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A Model of the biocomplexity of deforestation in tropical forest: Caparo case study

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Abstract: This paper presents some preliminary results with a multi-agents modeling approach to understand the complexity of deforestation in tropical forests. The approach was applied to the study of the deforestation of the Caparo Forest Reserve, in the western part of Venezuela. The model includes, among others, the following types of agents: several instances of settlers, government and lumber concessionaries. Settler agents represent people of limited economical resources that occupied land of the reserve with the aims of improving their socio-economical status and obtaining in the future the property of the occupied land. They use subsistence agriculture and they try to maximize the benefits from the land occupation, without knowing that they could generate ecological or environmental problems such as soil exhaustion, due to inexistent or poor management practices. The lumber concessionaires are represented by companies that are constantly supervised by the State; their work is to exploit the forest using management plans previously approved in agreement with the Government. In addition to the dynamical interactions of the agents, the used approach includes also a cellular automata model for the simulation of the dynamic of the natural system. Both aspects use representational tools developed in house: Galatea [Uzcátegui, 2002] for the multi-agents aspects, Actilog [Dávila, 2003] a logic language for the description of rules, and SpaSim [Moreno, 2001, 2003] for the Cellular automata aspects.

Keywords: Biocomplexity, Spatio-Temporal models, Multi-agents modeling and simulation.

1. INTRODUCTION

This study is a subproject of “Biocomplexity: Integrating Models of Natural and Human Dynamics in Forest Landscapes Across Scales and Cultures”
[http://www.geog.unt.edu/biocomplexity]
It is carried out at the Caparo Forest Reserve in Venezuela wit the aim to model and simulate land-use processes and changes in vegetation cover as a consequence of human actions and the effects of the changes in subsequent human decision-making.

Human behavior affecting forest sustainability is simulated using multi-agent models, there are rules to generate dynamics similar to what is observed at the forest reserve; meanwhile, forest dynamic is represented by a Cellular Automata.

Explicit modeling of human actions and their interaction with ecosystems will give policymakers information about the impact of their decisions on the future composition, structure, and functionality of local ecosystems. It will also facilitate a more informed analysis of the long-term consequences of private choices and public policies on the natural systems in which human systems are embedded and with which they interact [Acevedo et al. 2003].

The structure of this paper includes: a brief description of the Caparo Forest Reserve and the agents considered; models’ description; implementation details; and finally, the conclusions and comments about future work.

1.1 Case Study

The Caparo Forest Reserve, CFR, was created in 1961 and its original purpose was to support the development of the logging industry in the zone, while preserving one of the finest forests of Venezuela [CESIMO, 1998]. It is located southeast of the Barinas State, in the Venezuelan western plains region. Its extension is of 176,434

hectares, and it has been divided on three units to facilitate its management (Figure 1).
The study takes place in Unit I, an area of 53,358 hectares, which itself includes a special area called the Experimental Unit, that is used by the University of Los Andes for research and educational activities.

Currently, only 7,000 ha. survived (all in the Experimental Unit).Nevertheless, this area is still not exempted from deforestations due to agrarian settlement process.

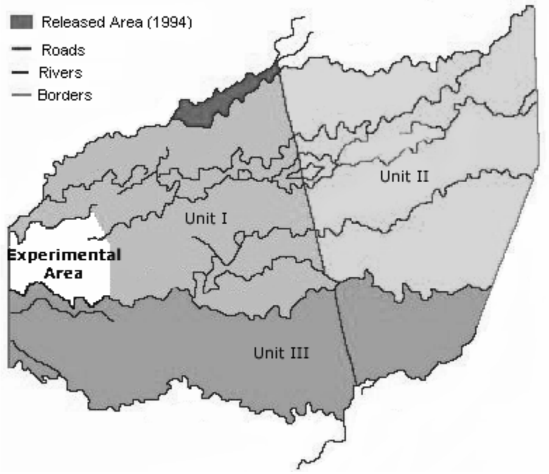

Figure 1. Caparo Forest Reserve Units [Jurgenson, 1994].

Many factors have contributed to forest disappearing in the CFR: unsuitable forest management of some lumber concessionaires, contradictions between different governmental organisms, poverty and the demand of lands for agricultural activities, and the existence of political interests in favor of settlements, among others factors [Ablan et al., 2003].

The following is a description of the most important characteristics of the agents implemented in the models.

1.2 Settler Agent
According to Rojas [1993], the first settlers took possession of a certain area at the reserve and practiced subsistence (i.e. slash and burn) agriculture. This surface could be an uncultivated land (previously deforested and unoccupied). Before five years, the soils are exhausted, and the harvests are no longer enough to sustain the settler and his family. Some settlers try to expand their farms at the expense of new deforestation. However, sooner or later, they will end facing the same situation. The alternative is to seed pasture for cattle (which gives value to the land) so that later, they will be able to sell its improvements to landlords or other settlers.

At this stage, pasture retailers and landlords acquire the improvements of primary settlers. Extensive cattle ranch dominates the land-use. After some years, the property of the parcels is transferred to the settlers, by application of the Agrarian Reform. Then the parcels are sold at very low prices, to landlords, politicians and cattle dealers who urged and supported the original settlements [Centeno, 1997]. This process, characterized by the concentration of the property, forces the initial group of settlers to move towards primary cycle settlements or to wage-earning work (as workers for landlords) [Sánchez, 1989].

There is in the model a settlement function that considers those places that are more attractive for this agent: land-uses without supervision, such as plantations, secondary bushes and prairies. At the same time, this function model the movement of the settlers using weighted by distance buffers around rivers, borders and roads.

1.3 Concessionary Agent
The lumber concessionaires are represented by private companies that have the function to carry out the forest exploitation and management plans in the reserve areas under the supervision of the Government.

The lumber concessionary agent implemented, makes a very simplistic and hypothetical forest management within the reserve: the lumber concessionaire exploits the forest and proceeds to plant commercial valuable species; furthermore, the concessionaire is in charge of forest plantations supervision during the first two years [Ablan et al., 2003].

In case that the concessionaire finds a settler on its assigned zone, there are two behaviors implemented: -the first one implies that the concessionary agent ignores the settler and continues the work at another place that is not occupied by settlers; - the second one implies that the concessionary agent informs to the Government about the settlements.

The implemented concessionary agent has a 30 year cycle and it is allowed to harvest 1,200 ha of "Forest" annually (Figure 2); after the concessionary acts on the site, the use of land is changed to "Logged Forest". Once the 30 year cycle is over, the concessionary could harvest the first compartment again (the concessionary area is divided in "compartments").

1.4 Government Agent
Three different behaviors or scenarios were implemented for the Government agent. These behaviors represent different ways of the role of the government at the CFR. Their specification is as follows:

1. The Government neither interacts nor interferes with the activities of the others agents. It does not have any monitoring activity. This is called the **“**Hands-off” government model**.**
2. The Government has a “strong” policy to keep settlers away from protected forest areas (called at our models as the “Pro-Forestry Government”). This agent has a monitoring process where any settler founded at the CFR area is evacuated. Furthermore, if the concessionary agent, on its exploitation process, finds a settler in the zone, the government agent receives the settlement’s information from the concessionary and the indicated settlers will be removed from the CFR area in the next government’s monitoring process
3. The Government has an “agroforestry” policy, which means that this agent monitors the forest area trying to protect it, but when he finds a settler, the settler will be relocated to a special area for agricultural activities. At the same time, the government agent receives settlements’ information from the concessionary agent and then the indicated settlers are relocated.

The “Pro-forestry” and the “Agroforestry” governments evaluate the concessionary’s exploitation and plantation quotas. The concessionary will be punished by the government in case the concessionary has failed the agreed quotas.

Monitoring is based on a function that considers the places that are more attractive for settlements (buffers around rivers, CFR borders, roads…).

2. THE MODELS

On the above specification, three computational models have been developed. They differ only in the implemented behavior of the Government agent.

Each model counts with a hundred settler agent instances (identified from 1 to 100), and one concessionary agent.

Land-use change is modeled as cellular automata. State transition rules are simplifications of the ecological dynamic of forest succession at the CFR. Other characteristics of the model are:

- Number of layers: 6.
    1. Land-uses Layer: each cell can be in any of the fifteen states described on the Figure 2.
    2. Time in Use Layer: used as a time count layer that indicates the time that a cell has spent remaining at a determined state.
    3. Population Layer: each cell can be in some of the following states: - 0 represents an unoccupied cell; - 1, there is a settler occupying the cell; - 2, there is a landowner occupying the cell.
    4. Supervision Layer: each cell can be in some of the following states: - 0, that represents a no watched over cell, - and 1, that indicates a watched cell.

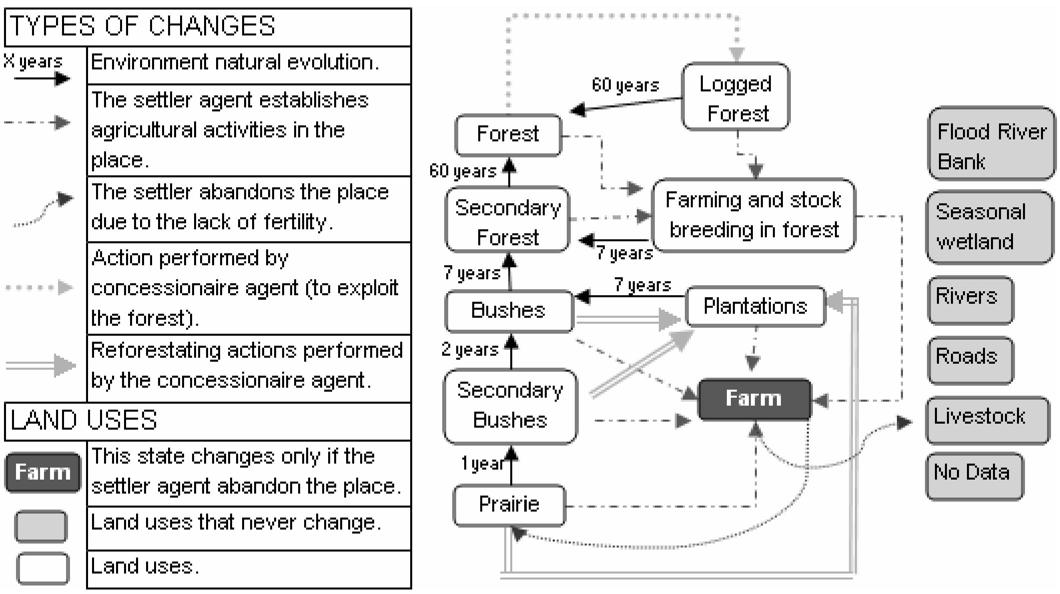

Figure 2 Land-uses Transition Graph

5. Settler Identification layer: if the cell is occupied by a settler the cell in this layer will have the identification number of the settler.
6. Compartment layer: it indicates the compartment’s sequence to be followed by the agent concessionary in his exploitation process.

- Moore Neighborhood (Zeigler et al., 2000) for every cell (this neighborhood includes the eight adjacent cells).
- State Transition Rules:
  - Each land-use can stay in that state until the cell remaining time in that states achieves the transition time indicated at Figure 2.
  - Permanent states are: Flood River Bank, Seasonal Wetland used for stockbreeding, Rivers, Roads, Livestock, and Farming.

2.1 Agent's Interactions with the environment

The interaction between the settler agent and the environment is described as follows:

1. A settler agent can establish a farm in a cell that is unoccupied and without supervision. Certain land-uses are preferred for the initial settlements, and once the settler is established, they will change the land usage to adapt it to its agricultural activities.
2. A settler agent can expand its funds at neighboring unoccupied and without surveillance cells.
3. Before five years, the soils are exhausted, and then the settler agent moves to another place inside the CFR. Once the place is left by the settler, the land usage is changed to prairie.

The concessionary agent interacts with the environment in the following ways:

1. To exploit the forest, the concessionary agent needs and unoccupied cell with a land usage equals to forest. Then, the land usage is changed to Logged Forest.
2. To reforest, the concessionary agent needs an unoccupied cell with a land usage equals to prairie or secondary bushes. Then the land usage is changed to plantations.

2.2 Sample of Agent's Rules

To detail settler agent's rules we use Actilog Language, which is a language to write generalized, (condition --> action), activation rules. The semantics of the language is based on the assumption that implications (conditional goals) can be used to state integrity constraints for an agent. These integrity constraints describe conditions under which the agent's goals must be reduced to plans that can be executed. See Dávila, [2003] for more details.

Here is a simplified example of the implemented rules:

FARMS EXPANSION: It is carried out whenever the settler finds a neighboring unoccupied land without supervision The next Actilog language code line indicates the only way to farm expansion:

```
if thinking_on expansion, not (occupied_land),
not (supervision) then funds_expansion.
```

3. IMPLEMENTATION

The implemented model is a multi-agent spatial explicit model, where agents are codified using GALATEA agents' library, while the space is modeled as cellular automata representing a simplified account of the dynamics of the environmental system. The cellular automata is implemented by means of the SpaSim-lib library. Both the libraries and the model are encoded in Java.

The simulation theory that explains the way we combined the simulator (SpaSim) with the tool that implements the agents (GALATEA) is presented in Moreno, [2002].

Galatea [Uzcátegui, 2002] is a multi-agent simulation platform that nicely fits with SpaSim [Moreno, 2002] for the sake of an integrated spatial, agent-based simulation model. Galatea provides for a collection of classes to model reactive and rational agents, with a scalable, logic-based, inference engine which will eventually allow the agents to perform meta-reasoning, of the kind required to reason about other agents' reasoning. For the time being, however, the agents are more of a reactive kind, with behaviors that can be modeled by means of generalized condition-action rules [Davila, 2003].

The methodological path used here tries to embed as much behavior as possible with simpler agent models in such a way that extensions, such as those required for meta-reasoning, remain computationally feasible. This is why the research has developed these simplified agent models, testing for their expressiveness and evaluating their validity progressively. In this respect, It coincides with the work done in Monticino et al. [2004], also reported in this congress volume. However, these models are not attached to decision theory. The reason for this is that, even though, decision-theoretical approaches have the advantage of their straightforward psychological interpretation, the same advantage can be achieved with logic based models, without having to pre-encode, in numerical values of the potential consequences, all the qualitative information about agents' preferences and assumptions for meta-reasoning.

SpaSim is software that allows the specification, simulation, visualization and analysis of spatial models in the same environment, using a friendly user interface while at the same time providing considerable flexibility. Square cells were used for the cellular automata to keep compatibility with most raster GIS systems in use. Also the software integrates simulation techniques (like cellular automata), spatial analysis, spatio - temporal analysis, and maps visualization [Ablan et al., 2003].

The implementation includes former processes that affect the evolution of the land-use cover, which are carried out by the already implemented agents. There are some other agents that have not been implemented yet, like politicians, Los Andes University, among others…

4. RESULTS

For each one of the government scenarios implemented, the model was run for 65 years, because this is the estimated time required to observe a transformation from a Logged Forest into a Forest. The initial state of the CFR corresponds to the land-use reported in Pozzobón [1996] et al. for the year 1987. Simulation results are portrayed as maps that show the spatial distribution of land-use types obtained in each of the scenarios.

In the Hands-off Government Model, at the end of the simulation the forest have been replaced by other types of land-uses, the dominant land-use being cattle and ranching activities.

On the other hand, in the pro-forestry government model, the settlers are finally removed from the CFR area, and the forest has the opportunity to achieve its original state.

The agroforestry government, at the end of the simulation the forest has the opportunity to achieve its original state, but the settlers have left the special place for agricultural activities and the landlords has occupied that zone for cattle and ranching activities

5. CONCLUSIONS

Simulation results agree qualitatively well with what is now known about land-use change, tropical forest succession and forest management in the area. On the contrary to what was believed a few decades ago, it takes vegetal succession in tropical forests relatively long periods to fully recuperate its original state, both in volumes of wood and in floristic diversity. For example, Guariguata & Ostertag [2002] and Gómez-Pompa & Vázquez-Yanez [1985] say that the process leading to the reappearance of the initial forest species in the way they were found at the moment of deforestation could take even around a hundred (100) years. Our results corroborate that the way in which the forests were managed, with a 30 year cycle, would end up compromising the availability of the forest's resources in the future, just as Martinez-Angulo (1955), Lamprecht (1956: cited by Kammescheidt et al. 2001) and Veillón (1971) had warned.

Some points to be improved at our future works:

- Population growth of settlers will be represented at future models representing the influence of government policies.
- The landlords will be implemented explicitly as agents. This will enhance agents' interactions as they would be able to expand their properties, acquire other settler improvements, etc.
- The government agent will implement a more detailed evaluation of the concessionary performance; measuring beyond exploitation and reforestation quotas.
- The ecological realism of the cellular automata will be improved by estimating its parameters from detailed gap-model simulations (as in Acevedo, et al. [2001], and Monticino, et al. [2002]).

Details of the work and future developments can be found at the www page of the project:
http://chue.ing.ula.ve/INVESTIGACION/PROYECTOS/BIOCOMPLEXITY/

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