A Multi-Agent Geo-Simulation Approach to Assess the Impact of Environment Changes on Crowd Behavior

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Abstract
Most works on crowd simulation have been devoted to the development of systems which aim at mimicking crowd movements in such a way that an external observer (spectator or game player) will have the illusion of observing a real crowd of people. Few works have addressed the issue of creating populations of virtual agents which reflect the behaviors of real persons attending specific facilities such as shopping malls or urban commercial areas, in order to understand the ways that these crowds react to the spatial characteristics of such environments and eventually to changes occurring in such environments. Another issue related to crowd simulation which has been neglected in previous works is the development of approaches and tools to exploit simulation outputs in order to support decision making. In our research work we are concerned with what we call multi-actor dynamic spatial situations (MADSS) involving a large number of actors acting in geographic spaces of various extents. In the MAGS Project we developed an approach and a software to simulate MADSSs. In this paper we present two aspects of our approach that provide new insights on crowd simulation: the creation of agent populations and the analysis of simulation outputs in order to support decision makers when exploring alternative scenarios to manage MADSSs. We illustrate these issues using the case of the MallMAGS System that we built in order to enable mall managers to assess the impact of different configurations of their malls on their customers’ shopping behaviors.

Keywords
Multi-agent geosimulation, agent population creation, simulation output analysis, customer behavior in shopping malls, OLAP-SOLAP techniques

1. Introduction

The simulation of crowds in virtual worlds is a topic which becomes increasingly important in various application domains such as games, computer animation, film production, immersive virtual environments, the study of crowd movements such as the evacuation of public facilities as well as the simulation of crowd behavior in various environments taking into account sociological characteristics of individuals and group behaviors [1]. Several works have been carried out on the simulation of crowds for various purposes such as the study of group formation and crowd motion to support architectural design [2], the analysis of emergency evacuation conditions [3], the simulation of the physical aspects of crowd
dynamics [4], the study of pedestrian flows [5] and the development of virtual reality training system used in various domains such as urban emergency situations [6].

Most works on crowd simulation have been devoted to the development of generic models, algorithms and systems which aim at mimicking the movements of individuals in a crowd in such a way that an external observer, be he a spectator of a movie, a game player or a user immersed in a virtual environment, will have the illusion of observing a real crowd of people [7]. Few works have addressed the issue of creating populations of virtual agents which reflect the behaviors of real persons attending specific facilities such as shopping malls or urban commercial areas, in order to understand the ways that these crowds react to the spatial characteristics of such environments and eventually to changes occurring in such environments. The systems which have been developed in this area are either based on simulation techniques such as cellular automata [8] which are too limited to plausibly simulate the complex spatial behaviors of people navigating in a geographic space, or do not take into account the people’s capabilities of perceiving space and its content [9].

Another issue related to crowd simulation which has been neglected in previous works is the development of approaches and tools to exploit simulation outputs in order to support decision making. This is a critical issue in application domains in which users want to exploit crowd simulation to assess the impact of various intervention scenarios and to anticipate possible reactions of crowds. In our increasingly interconnected and fast-changing world, decision makers from various sectors (governmental, military, industrial, medical, social) need to deal with what we call multi-actor dynamic spatial situations (MADSS) involving a large number of actors acting in geographic spaces of various extents. There are numerous MADSSs that need to be monitored in order to insure human security (flood, earthquake, wildfire), respect of public order (crowd monitoring, evacuation of people, peace-keeping activities) or adequate use of infrastructures (i.e. monitoring of people and households transportation and shopping habits to better plan urban infrastructures). When dealing with MADSSs, decision makers need appropriate tools, especially to anticipate the consequences of their decisions. In the MAGS Project we developed an approach and the MAGS system in order to simulate MADSSs. The MAGS System [10] is a multi-agent geo-simulation platform that enables us to generate geo-simulations involving thousands of agents (with memory, perception, navigation, decision making capabilities) immersed in a 2D or 3D virtual environment created using data from geographic information systems (GIS).

In this paper we present two aspects of the MAGS Project which provide new insights on crowd simulation: the creation of agent populations and the analysis of simulation outputs in order to support decision makers when exploring alternative scenarios to manage MADSSs. We illustrate these issues using the case of the MallMAGS System [11] that we built to enable mall managers to assess the impact of different configurations of their malls on their customers’ shopping behaviors. We worked with data from Square One Mall in Toronto area.

In Section 2 we list some requirements for a geo-simulation system that will be able to simulate MADSSs. We also present some important characteristics of the MAGS platform which is used to simulate MADSSs. Section 3 presents our approach and tools which are based on OLAP (On Line Analytical Processing)-SOLAP (Spatial On Line Analytical Processing) techniques: they are used to collect and analyse data in order to create agent populations for MADSSs. Section 4 gives an overview of the tools that we use to gather data during a geo-simulation and to analyse it. We also show how a decision maker can use these tools to compare different scenarios. Section 5 concludes the paper.
2. Requirements for a tool to simulate and assess MADSSs

In order to simulate multi-actor dynamic spatial situations (MADSS) in ways that may be useful to decision makers, the simulation approach and tools need to satisfy several requirements: 

- **Req1** the virtual simulation environment must accurately reflect the characteristics of the real geographic environment in which the MADSS takes place;
- **Req2** the agent population created for the simulation must reflect the characteristics of the real actors involved in the MADSS (socio-demographic, preferences, goals, behaviors, etc.);
- **Req3** the simulation engine must provide the agents with capabilities that reflect the way people interact with the geographic environment when they are involved in the MADSS;
- **Req4** the user must have access to tools that facilitate the creation of different scenarios (changing the population’s and the environment’s characteristics);
- **Req5** the user must be able to specify the kind of data that he wants to get from the simulation, and
- **Req6** he must have access to tools to easily analyse this data and to compare the outcomes of different scenarios.

In order to comply with Req1 and because we usually need to simulate the behaviors of hundreds or thousands of autonomous agents, the most appropriate way to simulate MADSSs is to use a multi-agent geosimulation approach. Geo-Simulation is a new form of simulation that became popular in geography and social sciences in recent years [12]. It is a useful tool to integrate the spatial dimension in models of interactions of different types (economics, political, social, etc.). Koch [13] and Moulin [10] presented MultiAgent Geo-Simulation as the coupling of two technologies: multi-agent based simulation (MABS) [14] and geographic information systems (GIS). Based on the MABS technology, the simulated entities are represented by software agents which autonomously carry out their activities. They can interact and communicate with other agents. Using the GIS technology, spatial features of geographic data can be introduced in the simulation in order to accurately represent the characteristics of the geographic space.

Several applications have been developed to simulate different kinds of behaviors in spatial environments such as wayfinding [8], the movements of agents in an environment simulated by cellular automata [9] and people movements in a large scale environment representing a town [13]. In these applications, the spatial features of the simulation environment (SE) are represented using maps or cellular automata, but the agent capabilities are often limited. For example, they are not able to effectively perceive the environment and to react to these perceptions. In order to comply with Req3, we need more advanced techniques such as the ones that we implemented in the MAGS platform [10] in which agents are able to perceive the elements contained in the environment, to navigate autonomously inside it and to react to changes occurring in the environment. In order to comply with Req2, we need a method and tools to gather and analyse data about the real population of actors involved in the MADSS in order to create the population of agents used in the geo-simulation (See Section 3). In order to comply with Req4, we need a tool to specify different scenarios: The MAGS platform provides such a scenario management tool. In order to comply with Req5 and Req6, we need tools to gather simulation outputs and to record them in structures that may be easily manipulated by users (See Section 4).

In the rest of this section we present the main features of the MAGS System that are relevant to the present discussion. MAGS agents have several knowledge-based capabilities:

- **The agent perception process:** In MAGS agents can perceive (1) terrain characteristics such as elevation and slopes; (2) the elements contained in the landscape
surrounding the agent including buildings and static objects; (3) other mobile agents navigating in the agent's range of perception; (4) dynamic areas or volumes whose shape changes during the simulation (ex.: smoky areas or zones having pleasant odors). Each agent has a perception field (a cone shaped area whose range and angle are parameterized) which enables it to perceive other agents, environment objects and terrain features in a realistic way.

- The agent navigation process: MAGS agents can use two navigation modes: Following-a-path-mode in which agents follow specific paths which are stored in a bitmap called Ariadne-Map or Obstacle-avoidance-mode in which the agents move through open spaces avoiding obstacles. In MAGS the obstacles to be avoided are recorded in a specific bitmap called Obstacles-Map. The Following-a-path-mode enables MAGS agents to simulate pedestrians’ movements on pavements or car movements on roads in an efficient way. The Obstacle-avoidance-mode enables an agent to go anywhere and to avoid other agents and obstacles that it perceives in its perception field [10].

- The memorization process: MAGS agents have three kinds of memory: Perception memory in which an agent stores what it perceived during the last few simulation steps; Working memory in which the agents memorize what they perceive in one simulation and Long-term memory in which the agent stores what it perceived in several simulations [15].

- The agent's characteristics: In MAGS an agent is characterized by a number of variables whose values describe the agent's state at any given time. We distinguish static states and dynamic states. A static state does not change during the simulation and is represented by a variable and its current value (ex.: gender, age group, occupation, marital status). A dynamic state is a state which can possibly change during the simulation (ex.: hunger, tiredness, stress). A dynamic state is represented by a variable associated with a function which computes how this variable changes values during the simulation. Using the function parameters, the system can simulate the evolution of the agents' dynamic states and trigger the corresponding behaviors [10].

- The objective-based behavior: In MAGS an agent is associated with a set of objectives that it tries to reach. The objectives are organized in hierarchies composed of nodes which represent composite objectives and leaves that represent elementary objectives which are associated with actions that the agent can perform. Each agent owns a set of objectives corresponding to its needs which we usually specify in a similar way as [16]. An objective is associated with rules containing constraints on the activation and on the completion of the objective. Constraints are dependent on time, on the agent's states and on the environment's states. The selection of the current agent's behavior relies on the priority of its objectives. Each need is associated with a priority which varies according to the agent's profile. An agent may have several profiles (i.e. housewife, secretary, mother), each of them corresponding to a set of typical needs and objectives. An objective's priority is primarily a function of the corresponding need's priority. It is also subject to modifications brought about by the opportunities that the agent perceives or by temporal constraints [10].

- The agent communication process: MAGS agents can communicate with each other by exchanging messages using mailbox-based communication.

- The spatial characteristics of the environment and static objects are generated from data stored in a geographic information system and in related databases (See Figure 1 for a 2D view of the environment in the MallMAGS system). These spatial characteristics are recorded in a raster mode which enables agents to directly access the information contained in various bitmaps that encode different kinds of information about the virtual environment and the objects contained in it. The Agents-Map contains the information about the locations of agents and the static objects contained in the environment. The Obstacles-Map contains the locations
of obstacles, the *Ariadne-Map* contains the paths that can be followed by mobile agents, the *Height-Map* represents terrain elevations. The information contained in the different bitmaps is used by the agent’s perception and navigation algorithms. In MAGS the simulation environment is not static and can change during the simulation. For example, we can add new obstacles, or gaseous phenomena such as smoke and dense gases which are represented using particle systems [10].

- The MAGS System provides a *Scenario-Manager* that enables a user to create a scenario in which he specifies the characteristics of the simulation environment (ex. the mall), the characteristics of the objects (ex. stores, kiosks, etc.) and of active agents (ex. Shopper), in the simulation. The agents’ characteristics correspond to their static and dynamic variables, their needs and goals, profiles and behaviors. The scenario manager also allows the user to specify the time and location of the appearance of agents in the virtual world, to eventually assign them high priority objectives and to specify events that may be triggered under specific conditions (i.e. an explosion or a fire spreading). All the specifications are recorded in scenario files which are used to initialize the simulations.

3. Creating agent populations to simulate MADSSs

In this section we propose an approach and tools to gather and analyse data about the real population of actors involved in the MADSS in order to create the population of agents used in the geo-simulation. The first step in this approach is to identify the agent models which are relevant to simulate the characteristics and behaviors of the actors involved in the MADSS.

In the case of the customer behavior in shopping malls, we conducted an extensive literature survey in several disciplines (consumer behavior, marketing, social psychology, etc.). According to several studies, the shopping behavior is influenced by several factors:

- **Internal factors**: Demographic (gender, sex, marital status, life-cycle, sector of employment, etc.), personality, values, culture, attitudes, habits, preferences, emotional factors [17].

- **External factors**: Family, reference groups, social class, etc. [17].

- **Situational and contextual factors**: The environment ambiance (music, odors, temperature, etc.), the spatial and geographic configuration of the environment (layout of the stores, etc.)
textures, color, etc.), the social aspects of the environment (the attendance of other people, staff, etc.), time (time period in a day, in a week, etc.) and the expected duration of shopping [18].

The shopping behavior can be thought of as composed of several processes [19] such as: 1) recognizing shopping motivations, 2) retrieving information used to search for stores (internal search from memory or memorization process; and external search in the environment or perception process), 3) evaluating alternatives (choose a particular store), 4) decision making before visiting a shop, 5) post-decision process (evaluation of the experience after the visit).

Since we found no complete model of customer’s shopping behaviors, we created a model for our shopper agent which includes knowledge (K) and behavior characteristics (B), both spatial (S) and non-spatial (NS). Here are some examples of these characteristics. NS-K: stores’ name and specialty; S-K: locations of stores and entrances; S-B: perception of objects in the environment, memorization of routes; NS-B: perception and memorization of non-spatial information such as ads, store window presentation (for more details see [11]).

In order to get data about the customer population visiting the Square One Mall, we built a thirty-pages questionnaire in order to collect most of the data needed to measure the factors characterizing the customer’s characteristics, his knowledge of the mall and stores, as well as his goals and preferences. The survey took place in October 2003 and we got about 390 filled questionnaires. Thanks to this survey, we collected a lot of non-spatial data (customer’s demographic profile, habits, interests and preferences) and spatial data about the shopper spatial knowledge (preferred entrance doors and parking lots, usual paths followed during the shopping trip, the shopping areas which are best known). The data collected on paper questionnaires has been recorded in a MS Access database thanks to a system that we developed using MS Visual Basic in order to capture both spatial and non-spatial information.

In order to analyze the large number of collected data, we used an approach based on On Line Analysis Processing (OLAP) for the non-spatial data analysis and on Spatial On Line Analysis Processing (SOLAP) for the spatial data analysis [20]. The OLAP-SOLAP approach is a multidimensional technique based on dimensions and measures. Dimensions represent the analysis axes while measures are the numerical attributes being analyzed against the different dimensions (e.g., age group of a person can be considered as a dimension). A dimension contains members which are hierarchically organized into levels (e.g., young, teenager, and old can represent a hierarchy of the dimension age group), each level having a different granularity going from coarse at the most aggregated level to fine at the most detailed level. The measures at the finest level of granularity can be aggregated following the hierarchy and provide information at the higher levels according to aggregation rules or algorithms.

In our case we used an OLAP analysis to analyse non-spatial variables (Dimensions). We also determined the influence of one dimension on another. For example, we analysed the influence of the gender dimension on the color or music preferences dimensions. Using a SOLAP analysis we analysed the relationship between a spatial dimension of the environment and a non-spatial dimension of the Shopper agent. For example, we determined the relationship between the Gender dimension of a shopper and the choice of the shopping corridor or entrance door in the shopping mall.

Figure 3.a presents the entrance doors of the first floor of the Square One shopping mall and Figure 3.b presents the graphical representation of the distribution of the participants on the dimension Floor_Entrance_Door in the shopping mall. We can see in Figure 3.b that the most frequented mall’s doors are Door 0 (97 shoppers) and Door 10 (125 shoppers). The multidimensionality characteristic of the OLAP-SOLAP approach can tell us that among these 125 shoppers who enter by the door 10 there are 65 females and 60 males. Among these
females, 31 have an age between 13 and 25 years, 26 have an age between 26 and 50 years and 8 have are aged over than 51 years. The OLAP-SOLAP technique has the advantage to present these results rapidly (on the fly) and easily. Many other analysis have been carried out on our data and led to the automatic generation of a population of 390 shopper agents whose characteristics reflected those of the surveyed customers. This population of shopper agents was input in the MAGS Platform to carry out geosimulations. Shopper agents are initialized with a list of specific stores or kiosks to visit. The lists are generated before the simulation on the basis of the agents’ characteristics and the data collected during the survey. Each agent enters by a particular entrance and starts the shopping trip. Based on its position in the mall, on its knowledge (memorization process) and on what it perceives in the mall (perception process), the agent chooses the next store or kiosk to visit (decision making process). When it chooses a store or kiosk, it moves in its direction (navigation process). Sometimes, when it is moving to the chosen store or kiosk, the agent may perceive another store or kiosk (perception process) which is in its shopping list and that it did not know before. In this case, the shopper agent moves to this store or kiosk and memorizes it (memorization process) for its next shopping trips. The shopper agent goes on until it visits all the stores or kiosks remaining in its shopping list or until it has no time left. If it has still time for shopping and some stores or kiosks of its list are in locations unknown by the agent, it starts to explore the shopping mall, searching for these stores or kiosks. When the shopper agent reaches the maximum time allowed to the shopping trip, it leaves the mall. Figure 2 presents a snapshot of the 3D environment of MallMAGS System in which we see shopper agents moving around.

Here are some technical details. In the MAGS system, the number of frames which varies between 30 and 100 frames per second, depends on the number of elements to visualize on the screen. Interestingly, we can simulate a large number of agents: for example, if the agents’ structures are simple, we can simulate up to seven or eight thousands of agents on a Pentium III 1000 MHz with 512Mo memory and using Microsoft Windows 2000 Pro (this number may increase with the capacity of the machine). In MallMAGS, we simulated 390 shopper agents with complex structures and behaviors and up to 200 agents representing stores and kiosks.
4. Use the geosimulations for decision making

In order to gather data about the simulation, we created Observer Agents which can be introduced in the virtual environment in order to collect data about the mobile agents which enter their perception field. Figure 1 shows the locations of the observer agents (red dots) in the Virtual Square One Mall. We located observer agents at the entrances of the virtual shopping mall in order to record the number of shopper agents entering and exiting the shopping mall. Other observer Agents have been positioned in corridors in order to count the number of shopper Agents passing by. Metaphorically, these observer agents play the role of the persons who carried out the survey in the real Square One Mall. In order to facilitate the analysis, an observer agent gets all the data associated to each shopper agent entering its perception field (which has been adapted for the collection process) and records this data in files which have the same structure as the files recording the data obtained from the survey with real customers. In this way we can verify that the population of shopper agents ‘behaves’ in a similar way as the customer population surveyed in the Square One Mall. We can collect non-spatial and spatial results during the simulation. When the simulation execution ends, we can analyse the contents of the files generated by the observer agents, using again our OLAP and SOLAP techniques and tools. For example, we can compare data gathered by different observer agents (Figure 4).

![Comparing data collected by different observer agents](image)

**Figure 4:** Comparing data collected by different observer agents

Decision makers can use our geosimulation platform to compare various scenarios, either by changing the characteristics of the agent population or by modifying the configuration of the virtual environment and evaluating the impacts of these changes on the agent population in terms of behavior alteration (i.e. changes of agent’s routes) and/or modifications of values of various agent variable (i.e. changes in agents’ level of satisfaction).
In the case of Virtual Square One, mall managers wanted to assess the impact of changes in the mall configuration such as changes of the location of stores. Indeed, deciding about stores’ locations in a mall is widely recognized as the most decisive factor to determine retails success or failure. As it has been noted over many years, good locations are ‘the keystone to profitability’ [21]. In order to illustrate how our tool can be used to compare mall configurations, we kept the same shopper agent population (Section 3) and we elaborated two scenarios in which the locations of two main stores were exchanged.

The simulation for this first scenario (Figure 5.a) generated output data about the itineraries that the shoppers agents took in the shopping mall. In scenario 2 we exchanged the location of two department stores: Wal-Mart and Zellers (Figure 5.b). We launched the simulation again and MallMAGS generated the output data about the itineraries of the same population of Shoppers agents. In these figures the flow of the agents Shoppers which pass through a corridor is represented by a line which is attached to this corridor. The width and the color of this line are related to the flow of shoppers agents which pass through the corridor. If this flow grows, the width of the line grows and its color becomes darker. By comparing the output data of the two scenarios, we notice the differences between the paths that the shopper agents followed to attend the two department stores. The simulation output analysis shows that corridor X is less frequented in scenario 2 than in scenario 1 (Figure 5.a). However, corridor Y is more frequented in scenario 2 than in scenario 1 (Figure 5.b).

By a data analysis on the characteristics’ dimension of the shopper agent we found out that in scenario 2, most of the shopper agents that go through corridor Y are female and they come to the mall to visit female cloth stores. If the mall manager chooses the mall configuration of scenario 2, he may think of renting the spaces along corridor Y to female cloth stores.

5. Conclusions

In this paper we presented a multi-agent geo-simulation approach and the associated software to simulate crowd behavior in MADSSs. We emphasised two main aspects of our work: tools used to create plausible agent populations to simulate particular MADSSs and tools used to gather data during a geo-simulation and to analyse it. We also showed how a decision maker can use these tools to compare different scenarios. We illustrated our approach using the case of customers’ shopping behaviors in a mall. Our approach can be applied to various cases of
MADSSs. However, we must emphasize that in each particular case the designer will have to customize the way simulation output data is gathered and analysed, taking into account the objectives and needs of the decision makers when it comes to a particular simulation. Hence, our future works will be to develop multi-agent geo-simulations for other types of MADSS in order to gain experience using such an approach to support decision making in various application domains. In addition, in our future works, we will demonstrate it would be interesting to investigate how our approach and tool scale with more complex scenarios simulations apply to particular scenarios such as the simulation of evacuation or panic one such incidents [23] [24].

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