Agent-oriented model for simulation of complex systems with spatial component

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Abstract: The purpose of this paper is to present a new approach for agent-oriented simulation of complex systems with spatial component based on coupling between multi-agent systems and geographic information systems. We propose a generic model of agent-oriented simulation that we will apply to the field of land use planning. In fact, simulating the evolution of the urban system is a key to help decision makers to anticipate the needs of the city in terms of installing new equipment and opening new urbanization areas to install the new population.

Keywords: Multi-agent system, Geographic information system, Modeling, Simulation, Complex system, Land use planning.

1. INTRODUCTION

The agent-oriented simulation has been developed considerably in recent years and is now used in a growing number of sectors, where it is gradually replacing the micro-simulation and the object-oriented simulation.

In this paper, we propose a generic model for agent-oriented simulation of complex systems with spatial component. This model is based on two modules:

- A GIS module: to instantiate the simulation engine.
- A MAS module: to represent the interactions between the different agents of the system

We apply our model to the field of land use planning. In fact, we will study the urban system and simulate its long term evolution through a backdrop of demographic change in a spatio-temporal heterogeneous environment. Our objective is to understand how public policy can influence the transformation of cities, especially in regard to the opening of new urban areas and installing new equipments.

2. STATE OF THE ART

In this section, we will detail the multi-agent systems, complex systems and agent-based modeling. These three points are the core of our design model simulation.

2.1 Multi agents approach

2.1.1 Notion of agent

An agent is a physical or virtual feature, which owns all or part of the following: [1]

- Located in an environment: means that the agent can receive sensory input from its environment and can perform actions that are likely to change this environment.
- Independent: means that the agent is able to act without the direct intervention of a human (or another agent) and he has control of its actions and its internal state.
- Flexible means that the agent is:
  - Able to respond in time: it can sense its environment and respond quickly to changes taking place.
  - Proactive: it does not simply act in response to its environment; it is also able to behave opportunistically, led by its aims or its utility function, and take initiatives when appropriate.
  - Social: it is capable of interacting with other agents (complete tasks or assist others to complete theirs).

2.2.2 Multi agents system

A multi-agents system (MAS) is a system composed of a set of agents situated in some environment and interacting according to some relations. There are four types of agent architecture [2]:

- Reactive agent: is responding to changes in the environment.
- Deliberative agent: makes some deliberation to choose its actions based on its goals.
- Hybrid agent: that includes a deliberative as well as a reactive component
- Learner agent: uses his perceptions not only to choose its actions, but also to improve its ability to act in the future.

2.2 Complex system

A complex system is a set consisting of a large number of interacting entities that prevent the observer to predict its
feedback, behavior or evolution by calculation. It is characterized by two main properties [3]-[4]:

- Emergence is the appearance of behavior that could not be anticipated from the knowledge of the parts of the system alone.
- Self-organization means that there is no external controller or planner engineering the appearance of the emergent features.

This type of complex systems is called "Complex Adaptive Systems" (CAS). System adaptation is ultimately concerned with the adaptation of each individual element of the system, since there is no centralized control and therefore no single “object” that represents the entire system.

### 2.3 Agent-Based Modeling of Complex Systems

We note that the Agent-Based Modeling (ABM) is well suited to complex adaptive systems. In fact, the various components of these systems can be represented by agents. We mention below four characteristics that show why Agent-Based Modeling is well suited to complex adaptive systems [4]-[5]:

- Emergence: ABMs allow to define the low-level behavior of each individual agent in order to let them interact (over time and space) to see whether some emergent property arises or not, and if it does, under which circumstances.
- Self-Organization: ABMs do not have any kind of central intelligence that governs all agents. On the contrary, the sole interaction among agents along with their feedbacks is what ultimately "controls" the system. This lack of a centralized control is what enables (and enforces) its self-organization.
- Coupled Human-Natural Systems: ABMs allow considering together both, social organizations with their human decision-making with biophysical processes and natural resources. This conjunction of subsystems enables ABMs to explore the interrelations between them, allowing analyzing the consequences of one over the other.
- Spatially Explicit: the feature of ABMs of being able to spatially represent an agent or a resource is of particular interest when communications and interactions among neighbors is a key issue. This can either imply some kind of internal representation of space or even the use of a Geographical Information System (GIS) with real data. This feature is of special interest in the case of agro-ecosystems.

### 3. Agent-Oriented Simulation vs Classic Simulation

#### 3.1 Definitions

Simulate is to reproduce a phenomenon in order to [6]:

- Test hypotheses to explain the phenomenon.
- Predicting the evolution of the phenomenon.

Model is a simplified picture of reality that we use to understand the functioning of a system based on a question.

#### 3.2 Classic Simulation

##### 3.2.1 Continuous models

Continuous time models are characterized by the fact that in a finite time interval, the system state variables change value continuously [6]-[7].

The simulation of continuous models encounters the difficulty of reproducing the continuity of the system dynamics due to the nature of the digital computer (solution: use of numerical integration methods).

##### 3.2.2 Discrete models

The evolution of variables' state of the system is discretely at a time \( t + \Delta t \) [7].

The simulation of discrete models can be summarized in two steps:

- Determine the function that implements the system dynamics.
- Increment time by one unit.

In this type of simulation the choice of the time step is very important because:

- If a large time step:
Problem of management competitive events;
Events in rapid occurrence are not considered.

• If small time step:
  Problem of decomposition behavior in elementary behaviors.

3.2.3 Discrete event models
The time axis is generally continuous; it’s represented by a real number. However, unlike continuous models, the system state variables change discretely at precise moments that are called events.

![Figure 4 Discrete event models](image)

In this type of simulation, there are three policies implementation:

• Scheduling of events: during the simulation, the future events that must occur on the system are predetermined;
• Analysis of activities: during the simulation, the events are not planned but triggered when certain conditions are met (collision of two vehicles, ...);
• Interaction process: this approach is the combination of the two others.

3.3 Limits of Classical Simulation
In the classical simulation, we found the following limits [6]:

• Equation in model with a large number of parameters;
• Difficulty of passing micro/macro, unable to represent different levels;
• No representation of behavior, but their results;
• Lack of realism (social sciences...);
• Does not explain the emergence of space-time structures;
• Difficulty of modeling the action.

3.4 Agent-Oriented Simulation
Agent-Oriented Simulation (AOS) is now used in a growing number of sectors, where it gradually replaces the various techniques of micro simulation and object-oriented simulation. This is due to its fundamental characteristics which are [6]-[9]:

• Representation as computer agents (state, skills, abilities, resources);
• Representation of possible interactions between agents;
• Representation of space-time environment (agent is located).

This apparent versatility make the AOS the best choice for simulating complex systems and it spreads in a growing number of areas: sociology, biology, physics, chemistry, ecology, economics, land use planning, etc.

The four aspects of a simulation model are:

• Module behavior: it relates to the deliberative process modeling agents;
• Module environment: the problem is to define the various physical objects in the world and the dynamics of the environment;
• Module scheduling: it concerns the modeling of the flow of time and the definition of scheduling used;
• Module interaction: it relates specifically to the modeling result of the actions and interactions they entail at time t.

4. Proposed Approach
4.1 System Architecture
The simultaneous use of a geographical information system and a multi-agents system introduces an additional level of modeling complex system with spatial component. We propose the following architecture:

![Figure 5 Proposed architecture](image)

• The module "GIS" is a descriptive representation of the reality that is used to initialize the multi-agent model, it contains the data to instantiate each one of the agents;
• The module “MAS” is used to model the real system and generate simulations involving agents that react and interact and so it can test scenarios.

4.2 Generic model of agent-oriented simulation
To simulate complex systems with spatial component, we propose the following generic model:

![Figure 6 Generic model for agent-oriented simulation](image)
- The environment is heterogeneous composed of objects and spatial agents;
- Spatial Agent: This is the basic entity that represents the spatial part of our simulator. Each spatial agent has its own behavior;
- Agent manager: it is the agent that creates and acts on all environmental agents. Also, it interacts with the scheduler agent to determine the scheduling of its actions on the agents. It is responsible for the initialization of the simulation;
- Agent scheduler: Its role is to schedule the actions of the agents on the environment;
- Agent decision maker: it has several rules that must be applied to the environment

5. APPLICATION

5.1 Problematic of land use planning

We propose to apply our architecture to the field of land use planning. Our goal is to understand how public policy can influence the transformation of cities, especially in regard to the opening of new urban areas and installing new equipment. The simulation will determine when, during the dynamic of the city, public policy can act and have the most impact. As the modeling context we choose the city “Casablanca”, and more specifically the district “Dar Bouazza”.

5.1.1 Population dynamic

The population of Casablanca was established in the 2004 census, approximately to 3.63 million residents, 3 325 000 in urban areas and 305 000 in rural areas. It has an annual growth (50 500 persons per year) For the district Dar Bouazza, it has a population of 115367 residents with a growth rate of 9.8% [10].

5.1.2 Spatial dynamic
- Not enough housing: Housing remains a subject of major concern for the government. In fact, the insufficient offer of housing is a major problem in the field of land use planning.
- Lack of equipment in some region: the district “Dar bouazza” is experiencing an apparent lack of equipment.
- Lack of green spaces: Casablanca knows deficiencies of green spaces. The average is less than 1m² of public green space per resident, compared to the standard 10 m² per resident of the World Health Organization.

5.2 Agent-oriented simulation model

We apply our agent-oriented model in the context of land use planning, the system consists of: Agent Manager, Agent scheduler, LandUseAgent and two agents decision maker.
taking them from its target list (starting from the highest potential of the cells).

### 5.3 Realization

To implement our model, we chose the multi-agent simulation platform Repast Simphony 2.0 [11] and the GIS software ArcGIS. Our work environment is:

![Environment work](image)

Figure 8 Environment work

The initial state of the simulator:

![Initial state of the simulator](image)

Figure 8 initial state of the simulator

Legend :
- Bare land
- Built land
- Industrial area
- Green space

After five iterations, the population of “Dar Bouazza” has increased from 115,367 to 171,896 residents. To install the new population, UrbanAgent will open new areas to urbanization. It calculates the demand and changes a number of cells of the SpaceAgent (starting from the highest potential of the cells) to built land. The choice of cells to change is done in a random way. We obtain the following result:

![Results of the simulation](image)

Figure 9 Results of the simulation after five iterations

### 6. Conclusion

In this paper, we propose architecture based on coupling between the two systems GIS and MAS. We also propose an agent-oriented simulation model for simulating complex systems with spatial component. We applied our model to the field of land use planning. Our objective is to simulate the evolution of the city based on two dynamics: population dynamics and spatial dynamics. The results show that after five iterations, it will be necessary to open about 100 ha to urbanization.

As perspectives to our work, we will enrich the knowledge base of Decision maker agent. In fact, more this model will be enriched by heating engineers (City planners, statisticians, sociologists …) more it can help decision makers to have several simulation scenarios. Also, we can detail the agent scheduler to show how the scheduling system can influence the outcome of the simulation.

### References


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Fatimazahra Barramou received her engineer degree in Geographic Information System in 2009 at the Hassania School of Public Works (EHTP : École Hassania des Travaux Publics), Casablanca, Morocco. In 2010 she joined the system architecture team of the National and High School of Electricity and Mechanic (ENSEM: École Nationale Supérieure d’Electricité et de Mécanique), Casablanca, Morocco. Her actual main research interests concern Modeling and simulating complex systems based on Multi-Agent Systems and GIS.

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