Coupling Multiagent Simulation and GIS – an Application in Waste Management

NIKOLAOS V. KARADIMAS, GEORGE RIGOPOULOS, NIKOLAOS BARDIS
National Technical University of Athens,
School of Electrical & Computer Engineering,
Zografou Campus, 157 80 Athens, Greece
GREECE

Adj. Assistant Professor
Department of Automation
Technological Education Institute of Halkis
34400 Psahna, Halkis, Evia, Greece

Abstract: - Urban solid waste management is one of the most demanding issues of today’s urban areas, requiring large investments for efficient daily collection. Decision makers in the field face many complex decisions varying from solid waste collection to strategy development for the entire urban solid waste management process. Although several researchers have proposed algorithmic solutions and optimization techniques, not a single approach can handle all the variations. We propose a model for dealing with the complexity of the field based on integration of GIS data and multiagent simulation into an intelligent decision support system. This paper demonstrates the model and our initial work towards developing the system. In general, the collection process is abstracted to an agent model, simulation scenarios are executed and results are validated against field data. Our approach provides substantial benefits for the decision makers in the field, enabling them to experiment with possible scenarios and optimize their decisions.

Key-Words: - Multiagent Simulation, GIS, Waste Management

1 Introduction and motivation
Urban areas face nowadays many challenging issues. One of the most demanding ones is solid waste management, since it requires efficient and effective decisions from stakeholders. However, due to the intrinsic complexity of environmental and urban systems, decision makers in the field need intelligent tools in order to optimize their decisions. Geographic Information Systems (GIS) provide a platform to deal with such complexity providing tools for modeling and visualization. Researchers have been using digital terrain representation, overlay and distance mapping techniques to model urban and environmental systems [1]. In addition, temporal extensions of GIS [2] have also been utilized for dynamic and temporal issues of such systems. Cellular Automata (CA) [3] and Agent based modeling [4] provide useful methods and tools to model and visualize such complex phenomena. According to the CA approach urban and environmental systems are considered as self organized and global patterns emerge as a result of local interaction. In the agent based approach the population of a real system is abstracted to its artificial counterpart. Each member of the population is represented by an agent with built-in behaviors. Macro behavior thus emerges from micro behaviors, enabling the study of complex environmental and urban phenomena by executing appropriate simulations.

This paper demonstrates our initial work towards integrating GIS and Multiagent Based Simulation (MABS) towards an intelligent Decision Support System (DSS). The application field is the urban solid waste management process, where we argue that this approach provides substantial benefits for the decision makers. In the remainder of the paper, we provide some background on agents and multiagent simulation (Section 2), present an overview of the proposed model (Section 3) and conclude with some initial findings and discussion (Section 4).

2 Background and relevant work

2.1 Agents
What is an agent? A formal description of the autonomous agent is “a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the
future” [5]. Thus an autonomous agent could be humans, animals, autonomous mobile robots, artificial life creatures, and software agents.

2.1 Multiagent Simulation (MAS)
Agent based modeling and simulation has been lately used in various scientific areas that study complex systems [6]. The term simulation means the process of building a computer-based experiment written in a computer language. “Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system. “ [6].

The initiation of simulation is a target system from real life that provides re-searcher some preliminary empirical data and findings, enough to build an abstraction or hypothesis that reflects the behavior of the real system. Abstraction is not always complete or valid, so according to scientific method an experiment should be executed to validate abstraction against reality. In cases where lab experiments are feasible the validation process is based on experimental findings. However there are research areas such as social or economic domains, where lab experiments are not feasible. For such domains simulation provides a useful method for validation against empirical data.

A simulation model is a computer program that is constructed based on the abstraction, and executed in the context of a computer environment in order to support or not the hypotheses of the abstraction. Validation refers to the methodology of testing simulation results with empirical data in order to validate the abstraction hypothesis of simulation. Epistemological questions regarding the validity of simulation against lab experiments as a method for scientific knowledge have been raised during last years where agents have been used extensively. However, in social domain and decision support processes simulation provides a valid method for understanding macro patterns of the target domain that emerge from micro interactions between individuals. Jager [7] also argues towards using multi agent simulation as appropriate methodology for the study of social phenomena that is not possible to be studied in a lab, and proposes a meta-model of behavior for developing agent rules that may be used to formulate agent behavior in an agent-based simulation [8].

2.2 GIS

GIS provide tools to administer and manipulate information and geographical with respect to underlying complexity and spatial relations. Several application domains ranging from ecological modeling to urban development may be abstracted within a GIS. GIS software enhances decision making in policy, economy and administration, based on spatial information [9]. Main components of GIS are software instruments for analysis and administration of data and the geographic data base. Most GIS also provide graphical user interfaces for visualization increasing the usability for users.

2.3 Relevant research
Following we mention some relevant studies which refer to GIS and Multiagent modeling within complex systems such as environmental and urban ones. Gonçalves et al. [10] propose a framework for coupling GIS and MAS for the study pf complex dynamic systems. They use static coupling between MAS and the GIS package and demonstrate an application in environmental issues deriving from stonecutting industry companies. Koch [11] demonstrates an approach of integrating GIS and MAS using SWARM platform and ArcView GIS, in order to model and simulative households’ behavior. Batty and Jiang [12] study space-time dynamics combining GIS and Cellular Automata, as well as agent-based modeling and multi-agent simulations. They illustrate their findings in route finding in systems where distance and direction are largely unknown; spatial systems where gradients are important in directing movement and location such as river systems and watersheds and systems where viewsheds are critical to measuring geometric properties such as in building complexes and landscapes. Jiang [13] studies modeling environmental and urban systems within GIS using agent-based approach. Finally, Schule et al. [14] demonstrate a file-based coupling that is integrated into a process model for developing Multi-Agent Simulation with a GIS-based environmental representation.

3 Proposed model

3.1 Technology and Architecture
Technology selection was based on requirement of interoperability. Major issues were compatibility with existing platforms and applications, performance, ability to use existing hardware and operating environment. For the above reasons we
selected Java as the platform for the MAS, and Oracle RDBMS for the database components. In more details, in order to be easily integrated into various infrastructures and be web deployed, Java 2Enterprise Edition (J2EE) was selected for the building of the DSS module. Java 2Enterprise Edition is an architecture for building server-side deployments in the Java programming language and may be used to build traditional web sites, software components, or packaged applications. For the MAS engine and simulation development Java/SWARM platform was selected. Swarm is a Java library which implements agent-based technology and can be used to model MAS of complex systems. The SWARM project [15] is designed to serve as a generic platform for modeling and simulating complex space-time dynamics. It provides a set of classes for the definition of agents’ properties and behaviors. Although various projects have been developed on the SWARM system [16], SWARM requires advanced programming skills. However, several attempts have been made to provide simple platforms based on SWARM engine [17].

ArcView GIS software was selected to visualize real field data from various sources. Oracle RDBMS was selected for the databases and JDBC interface is used for connection between core DSS module and databases. Finally, XML interface is used between clients and DSS module. Since GIS software and simulation engine are not integrated into one product, we link them together. In general four alternatives are available:

- **loose coupling**: GIS- and Simulation-Software are two different products and the data of one are integrated into the other
- **tight coupling**: GIS functionality is implemented in Simulation-Software or vice versa
- **direct co-operative coupling**: GIS- or Simulation-Software is working as Server or Client and while using just one interface, the Server-Software maintains in the background
- **indirect co-operative coupling**: A third programming environment couples both GIS and Simulation Software

We follow a loose coupling approach for the integration of SWARM and GIS. All necessary data are exchanged between the two platforms using a data file with appropriate format. Initially, GIS data are generated and imported into the MABS system. At the end of the simulations, response data are sent back to GIS for further processing.

### 3.2 Model

Below we demonstrate an overview of our model, which is part of an ongoing project towards intelligent decision support for waste management in urban areas. We have gathered both qualitative and quantitative data from several sources regarding population and present garbage trucks routing. According to these data, we have developed a number of GIS maps representing accurately the domain. In order to couple GIS with the multiagent system, we abstracted GIS maps to 2D lattices, where waste bins are represented as points, and actual distances are converted to appropriate units (fig. 1).

![Fig. 1. GIS map transition to 2D lattice](image)

Next, in order to create the agent model, garbage trucks are represented as intelligent agents (fig. 2) with the following characteristics:

- **Limited waste capacity**
- **Limited time on the field**

and equipped with the following operations:

- **Collect waste bin**
- **Follow path**
Next, several simulation scenarios are executed based on GIS data from the field. Each agent follows a route at the 2D lattice, collects waste bins up to the specified time and capacity limit (fig. 3).

From the initial simulations preliminary results have been collected and analyzed (fig. 4). In addition, we validate the simulation outcomes against data collected from daily field garbage trucks’ routes.

Further work includes full development of the intelligent decision support system that will utilize both GIS input and MAS in an integrated system, suitable for facilitating decision makers of the domain.

5 Conclusion

In this paper we presented an overview of our ongoing work towards an intelligent decision support system for waste management. Within this approach we integrate GIS and multiagent modeling and simulation following some recent approaches. From our initial findings, simulation in combination with GIS input provides substantial benefits in dealing with urban solid waste management for stakeholders of the domain.

References:


[12] http://www.rwthaachen.de/geo/Ww/deutsch/MultiAgentsKoch.PDF


