Environmental Knowledge Management and Spatial Business Rules in the SPeCS Collaborative Framework

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Abstract. Good acquaintance with an organization's business rules is an undeniable success factor in a decision-making process. In environmental studies, decisions are multidisciplinary, rule oriented and are very much related to spatiality. SPeCS (Spatial Decision Support Collaborative System) is a framework which intends to support the aspects of multi-criteria spatial analysis within a distributed GIS architecture. This work has the following objectives: *i*) to define spatial business rules, so common in environmental studies; *ii*) to emphasize the importance of having the appropriate resources and techniques for managing this spatial knowledge; *iii*) to present a proposal complementing knowledge management in SPeCS with the appropriate support for spatial business rules; iv) and to validate some of the ideas presented through an implemented prototype.

Keywords

Knowledge Management, Spatial Business Rules, Spatial Decision Support Collaborative System, Business Intelligence, GIS

1 Introduction

"If we only knew what we know", phrase that has been very much quoted, expresses really well the concern of modern organizations and scientific groups who wish to acquire and maintain a competitive edge. They need to have available promptly relevant knowledge so that quality decisions can take place. But this relevant knowledge, in the form of data, rules, models or tacit knowledge (knowledge present only in the heads of specialists), can be located anywhere in the world. How can we take advantage of this collective knowledge if our local repositories are incomplete? With a good sense of cooperation, along with hard work and technology, we can capture the knowledge we need, share it, discuss it, validate it and generate new knowledge from it. But how do we do this with spatial knowledge? Well, we use the same premises for any kind of knowledge and build upon them. The Internet already supplies us with a practical and inexpensive start off – the possibility of communication - so it is up to us to establish the protocols, environment and tools for cooperative spatial knowledge integration in GIS(Geographic Information Systems).

The need to share knowledge from heterogeneous and distributed sources has been present during the evolution of Geomatic technology. This results from the great volume of spatial data stored in different GIS (distributed over diverse political jurisdictions), the growing complexity of environmental analyses and the high cost of data acquisition. Just as with alphanumeric data, in spatial data there is a need for the definition and enforcement of certain rules to maintain data integrity. From well defined spatial rules, tested models and trustworthy data, new rules, models and data can be inferred or generated, and, thus, contribute to the business's intelligence.

Considering that GIS users belong to specific application areas which represent different competencies, political agendas and social interests, and often lack the knowledge about other areas with which they may have to work with, we propose the use of SPeCS [7]. SPeCS supplies a collaborative work environment increasing synergy and user cooperation during data interchange between the GIS knowledge sources. SPeCS is composed of three functional layers: Decision Tools, Knowledge Tools and Data Integration Layer. Our work resides in the second layer.

This work emphasizes the importance of adequately managing knowledge, introduces tools for knowledge management in the SPeCS Framework, refines these tools, proposes the general lines for the management of spatial business rules in SPeCS and uses C and Prolog to implement a simple prototype to enforce a rule over a spatial database.

The text is organized as follows: section 2 reviews the concept of knowledge management and its importance in an environmental decision making process; section 3 introduces SPeCS, its functional modules and its knowledge management facilities; section 4 discusses environmental knowledge management using business rules; in section 5, we present our proposal for improving environmental knowledge management in the SPeCS framework with the treatment of spatial business rules; section 6 presents some experimental results; section 7 concludes our work; and section 8 brings the references used.

2 Knowledge Management

The value of knowledge is a function of applicability, context and usefulness. There is a cost for "ignorance", in other words, there is a cost for "not knowing", "not using" or "not generating new knowledge" [2]. The following two sections shall explain what we mean by knowledge management and its importance in an environmental decision process.

2.1 What we mean by Knowledge Management

According to Mark H. Friedman [4], Knowledge Management is the ability to create and transfer as much of the right knowledge as possible to support as many people as possible in the best way in order to have a positive impact on the business. It's about bringing the full weight of the company's knowledge base (hardware, software and people) to bear, in a relevant and useful manner, the requirements of the user, thus enabling the individual and the organization to learn and adapt.

Jay Liebowitz [6] describes Knowledge Management as the process of creating, securing, capturing, coordinating, combining, retrieving and distributing knowledge. Figure 1 summarizes this process:

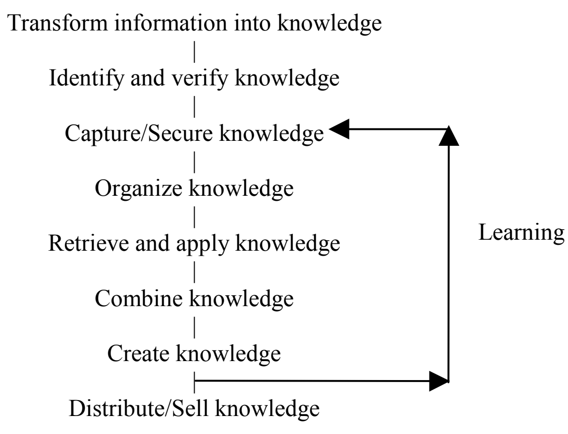

Fig. 1. **The Knowledge Management Process [6]**

The main objective of a knowledge management process is to permit that the organization may function in a more "intelligent" manner. From this objective emerges the term "organizational intelligence", which denotes the capacity of an organization to absorb knowledge, to combine it with pre-existent and to generate new knowledge, in a way similar to human learning and reasoning. In other words, the more efficient the knowledge management process in an organization, the higher is its organizational intelligence, and, therefore, also the higher is its potential for quality decisions.

The use of efficient knowledge management techniques is of great support to an environmental decision process for it permits that precise knowledge be available at the convenient moment

2.2 The Importance of Knowledge Management in an Environmental Decision Making Process

The decision-making process in the environmental context, as in any business, can be reactive or proactive. A reactive decision process occurs when a problem already exists, thus demanding a solution. Proactive decision processes identify an interesting opportunity or anticipate a certain problem that may occur. Reactive processes can be associated to active rules, while proactive processes can be associated to deductive rules.
An environmental decision making process involves five phases: environmental problem identification, solutions design, solution choice, monitoring and knowledge generation [12]. These phases are totally compatible with the knowledge management process as depicted in Figure 1. An environmental problem decision process is described below:

1. Environmental Problem Identification – in this phase the decision maker identifies a problem or foresees an opportunity to act on the environment;

2. GIS Solutions Design – here, the information plans necessary to the solution of the problem are identified, the geographic objects' features are determined, the definition and behavioral rules are specified, and the spatial operations to be executed are pointed out;

3. GIS Solution Choice – this phase involves the selection and implementation of the best solution;

4. Monitoring – the solution chosen is evaluated for adequacy to the original problem.

5. Knowledge Generation – new knowledge shall be generated from the experience gained from the solution to that environmental problem.

3 SPeCS – A Spatial Decision Collaborative Support Framework

SPeCS (**S**patial D**e**cision **C**ollaborative **S**upport) offers a common, flexible and easy to use cooperative work environment where the members of a group may be geographically distributed in heterogeneous environments and still interact during a decision making process [7]. The following sections illustrate SPeCS' functional modules and present its knowledge management facilities.

3.1 Functional Modules

The main functional modules that compose the SPeCS framework are: Decision Tools, Knowledge Tools, Integration Layer and Knowledge Repositories. Figure 2 details SPeCS' main modules:

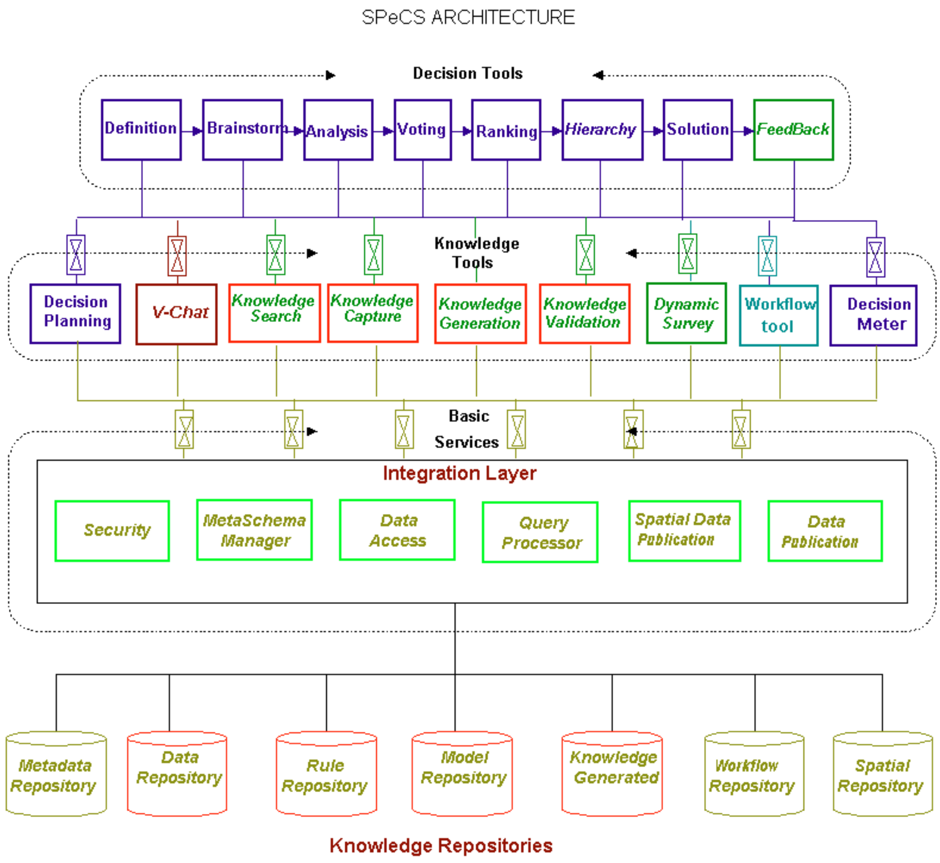

Fig. 2. **SPeCS Functional Modules [9]**

The *Decision Tools* represent and coordinate the activities involved in a decision making process from the problem definition phase to the specification and documentation of all solutions created by the discussion. Argumentation elements and props can be geo-referenced. These tools offer an environment where members of a group can prioritize issues, perform different types of voting (yes/no, multiple choice and weighed choice), evaluate different criteria, elaborate documents in group, perform brainstorming, analyze projects, rank solutions, etc.

The *Knowledge Tools* module includes mechanisms for decision planning and meter, visual chatting, survey control and knowledge management. The knowledge management tools shall be better depicted in the next section.

The Decision Planning tool allows the customization of the decision workflow disabling and introducing decision steps in accordance to the problem solving features.

The V-Chat (Visual Chat) tool encapsulates Chat, Forum and email facilities. However, the basis of the conversation is a semantic framework, allowing the reuse of decision argumentation.

A Dynamic Survey tool was implemented to help researchers cope with the constant changes in the GIS requirements enabling easy change of survey structure and attributes. This will also be used to capture the feedback from local actors to be compared with those from others regions where some kind of interference has been made in the past by group decisions, allowing a measure of decision efficiency. The Decision Meter tool can compare solutions proposed in the past and the actual results to improve the conceptual basis for future decision, so researchers can discover the success and failure factors to improve and make better decisions. A Workflow Engine is also in development to allow a smooth interaction with the GIS environment.

The Integration Layer permits the integration and sharing of heterogeneous data sources using mediation techniques providing interoperability among the data repositories spread over the web, although maintaining their autonomy [9].

3.2 Knowledge Management in SPeCS

The purpose of the knowledge management tools in SPeCS is not only to offer technology for the creation of data, model and rule repositories, permitting that they be refined and validated in a heterogeneous collaborative environment, but also to generate semi-automatically new knowledge from the clean validated repositories. The basic knowledge management tools in SPeCS are:

- *Knowledge Search Tool*

A search tool for locating relevant information based on key terms from the Internet (similar to an Internet Search Engine), as well as locating key terms or metadata on participating databases.

- *Knowledge Capture Tool*

This tool is used to input new or provide access to existing rules, models and data in participating databases. New knowledge can be input directly in the form of a well known model, set of validated rules or clean data. It is important that the input knowledge be trustworthy because this knowledge shall the basis for the generation of new knowledge. If the knowledge being input is not yet trustworthy it should be indicated as this so that it may be validated through the decision tools.

- *Knowledge Generation Tool*

The Knowledge Generation component or Knowledge Engine provides the integration of rules, models and data for the generation of new knowledge. This component includes an Inference Machine, which is the sub-component responsible for the actual generation of new conclusions based on already trustworthy knowledge. These new conclusions must still be validated.

- *Knowledge Validation Tool*

This component is responsible for the retrieval of the knowledge that must be validated, its submission to the decision tools for consideration and depending on the approval of the knowledge submitted, its validation. To have validated knowledge means to be able to transfer the knowledge from the Knowledge Generated Repository to the Data, Rule and/or Model repositories, or in the case of knowledge input directly from the Knowledge Capture Component, a status change in its metadata repository to valid knowledge (fuzzy values). This validated knowledge can now be considered system knowledge and can be used in queries throughout the system as input for decision support with a certain degree of trust, as well as, used in the generation of new knowledge. Knowledge can change its status gaining more trust (approaching the fuzzy value 1), as it is validated. If knowledge is not validated, it cannot be considered in the generation of any knowledge and should not be put available as relevant knowledge to the system.

When dealing with the knowledge repositories, it is important that all group components share the same taxonomy so that they may enjoy the same standard of knowledge, thus encouraging consensus based on common premises. The absence of this type of perspective may lead to the failure of all effort put into the assembly of this structure, since the lack of common knowledge concerning the problem and the solution, makes it difficult for the group ideas and opinions to converge.

4. Environmental Knowledge Management Using Business Rules

4.1 Business Rules Conceptualization

A business rule is a statement that defines or regulates some aspect related to a business, representing the domain and the way a business works. The term *business* here is used to represent the object of study of any knowledge area and thus, not merely associated to the commercial transaction.

Having said this, the construction of a knowledge repository of business rules is an effort towards mapping and organizing knowledge related to a business so that it may be studied, shared, evolved, and, therefore, supply consistent support in a decision process.

There are many different classifications based on varied viewpoints for business rules, but for the sake of simplicity in our study, we chose a classification presented in the Guide Business Rules Project [5] which admits 4 categories (Definition of Terms, Definition of Facts, Constraints and Derivation). We simplified this classification where we consider that business rules can be classified as being of at least 3 natures: definition, behavioral or derivation.

A definition rule defines a term or expresses relationships between terms. A definition rule can easily be mapped to an Entity-Relationship Diagram. A behavioral rule regulates some kind of behavior. A rule of a behavioral nature generally restricts an action which can be a data update. A derivation or transformation rule permits the creation of new data or knowledge from existing ones [5][11]. Definition and derivation rules are data-driven and are also known as declarative rules for they describe a firing situation without necessarily making explicit the way the situation is detected [1]. A behavioral rule follows the event-condition-action paradigm, explicitly defining their activation [13]. In our study the action part of the paradigm shall be executed by some program or process outside of the rule.

In Environmental applications business rules can be enforced over:

- the geographic objects definition;
- information plans with inter-plan constraints defining if different plans of information may be combined;

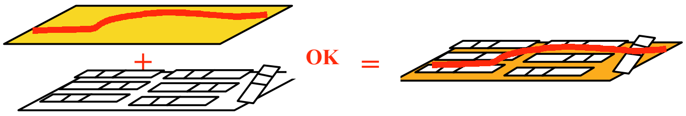

Fig. 3. **A spatial rule that permits the join of two information plans**

- applications and models with the regulation of what models or applications may be applied in a specific situation;
- spatial operations defining what spatial operations one can apply.

We have noticed that spatial business rules, in Environmental studies are, most frequently, implicit.

4.2 Spatial Business Rules in Environmental Knowledge Management

What differentiates a spatial rule from a non-spatial rule is the fact that there's the need of evaluating at least one predicate with a spatial operation. Therefore, it is necessary to map the spatial operations available in the GIS or spatial database into predicates.

Moreover, in environmental applications the spatial business rules can likewise also be of a definition, behavioral or of a derivation nature.

To better understand what we mean, we present the following examples:

i) Spatial Definition Rules:

Regions have adjacencies

Adjacency can be land

Adjacency can be water

Represented as:

$$\text{Region}(X) \text{ :- } \text{Adjacent}(X,Y) \cap \exists Y(\text{Land}(Y) \cup \text{Water}(Y))$$

In order to define that a region has adjacencies (land or water), it is necessary to apply the spatial operation of adjacency over X in relation to Y.

ii) Spatial Behavioral Rules:

A Brazilian national law prohibits the removal of the original vegetation 30 meters from a river's margin

$$\text{MinimumDistance}(Y,W,D) \text{ :- } \text{Region}(Y) \cap \text{Deforest}(Y) \cap \text{River}(W) \cap \text{Distance}(D \geq 30) \cap \text{IsContained}(Y,\text{Brazil}) \cap \text{Region}(\text{Brazil})$$

In order to constrain the planning of a deforestation area in a preservation area, there is the need to apply buffer operations over the river's features.

Most of the rules involved in environmental studies are of a behavioral nature for one of the main concerns is actually to constrain actions on the environment, thus preserving it.

iii) Spatial Derivation Rules:

What characterizes a derivation rule is the presence of an inference (or calculation), thus, automatically computing new information or producing new facts.

The borderline between spatial definition rules, behavioral and derivation rules is not always easy to perceive. The following specification rule of an island could be considered a definition, but it is better considered a derivation for it builds upon other definitions, characterizing an inference.

Island is land surrounded by water on all sides and land is not a continent

Island(X):- $\forall$Y Land(X) $\cap$ Region(X) $\cap$ Adjacent(X, Y) $\cap$ Water(Y) $\cap$ ~Continent(X)

This rule implies that the object Island is spatially defined as being a region with adjacent water on all points of the region, thus being necessary to apply at least the spatial operation of adjacency.

Another example is a decision rule for the estimation of the suitability of the use of precision farming techniques. This decision rule (a specialization of derivation rules) shall require spatial crossing operations of climate, soil and social economic information plans, along with the results of a hydric balance model to determine the suitability of the use of precision farming in a region. In this example, each input has its output weighed representing a result significant or not towards the establishment of the suitability of the use of precision farming techniques for the region considered. The derived knowledge, which is the suitability estimate, although not spatial, was derived with the use of enforced spatial rules. [15] has a working Forest Resource Management system which implements spatial derivation rules.

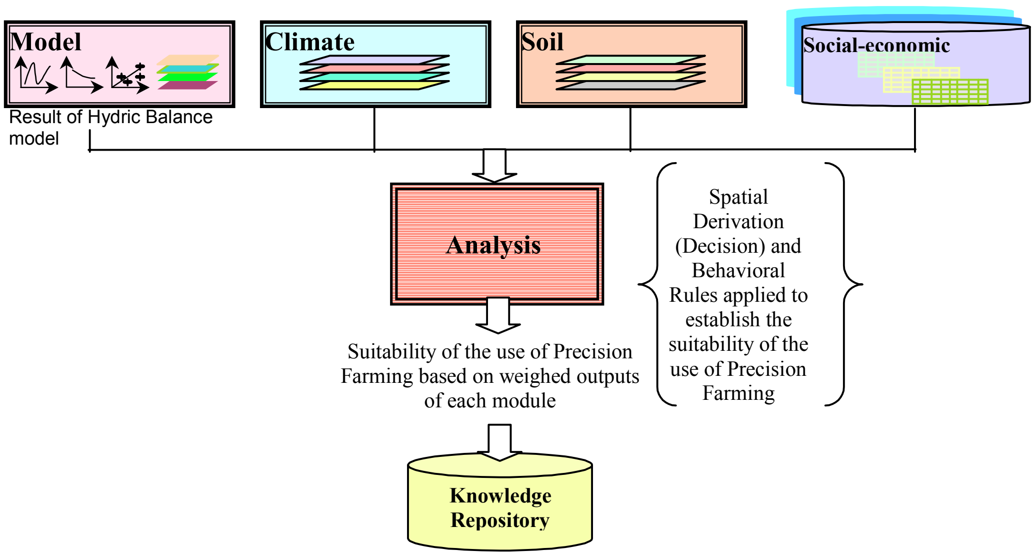

Fig. 4. **Example of decision rules (derivation)**

It is important to note that the knowledge derived from pre-existing rules through an inference engine (theorem prover) can be either new facts or new rules, rules which, in many cases, are even simpler. Thus, we can use derivation to generate an optimal set of rules, with simpler or fewer rules to maintain.

4.3 Considerations on Environmental Knowledge Management and the Formalization of Business Rules

In environmental applications, problems are very much related to spatiality, have a large presence of behavioral or constraining rules and are multidisciplinary.

In solving multidisciplinary problems in a collaborative distributed scenario, the ability to capture rules from different specialist perspectives is a great challenge. Each specialist, the agronomist, hydrologist the meteorologist, the ecologist, etc, can have different foci, experiences, and knowledge which can contribute to the creation and validation of a rule. The rule repository, once it mirrors consensus, will also be a powerful tool in complementing the validation process.

Date [3] and Ross [10] point out the importance of the formalization of business rules and emphasize the advantages of the declarative approach, for besides being more intuitive, it privileges rule adaptability or the ease of adaptation to eventual business changes.

A difficulty present in the management of business rules, whether spatial or not, resides in the fact that the knowledge bases must not hold logical incongruities. Formalizing these rules in a declarative language permits that they be converted into a first order logic representation, which can easily permit the identification of incongruities. Moreover, upon update of a rule, or a new rule insertion, the base's consistency can be tested against these incongruities. Thus, having a list of the conflicting rules shall undoubtedly aid in the problem's solution.

Another difficult task is the validation of legacy data. In addition to adapting the legacy data to the new format, it is also necessary to assure data integrity, or the quality and the accuracy of the legacy data. This data is usually entered into the new systems by some load procedure, and, therefore only then will it be verified against the business rules. This approach will work well for simpler rules, like simple integrity constraints, but not always will it be as efficient with rules more complex, particularly rules that involve derived data or past states not maintained by the previous system. Therefore, if the business rules are not formally established, the situation will demand the coding of procedures just to verify the validity of the tacit business rules, which would then be discarded after the initial load. The formalization of the business rules makes it possible for these procedures to be generated automatically in order to validate legacy knowledge.

5 Requisites for Environmental Knowledge Management in SPeCS with an Appropriate Support for Spatial Business Rules

At the moment, knowledge management in the SPeCS framework is present as a specification of the necessary tools that need to be implemented to manage data, models and rules. This work contributes to this specification refining it and adding to it the basic premises for the treatment of spatial business rules, so important to an architecture that wishes to address spatiality in order to be efficient in environmental applications.

First of all, for SPeCS, we propose the use of mediation technology, in a Rule Manager, with a tight control over the access of any type of data (spatial or not) for it shall be responsible for rule enforcement. This should be noted to guarantee that data might not be accessed by other means thus ignoring the rules.

An ideal Rule Manager in SPeCS would consider the following (generic to support spatial and non-spatial rules):

- Rule enforcement/disregard over all data sources and tools;
- Implementation of a mechanism for rule managing centralization (on each site), for it brings the following advantages:
  - Easier rule adaptability;
  - Consistency;
  - Thinner application development for the rules don't have to be replicated in every application that uses it;
- A high level rule specifier interface for the creation and update of rules;
- Consistency verification across the domain it shall be enforced over;
- Rule domain control;
- Rule metadata specification;
- Rule conflict resolution;
- A classification mechanism of the rules so that, for example, only rules related to a specific area be viewed;

- A tracking of rule history such as creation/update/drop dates, author, reason for creation/update/drop;
- A means for distribution or dissemination of the rule for possible enforcement in higher or wider domains.

Furthermore, the Rule Manager Tool should also consider the following:

- The rule's error message should be the rule itself [10]. For example:

There is national law that prohibits the removal of the original vegetation 30 meters from a river's margin.

For any violation of this rule, be it an attempt to construct an enterprise, a house, or a crop plantation, the system's error message should be the same. This approach has the advantage of training the user on the rule's semantics without explicit formal training.

- Some environmental data change in time, as, for example, the depth of a river;
- Some rules such as laws have a validity in time and have enforcement power over a domain;
- Exception treatment should be treated in the body of the rule itself;
- The possibility for legacy data validation.

As for the specific support for spatial rules:

As we have said, the difference between a spatial rule and a non-spatial rule is the need for evaluating predicates with the application of a spatial operation. The Rule Manager (RM) shall not worry about the actual execution of the operation, for this is the work of the GIS system (whichever it be), the RM's work shall be to regulate, in high level, the execution or not of the operation. Therefore the RM needs that the spatial operation to be executed be available in the GIS or spatial database for calling.

In the next section we shall present the experimental results obtained in the implementation of the specific support for spatial rules, in which, a simple rule manager invokes a GIS in order to evaluate spatially one of its predicates.

6 Experimental Results

In the intent of validating the ideas in this study, we implemented a small prototype. The implemented prototype follows the scheme exposed in Figure 5, where the spatial predicate validation is done in a form transparent to the rule definition itself, in other words, in the Rule Manager the definition of spatial rules is done in the same way as that of non-spatial ones.

We used SWI-Prolog [14], developed by the University of Amsterdam, both because of its bi-directional interface with the C language, and because of its capacity to provide the transparency needed. This permits the association of a C function and a Prolog predicate through an API. Other interesting functions are also available like conversion types between C and Prolog, unification mechanisms and parameter interchange between the two languages.

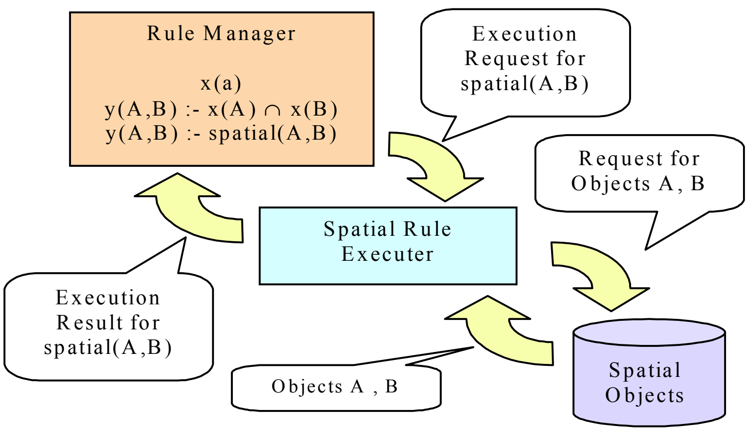

Fig. 5 – **The scheme for evaluation of a spatial predicate**

The are two ways of defining a new predicate: static and dynamic. The static definition permits the generation of a new Prolog executable with the new predicate built-in. The dynamic definition permits the loading of a dynamic library with the definition of the new predicate.

To illustrate the execution of the scheme above, we defined the following rule:

`Intersection_River_Road(R,O):-River(R)`∩Road(O)∩ `Intersection(R,O)`

where River(R) and Road(O) are non-spatial predicates and Intersection(R,O) is a spatial predicate. The predicate Intersection(R,O) must be associated to a procedure capable of executing it.

In the prototype we implemented an intersection test between two polylines through an algorithm based on scan line [8]. This routine receives two object ids, accesses the database to retrieve their representations and returns the result for the intersection test. As a next step we make this routine available in a Windows DLL, where the SWI-Prolog API is used for the passing of the parameters, the result's return, and the registration of the new predicate (Intersection(R,O)). Loading this DLL in SWI-Prolog we obtained the scheme in Figure 5 with the needed transparency, where the evaluation of the Intersection(R,O) starts the execution of the DLL routine. When using a commercial GIS like ArcInfo, the same integration can be achieved, for, in order to evaluate a spatial predicate the ArcInfo SDE API could be used in place of the Windows DLL.

7 Conclusions

Today, in environmental applications, as in many other application areas, we have a great deal of knowledge distributed over diverse formats and platforms. This knowledge, whether tacit or explicitly present in the form of documents, data, rules, models, etc, in order to be useful to a business, has to be put available in a usable manner, thus, the need for efficient knowledge management tools.

Our studies focused on the important role which spatial business rules play in a knowledge management process that aims to support quality environmental decisions in a distributed, multidisciplinary collaborative scenario (SPeCS). From these studies, we defined spatial business rules in the environmental context and proposed refinements on the way knowledge management should be done in SPeCS to, among other features, support the management of spatial business rules.

We proposed the implementation of a rule manager with the use of mediation technology with a tight control over the access of any kind knowledge repository in order to promote data access consistency and to guarantee rule enforcement.

We concluded that spatial business rules can be treated very much like any other kind of business rule. The special treatment involved, due to the spatiality of the rule, is that the spatial predicates involved must be translated into spatial operations. Our prototype implemented this feature exemplifying the integration between a simple Rule Manager and a spatial database.

As future investigation, we propose a more complete study of spatial rule generation, as mentioned at the end of section 4.2.

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