growth model for predicting spatial growth of an urban area," *Environment and Planning B: Planning and Design*, vol. 43, no. 3, pp. 580–597, 2016.

[13] A. Minelli, C. Tissot, M. Rouan, and M. Le Tixerant,

"Simulation of marine activities by coupling geographical information system and agent based model: improvements and technical achievements," *PeerJ Preprints*, vol. 4, p. e2231v2, 2016.

[14] D. J. Peuquet, "It's about time: A conceptual framework for the representation of temporal dynamics in geographic information systems," *Annals of the Association of american Geographers*, vol. 84, no. 3, pp. 441–461, 1994.

[15] C. M. Macal, "Everything you need to know about agent-based modelling and simulation," *Journal of Simulation*, vol. 10, no. 2, pp. 144–156, 2016.

[16] L. Hernández, C. Baladron, J. M. Aguiar, B. Carro, A. Sanchez-Esguevillas, J. Lloret, D. Chinarro, J. J. Gomez-Sanz, and D. Cook, "A multi-agent system architecture for smart grid management and forecasting of energy demand in virtual power plants," *IEEE Communications Magazine*, vol. 51, no. 1, pp. 106–113, 2013.

[17] C. Le Page, G. Abrami, N. Becu, P. Bommel, B. Bonté, F. Bousquet, B. Gaudou, J. P. Müller, and P. Taillandier, "Multi-platform training sessions to teach agent-based simulation," 2015.

[18] P. Taillandier, D.-A. Vo, E. Amouroux, and A. Drogoul, "Gama: a simulation platform that integrates geographical information data, agent-based modeling and multi-scale control," *Principles and Practice of Multi-Agent Systems*, pp. 242–258, 2012.

[19] D. Prunetti, A. Muzy, E. Innocenti, and X. Pieri, "Utility-based multi-agent system with spatial interactions: The case of virtual estate development," *Computational Economics*, vol. 43, no. 3, p. 271, 2014.

[20] T. Takabatake, T. Shibayama, M. Esteban, H. Ishii, and G. Hamano, "Simulated tsunami evacuation behavior of local residents and visitors in kamakura, japan," *International Journal of Disaster Risk Reduction*, vol. 23, pp. 1–14, 2017.

[21] L. Ma, B. Chen, S. Qiu, Z. Li, and X. Qiu, "Agent-based modeling of emergency evacuation in a railway station square under sarin terrorist attack," *International Journal of Modeling, Simulation, and Scientific Computing*, p. 1750022, 2016.

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