Environmental Decision Support: a Distributed Artificial Intelligence Approach

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Abstract

Decision making in any environmental domain is a complex and demanding activity, justifying the development of dedicated decision support systems. Every decision is confronted with a large variety and amount of constraints to satisfy as well as contradictory interests that must be sensibly accommodated.
The first stage of a project evaluation is its submission to the relevant group of public (and private) agencies. The individual role of each agency is to verify, within its domain of competence, the fulfilment of the set of applicable regulations. The scope of the involved agencies is wide and ranges from evaluation abilities on the technical or economical domains to evaluation competences on the environmental or social areas.
The second project evaluation stage involves the gathering of the recommendations of the individual agencies and their justified merge to produce the final conclusion. The incorporation and accommodation of the consulted agencies opinions is of extreme importance: opinions may not only differ, but can be interdependent, complementary, irreconcilable or, simply, independent. The definition of adequate methodologies to sensibly merge, whenever possible, the existing perspectives while preserving the overall legality of the system, will lead to the making of sound justified decisions.
The proposed Environmental Decision Support System models the project evaluation activity and aims to assist developers in the selection of adequate locations for their projects, guaranteeing their compliance with the applicable regulations.

1 Introduction

The goal of any environmental decision making activity is to find, whenever possible, the most appropriate location for new projects (roads, industries, hospitals, etc.). In such cases, appropriateness measures the degree of the fulfilment of the applicable regulations and simultaneous compliance with the specified project requisites.
This activity presents some well-defined features, such as:

Distribution of competence – The evaluation competences are distributed over a set of public (and private) agencies;

Multidisciplinarity – The knowledge handled by the system involves a large number of scientific fields (geology, biology, engineering, etc.);

Interdependency – The conclusions of the different agencies are interdependent, i.e., the final recommendation goes beyond the simple summation of the advices of the individual agencies;

Accommodation of different opinions – A great number of contradictory interests (social, economic, technical, etc.) have to be reconciled;

Dynamism – The continuous need to the updating of scenarios and the constant submission of new projects;

Complexity – Relating to the amount of criteria to apply, the large dimension as well as the heterogeneity of the data to be handled (large spatial and alphanumerical data bases).

Taking into account the above mentioned identified properties this paper focuses on the modeling of the distribution of competence among the involved evaluation agencies and the subsequent accommodation of different perspectives that may arise. Our aim is to develop an environmental decision support system for project developers that provides guidance in the selection of adequate locations for new facilities, verifying its compliance with the applicable regulations and the necessary satisfaction of the project requirements.
This paper is structured as following: a brief introduction to the DAI approach, a description of the adopted system and the agents architecture, an example as a means of explaining the system's behaviour better, and finally, the conclusions.

2 A DAI approach to Environmental Decision Support

The inherent distribution of competences and the need for the conciliation of the different opinions generated lead to adoption of the Distributed Artificial Intelligence and Belief Revision methodologies. Typically, Belief Revision techniques are applied in systems faced with incomplete and dynamic knowledge and are used to guarantee a knowledge base free of inconsistencies [Malheiro, 1996].
In the current approach, Belief Revision provides also the support for the conciliation of different perspectives. This conciliation of opinions is achieved through argumentation. Whenever a dead end is reached, the agents engage themselves in an argumentative process, and exchange the arguments they believe to be relevant to the clarification of their recommendations (see section 3 for an example).

2.1 System Architecture

The team of evaluation agencies is modeled as a community of cooperative autonomous agents, where each individual contributes with his share of problem solving and contains the necessary skills to perform justified synthesis of the different individual recommendations. The architecture of the resulting heterogeneous Multi-Agent System (Fig. 1) is composed of three types of agents:

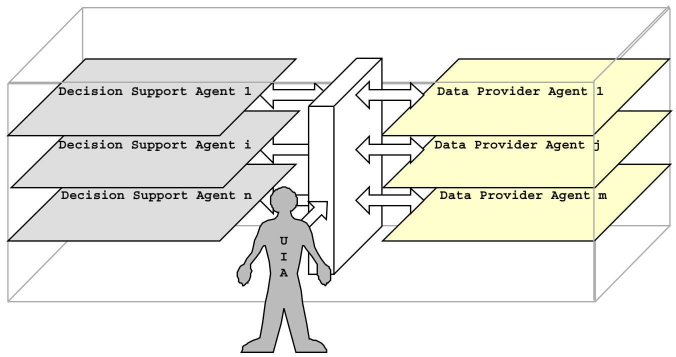

Figure 1: System Architecture

Decision Support Agents – They are *cognitive cooperative agents* who model the expertise of the agencies involved in the evaluation process. This expertise is expressed in terms of rules representing the applicable regulations within the individual agents domain of competence. These Decision Support Agents are able revise their initial recommendations after successful argumentations or in face of detected inconsistencies;

Data Provider Agents – They are *cooperative agents* that model the geographic area of interest. These agents are composed of large sets of spatial and alphanumerical data (transportation networks, streams, digital elevation model, soil type, etc.), typically stored in GISs;

User Interface Agent – Is a *cognitive cooperative agent* who acts as the interface between the system and the user. Allows the specification of the projects to be analised, in terms of requirements.

2.2 Agents' Architecture

The adopted multi-agent architecture is based on the architectural model proposed by the Esprit ARCHON project [Wittig, 1992]. The agents have a double layer architecture: the Cooperation Layer (CL) and the Intelligent System (IS) layer. While the latter contains the agent's domain knowledge based system, the former, holds the functionalities needed for the establishment of the inter-agent cooperative actions. A need for a

third layer, the Convergence Layer (CvL) occurs whenever pre-existing domain knowledge systems need to be included in the community.
The CL contains a model of the agent - the Self Model, as well as a model of its acquaintances - the Acquaintances Model. Based on these models, the CL determines when and what type of cooperative action to start, and guarantees that the data sent is relevant to the activity of the recipients through the use of a direct message passing mechanism. The CvL is responsible for translating the requests presented by the community into internally recognisable commands by the pre-existing domain knowledge systems. Depending on the type of agents different architectural options were adopted:

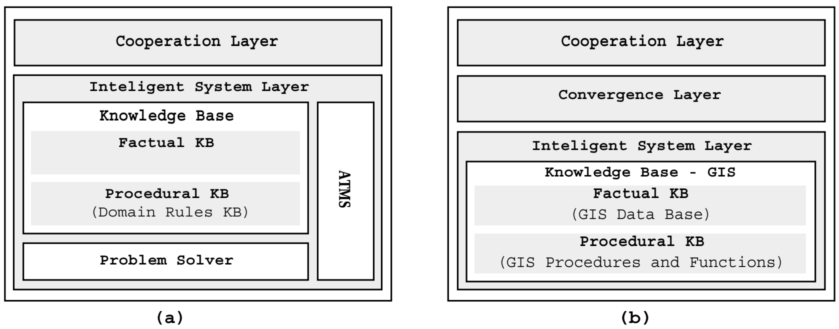

Figure 2: (a) Decision Support Agent Architecture; (b) Data Provider Agent Architecture

- Decision Support Agents – Composed of CL + IS. The Intelligent System Layer is a Belief Revision System composed of two modules: the problem solver and an Assumption Based Truth Maintenance System (ATMS) [de Kleer, 1986] (Fig. 2 (a));
- Data Provider Agents – Composed of CL + CvL + IS. The Intelligent System Layer corresponds to the associated domain knowledge database, the Geographical Information System (GIS). The translation of the requests presented to the GIS into GIS commands is performed by the Convergence Layer (CvL) (Fig. 2 (b));
- User Interface Agent – Composed of CL + IS. The role of the Intelligent System Layer is played by the user himself, by submitting new projects and simulating different requirements.

3 Example

The current goal of a community of 5 agents (User Interface Agent, three Decision Support Agents and one Data Provider Agent) is to establish the adequate location area for a new airport.

The UIA specifies the airport requirements:

$UIA: \ dimension(airport, 100)$
$UIA: \ shape(airport, rectangle)$
$UIA: \ orientation(airport, north - south)$
$UIA: \ prefered\_location(airport, north)$

The Decision Support Agents contain rules for airport locations:

$ag(ds, 1): \ IF \ type(airport) \ THEN \ slope(location, very\_smooth)$
$ag(ds, 2): \ IF \ type(airport) \ THEN \ intersects(location, railway)$
$ag(ds, 3): \ not \ yet \ participating$

The Data Provider Agent contains, stored in a GIS, the information about the candidate geographic area: the railways network, the terrain slope, the mountain area and the recreational park area.

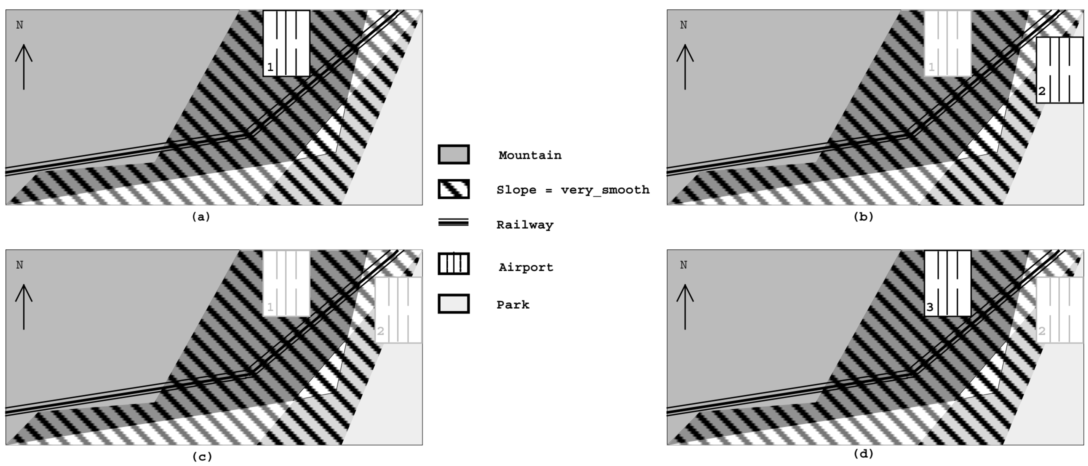

Figure 3: Example

The found airport location can be viewed in (Fig. 3 (a)).
Now, the third Decision Support Agent contributes with his share of problem solving, and a new rule is triggered:

$$ag(ds, 3): \ IF \ type(airport) \ THEN \ disjoint(location, mountain)$$

The system immediately revises its original airport location, since it has ceased to be valid, and finds a new valid location (Fig. 3 (b)). Finally, the user, through the UIA, adds a new requirement to the original project specification:

$$UIA: \ disjoint(airport, park)$$

The previous airport location becomes invalid and the system tries to find a new valid area to relocate the airport, but it fails to succeed (Fig. 3 (c)).

In a standard Distributed Belief Revision System the system effort to find an adequate location would have come to a halt. However, our decision support system goes one step further and starts an argumentative process among the agents. The aim of this argumentation is to let each agent clarify the reasons it holds for its conclusions, i.e., to have the agents exchange the arguments they possess to sustain their individual opinions:

$ag(ds,1)$ explains $ag(ds,3)$ what it means by $slope(airport, very\_smooth)$:

$$slope(airport, Slope < S\_max)$$

$ag(ds,3)$ explains $ag(ds,1)$ what it means by $disjoint(airport, mountain)$:

$$disjoint(airport, [Elevation > Elev, Slope > S\_min])$$

Both $ag(ds,1)$ and $ag(ds,3)$ analise the arguments exchanged and come to the conclusion that $ag(ds,1)\ S\_max\ <\ ag(ds,3)\ S\_min$. As a result the system locates the airport accordingly (it coincides with the initially found location) (Fig. 3 (d)).

4 Conclusions

The Environmental Decision Support System under development is a tool envisaged to provide developers with guidance in finding locations that comply with the applicable regulations. As a result, we hope to reduce drastically the time usually spent during the submission and evaluation phase, avoiding an endless period of alterations and subsequent project resubmissions.
Although the system prototype is still under development, the results we have been collecting, so far, allow us to be optimistic: the choice of the DAI paradigm to model the environmental project evaluation activity along with the development of methodologies supporting conciliation of perspectives are proving to be consistent with our goal.

References

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