Using Description Logics to Integrate Fishers' Ecological Knowledge in the Research of Artisanal Fisheries

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Abstract. The aim of this paper is to show the role that Knowledge Representation can play in the research of artisanal fisheries. In particular we concentrate on the epistemological and technological adequacy of implementations of Description Logics to represent fishers' ecological knowledge, so contributing to address some open methodological questions about its collection and use.
Keywords: fishers' ecological knowledge, knowledge representation, description logics.

1 INTRODUCTION

World fisheries are in crisis. According to the FAO [8], 69% of the world's marine stocks are either fully to heavily exploited, overexploited or depleted and therefore are in need of urgent conservation and management measures. The causes of the collapse of exploited marine populations have been the subject of wide debate, confronting hypothesis that center the problem in an excessive fishing effort which brings about overexploitation, against those that argue that fluctuations in population dynamics are attributable to natural environmental changes. Myers and other researchers in [19] and [20] studied the paradigmatic case of collapse of the cod fishery in Newfoundland and concluded that the overexploitation hypothesis is backed by scientific evidences which are much stronger than others related to environmental changes. The collapse of stocks constitutes the final stage of overexploitation generated by an excessive fishing effort. This process may be attributed either to a lack of appropriate scientific information or, on occasion, and in spite of suitable assessment, to faulty management systems or failure to enforce the compliance of several fisheries.

In the case of artisanal fisheries in Galicia (NW Spain) there are also a number of indicators that reveal overfishing [10][11]: 1) the virtual depletion and collapse of several stocks (for example lobster, spiny lobster, sea bream) whose catches are irrelevant today but historically were important in the area, 2) the time series of catches that, despite the problematic interpretation, show that there has been a decline in many cases from the 1940's-60's to the present time, such as in crustaceans, and 3) specific assessments, such as on the spider crab in the Ría de Arousa [9] reveal exploitation rates greater than 90% per fishing session. As well as showing indicators of overfishing, the following differential characteristics of the artisanal sector complicate the design of succesful management systems:

- From a biological standpoint, the species harvested by the artisanal coastal fleet of Galicia, and particularly the great majority of invertebrate species, present a number of characteristics which render useless the classical analytical models of finfish population dynamics used in the management of industrial fisheries. These species, sedentary benthic or mobile benthic/demersal, have a strong and persistent spatial structure and are characterised by the following: 1) complex life cycles (planktonic dispersing larval stages and sedentary or low mobile benthic or demersal postlarval stages), 2) a spatial distribution characterised by the existence of aggregations which are evident on different scales, 3) a population structure that could be defined as meroplanktonic metapopulations in which the postlarval stages make up a chain of local populations along the coast with low migration and dispersal levels and interconnected by a planktonic larval stage, and 4) the aggregated stock-recruitment relationship is not applicable to a segment of a metapopulation.
- In an industrial fishery, the relationships between the economic benefits obtained by the fishery and its biological and social complexity is high, which would make it possible to develop intensive lines of research. In terms of the artisanal coastal fisheries of Galicia, the economic yield of each one of the species harvested does not appear to be able to support specific lines of research which could complete our scientific incomplete knowledge.

Faced with these scenarios some argue that finding ways to incorporate fishers' participation would improve our capacity to manage fisheries sustainable. In [21] a methodology for collecting and integrating fishers' ecological knowledge into resource management is presented but the formal representation of this knowledge is not addressed. We believe that this formal representation using Artificial Intelligence (specifically Knowledge Representation) techniques could help not only in the acquisition and refinement of this knowledge but also it could facilitate to compare with other knowledge systems (scientific knowledge) and to observe possibly changes in these over time and the impact of both knowledge systems on management initiatives. The aim of this paper is to show that Description Logics and Terminological Systems are good candidates for this task. Also following this line of work, it is worth mentioning a fuzzy logic expert system whose knowledge base incorporates fishers' knowledge in the form of heuristic rules [17]. Consequently our approach complements the work in [21] and [17] both in content and methodological aspects.

The remainder of the paper is organised as follows. Next section defines the concept of Fishers' Ecological Knowledge (FEK) which is rooted in ethnoscience and cultural ecology traditions. Section 3

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argues that given the characteristics of FEK and what we want to do with it, Description Logics (DLs) are a good choice to represent FEK. In section 4 we describe our initial experiences with this methodology. The paper ends with some conclusions.

2 FISHERS' ECOLOGICAL KNOWLEDGE

FEK is a specialised branch of TEK (Traditional Ecological Knowledge). The concept TEK appeared in the mid-1980's, and social scientists have argued that it represents at least a critical supplement to scientific understanding. Mailhot [18] gave an explanatory definition:"the sum of the data and ideas acquired by a human group on its environment as a result of the group's use and occupation of a region over many generations".

FEK [21] typically includes not only categories of fish, but also information on behaviour, ecology, meteorology and oceanography, and references to time and space that can complement scientific knowledge. Moreover, FEK is an updated understanding that includes the latest changes occurring in the local marine environment. However, those who plan management policies are politicians working in collaboration with technicians from the administrations, and they do so unilaterally, entirely disregarding the knowledge of the fishers concerning their field of experience. Some examples that occurred in Galicia in recent years may serve as an illustration. Artisanal fishers used the traditional fish trap (cylindrical and closed) to fish velvet swimming crab and octopus. In order to regulate these resources, the administration required that fishers employ a more selective type of trap (squared and open) designed by its technicians to fish exclusively octopus. The fishers bought these new traps and soon discovered that they were inefficient. They required more work and produced less. The response of fishers was to replace the new traps with the traditional ones behind the back of the administration. This process went on for several years before the administration recognised its error and resulted in an economical setback for the artisanal fisheries. The government, in opposition to an important sector of fishers, also opened the fishing season for the velvet swimming crab at a critical time of its reproduction thus putting the stock in danger. This last example also happened for several years.

Therefore our main objective is to acquire new knowledge for the application to the sciences that are involved in designing management models for artisanal fisheries in Galicia. The more generic scope of knowledge that we will need to achieve the above goals will be centred, in turn, on acquiring knowledge and information on: coastal ecosystems, population dynamics, descriptions of habitats and bottom types, interactions and relationships between species, behaviour and feeding habits, reproductive zones and seasons, climate (atmospheric and oceanic) influences on the species, stock assessment of fishes, crustaceans and molluscs, reconstruction of the history of marine ecosystems in relatively short periods, etc. After filtering, systemising and formalising fishers' ecological knowledge, it can contribute to broaden the understanding of many of these topics.

3 METHODOLOGICAL CHOICE: DESCRIPTION LOGICS

It has been recognised [21] that the main hurdle associated with combining science and FEK is one of methodological nature: finding ways to combine these two knowledge systems. In [21] and other works, methodologies and research techniques to acquire traditional knowledge are described. These include: analysis of discourse, selection of information, semi-guided open interviews, surveys on specific points of knowledge, analysis of the distribution maps of the resources and habitats drawn up by the fishers, and other documents of a functional nature that they may have such as notebooks and graph interpretations (depth sounder, radar), etc. It is a fact that this work is being done almost exclusively by anthropologists and this knowledge circulates mostly through channels of dissemination of maritime anthropology. If this knowledge is represented in a formal manner, this knowledge can be refined, reused, shared with others or integrated with biological knowledge in a principled way. Therefore Knowledge Representation (KR) plays an important role to improve the knowledge of biologists, technicians, anthropologists and fishers, with the ultimate goal of designing better fisheries policies.

Two main properties of FEK is that it is a very large body of knowledge and it is subject to continous changes. The anthropologist owns FEK and he/she considers the work of formalising FEK as part of his/her research. This situation has motivated us to try a methodology where the anthropologist is not only an end-user of the resulting knowledge-based system. He/she is involved in the knowledge engineering process from the beginning. We claim that at least the anthropologist is able to decompose the domain into its characteristic elements and possibly capable of expressing them in a computer language. However these tasks must be accomplished in the framework of a formal model since the lack of a formal semantic foundation could lead to several problems such as inconsistencies or circular definitions. Therefor to be successful, the Knowledge Representation Language (KRL) must be carefully selected. Epistemological adequacy must be given by the nature of FEK. Note that one of the major components of FEK are the categories used by fishers to classify components of the environment and the organization of these categories into the system of representation. From a technological perspective we need an expressive enough language but small and easy to learn. Implementations of DLs seem to be the right choice.

DLs integrate from a logic and formal view research done in semantic networks, frame systems and other object-oriented representations, and constitute the formal successor of the family of KL-ONE languages [5]. During the last fifteen years the main issue of research in Description Logics has been the identification of the sources of intractability. The results of this research allow to depart from a very basic language and to increase expressiveness while ensuring computational tractability.

The primary aim of DLs is to express knowledge about concepts and hierarchies of concepts. DLs have declarative tarskian semantics and can be identified as sublanguages of First Order Logic (FOL). A concept expression is a general description of a class of objects in the target domain. Concept expressions are formed using various constructors, some of them expressing relations with other concepts (roles). Relations expressed by means of roles, can be qualified in several ways (type restrictions, value restrictions, number restrictions, etc.). Just by analyzing concept expressions, a taxonomy of concepts following generality-specifity criteria can be built. The efficient implementation of reasoning services is based on this hierarchical structure.

The basic blocks of the descriptive languages are atomic concepts

```
(createRole shape true)
(createRole rugosity true)
(createRole fastening true)
(createRole size true)
(createRole surface-closeness true)
(createRole height true)
(createRole fishes)
(createRole bordering true)
(createRole rocktype)
(createRole sand true)

(createConcept ROCK (and  (all rugosity (oneOf Smooth Rough))
                          (all shape (oneOf Rounded Flat))
                          (all fastening (oneOf Fastened Loose))
                          (all size (oneOf Small Medium Big))
                          (all surface-closeness (oneOf Near Far))
                          (all height (oneOf High Low))))

(createIndividual Bolo (and ROCK (fills rugosity Smooth)
                                 (fills shape Rounded)
                                 (fills fastening Loose)
                                 (fills size Small)))
(createIndividual Laxa (and ROCK (fills rugosity Smooth)
                                 (fills shape Flat)))
(createIndividual Peton (and ROCK (fills fastening Fastened)
                                  (fills height High)))

(createConcept FISH (oneOf Wrasse-female Wrasse-male Turbot
                    Sea-bream Velvet-swimming-crab Octopus Conger-eel Bib))

(createConcept ENVIRONMENT (and (all bordering (oneOf Yes No))
                                (all rocktype ROCK)
                                (all sand (oneOf Yes No))
                                (all fishes FISH)))

(createConcept VEIRADAS (and ENVIRONMENT (fills bordering Yes)
                                         (fills sand Yes)))
(createConcept OIADOS (and ENVIRONMENT (fills bordering No)
                                       (fills rocktype Bolo)
                                       (fills sand Yes)))
(createConcept RODAS (and ENVIRONMENT (fills bordering No)
                                      (fills rocktype Peton)
                                      (fills sand Yes)))
(createConcept BOLEIRAS (and ENVIRONMENT (fills bordering No)
                                         (fills rocktype Bolo)
                                        (fills sand No)))

(createRule one VEIRADAS (and   (fills fishes Wrasse-female)
                                (fills fishes Wrasse-male)
                                (fills fishes Turbot)
                                (fills fishes Sea-bream)
                                (fills fishes Velvet-swimming-crab)
                                (fills fishes Octopus)))
(createRule two OIADOS (and (fills fishes Conger-eel)
                            (fills fishes Wrasse-male)
                            (fills fishes Turbot)
                            (fills fishes Sea-bream)
                            (fills fishes Velvet-swimming-crab)
                            (fills fishes Wrasse-female)))
(createRule three RODAS (and   (fills fishes Bib) ))
(createRule four BOLEIRAS (and  (fills fishes Conger-eel)
                                (fills fishes Octopus)
                                (fills fishes Velvet-swimming-crab)))
```

Figure 1. Terminological Knowledge Base written in CLASSIC

and roles. Atomic concepts can be considered as unary predicates and atomic roles can be considered as binary predicates. Atomic concepts and roles are combined to build complex concepts and roles. Semantics allows the interpretation of concepts as subsets of objects (here called individuals) of the domain and the interpretation of roles as binary relations between objects of the domain. Therefore the extension of a concept is a set of individuals and the extension of a role is a binary relation between individuals. Also following the semantics of language constructors the equivalent in FOL of any concept or role expression can be obtained.

Satisfiability and subsumption are the basic inferences in DLs. A concept is satisfiable if it can have a non-empty extension. A concept C is subsumed by a concept D if the extension of C is always a subset of the extension of D. Other inference tasks of great utility such as equivalence or classification can be reduced to satisfiability and subsumption. Reasoning about individuals is also provided with these logics. Since the seminal works in the field [14] [15], reasoning in DLs and the tradeoff between between expressiveness and tractability have been deeply studied, leading to important results (see [7] for a survey).

Terminological languages (also called concept languages) are implementations of DLs. Classic [22] and Fact [13] are examples of well-known terminological languages. These languages allow to define concepts and roles, to organize them by means of taxonomies, to define individuals and to do inferences on these elements and structures. Practical applications of description logics (terminological systems) using these and other terminological languages exist in a wide variety of domains: data and knowledge management systems [3][2], global information systems [16], clinical information systems [23] or software engineering [6].

In our project we choose to use Classic for several reasons. The language is expressive enough to be useful and limited in a way that tractable reasoning is assured. The language is simple and small enough to be really usable because it can be learnt by non-experts in computer science. Even a methodology for using Classic has been published [4]. This knowledge engineering methodology has been elaborated emphasizing the modeling choices that arise in the process of describing a domain and the key difficulties encountered by new users. The language has additional features that increase usability such as a limited forward-chaining rule system and the possibility of concept definitions written as test functions in a procedural programming language. However, these additional features are designed following the principle that user code cannot subvert the knowledge representation system -that is, these additional features have to be maintained opaque and should not destroy the correspondence between the reasoning subsystem and the formal semantics-. Lisp, C and C++ implementations of Classic exist, and an API (Application Programmer's Interface) is available. The distribution is now being handled by Bell Labs where licenses for research and commercial use can be obtained [1].

4 PUTTING IT INTO PRACTICE

This section illustrates how we are putting this methodology to work. We must remember that our goal is not only to represent FEK but also that the anthropologist become involved in this task.

Firstly the anthropologist must acquire the basics notions of descriptive languages: individuals, concepts, roles and taxonomies. This can be done in an informal but fairly way without resorting to formal model-theoretic notions. DLs are particularly well suited to this process because their basic elements can be explained just using elementary set-theoretic and algebra notions.

The process itself of developing a Knowledge Base (KB) in a terminological language is a knowledge engineering process where the key is finding the way to break the domain into individuals, concepts and roles. In the case of Classic a methodology especially devised for beginners in using Classic is available [4]. Though this method may oversimplify some aspects of the knowledge representation process, it is ideal for our purposes of introducing the anthropologist in using Classic. The method consists of twelve basic steps exemplified with the *wine and meal* example: 1) enumerate object types, 2) distinguish concepts from roles, 3) develop concept taxonomy, 4) isolate individuals and for each individual try to determine all of the concepts that describe it, 5) determine properties and parts, 6) determine number restrictions, 7) determine value restrictions, 8) detail unrepresented value restrictions, 9) determine interrole relationships, 10) distinguish essential and incidental properties, 11) distinguish primitive and defined concepts, 12) determine disjoint primitive concepts.

The next phase in our work is one of practice with this method through the use of real examples extracted from FEK. For instance, the anthropologist have useful knowledge about rocks (*laxa*, *bolo*, *petón*), clusters of rocks (*veiradas*, *oiados*, *boleiras*, *rodas*) and species associated with these *environments*. Following the method, this domain is decomposed into elements of the terminological language. The result is an informal representation that must be transformed into a Classic KB. To serve as an example, figure 1 shows a KB written in CLASSIC. The following lines explain the meaning of the KB. The first ten terminological axioms define the set of roles of the KB using the function `createRole`. Roles are the entities that represent the properties of individuals. They map individuals to other individuals. The roles of a individual can be filled by individuals (the role fillers) or have their potential fillers restricted by concepts, or both. Each role definition includes the name of the new role and the boolean specifies whether the role is an attribute. An attribute is a role that have at most one filler. For instance, `size` is an attribute because we use this role to model a property for rocks and a rock is supposed to have an only size. On the contrary, `fishes` is not an attribute because this role models the relationship between an environment and the fishes within it. Clearly, within an environment different species can occur. The first six role axioms correspond to properties for rocks and the last four role axioms define environments' features. After creating the roles, we define the concept `ROCK` by means of the function `createConcept`. In this terminological axiom the symbol `ROCK` is the name of the concept being defined and the description is the concept definition. An `and` concept constructor forms the conjuction of some number of descriptions. An `all` restriction specifies that all the fillers of a particular role must be individuals described by a particular description and `one-Of` is a concept constructor which forms a concept enumerating its individuals. Therefore, the axiom defining `ROCK` includes a domain constraint for each one of the properties of a rock. In this case, the domain is constrained by specifying the set of individuals that can be fillers for each role. For instance, the rugosity of a rock has to be either smooth or rough or the shape has to be either rounded or flat. Individuals are specific instances of concepts that are used to represent the real-world objects of the domain. Individuals are created by means of the function `createIndividual`. In the function call, the first symbol is the name of the individual being created, and the description is the definition of the individual. The `fills` concept constructor specifies that a particular role is filled by the specified individuals. Once a rock is defined, the individuals `Bolo`, `Laxa` and `Peton` are created. As an example, `Laxa` is an individual belonging to the concept ROCK whose rugosity is smooth and whose shape is flat. The definition of the concept `FISH` simply specifies the set of its individuals. The concept `ENVIRONMENT` models *envinroments* as sets of individuals whose `rocktype` property is constrained to be a `ROCK` (`(all rocktype ROCK)`) and where several types of fishes can occur (`(all fishes FISH)`). Environments can have sand (`(all sand (oneOf Yes No))`) and can border other elements (`(all bordering (oneOf Yes No))`). `VEIRADAS`, `OIADOS`, `RODAS` and `BOLEIRAS` are subconcepts of `ENVIRONMENT` with specific fillers for the involved roles. Specific instances (individuals) of these concepts representing specific locations of this envinronments could be added to this knowledge base. The final lines of the KB define several rules via the function `createRule`. A rule consists of an antecedent, which must be a concept, and a consequent, which is a concept description. As soon as an individual is known to belong under the antecedent concept, the rule is fired, and the individual is deduced to belong under the consequent description. The individual does not need to be described by the consequent in order to be classified under the antecedent. Once the rule is fired, the individual is further classified based on the new information provided by the rule. These rules allow us to infer automatically the set of species that occur in a given environment. For instance, from the third rule, each individual belonging to the concept `RODAS` has the species bib as one of its fillers for the role `fishes`. This way, when defining an environment we do not have to specify the set of fishes that occur, but the system infers them automatically.

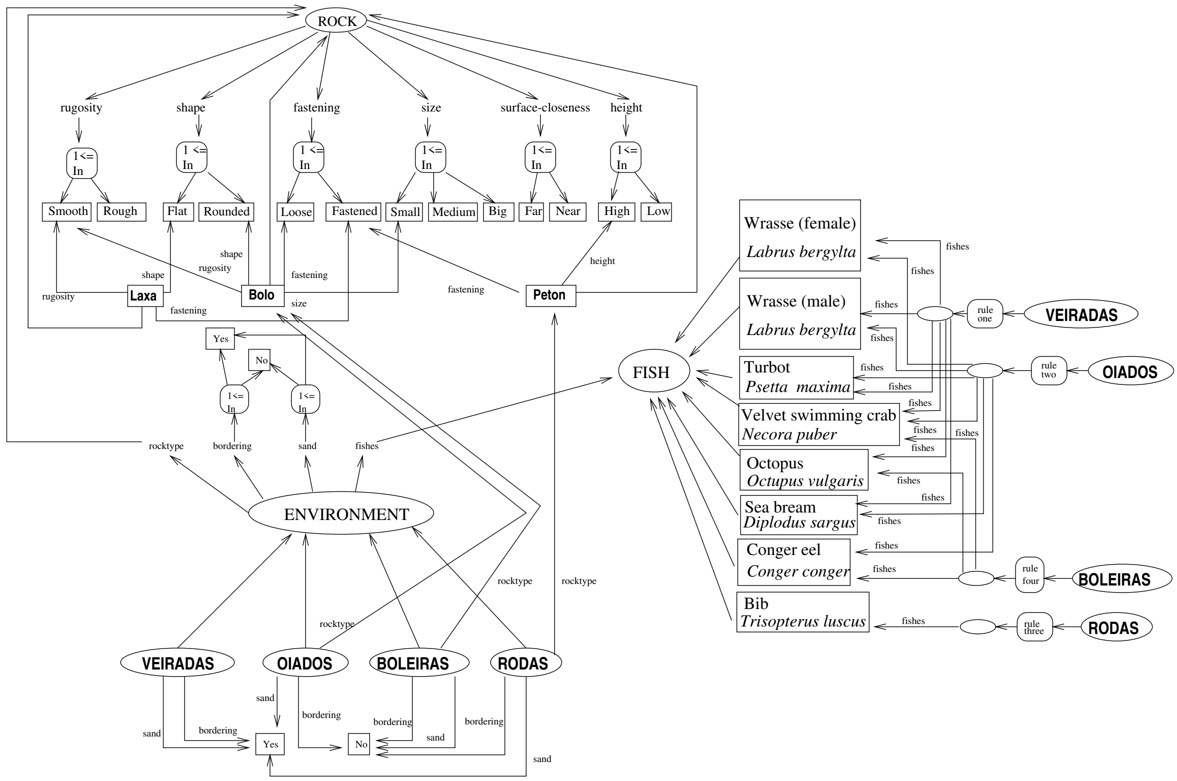

Figure 2. Graphical representation of the terminological knowledge base

The use of rules permits to distinguish between definitional and incidental properties. The set of fishes living in a given environment is not a definitional aspect for the environment but the definitional aspects of an environment, i.e. shape, rocks, etc., are the elements that really determine the set of fishes which can live within those conditions.

At this stage we have found a major difficulty when the anthropologist is confronted with the real syntax of Classic. For this reason the computer scientist is writing the KBs and producing graphical representations like the one that is shown in figure 2. In this graphical representations we use the notation of [12]. It is important to point out that, for the sake of clarity, we allow duplication of graphical nodes that are associated with a single knowledge representation element. Note also that the graphical syntax of [12] allows only defined concepts as consequents in rules, but Classic allows any concept description in the consequent part of a rule and not just a defined concept. These unnamed concepts are simply represented in figure 2 as ovals without labels. We have recognised a multiple purpose of this graphical representation: 1) it reinforces the knowledge engineering methodology, 2) it has been used to explain FEK to biologists and technicians and 3) it has motivated us to build a graphical interface for the terminological language which would facilitate the task of writing Classic KBs thus giving more weight to the role of the anthropologist in the knowledge engineering process.

5 CONCLUSIONS

We have presented a methodology to incorporate Fishers' Ecological Knowledge in the research of artisanal fisheries based on a knowledge representation formalism and a knowledge engineering technique and we have illustrated it with some initial work. We think that this approach can be considered in other domains where Traditional Ecological Knowledge can be incorporated into the management of natural resources.

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