MASE: Multi-Agent System for Environmental Simulation

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Abstract. *MASE is a multi-agent system designed as a framework to characterize, predict and explore the land-use change dynamics. It aims to assist the decision-making process by the use of environmental simulations, which is based on a hybrid modeling technique. The methodological two-fold approach intends to form a solid backbone and a replicable parameterization process. The framework is illustrated with a case study of the Brazilian Cerrado using a spatially explicit model.*

1. Introduction

Environmental policy and management is a complex problem since it involves the integration of many actors with a cross-disciplinary knowledge of socio-ecological processes. Among the existing challenges to be overcome there is the Land Use and Cover Change (LUCC) processes, which are amongst the most pervasive and important sources of recent alterations of the Earth's land surface [Houet et al. 2010]. LUCC research aims to support insightful management of land resources in order to avoid irreversible damage [Le et al. 2008].

The environmental domain demands the integration of different resources, among them, computer methods, techniques and tools to help dealing with the complexity of real models. In computer science multi-agent system (MAS) and multi-agent-based simulation (MABS) can contribute to the analysis of scenarios through agent representation of different human interaction patterns, that are essential to a better understanding of real environmental problems, including social, economical and physical aspects.

MAS explicitly represent human decision making processes by means of agents, presented as autonomous computer entities interacting directly with themselves and the environment, in order to achieve goals [Naivinit et al. 2010]. MABS of LUCC can inform policy setting and decision-making processes on the use and management of land resources. The simulation results can represent the causal chains and feedbacks of LUCC, and thus be used as learning instruments for understanding the system dynamics and to explore future scenarios by testing the effect of land policies [Verburg 2006].

In this paper we present research efforts to apply MAS and MABS techniques in order to define a conceptual model to characterize land use change dynamics. The conceptual model definition allowed the development of a tool to assist the decision-making process by the use of environmental simulations, which is entitled MASE: *Multi-Agent System for Environmental simulation*. Section 2 presents the backbone of the conceptual model and the MASE system. Section 3 illustrates with the Brazilian Federal District case and Section 4 discus conclusions and future work.

2. MASE overview

In order to form a solid backbone for the conceptual model, using MAS and MABS to LUCC modeling and simulation, a methodological two-fold approach was adopted based on: (i) the systematic and structured empirical characterization of the model [Smajgl et al. 2011]; and (ii) the conceptual structure definition according to the agent-based model documentation protocol - Overview, Design concepts and Details [Grimm et al. 2006].

The empirical characterization and the conceptual structure of the model were defined by a group of ecologists from the University of Brasilia (UnB) and from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). The motivation behind this group was to forge the MASE system by its potential users: researches and land-use decision makers.

MASE was developed based on the conceptual model definitions using a hybrid modeling technique applying: top-down and bottom-up structure [Verburg 2006]. MASE enables modeling and simulations of LUCC dynamics using a configurable user model. The MASE architecture involves different classes and sub-classes of agents. Each agent class is related to the definition of entities responsible for specific decision-making, execution of actions, perceiving the environment and the execution of the time-steps in the simulation. For a complete description of MASE see Ralha et al. (2013).

The first version of MASE prototype uses five classes of agents as presented in Table 1: GRID Manager, Spatial Manager, Transformer Manager, Cell Agent and Transformer Agent. New instances of these classes can be created and expanded as the modeling of different agent behaviors emerge. There are linked images related to the agent classes, e.g., the map of urban areas are associated with urban agents which forms a specific level of simulation. Figure 1 presents MASE defined architecture.

Table 1. The structure of MASE class agents

Agent Class	Type of agent	Number of instances	Actions
GRID Manager (GRIDM)	Goal-based	1	Promote interface parameterizations defined by users Manage start, pause and end of agents Receive agents state for the visualization Promote agents state visualization for the user
Spatial Manager (SM)	Goal-based	1	Set the instances of cells to simulate Get orders from GRIDM and replicates to cells Receive the states of cells and replicates to GRIDM
Transformer Manager (TM)	Goal-based	1	Set the instances of TA for simulation Get orders from GRIDM and replicates for TA Receive TA states and replicates to GRIDM
Cell Agent (CA)	Reflexive agent with internal state	Set by the user	Perception: Receive tasks from SM Inform state to SM agent Begin land/vegetation recovering or stop it Signal whether or not land is occupied by TA
Transformer Agent (TA)	Reflexive agent with internal state	Set by the user	Perception: Receive tasks from TM Inform state to TM agent Request position change to TM agent Moving from one cell to another Explore the cell Identify if cell has exhausted its ability to be exploited

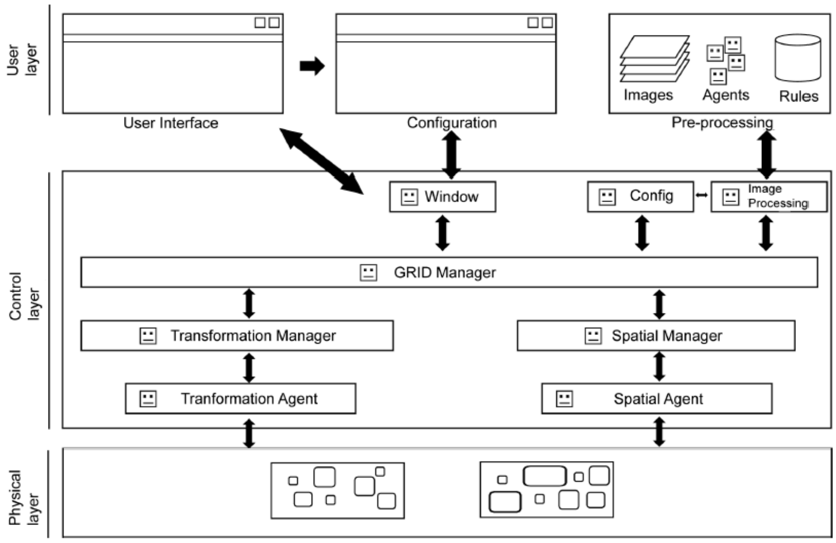

Figure 1. MASE architecture

As a spatially model implementation, MASE uses an explicit approach since it can receive a set of input images to simulate land changes. The space is represented through a grid, or a set of cells, that is occupied by computational agents that interacts. It is a different concept from cellular automata, where each cell in the grid has a finite number of states and changes over time according to a fixed rule. The MAS allows each cell to know its own state and change according to the action of a Transformer Agent and according to its perceptions of the simulation environment. Transformer Agents may have different behavior, as a consequence, neighbor cells might be under unique land use constraints at the same execution time step.

The development of MASE was performed using the Java Agent Development Framework (JADE), version 4.0. JADE is a Java middleware for developing and executing agent-based applications. For the image manipulations we used the open source ImageJ Library. The agent interaction protocol used in MASE allows the simulations of cooperative and competitive agent interaction. MASE was developed at the UnB as a research project, but although the intensive implementation efforts conducted it is still a prototype (https://sourceforge.net/p/mase-unb).

3. The Federal District case

The Brazilian Federal District Cerrado was chosen for a study case since it is the major savanna-like ecosystem in Brazil. It has 68.11% of its 5,789 km^2 of native vegetation cleared, even having 90% of protected area by law (strict protection or sustainable use). The input of the simulation used two maps: the initial time (2002 – t0) and a subsequent time (2008 – t6). The maps were obtained by a semi-supervised classification technique of LANDSAT ETM satellite images performed by IBAMA for the deforestation control of the Cerrado. The total area of study was divided into cells, in which every set of four cells represents one hectare, which is represented by a different Cell Agent. The physical state of the cells is monitored (cell conservation). They can be influenced by six proximal variables defined by the user (Figure 2): (a) railways, (b) highways, (c) water courses (rivers), (d) water bodies (lakes), (e) streets, and (f) buildings. The input of the proximal variables is done in form of map layers that might affect the behavior of Cell Agents and Transformer Agents.

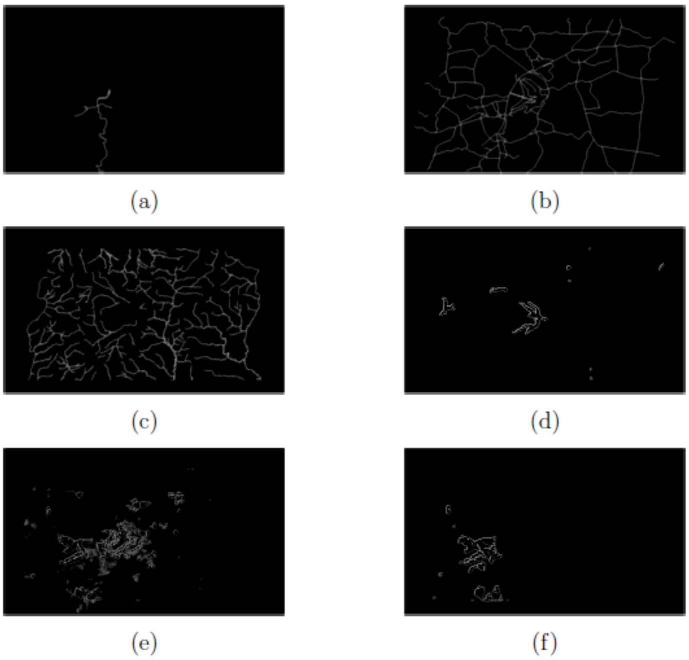

Figure 2. Proximal Variables defined for the Cerrado case

In the simulation process, the human factor over the land is represented by two different Transformer Agent types: farmer and rancher. Each one has a predefined goal and behavior set by the user. The political aspects are also taken as a compelling force in the simulation, translating the Federal District Spatial Plane (PDOT) onto an influence matrix for the agents who will change the use of the land.

The simulation results are illustrated in Figure 3. According to the scientifically rigorous method of Pontius et al. (2008), our simulation results indicate the potential of the presented multi-agent model system. Considering the accuracy of the simulations using MASE, the application results were better than the null model, what examines both the behavior of the model and the dynamics of the landscape. MASE was able to use the correct or nearly correct net quantities for the categories in the prediction map.

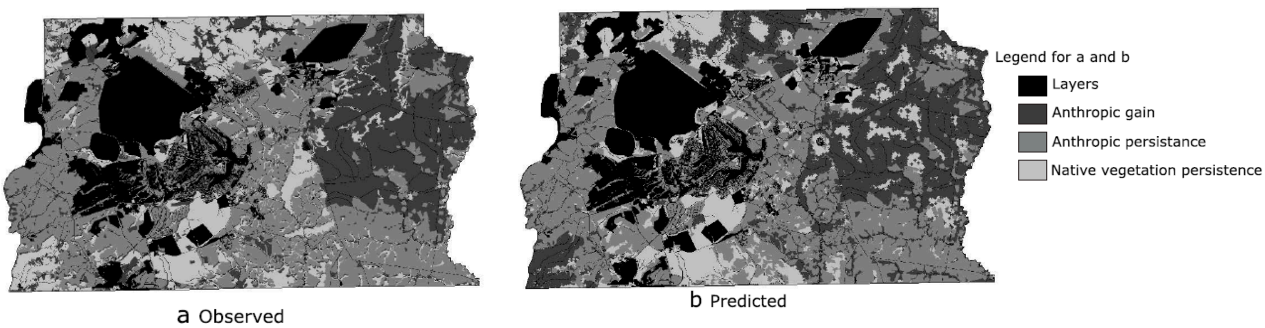

Figure 2. Simulation results for the Federal District maps: a) observed change 2002–2008, and b) predicted change 2002–2008

4. Conclusions

The MASE system is a multi-agent model system to simulate LUCC dynamics, using multiple agents to represent the interaction among different agent types. Considering the experimental results presented so far, we consider the multi-agent model system presented represents an interesting alternative for LUCC simulation developers. The model is done in a spatially-explicit, integrated and multi-scale manner, being important for the projection of alternative pathways for conducting experiments that test human understanding of key processes in land-use changes.

The MASE systems prototype is hardcoded. Future work aims to improve the system interface and usability, aiming a general purpose LUCC simulator that can be used to create, set and calibrated environment models, regardless users modeling experience. Future works will also increase agent's rationality and autonomy, both challenging aspects of intelligent agent research.

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