DEVELOPING 2D-3D AGENT BASED SIMULATIONS IN GEOGRAPHIC ENVIRONMENT: AN APPROACH AND ITS APPLICATION TO SIMULATE SHOPPING BEHAVIOR IN A MALL

Walid Ali
Bernard Moulin
Computer Science Department
Research Center on Geomatics
3904 Pav. Pouliot, Laval University, Ste-foy, QC, Canada
{Walid.ali, Bernard.moulin}@ift.ulaval.ca

KEYWORDS.
Simulation method, Agent-Based Simulation, Geosimulation, Shopping behavior, Shopping Mall.

ABSTRACT.
Agent Based Simulation (ABS) differs from other kinds of computer-based simulations in that (some of) the simulated entities are modeled and implemented in terms of agents. The agents' capabilities make ABS an attractive simulation concept. Several researchers proposed methods and approaches to develop ABS applications. Unfortunately, none of these methods or approaches takes into account the spatial and geographic aspects of the system to be simulated or those of the simulation environment. In our research we are interested in Agent-Based geosimulation and we focus on the use of the ABS paradigm to build simulations of human behaviors in geographic environments. This paper aims to present a new generic approach that can be used to develop agent-based geosimulation applications which simulate various kinds of system or agents' behaviors in georeferenced virtual environments. In order to illustrate this approach, we present a practical example of an agent-based geosimulation application which simulates the shopping behaviors of customers in a virtual georeferenced world representing a shopping mall. We also show how mall managers can use this type of simulation to make informed decisions about mall's configuration with the objective of making the mall more comfortable to shoppers.

INTRODUCTION

"Agent-Based Simulation (*ABS*) differs from other kinds of computer-based simulation in that (some of) the simulated entities are modeled and implemented in terms of agents (Davidsson, 2000). The agents' capabilities make ABS more attractive than traditional simulation approaches such as Discrete Event Simulation (*DES*), the Continuous Event Simulation (*CES*), and the Object Oriented Simulation (*OOS*). Several applications are created using the ABS paradigm. Our research concentrates on the use of ABS to build simulations of human behavior in virtual spatial environments. "The simulation of human behavior in space is an extremely interesting and powerful research method to advance our understanding of human spatial cognition and the interaction of human beings with the environment" (Frank et al. 2001). Several researchers used this paradigm to develop applications that simulate different kinds of behaviors in spatial environments. For example, (Raubal, 2001) and (Frank et al. 2001) presented an application which simulates wayfinding behaviors in an airport. (Dijkstra et al. 2001) used cellular automata to simulate pedestrian movements in a shopping mall. (Koch 2001) simulated people movements in a large scale environment representing a town. In these applications, the spatial features of the simulation environment (SE) are represented using maps, cellular automata, etc. Other researchers, like (Moulin et al. 2003), (Mandl 2000) and (Koch 2001) emphasized the importance of using Geographic Information Systems (*GIS*) to represent the spatial and geographic features of the simulation environment. With a good representation of the spatial features of the SE it is possible to create more plausible simulations of agents' behaviors in spatial or geographic environment such as pedestrian movement, migrations, road traffic, etc. With the multitude of applications that emphasize the spatial features of the SE, some simulation sub-fields appeared such as *spatial simulation*, *urban simulation*, etc. (Benenson and Torrens 2004). Recently, a new form of simulation called *geosimulation* became popular in geography and social sciences in recent years. It is a useful tool to integrate the spatial dimension in models of interactions of different types (economics, political, social, etc.) (Mandl 2000). This form is supported by advances both in geographical sciences and in fields outside geography (Benenson and Torrens 2003). (Mandl 2000), (Koch 2001) and (Moulin et al. 2003) presented MultiAgent-Based Geo-Simulation as a coupling of two technologies: The ABS technology and the GIS one.

- Based on the ABS technology the simulated entities are represented by software agents which autonomously carry out their activities. They can interact and communicate with other agents. They may be active, reactive, mobile, social or cognitive (Koch 2001).

- Using the GIS technology, spatial features of geographic data can be introduced in the simulation. The GIS plays an important role in the development of geosimulation models. New methodologies for manipulating and interpreting spatial data developed by geographic information science and implemented in GIS have created added-value for these data (Benenson and Torrens 2003).

There are several research works dealing with simulation development methods and applications. For example, we can cite (Zeigler 1979) (Fishwick 1991) (Fishwick 1995) (Tuncer et al. 1984) (Curwood and Balderston 1963) (Banks 1998) (Averill and Kelton 2000) (Anu 1997) (Groumpos and Merkuryev 2002) who proposed various simulation methods and applications. As mentioned in (Drogoul et al., 2002), these methods and approaches, although useful when it comes to understand how to design a simulation, have some major drawbacks: (1) they do not specifically address MultiAgent Based Simulation, but rather computer simulation in general; (2) they are mainly task-oriented, rather than model-oriented, and make it difficult to understand the difficulties found in translating conceptual to computational models. (Ramanath and Gilbert, 2003), (Drogoul et al., 2002) presented generic methods and applications for ABS but, unfortunately, none of these methods or applications takes into account the spatial and geographic aspects of the system to be simulated or those of the simulation environment. In our work we are interested in agent-based geosimulation which is a recent concept in the computer simulation fields and especially in ABS. Based on our literature review we did not found any method to support the development of agent-based geo-simulations involving a large number of autonomous agents evolving in a georeferenced or geographic virtual environment (Ali and Moulin 2005).

In this paper we propose a generic approach to develop agent-based geosimulations that simulate various kinds of *spatial* agent behaviors in virtual geographic environments. We mean by *spatial behavior,* a behavior which is performed in a geographic environment and relates to the spatial features of such an environment. In this paper, we illustrate our approach using an application simulating customers' shopping behavior in a mall called *Square One* in Toronto. To simulate the shopping behaviors, which take place in a geographic environment, we need to use a multiagent geosimulation approach in order to take into account the spatial characteristics of hundreds of shoppers' activities (perception, displacements, etc.) in the virtual geographic environment (Ali and Moulin 2005).

The paper is organized as follows. In Section 2 we present the main steps of our generic approach for the development of agent-based geosimulations. In Sections 3 and 4 and in order to illustrate our approach, we show how it enabled us to simulate the shopping behavior of customers in a virtual shopping mall. In Section 4 we present how shopping mall managers can use our shopping behavior simulation prototype to make informed decisions about their mall configuration in order to make it more comfortable and attractive to customers. In Section 5, we present related works and we conclude the paper.

CREATION OF A 2D-3D MULTIAGENT GEOSIMULATION

Figure 1 depicts the main steps of our approach. These steps are illustrated using the shopping behavior simulation application.

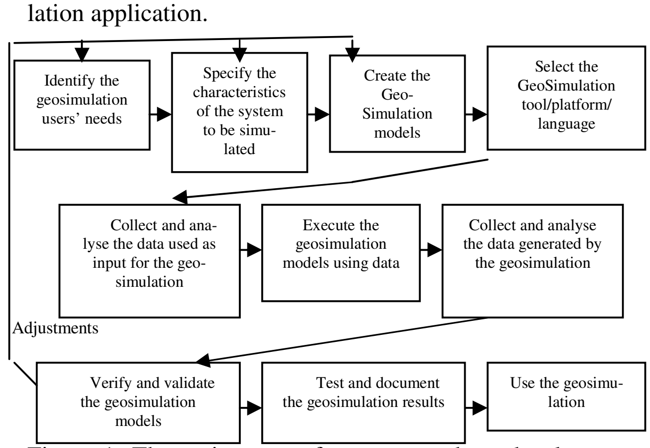

Figure 1. The main steps of our approach to develop multiagent geosimulation

The following sub-sections present the first steps that we propose to follow in order to systematically create geosimulations. The text presenting each step is printed in italics.

Identify the Geo-Simulation users' needs

Simulation applications are generally used to support decision making. In geo-simulation applications decisions are influenced by the spatial characteristics of the simulated system and the geographic features of its environment. Before developing a geo-simulation application we must study in detail the needs and goals of its future users. This step is very important because it helps designers to identify future users, the goals and limits of the system and the goals and limits of the simulation.

In the case of our shopping behavior geosimulation application the users (mall managers) wanted to use the application to simulate and visualize in 2D and 3D customers' shopping behavior in a shopping mall and to assess the influence of different shop locations on the customers' behavior. This evaluation of different mall configurations would help them to make changes in the mall in order to provide customers with a more attractive and comfortable shopping environment. Based on these needs we can limit the context of the geosimulation application to the spatialized *shopping behavior* of customers in a *shopping mall.*

Specify the characteristics of the system to be simulated

Based on the users' needs we must identify the characteristics of the system to be simulated as well as its environment, including all the relevant spatial and non-spatial features within the limits that were defined in the previous step. This step is important because it prepares the ground for the following steps.

In our shopping behavior simulation case we studied the shopping behavior (the system) of people in a mall (the environment). After several months of study of the literature from several disciplines (consumer behaviour, marketing, social psychology, etc.) we got the following results.

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. (Duhaime et al. 1996).

- *External factors*: Family, reference groups, social class, etc. (Duhaime et al. 1996).

- *Situational and contextual factors*: The environment ambiance (music, odors, temperatures, etc.) (Deborah et al. 1991), the spatial and geographic configuration of the environment (layout of the stores, textures, color, etc.), and the social aspect of the environment (the attendance of other people, staff, etc.) (Eroglu and Gilbert 1986).

- *Other factors*: The temporal factor (period of time in the day, in the week, in the month, in the year, etc.), expected duration of shopping.

The shopping behavior can be thought of as composed of several processes such as (Petrof et al.,1978)**:** 1) *recognizing shopping motivations*, 2) *information retrieval* used to search for stores where to shop (internal search from the memory or memorization process; and external search in the environment or perception process), 3) *evaluating of alternatives* (choose a particular store), 4) *decision making* before visiting a shop, 5) *post-decision process* (evaluation of the experience after visiting a shop).

The presentation of the details of these factors and processes is not in the scope of this paper. For more details refer to (Duhaime et al. 1996), (Petrof et al. 1978) and (Deborah et al. 1991).

Create the geosimulation models

In order to be able to simulate the studied system using a computer, we must model it as well as its environment, taking into account their spatial and non-spatial aspects. Since our simulation approach is based on the agent technology, we use an agent-oriented design method to create the models and represent the entities of the simulation. The Agent-Based Unified Modeling Language (AUML) (http://www.auml.org/) is an example of such a method. In a simulation we can distinguish two categories of entities: passive and active agents.

The Passive Agent model (PA) is used to specify entities which do not have behaviors. Usually, the most important elements of the simulation environment belong to this category. We must characterize the spatial and non-spatial ***structures*** of the passive agents. In the shopping behavior simulation case the majority of the shopping mall entities such as stores, kiosks, toilets, doors, entertainment areas, rest areas, smoking areas and parking lots are represented by this category of agents.

- *Non-spatial structure (The Store PA)*: The non-spatial structure of a Store PA contains the information which is specific of a particular store in the virtual SE. For example this structure contains the Store_Identification, the Store_Name, the Store_Speciality, etc. The details of the non-spatial structure of the others PA are not given in this paper.

- *Spatial structure (The PA of the spatial environment)*: The 2D spatial (geographic) structure of the spatial environment PA is modeled using the GIS software GeoMedia (http://www.intergraph.com/). Figure 2.a presents the 2D spatial structure (GIS) of the first floor of the Square One Mall. To create the 3D spatial structure of the PA, we use the software 3DStudioMax (http://www.techanim.com/). A portion of the 3D spatial structure of the first floor of the Square One Shopping Mall is displayed in Figure 2.b. To make our simulation environment more realistic we used pictures of stores windows as textures that were put on the facades of the stores in the virtual

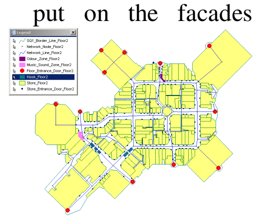

Figure.2.a: The 2D spatial structure of the simulation environment agents

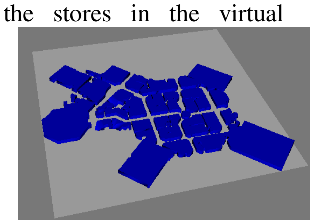

Figure.2.b: The 3D spatial structure of the simulation environment agents

The Active Agent model (AA) is used to specify entities having behaviors. These entities actively participate in the simulation. In this model we specify the ***data structures*** of the entities (spatial and non-spatial structures) and their ***behaviors*** (spatial and non-spatial behaviors). In the shopping behavior case we only consider one category of agents which represent the shoppers.

- *The non-spatial structure (The Shopper AA)*: In the non-spatial structure of the Shopper agent we take into account the shopper's characteristics which can influence the shopping behavior in a shopping mall. We specify the agent's demographic profile (identification, name, gender, age group, etc.), preferences, habits, shopping goals, emotional states, as well as dynamic variables (hunger, thirst, etc.), possession state (what the agent owns), agent's knowledge (what the agent knows in the mall: the stores, the toilets, etc.), etc. A dynamic variable is a variable whose values change during the course of the simulation. Dynamic variables can be used to activate certain behaviors. For example, when the need to go to the toilet reaches a certain threshold, the goal of finding a toilet becomes a priority (Moulin et al. 2003))

- *The spatial structure (The Shopper AA)*: The spatial structure of the Shopper AA depicts the spatial representation of the agent in the simulation environment. For example, in the 2D simulation, the spatial structure of the Shopper AA can be a point, a circle or a square. In the 3D simulation, we represent the agents' spatial structure using a 3D shape (a 3D mesh) which represents a young man/woman, an old man/woman; we can choose the colors of clothes.

- *The non-spatial behavior*: In the non-spatial behavior of the Shopper AA are included the main processes of the shopping behavior which are not related to the external environment such as the needs detection process, the internal information retrieval process, etc.

- *The spatial behavior*: The spatial behavior of the shopper agent depicts the agent's interactions with the simulation environment (movement, obstacle avoidance, path finding, etc.). For example, in a 2D spatial behavior we can see the agent move from one location to another. In a 3D spatial behavior, and using a 3D mesh animation, the agent "walks" in the 3D model of the shopping mall.

Select a geosimulation tool/platform/language

During this step the designer must choose the simulation tool, platform or language that will be used to execute the simulation models. Several simulation tools, platforms and languages can be used to simulate systems or behaviors. Naturally, a question arises: How to select the appropriate simulation platform or tool for a given application? Metrics to evaluate simulation tools include modeling flexibility, ease of use, modeling structure (objects, agents, etc.), code reusability, graphic user interface, animation, hardware and software requirements, output reports, customer support, and documentation.

For our shopping behavior simulation we used a generic platform called MAGS (Multi-Agent Geo-Simulation) (Moulin et al. 2003) which can be used to develop agent-based geosimulations that involve a large number (thousands) of autonomous software agents interacting in virtual geographic environments (VGE). In MAGS the agents are capable to perform "cognitive" and spatial activities in the VGE because they perceive the objects contained in the virtual spatial environment, the features of the ground, paths, roads, buildings and other static objects as well as the other moving agents (Moulin et al. 2003). They are also able to navigate autonomously in the simulation environment based on their perception and memorization mechanism (Perron and Moulin 2004). They also make decisions based on their goals and sub-goals whose priority varies in function of their needs (physiological, social, emotional, etc.) represented by dynamic variables. The needs may be prioritized according to Maslow's classification (Maslow, 1970).

Collect and analyse the data used as input to the Geo-Simulation

In this step we collect data and transform it in order to feed the simulation models. If it is acceptable to input random data in the simulation models, this step can be very simple but the simulation may be unrealistic. But, if we want to use real data we must collect and analyse it before feeding it in the system. Since we deal with geosimulations, we must collect and analyse both non-spatial and spatial data. In our approach we use OLAP and SOLAP techniques to analyse the input data.

For the shopping behavior simulation case and in order to have a realistic simulation we used real data that our team collected in the Square One shopping mall. In this section we briefly explain how we collected the data and which techniques we used to analyse it.

The data collection: The data characterizing the spatial environment is recorded in a GIS and obtained after processing different documents: maps, descriptions of stores, etc. For the creation of the shopper agents we did not have any data. Consequently, we decided to build a survey to collect data about real shoppers visiting the shopping mall. Thanks to this survey that was conducted in the Square One mall during October 2003, we collected about 390 filled questionnaires. In these thirty-pages questionnaires 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, preferred parking lots, usual paths followed during the shopping trip, the shopping areas which are best known in the shopping mall). The data has been collected on paper questionnaires. In order to digitalize this data, and using Microsoft Visual Basic, we programmed a software that is used to input non-spatial and spatial data about the shoppers into a Microsoft Access database.

The data analysis: OLAP and SOLAP analysis: The survey provided lots of non-spatial and spatial data which must be analysed. To do this analysis we used a multidimensional analysis approach based on *On Line Analysis Processing* (OLAP) for the non-spatial data and on *Spatial On Line Analysis Processing* (SOLAP) to analyse the collected spatial data (Bédard and al. 2001). OLAP-SOLAP approach is geared towards decision-support as it is designed from the start to be *easy* and *rapid* (Rivest et al. 2001).

For the shopping behavior simulation case, an example for the OLAP and SOLAP analysis results is presented in the two following points.

- *OLAP analysis*: Using OLAP analysis we can analyse non-spatial variables which are called *Dimensions*. We can also determine the influence of one dimension on another. For example, we can determine the influence of the gender dimension on the color or music preferences dimensions. Actually, we analysed results about all the dimensions of our model of the Shopper agent. We can further analyse the data by combining dimensions together.

- *SOLAP analysis*: Using a SOLAP analysis we can determine the relationship between a spatial dimension of the environment and the non-spatial dimension of the Shopper agent. For example, we can determine the relationship between the Gender dimension of a shopper and the choice of the shopping corridor or the shopping floor in a 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).

Figure. 3.a: The entrance doors of the first floor (Square One Mall)

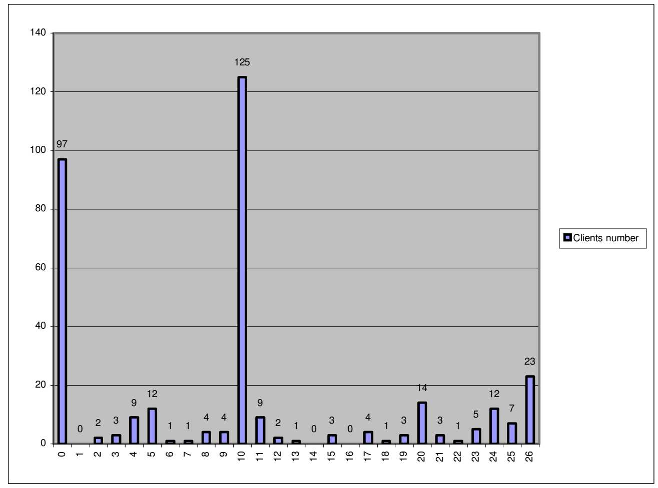

Figure. 3.b: The distribution on the Floor_Entrance_Door dimension

RUN & VALIDATE THE GEOSIMULATION

In this section we present the steps of our method which consist in running the geosimulation, collecting relevant data generated by the simulation, and validating the geosimulation models, and using the geosimulation for decision making.

Execute the geosimulation models

During this step we implement the simulation models on the selected simulation tool/platform/language using the data characterizing the system and its environment. During this step we must respect the constraints and limits of the selected tool/platform/language such as the input data structures.

To develop our shopping behavior simulation, we used the MAGS platform. For each simulation we must prepare a simulation scenario. In such a scenario, we must indicate for example which percentage of shopper agents (with specific characteristics) enter at each door at given times. To create this scenario we use a dedicated interface that belongs to the MAGS platform.

After the simulation scenario preparation we can execute the simulation models in the MAGS simulation engine. Figures 4.a and 4.b present respectively 2D and 3D screen of the simulation execution using MAGS. In this figure we can see the shopper agents who navigate in the environment and visit stores to achieve their shopping goals.

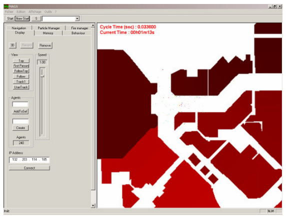

Figure.4.a: A 2D simulation execution: The shopping behavior in the Square One shopping mall (Toronto)

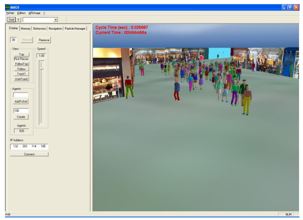

Figure.4.b: A 3D simulation execution: The shopping behavior in the Square One shopping mall (Toronto)

In the simulation prototype the Shopper agent comes to the mall to visit a list of specific stores or kiosks (by name or type) that are chosen on the basis of the agent's characteristics and of the data collected during the survey. It enters by a particular door and starts its shopping trip. Based on its position in the mall, on its spatial knowledge (memorization process) and on what it perceives in the mall (perception process), it makes decision about 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 toward the chosen store or kiosk, the agent can perceive another store or kiosk (perception process) that is in its shopping list and that whose location was not in its memory. 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 accomplishes this behavior continually until it visits all the stores or kiosks which were on its visit list or until it runs out of time for its shopping trip. If the shopper agent 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 to search for stores or kiosks (exploration mode). When the shopper agent reaches the maximum time allowed to the shopping trip, it leaves the mall.

The Shopper agent can also come to the mall without a specific list of stores or kiosks in order to explore it. In this exploration mode the Shopper agent follows its preferred paths in the shopping mall. In this mode the moving action of the Shopper agent to the stores, kiosks, music zones, odor zones, lighting zones, is directed by its habits and preferences. For example, if the Shopper agent likes *cars* and it passes in front of a car exhibition, it can move and stop to attend this exhibition. To extend our simulation prototype we can simulate the shopper reactions to the mall's atmosphere. We can insert special agents that broadcast music, lighting or odor in specific areas. When the shopper agent is in the exploration mode; if it perceives and likes the music or the lighting or the odor broadcasted in these areas, it can move toward them and possibly enter the store increasing its level of satisfaction.

During its shopping trip the Shopper agent can feel the need to eat or to go to the restroom (simulated by a dynamic variable reaching a given threshold). Since these needs have a bigger priority than the need to shop or to play, the agent temporarily suspends its shopping trip and goes to the locations where it can eat something or to the restrooms. In our geosimulation prototype the priorities of the activities of the shopping behavior are defined on the basis of Maslow's hierarchy of needs (Maslow 1970).

Collect and analyse the data generated by the Geo-Simulation

To be useful, the simulation application must return meaningful results. Based on these results and on the analysis of these results, the users can make decisions. In our approach and in order to analyse the simulation output data, we use the same OLAP and SOLAP analysis techniques that are used to analyse the simulation input data. It is important to indicate that the simulation output data is generated by a specific type of software agents: Observer agents.

In the example of the shopping behavior simulation we collect data from the models execution thanks to special software agents called *Observer Agents*. The role of an observer agent is to collect data from the shopper agents which come nearby (in the observer agent's perception range) and to store this data in files or databases. When the simulation execution ends, we can analyse the contents of these files or databases in order to make a report about the simulation results. We can collect non-spatial and spatial results during the simulation. Using again our OLAP and SOLAP techniques and tools we can analyse these results. For the shopping behavior simulation example, we designed the structure of the Observer Agents that collect the simulation results and then we worked on the analysis of these results. For example, Observer agents located at the entrances of the virtual shopping mall record the number of Shopper Agents entering and exiting the shopping mall. Other Observer Agents count the number of Shopper Agents going through specific areas. Other Observer Agents collect different data such as the Shopper Agents' satisfaction when exiting the shopping mall. This Observer agents' activity is similar to conducting a survey in the virtual environment of the same kind as the one we conducted in 2003 in the real shopping mall. Hence, we are able to use the same OLAP and SOLAP analyses that we used to analyze the data of the survey conducted with real shoppers.

Verify and Validate the Geo-simulation models

During this step we can compare the simulationmodels under known conditions with the system that we simulate. This step not only ensures that the model assumptions are correct and consistent, but also enhances the users' confidence in the simulation models (Anu 1997).

Based on the simulation input data and the simulation results we can verify and validate our simulation models.

In the case of shopping behavior simulation, we did not perform this step yet. To this end, we are investigating various verification and validation techniques to verify and validate simulation systems. These techniques have to be customized for geo-simulations. Currently, we plan to use the technique of validation by comparison between the simulation models and the real system which is simulated. We plan to collect data about real shoppers in another mall and compare them with the Agent-Based Geo-Simulation output results in order to validate the shopping behavior models.

Test and document the Geo-Simulation

During this step we document and test the simulation. In the documentation we present the results of the system analysis, the simulation models, the selected tool/platform/language, a guide to use the simulation interface, the input/output data analysis results, etc.

Currently, we have documented a large part of our shopping behavior Geo-Simulator. We hope to complete this documentation and to deliver it to the final users (the Square One shopping mall managers) in the coming months.

Use the geosimulation for decision making

The last step of our approach is to exploit the results of the multi-agent Geo-Simulations in order to for example:

- Understand the system to be simulated by observing various simulations carried out over long periods of time using the Geo-Simulation platform.

- Compress time to observe a system over long periods or expand time to observe it in details. To this end, the user can control the simulation time step.

- Experiment the system in new situations or contexts in order to assess the influence of different decisions.

Our shopping behavior simulation can be used by shopping mall managers to make decisions related to *the spatial configuration of the shopping mall.* The shopping mall manager can change the spatial configuration of the virtual mall (change a store features or position, close a door or a corridor, etc.). For each change he runs the simulation and collects the results. By comparing these results he can make decisions about the best spatial change or configuration for the shopping mall. How to propose a systematic way to carry out these comparisons is still an open research area.

To illustrate the use of the Shopping behavior geosimulation tool we used 2 simulation scenarios. In the first one we launch a simulation with a population of 390 shoppers similar to the population of customers interviewed during the October 2003 survey (Figure. 5.a). This first scenario generates for us output data about the routes that the Shoppers Agents follow in the shopping mall. In the second scenario we exchange the location of two department stores: *Wal-Mart* and *Zellers* (Figure. 5.b). We launch the simulation again and we generate the output data about the routes of the same population of Shopper Agents. By comparing the output data of the two scenarios we notice the difference of the paths that the Shopper Agents followed to attend *Wal-Mart* and *Zellers* stores (Figures 5.a and 5.b). In these figures the flow of the Shopper Agents which pass through a corridor is represented by a line which is drawn in the middle of this corridor. The width and the color of this line are proportional to the flow of Shoppers agents that pass through the corridor. If this flow grows, the width of the line grows and its color becomes darker. 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 can see 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.

The data analysis of the geosimulation output (non-spatial and spatial data) is implemented in an analysis tool that we developed using *Microsoft Visual basic 6.0*. This user-friendly tool uses the data generated in "Output files" by the *Observer* Agents. Then, based on a "Dimension file" which contains a hierarchy of dimensions, it computes measures for one dimension (i.e.. Gender or Age group) or for a combination of dimensions (i.e. Gender and Age group) using an OLAP (On Line Analytical Processing) analysis approach. These measures are recorded in "Analysis files". Then, the tool's interface uses the data contained in the analysis files in order to display multidimensional non-spatial and spatial results. Non-spatial analysis is the result of crossing non-spatial dimensions related to shopper agents. Spatial analysis is the result of crossing non-spatial dimensions with the position of each Observer Agent (corridor) which represents a spatial dimension.

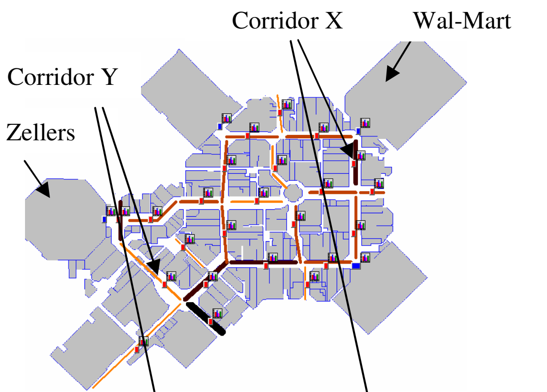

Figure. 5.a: The spatial data analysis in Scenario 1

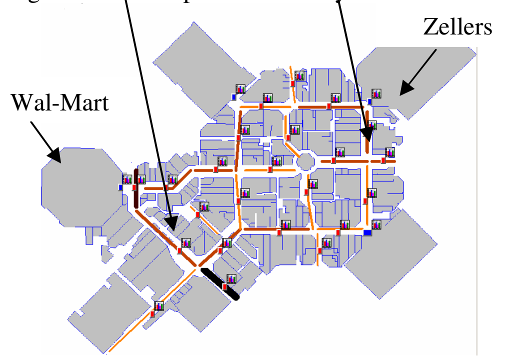

Figure. 5.a: The spatial data analysis in Scenario 2

RELATED WORKS AND CONCLUSION

Some systems such as as traffic systems, urban systems are spatially explicit (objects are associated with locations in geographic space) and exhibit mobility (they move around in the environment). It is relevant to simulate them using the ABS paradigm. Unfortunately, we cannot follow one of the methods or approaches proposed by (Zeigler 1979) (Fishwick 1991) (Banks 1998) (Anu 1997) (Groumpos and Merkuryev 2002) (Ramanath and Gilbert, 2003) (Drogoul et al., 2002) to simulate them. The reason is that these methods do not take into account the spatial and geographic aspects of the system to be simulated or those of the simulation environment. In our work, we are restricted to a recent simulation concept called geosimulation and we propose a generic approach which can be followed to develop 2D-3D Agent-Based applications that simulate some behaviors which are performed in geographic environments. What distinguish our approach is that we take into account the geographic characteristics of the agents and their virtual environment when we develop the simulation. These characteristics are not taken into account (or at best only partially) by existing methods despite their importance in the system to be simulated.

To illustrate this approach we presented an Agent-Based geosimulation application in which we simulate the customers' shopping behavior in a virtual mall. Our simulation prototype is still under development. Consequently, we did not illustrate some of steps of the proposed approach, but this will be done in the near future.

In few months we hope to go through the two final steps (verify/validate our Agent-Based geosimulation models and test/document the geo-simulation) of our approach and to apply them to our simulation prototype in order to deliver a final simulator to its future users.

In conclusion, our research has a very good potential for innovation. To our knowledge it is one of the most elaborated existing simulations of shoppers behavior in a mall because it takes into account both the agent's cognitive abilities (perception, memorization, decision making) and the spatial behaviors of shoppers when moving in a georeferenced environment.

ACKNOWLEDGE

This research is supported by GEOIDE, the Canadian Network of Centers of Excellence in Geomatics, and by the Defense research center (RDDC Valcartier).

REFERENCES

Ali W., Moulin B. 2005. "Towards a generic approach to develop 2D-3D Multiagent Geo-simulation". to appear in the proceedings of the Agent Directed Simulation (ADS'05) (Part of the 2005 Spring Simulation Multi-Conference (SpringSim'05)), San Diego, California (USA), 2-7.

Anu M. 1997. "Introduction to modeling and simulation", Proceedings of the 29th conference on Winter simulation, p.7-13. December 07-10, Atlanta, Georgia.

Averill M. L., Kelton W. D. 2000. "Simulation modeling and analysis". Edited by Averill M. Law, W. David Kelton.

Banks J. 1998. "Handbook of simulation: principles, methodology, advances, applications, and practice". Edited by Jerry Banks.

Bédard Y., Rivest S., Marchand P. 2001. "Toward better support for spatial decision making: Defining the characteristics of Spatial On-Line Processing (SOLAP)". Geomatica, the Journal of the Canadian Institute of Geomatics, Vol. 55, No. 4, p. 539-555.

Benenson I., Torrens P. 2003. "Geographic Automata Systems: A New Paradigm for Integrating GIS and Geographic Simulation". In proceedings of GeoComputation conference, p. 24-30, Southampton, UK.

Curwood A. H. and Balderston F. E. 1963. "Symposium on simulation models: methodology and applications to the behavioral sciences". Edited by Austin Curwood Hoggatt and Frederick E. Balderston.

Davidsson P. 2000. "Multi Agent Based Simulation: Beyond social simulation". In Moss, S. and Davidsson, P. (Eds.) *Multi Agent Based Simulation*, Springer Verlag LNCS series, Vol. 1979.

Deborah J., Macinnis C., Whan P. 1991. "The Differential Role of Characteristics of Music on High- and Low-Involvement Consumers' Processing of Ads". The Journal of Consumer Research, Vol. 18, No. 2, p. 161-173.

Drogoul A., Vanbergue D., Meurisse T. 2002. "Multi-Agent Based Simulation: Where are the Agents?". In Proc. of MABS'02 (Multi-Agent Based Simulation, Bologna, Italy, July 2002), LNCS, Springer-Verlag.

Dijsktra J., Harry JP., Bauke U. 2001. "Virtual reality-based simulation of user behavior within the built environment to support the early stages of building design". In M. Schreckenberg and S.D. Sharma (ed.): Pedestrian and Evacuation Dynamics. Springer-Verlag, Berlin. p. 173-181.

Duhaime, Kindra, Laroche, Muller. 1996. "Le comportement du consommateur". 2ème édition. Gaétan Morin, éditeur.

Eroglu A., Gilbert D. 1986. "Retail Crowding: Theoretical and Strategic Implications". Journal of Retailing, 62 (Winter), p. 346-363.

Fishwick P. A. 1991. "Knowledge-based simulation: methodology and application". Fishwick P. A. and Modjeski R. B., editors. Springer Verlag, 1991.

Fishwick P. A. 1995. "Simulation model design and execution: building digital worlds". Edited by Paul A.

Frank A.U., Bittner S., Raubal M. 2001. "Spatial and cognitive simulation with multi-agent systems". in D. Montello (edt.), Spatial information Theory: Foundations for Geographic Information Science, Springer Verlag, LNCS 2205,124-139.

Groumpos P., Merkuryev Y. 2002. "A methodology of Discrete-Event Simulation of Manufacturing Systems: an overview". Studies in Informatics and Control: with emphasis on useful applications of advanced technology. Volume 11 Number 1, p. 103-110.

Koch A. 2001. "Linking Multi-Agent Systems and GIS-Modeling and simulating spatial interactions-". Department of Geography RWTH Aachen. Angewandte Geographische Informationsverarbeitung XII, Beiträge zum AGIT-Symposium Salzburg 2000, Hrsg.: Strobl/Blaschke/Griesebner, Heidelberg, p. 252-262.

Mandl P. 2000. "Geo-Simulation- Experimentieren und Problemlösen mit GIS-Modellen". In Angewandte Geographische Informationsverarbeitung XII, Hrsg.:Strobl/Blaschke/Griesebner, Wichmann Heidelberg, p.345-356.

Maslow A. 1970. "Motivation and Personality". 2nd ed., Harper & Row,

Moulin B., Chaker W., Perron J., Pelletier P., Hogan J. 2003. "MAGS Project: Multi-agent geosimulation and crowd simulation". In the proceedings of the COSIT'03 Conference, Ittingen (Switzerland), Kuhn, Worboys and Timpf (edts.), Spatial Information Theory, Springer Verlag LNCS 2825, p. 151-168.

Perron J., Moulin B. 2004. "Un modèle de mémoire dans un système multi-agent de géo-simulation", Revue d'Intelligence Artificielle, Vol 18/5-8, Hermes.

Petrof V. 1978. "Comportement du consommateur et Marketing". La presse de l'université Laval.

Ramanath A.M., Gilbert N. 2003. "Toward a Methodology for Agent-Based Social simulation Research". Agent-Based Social Simulation Special Interest Group Meeting (Agent-Oriented Software Engineering and Simulation session), p. 3-24, Barcelona, Spain.

Raubal M. 2001. "Agent-Based Simulation of human wayfinding. A perceptual model for unfamiliar building". PhD thesis. Vienna University of Technology. Faculty of Sciences and Informatics.

Rivest S., Bédard Y., Marchand P. 2001. "Toward Better Support for spatial decision making: Defining the characteristics of spatial on-line analytical processing (SOLAP) ". Geomatica Vol. 55, N. 4., p.539-555.

Tuncer I. O., Zeigler B. P., Elzas M. S. 1984. "Simulation and model-based methodologies : an integrative view". NATO Advanced Study Institute on Simulation and Model-based Methodologies: an Integrative View (1982 : Ottawa, Ont.).

Ziegler B. P. 1979. "Methodology in systems modelling and simulation". Proceedings of the Symposium on Modelling and Simulation Methodology, held at the Weizmann Institute of Science, Rehovot, Israel, August 13-18.

AUTHORS BIOGRAPHIES

ALI W. obtained a Master degree in Computer Science from Laval University (Quebec). He is now a PhD Student (supervised by Bernard Moulin since 2001). He is mainly interested in using multi-agent systems to simulate behaviors and phenomena in virtual spatial environments. He is working on a project whose goal is to simulate shopping behavior in shopping malls using geosimulation and multi-agent systems.

MOULIN B. obtained an engineering degree from Ecole Centrale de Lyon (1976), a degree in Economics (University Lyon2) and a PhD (applied mathematics-computer science, University Lyon1 (1979)) all in France. He is currently a full professor at Laval University in the Computer Science Department. He is also one of the main researchers of the Research Center in Geomatics at Laval University. He has been working on software engineering and artificial intelligence for more than 20 years. He is supervising research projects mainly supported by the Natural Sciences and Engineering Research Council of Canada, the FQRNT fund of Quebec, the Network of Centers of Excellence in Geomatics GEOIDE and the Defence Research and Development Center at Valcarier. His main interests are: multi-agent systems, agent-based geosimulation, applications of AI techniques in geomatics, modeling and simulation of software agents' conversations.