

## **FUZZY AGENTS: A HYBRID TOOL FOR EXPLORING COASTAL ZONE SPATIAL PROCESSES**

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### **RESUMO**

A dinâmica das interações de grupos de usuários com o meio ambiente tem se intensificado a ponto de ameaçar a disponibilidade dos recursos naturais. As previsões para as zonas costeiras, em especial, apontam para o esgotamento de recursos e para a perspectiva de superpopulação. O estudo do impacto de ações humanas nessas zonas por meio de modelos matemáticos apresenta limitações em capturar a natureza da percepção dos atores e em expressar a sua conseqüente distribuição no espaço. A presente tese propõe um modelo de simulação baseado em agentes para a análise de cenários de ocupação de zonas costeiras, a partir da modelagem da percepção espacial desses agentes, construída através de Lógica Difusa. A modelagem baseada em agentes trata-se de novo enfoque para simulações e envolve a reprodução do mundo real em um virtual, onde são conduzidos experimentos. Nesse universo virtual, cada agente é representado como uma entidade independente, capaz de agir localmente, em resposta à sua percepção, comportamento e alterações de parâmetros ambientais. A Lógica Difusa vem sendo empregada com bastante sucesso no manuseio da incerteza associada ao mundo real e permite a utilização de termos lingüísticos em sistemas computacionais. O desenvolvimento de um protótipo possibilitou a comprovação da viabilidade de aplicação do modelo em casos reais, bem como a captura de comportamento real de indivíduos em zonas costeiras. Além disso, a aplicação do modelo em um caso real demonstra o seu poder de previsibilidade e o subsídio a estudos ambientais por meio de simulação computacional, indicando um grande potencial para testes de hipóteses sobre o papel que cada indivíduo representa no funcionamento global de um sistema.

### **ABSTRACT**

The interaction dynamics between user groups and environment has increased to threaten natural resources availability. Overpopulation and environmental resources loss are common predictions for coastal zones in particular. Numerical models have been used to study human impact in these zones, with limited capability to handle actor's perception and spatial distribution though. This dissertation proposes an Agent-based Model simulation for analyzing land occupation scenarios from people's spatial perception and behavior that are coded through fuzzy logic. Agent-based Model is a recent simulation approach, which involves reproducing a real world system into a virtual one, where experiments shall be performed. In the virtual universe, each agent is represented by an independent entity that is capable of acting locally in response to its perception, coded behavior and environmental changes. Fuzzy logic, in addition, has been used with relative success to handle real world uncertainty and linguistic terms in computational systems. A prototype of this hybrid model has demonstrated its viability as well as its ability to handle people's spatial perception and behavior. A study case verifies the model potential application in studies and predictions of land occupation in a coastal area, including hypothesis test of each actor's role in the system functioning.

Palavras-Chave: agentes inteligentes; modelo baseado em agentes; lógica difusa; inferência difusa; gerenciamento costeiro.

### **1. INTRODUCTION**

The interaction dynamics amidst coastal user groups and the environment has increased to threaten natural resources availability. Overpopulation and loss of environmental resources are common predictions for coastal zones. Numerical models have been used to study human impacts in these zones, with limited capacity to handle user groups' spatial perception and their consequent distribution. This paper proposes a Fuzzy Agent-based Model (SPERB, 2002) simulation for analyzing land occupation scenarios from people's spatial perception and behavior. Both perception and behavior are explored through natural language (linguistic terms).

### **2. FUZZY AGENT-BASED MODEL**

Agent-based Model – ABM is a recent simulation approach, which involves reproducing a real world system into a virtual one, where experiments shall be performed (BOX, 2000; DEADMAN, SCHLAGER & GIMBLETT,

2000; HOOD, 2000; LANGTON, 2001; TESFATSION, 2002). In the virtual universe, each agent is represented by an independent entity that is capable of acting locally in response to its perception, coded behavior and environmental changes. Fuzzy logic (ZADEH, 1965), in addition, has been used with relative success to handle real world uncertainty and linguistic terms in computational systems. A prototype of a hybrid model (Fuzzy Agent-based Model - FAM) that combines both approach previously described was implemented in C++ in order to address the following questions:

- Is it viable to develop spatial dynamic simulation model for coastal zones that are based on ABM and Fuzzy Logic?
- Coastal users' pattern of behavior obtained by spatial analysis might be used to construct such models?
- This kind of model provides results that correspond to the real behavior of coastal users?

### 3. CONCEPTUAL MODEL

In order to test the FAM ability to study coastal zone spatial processes it is assumed that particular patterns of behavior might be observed for each coastal user group as response to their perception and needs towards environmental resources (environmental attributes). Both perception and behavior are studied through natural language and coded as fuzzy rules in an inference system, which is the decision engine behind each agent behavior. The inference system employs perception maps that derive from spatial analysis as the agent input information, while the output is a synthesis of the spatial perception. This synthesis is represented as a mental map and stands for the artificial world where the agent lives. The agent's agenda (behavior) is to seek in this artificial world the place that best fulfills its needs. This conceptual model is presented in Figure 1.

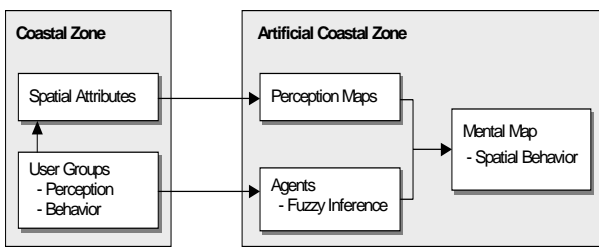


Figure 1. FAM conceptual Model.

**Behavior Codification:** spatial attributes are considered the driving force for user groups' spatial distribution. Thus, an agent will behave according to its perception towards one or more spatial attribute. For example, a tourist might seek for a quiet place with waves to stay in a beach. Quiet place and waves are spatial attributes that fulfill his needs. This rule can be expressed through fuzzy logic, as presented in Figure 2. It should be noticed that quiet and waves are actually values related to the attribute human density and beach dynamics, respectively. Perception towards these two attributes may assume several values, such as quiet.

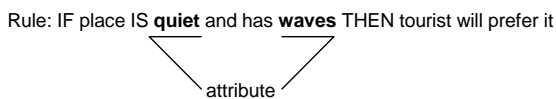


Figure 2. Example of an inference rule expressed in natural language.

**Mental Map:** a mental map is built upon perception maps and coded behavior in the agent's fuzzy inference engine as their synthesis represented in a map. This map is what the agent sees in the virtual world (Figure 3).

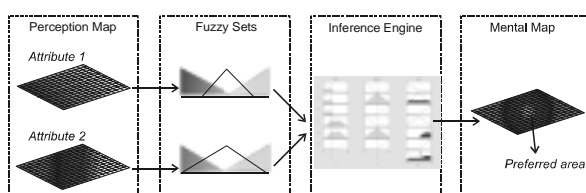


Figure 3. Mental map construction.

**Agent's Agenda:** it consists in the search for the area that has the highest values in the mental map. This is done via a simple scan for the highest neighborhood cell value (Figure 4). The agent moves to the highest value cell each time step until it is in a "stable state". Whenever there are two or more values that hold the same highest value, a random decision is taken among those cells.



Figure 4. Agent's cell election and movement to accomplish with his agenda.

The presence of an agent in a cell might impact any spatial attribute (perception map) that is considered in the artificial universe. If two or more agent group share perception maps, then an agent can sense others presence indirectly. This is called agent impact and it consists of a penalization in the value of the cell in the perception maps.

### 4. STUDY CASE

A study case was constructed to answer those three questions. The rapid growth in Ingleses beach, Santa Catarina – Brazil was selected as study case. A GIS study was conducted in order to identify spatial attributes and user groups for a period of 20 years, defining at macro level the central area, periphery and roads as spatial attributes (Figure 5). Spatial attributes and perception maps are presented in Figures 6 to 9. Preference rules were set according to the distance from the spatial attribute resulting in mental maps for each agent (Figure 10 and 11).

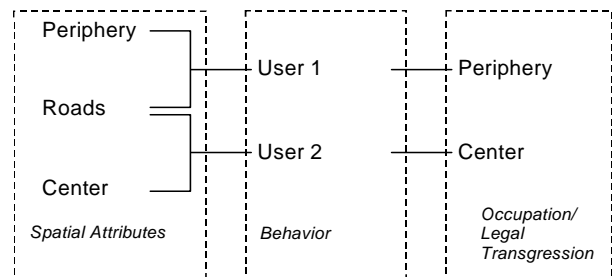


Figure 5. Spatial attributes and user groups.

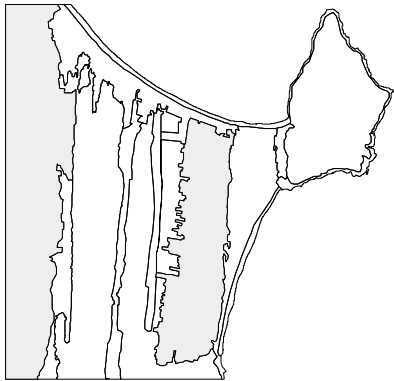


Figure 6. Spatial attribute periphery.

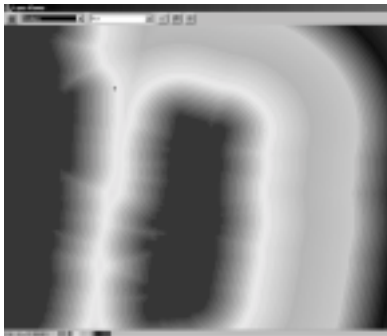


Figure 7. Periphery perception map.



Figure 8. Spatial attribute roads.

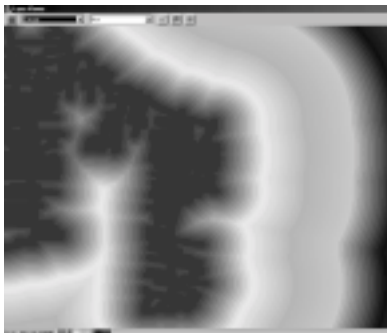


Figure 9. Roads perception map.

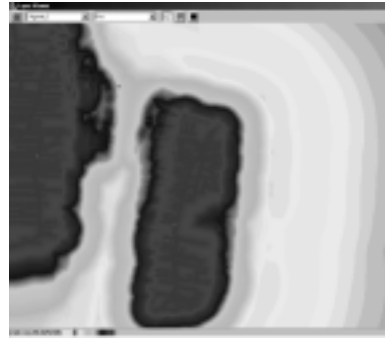


Figure 10. Mental map for periphery (User 1).

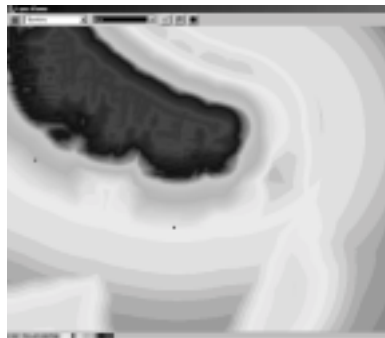


Figure 11. Mental map for center (User 2).

## 5. CONCLUSION

Simulations with 92% of similarity with real data (**Erro! A origem da referência não foi encontrada.**) have demonstrated the model viability as well as its ability to handle people's spatial perception and behavior. A study case has shown that spatial analysis can be used to define user groups' behavior, verifying the model potential application in studies and predictions of land occupation in a coastal area. The simulation result allows assuming that the model was able to capture general rules of perception and behavior that defines user groups' spatial distribution.



Figure 12. Real data distribution.



Figure 13. Simulated distribution.

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