From Geo to Eco-Ontologies

Frederico Fonseca[1] **James Martin**[2] **Andrea Rodriguez**[3]

[1]School of Information Sciences and Technology
Pennsylvania State University
University Park, PA 16802, USA
Email: fredfonseca@ist.psu.edu

[2]Psychology Department
Pennsylvania State University
University Park, PA 16802, USA
Email: jxm24@psu.edu

[3]Departamento de Ingeniería Informática y Ciencias de la Computación
Universidad de Concepción
Chile
Email: andrea@udec.cl

Abstract

Ecology is a subject of great debate today among scientists, governments, and the general public. Issues such as global warming and biodiversity require a mutual agreement among different groups of people. Many times these groups are separated by language, political interests, and culture. Environmental Information Systems need to integrate data from different Geographic Information Systems causing problems of semantic heterogeneity. However, before this kind of information sharing can happen among different communities, the concepts that people have about the real world must be explicitly formalized; such an explicit formalization of our mental models is called an ontology. Ontologies have been suggested as one of the options to address the problem of integrating diverse geographic information sources based on semantic values. In this paper we discuss options to structure such ontologies. First we discuss the use of hierarchies and roles in the structure of geographic ontologies. We chose a hierarchical organization, because hierarchies are a good way of representing the geographic world. Since the way people view the same geographic phenomena can change over time, we used the concept of roles. Then we discuss what are the characteristics of an ecological ontology that makes it different from a geographic ontology. We elaborate some of the fundamental characteristics of ecological ontologies and draw attention to the formal differences between ecological and geographical ontologies.

> *Our own survival depends on understanding that not only are we coupled to our own conceptualization of ecosystems and ecological order, but also the embodiments of our own ways of thinking about them and acting on them(Gregory Bateson quoted in* (Harries-Jones, 1995)

1 Introduction

There is a growing awareness of the problems that we face today regarding our environment. Citizens and Government need Information Technology to support their efforts in shaping public policies and managing natural resources. The shift of information systems that deal with the environment from research to practical applications lead to a new field called *Environmental Informatics* or *Environmental Information Systems* (Radermacher *et al.*, 1994).

Environmental Information Systems need to integrate data from different Geographic Information Systems (Voisard, 1995). Therefore, these kind of systems need to handle semantic heterogeneity (Sheth, 1999). Semantics of information integration is getting more attention from the research community (Worboys and Deen, 1991; Kuhn, 1994; Kashyap and Sheth, 1996; Bishr, 1997; Câmara *et al.*, 1999; Gahegan, 1999; Harvey, 1999; Sheth, 1999; Rodríguez, 2000). The support and use of multiple ontologies (Wiederhold and Jannink, 1998; Chandrasekaran *et al.*, 1999) is a basic feature of modern information systems because they support semantics independently of data representation in the integration of information. Ontologies capture the semantics of information and can be used to store the related metadata enabling this way a semantic approach to information integration. In order to increase the availability and improve the access to environmental data it is necessary to have better metadata (Günther and Voisard, 1998).

Ontology has been a strong research topic lately. In a recent *Communications of ACM* issue on Ontologies, Gruninger and Lee (2002) discuss the increasing use of ontologies and what is necessary to improve the results in the field. The use of ontologies today range from communication between humans and computer systems to computational inference and use and reuse of knowledge. The increasing use of ontologies in information systems lead to a new sub-field, ontology engineering, which intends to support ontology development and use.

Geographic Information in not an exception. In an IJGIS special issue on ontologies, Winter (2001) asks if ontologies are only a buzzword if they really represent a paradigm shift in GI Science. The active research in the use of ontology related to geographic information (Mark, 1993; Frank, 1997; Smith, 1998; Smith and Mark, 1998; Bittner and Winter, 1999; Fonseca and Egenhofer, 1999; Rodríguez *et al.*, 1999; Smith and Mark, 1999; Câmara *et al.*, 2000; Frank, 2001b; Smith and Mark, 2001) shows that it is really a new paradigm. However, only recently ontologies for ecology have been addressed (Frank, 2001a; Smith, 2001). Smith and Varzi (1999b; 1999a) stress the need to develop formal ontologies in the field of ecology. In this paper we extend the work of Rodríguez (2000) and Fonseca (2001) on the structure of ontologies for the geographic world, geo-ontologies, into the realm of ontologies that represent the environment, eco-ontologies. We highlight the structural differences that should be taken into account when we move from geo-ontologies to eco-ontologies.

The remainder of this paper is organized as follows. Section 2 reviews how ontologies can support the development and use of information systems. Section 3 presents a review of the work on the representation of geo-ontologies. In section 4 we elaborate some of the fundamental characteristics of ecological ontologies and draw attention to the formal differences between ecological and geographical ontologies. In section 5 we compare our approach in the study of eco-ontologies to the work of Smith (2001) and Smith and Varzi (1999a). Section 6 presents conclusions and future work.

2 Ontology-Driven Information Systems

Ontology-driven information systems (Guarino, 1998) are based on the explicit use of ontologies at development time or at run time. The use of ontologies in GIS development has been discussed by Frank (1997) and Smith and Mark (1998). Ontology playing a software specification role was suggested by Gruber (1991). Nunes (1991) pointed out that the first step in building a next-generation GIS would be the creation of a systematic collection and specification of geographic entities, their properties, and relations. Ontology plays an essential role in the construction of GIS, since it allows the establishment of correspondences and interrelations among the different domains of spatial entities and relations (Smith and Mark, 1998). Frank (1997) believes that the use of ontologies will contribute to better information systems by avoiding problems such as inconsistencies between ontologies built in GIS, conflicts between the ontological concepts and the implementation, and conflicts between the common-sense ontology of the user and the mathematical concepts in the software. Bittner and Winter (1999) identify the role of ontologies in modeling spatial uncertainty like the one often associated with object extraction processes. Kuhn (1993) asks for spatial information theories that look toward GIS users instead of focusing on implementation issues. Ontology use can also help GIS to move beyond the map metaphor, which sees the geographic world as layers of independent information that can be overlaid. Several inadequacies of the map metaphor have been pointed out (Kuhn, 1991).

There is a difference in the definition of ontology in the philosophical sense and in the way the term is used in the Artificial Intelligence (AI) field (Guarino, 1998). In AI, ontology is seen as an engineering artifact that describes a certain reality with a specific vocabulary, using a set of assumptions regarding the intended meaning of the vocabulary words. Meanwhile, in the philosophical arena, ontology is characterized as a particular system of categories reflecting a specific view of the world. Smith (1998) notes that since, to the philosopher, ontology is the science of being, it is inappropriate to talk about a plurality of ontologies, as engineers do. To solve this problem Smith suggests a terminological distinction between referent or reality-based ontology (R-ontology) and elicited or epistemological ontology (E-ontology). R-ontology is a theory about how the whole universe is organized, and corresponds to the philosopher's point of view. An E-ontology, on the other hand, fits the purposes of software engineers and information scientists, and is defined as a theory about how a given individual, group, language, or science conceptualizes a given domain. The use of an ontology, translated into an active information system component, leads to Ontology-Driven Information Systems (Guarino, 1998) and, in the specific case of GIS, leads to Ontology-Driven Geographic Information Systems (ODGIS) (Fonseca and Egenhofer, 1999). ODGIS are built using software components derived from various ontologies.

3 Representation of Geo-Ontologies

Representing geographic entities–either constructed features or natural differentiations on the surface of the earth–is a complex task. The diversity of things covered in a geo-ontology make GIS ontologically more demanding than traditional systems (Frank, 2001b). Besides that, the dual nature of geographic entities reflected in the field-object model adds to more complexity in geo-ontologies. Smith and Mark (1998) distinguish between *bona fide* objects, which are associated to some "objective" reality (such as rivers and roads) and *fiat* objects that exist only as a consequence of our conceptualization (such as census tracts, country boundaries, and vegetation types). They also argue that "fiat objects may in fact in many cases be much more field than object-like".

Geographic entities are not merely located in space, they are tied intrinsically to space (Smith and Mark, 1998). For instance, boundaries that seem simple can in fact be very complex. An example is the contrast between soil boundaries, which are fuzzy, and land parcels whose boundaries are crisp. Users who are developing an application can make use of the accumulated knowledge of experts that have specified an ontology of boundaries instead of dealing with these complex issues by themselves. The same is true for ontologies that deal with geometric representations, land parcels, and environmental studies. Users should be able to create new ontologies building on existing ontologies whenever possible.

Smith and Mark (1998) present the reasons for building an *ontology of geographic kinds*. This ontology will enable the understanding of how different information communities exchange geographic information. The study of the ontology of geographic kinds highlights certain characteristic types of distortions that are involved in our cognitive relations regarding geographic phenomena. Geographic information systems need to manipulate representations of geographic entities, and the ontological study of the corresponding entity types, especially those at the basic level, will provide default characteristics for such systems. Entity types present in ontologies can be use to improve the way data is exchanged based either in the semantic or in the representation aspects. Furthermore, the ontology of the geographic space, of the geographic objects and of the phenomena of the geographic space is different from other ontologies because topology and part-whole relations play a major role in the geographic domain. Topology is important because geographic objects can prototypically be connected or contiguous, scattered or separated, closed or open. A theory of part and whole, or mereology (Simons, 1987), is important because geographic objects are typically complex and have constituent parts (Smith and Mark, 1998). (Smith, 1995) introduces mereotopology, a combination of topological methods with the ontological theory of part and whole.

3.1 Entities

In order to represent geographic phenomena using ontologies, Rodríguez (2000) classifies the distinguishing features into *functions*, *parts*, and *attributes*. This classification attempts to facilitate the implementation of the entity class representation as well as to enable the separate manipulation of each type of distinguishing feature. Considering that entity classes correspond to nouns in linguistic terms, her work matches Miller's (1990) description of nouns. Using a lexical categorization, parts are given by nouns, functions by verbs, and attributes by nouns whose associated values are given by adjectives or other nouns. As with entity classes, more than one term may denote the same feature (i.e., synonymy) or a term may denote more than one feature (i.e., polysemy).

The notion of use-based semantics (Kuhn, 1994) leads Rodríguez to consider functions as one of the distinguishing features of an entity class representation. Function features are intended to represent what is done to or with a class. For example, the function of a *college* is to *educate*. Thus, function features can be related to other terms such as *affordances* (Gibson, 1979) and *behavior* (Khoshafian and Abnous, 1990). In the spatial domain, parts play an important role for the description of spatial entities. Parts are structural elements of a class, such as *roof* and *floor* of a *building*. It is possible to make a further distinction between "things" that a class may have ("optional") or must have ("mandatory"). While the part-whole relations work at the level of entity class representations and leading to the definition of all the entity classes involved, part features can have items that are not always defined as entity classes in this model. Finally, attributes correspond to additional characteristics of a class that are not considered by either the set of parts or functions. For example, some of the attributes of a building are *age*, *user type*, *owner type*, and *architectural properties*.

3.2 Hierarchies

One common solution is to use hierarchies to represent ontologies. Hierarchies are also considered a good tool for representing geographic data models (Car and Frank, 1994). Besides being similar to the way we organize the mental models of the world in our minds (Langacker, 1987), hierarchies also allow for two important mechanisms in information integration: generalization and specialization. Many times it is necessary to omit details of information in order to obtain a bigger picture of the situation. Other times it is mandatory to do so, because part of the information is only available at a low-level of detail. For instance, if a user wants to see bodies of water and lakes together, and manipulate them, it is necessary to generalize lake to body of water so that it can be handled together with bodies of water. Another solution would be to specialize bodies of water by adding more specific information. Hierarchies can also enable the sharing and reuse of knowledge. We can consider ontologies as repositories of knowledge, because they represent how a specific community understands part of the world. Using a hierarchical representation for ontologies enables us to reuse knowledge, because every time a new and more detailed entity is created from an existing one it is necessary to add knowledge to previous existing knowledge. When we specify an entity lake in an ontology, we can create it as a specialization of body of water. In doing so we are using the knowledge of specialists who have early specified what "body of water" means. The ramifications of reusing knowledge are great and can improve systems specification by helping to avoid errors and misunderstandings. Therefore, we choose to use hierarchies as the basic structure for representing ontologies of the geographic world.

The choice of hierarchies as the representation of the ontologies leaves us with a new problem, however. Many geographic objects are not static: they change over time. In addition, people view the same geographic phenomenon with different eyes. The biologist, for instance, looks at the lake as the habitat of a fish species. Nonetheless, it is still a lake. For a Parks and Recreation Department the same entity is a lake, but it is also a place for leisure activities. Or legislation might be passed that considers the same lake as a protected area. For instance, the biologist's lake can be created by inheriting from a specification of lake in a hydrology ontology and from a previous specification of habitat in an environmental ontology. One of the solutions for this problem is the use of multiple inheritance. In multiple inheritance a new entity can be created from more than one entity. Multiple inheritance has drawbacks, however. Any system that uses multiple inheritance must solve problems such as name clashes, that is, when features inherited from different classes have the same name (Meyer, 1988). Furthermore, the implementation and use of multiple inheritance is non-trivial (Tempero and Biddle, 1998). We chose to use objects with roles to represent the diverse character of the geographic entities and to avoid the problems of multiple inheritance. This way an entity is something, but can also play different roles. A lake is always a lake, but it can play the role of a fish habitat or a role of a reference point. Roles allow not only for the representation of multiple views of the same phenomenon, but also for the representation of changes in time. The same building that was a factory in the past must be remodeled to function as an office building. So it is always a building, but a building playing different roles over time. In our framework, roles are the bridge between different levels of detail in an ontology structure and for networking ontologies of different domains.

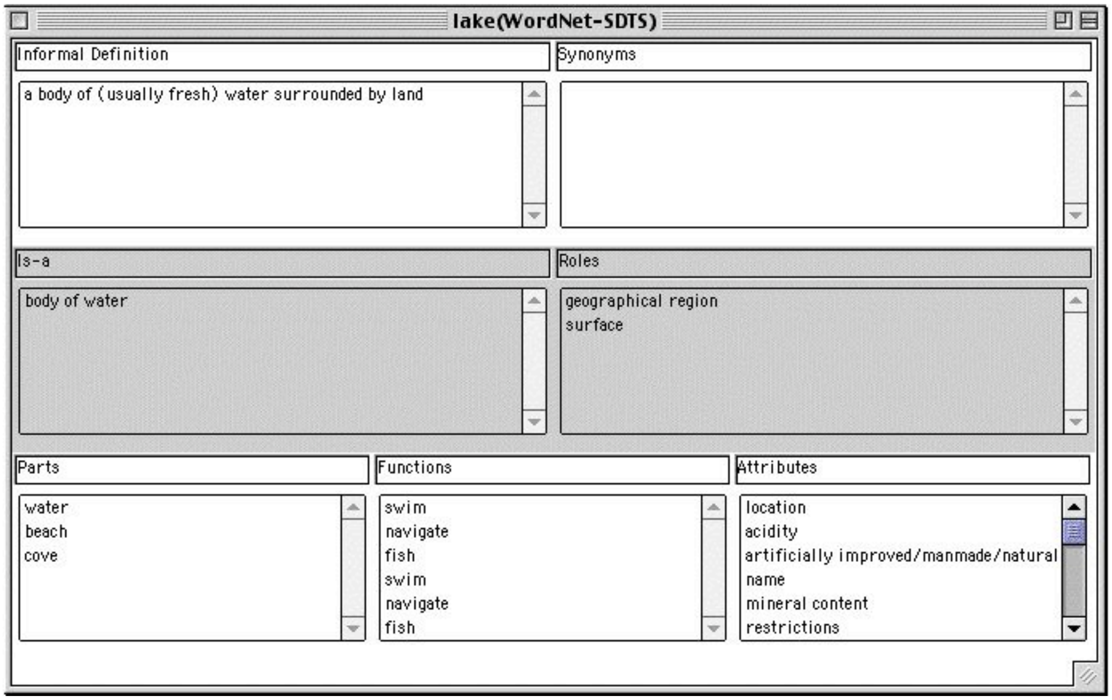
3.3 Roles

One of the advantages of using geographic information systems based on ontologies is the ability of having multiple interpretations to the same geographic feature. Here we address the question of how the objects in a geographic database can be associated with more than one class present in the ontology hierarchy.

Classes are typically organized hierarchically, taking advantage of one of the most important concept in object-oriented systems: *inheritance*. It is possible to define a more general class, containing the structure of a generic type of object, and then specialize this class by creating subclasses. The subclasses inherit all properties of the parent class and add some more of their own. For instance, within a local government you can have different views and uses for land parcels. A standardization committee can specify a land parcel definition with general characteristics. Each department that has a different view of a land parcel can specify its own land parcel class, inheriting the main characteristics from the general definition of land parcel and including the specifics of the department. In this case, we can have a land parcel definition for the whole city, and derived from it, two different specializations, one for tax assessment and the other for building permits. When a given class inherits directly from only one class, it is called *single inheritance*, whereas when a class inherits from more than one class, it is called *multiple inheritance* (Cardelli, 1984). Multiple inheritance is a controversial concept, with benefits and drawbacks. Although the implementation and use of multiple inheritance is non-trivial (Tempero and Biddle, 1998), its use in geographic data modeling is essential (Egenhofer and Frank, 1992).

In order to represent the diverse character of the geographic entities and avoid the problems of multiple inheritance we opted for using objects with *roles*. When defining an entity in an ontology it is important to clearly establish an identity. Here, an object is something, it has an identity, but it can play different roles. Guarino (1992) presents an ontological distinction between role and natural concepts using the concept of *foundation*. For a concept α to be founded on another concept β, any instance χ of α has to be necessarily associated to an instance y of β *which is not related to* χ *by a part-of relation*. Therefore, instances of α only exist *in a more comprehensive unity* where they are associated to some other object. A role is a concept that is founded but not semantically rigid. A natural concept is essentially independent and semantically rigid.

A role can be seen as an attribute of an object. In object orientation, and in this paper, a role is a slot, while for the database community it is a relation. Instead of using multiple inheritance, where, for instance, a downtown building is at the same time a building and a shopping center, we can say that this entity is a building that plays a *role* of a shopping center. Maybe the building was once a factory and later remodeled to be a shopping facility. In this paper, this building is seen as being always a *building* and playing during its lifetime two roles, i.e., *factory* and *shopping facility*. This way an object can play many roles. This structure for representing ontologies is extended from Rodríguez (2000) with the addition of *roles* (Figure 1).



lake(WordNet-SDTS)

Informal Definition
a body of (usually fresh) water surrounded by land

Synonyms

Is-a
body of water

Roles
geographical region
surface

Parts
water
beach
cove

Functions
swim
navigate
fish
swim
navigate
fish

Attributes
location
acidity
artificially improved/manmade/natural
name
mineral content
restrictions

Figure 1 - Basic structure on a geo-ontology class

4 A Self-Organizing Framework For Representing Ecological Ontologies

In this section, we elaborate some of the fundamental characteristics of ecological ontologies, draw attention to the formal differences between ecological and geographical ontologies. We argue that a key ideal specification of eco-ontologies is the notion of teleological organization. The teleological organization of ecosystems embodies a fundamental distinction between eco and geo-ontologies. Working out what teleological organization of eco-ontologies entails will reveal essential characteristics of eco-ontologies and their differences from geo-ontologies.

4.1 A preliminary definition of eco-ontologies.

The term ecology is derived from the Greek term hoikos that is translated as house, household, or home. As such, ecology is aimed at describing the dimensions of an eco-environment that supports, or provides a home for, various biological species and the biological system as a whole. The environment is conceived as a context that enables, or is a means to, biological life. Moreover, the whole biological system embedded in a physical environment is itself seen as an important aspect of the eco-environment of the species and individuals that compose the biological system. To summarize, ecology deals with environmental systems, both biological and non-biological, as means of species survival. These systems occupy a spatial location during a certain period of time.

The relation of means to ends embodied in the above description suggests that ecosystems may be conceived as teleological in character. The ecosystem is a means to the life of its constituents and also an end in relation to those constituents. In this context, we propose to examine the implications of the hypothesis that the fundamental characteristic of ecological ontologies is that they are a species of self-organizing system, in the sense stipulated by Kant (2000) in his Critique of Judgment. In particular, for Kant, a self-organizing system is one in which each of the components of the system are (either directly or indirectly) both means and ends in relation to the whole system and, consequently, to its other components. As an example, symbiotic relations such as those between certain insects and flowering plants are characteristic of self-organizing systems. The bee is a means to (i.e., plays the role of) fertilizing the plant, and the plant is a means to (plays the role of) nourishing the bees.

There is an important sense in which things may be said to be purposes of Nature. Kant says, "I should say in a preliminary fashion that a thing exists as a purpose of Nature when it is cause and effect of itself, although in a two-fold sense." Consider the case of a tree. In the first sense when a tree procreates, it produces another like itself. In this case, we see the species, of which the tree is a member, in the process of causing itself. In the second sense, we can see the metabolic activities of the tree as involved in the production of the tree itself. Note further, that the whole of the tree is causally dependent on the parts – for example, the leaves – that are in turn causally dependent on the whole. For a more current discussion of recursion and causation, see Spencer-Brown (1972) and Kauffman and Varela (1980).

The parts and the whole are reciprocally dependent upon one another. "In such a product of Nature each part not only exists by means of all the other parts but is also regarded as existing for the sake of the others and of the whole, that is, as an instrument (organ) (Kant, 2000)." However, this definition is still lacking because the parts of any organized product of human invention (a watch for example) can be considered as being for the sake of the others. But human invention is not a component of Nature in the sense in view in this discussion. Accordingly, it must be additionally stipulated that the parts of a Natural self-organizing system can be considered as causally producing one another. Kant concludes that "an organized product of Nature is one in which everything is reciprocally ends and means."

It is very interesting that this sort of analysis introduces, in a natural way, a teleological dimension into the description of an ecological system. Under its guidance, one begins to see an ecological sense in which it is appropriate to ask what something is for, or what its function (or, role) might be in the ecological system. Of course, if one ignores the reciprocal means-end analysis Kant pointed to, one might describe the causal antecedents of any number of events but fail to see the ecological system. Moreover, it would not be possible for such an investigator to identify the events or relations that are ecologically relevant, or to distinguish them from the indefinitely large set of events and relations that are of subsidiary importance in understanding the ecological system. For example, in examining the mammalian body there are many relatively subsidiary questions one might ask about the heart – such as what color it is when viewed on the laboratory dissection table. On the other hand, if one knows that the function, or role, of the heart is to move the blood, and that it is through that function that the heart enables the continued existence of the other organs of the body, and thus its own continued existence as well, then one is directed to ask questions concerning the heart that are relevant to the function of the whole body of which it is a part. Specifically, one is led to ask <u>how the heart moves the blood</u>. Similarly, the question of the role of a structure or relation in the function of an ecological system as a whole is central to an ecological level of analysis.

4.2 The essentially temporal character of eco-ontologies.

Ecological ontologies, then, must be represented in terms that allow us to capture their genuinely self-organizing, ecological nature (i.e., the ecological level of analysis). More formally, such self-organizing systems have the characteristic of recursion in the sense that A=>B=>C=>A=>B=>, etc. This description reveals the essentially temporal character of eco-ontologies. In contrast with the essentially spatial character of geo-ontologies, eco-ontologies are fundamentally temporal in character. The spatial character of geo-ontologies contributes to the hierarchical organization of geo-systems. The temporal character of eco-ontologies on the other hand is a function of the recursive process that is essential to their definition.

So why is time so different in eco-ontologies? It is because for living beings the clock is ticking all the time and very fast. Organisms in a ecological system have a short span of life compared to regular geographic features that can last millions of years. Today, for a living being, is different from yesterday because he/she is older. Many living beings learn from their experiences, which makes today even more different from yesterday from their point of view.

There is, of course, a possibility of hierarchical relations in eco-ontologies. However, in this case the hierarchies are functional and dynamic in nature. For example, at one level of analysis, the heart may be seen as moving the blood. At a subordinate level of analysis, moving the blood may be seen as pumping the blood, etc.

4.3 The elimination of a neutral ground from eco-ontologies

Geo-ontologies characteristically presuppose a neutral ground of facts or objects that are capable of various patterns of organization according to different interpretive frameworks. It is assumed that the basic facts are neutral and independent of interpretive framework. In this view, interpretation may affect the hierarchical organization and grouping of the basic facts, but it does not affect the facts themselves. The basic facts, then, provide an independent and objective foundation – a kind of natural starting point – that may be variously classified depending on the needs and assumptions of those creating the ontologies. However, the presence of a common foundation assures that the different organizational structures imposed on that foundation be systematically relatable by virtue of their association to the common foundation. From this point of view, the problem of combining two ontologies can be approached by reference to the neutral foundation that is assumed to be the common base of both ontologies.

In contrast, the eco-ontologies described above possess no natural starting point. Insofar as each component of a self-organizing system is both a cause and an effect of the other components, and the whole as well, there exists no independent and objective foundation for the classificatory development of hierarchies. The point of departure for an abstractive analysis of an eco-ontology may be determined by a decision to take certain events – or, nodes in the network of recursive relations – as a starting point for analysis, but those nodes have no absolutely independent ontological status. It is understood from the beginning that the choice of a particular basis for analysis is determined by the fruitfulness of the analysis that follows from it, rather than the objective independence of the basis. Obviously, the problem of combining eco-ontologies will require rethinking in light of the differences between geo and eco-ontologies.

4.4 Eco-ontologies and the doctrine of internal relations.

The doctrines of internal and external relations are different views concerning the role of relations among terms in determining the meanings of those terms. The doctrine of external relations holds that the meaning of a term is given independently of its relations to other terms. The specification of such relations is external to the meaning of the term under consideration. It is fairly clear that the doctrine of external relations is naturally associable with the geo-ontological presupposition of a neutral and independent ground. Such a ground would provide a basis for the definition of terms that would be independent of the relations among those terms.

In contrast, the doctrine of internal relations holds that the meaning of a term is not separable from the relations between that term and other terms with which it may be associated. Those relationships are internal to the meaning of the term in question. The meaning of a term is not independent of the place of that term in the network of relations with other terms that constitute the description of the ontology to which it has reference. In the absence of an independent foundation, the meanings of the terms referring to eco-ontologies are evidently defined in terms of their relationships with one another. The network of relations that describes an eco-ontology would embody the meanings of the nodes of the network. Accordingly, the cataloguing of those relations would constitute a description of the meanings of the terms referring to network nodes.

5 A Comparison with Smith and Varzi's Eco-Ontologies

Our approach to eco-ontologies differs from and complements the work of Smith (2001), and Smith and Varzi (1999a) in a number of ways. To begin with Smith and Varzi present an essentially spatial model of ecological ontologies. For example, in discussing the important ecological notion of a niche, Smith and Varzi (1999a) hold that "a niche is not a location, but a location in space that is defined additionally by a specific constellation of ecological parameters such as degree of slope, exposure to sunlight, soil fertility, foliage density, and so on. It is, we might say, and ecological context"(p.339). Smith and Varzi aim at a formal theory of this notion.

In the first place, the direction we have followed aims at acknowledging the temporal, as well as the spatial, aspects of ecological systems. The recursive temporality of biological systems envisaged by Kant seems to us to be an essential aspect of ecological systems in that it allows for a representation of function, and the characteristically dynamic and equilibrative character of ecological systems. We think that a niche is dynamic and temporal, as well as spatial. The description Smith and Varzi give does not recognize the role of the organism in maintaining the niche-like character of its ecological context. When, for instance, the value of one of the 'ecological parameters' to which they refer (e.g., exposure to sunlight) moves beyond certain critical limits determined by the biology of the relevant organism, then the organism may move from place A, to discover more shade, in place B. But it would be insufficient to simply extend our notion of the organism's ecological niche to include B as well as A for the reason that B is only a good place for the organism during the noon hour. At other times, B is not a niche for the organism. A might be a good place for the morning, B, a good place for noon, and, C, a good place for the afternoon, and, D, a good place to spend the night. Clearly, a purely spatial, non-temporal specification of a niche, and one that ignores the function of the organism in creating its niche, is insufficient.

Second, we value the flexibility inherent in the recursive analysis in that it does not suppose either a unique ontological or a unique epistemological foundation that forms the basis for hierarchical classification. Rather, the point of departure for a given analysis is flexible, depending on the purposes and perspective of the one engaging in the analysis. In contrast, a fully spatial model, such as that proposed by Smith and Varzi, is naturally hierarchical. It presumes that there is one and only one appropriate starting point for classification – a collection of natural samples. But it seems likely that different observers, guided by differing purposes and perspectives, taking for granted differing points of departure, will describe different ontologies. The world is ambiguous. Our approach will allow, to some extent, for the representation of that ambiguity. This capacity would seem essential for establishing communication among different ontological perspectives.

Third, the literal spatiality of the Smith and Varzi scheme appears inadequate to an analysis of human ecology. Suppose it is said of a young scholar that he has found a niche in the field of ontology research. This is, we think, both a meaningful and common mode of expression. Clearly, some form of spatiality is involved in this locution. A 'field,' even a field of research, is conceived spatially in some sense. Moreover, such a field may be a niche for a scholar in a sense we can all understand. At a relevant level of discourse we can consider the scholar as part of a self-organizing psycho-social system in which the components are both means and ends in relation to one another. However, remains to be shown that a 'field of research' possesses the topological characteristics Smith and Varzi require for the description of ecological niches. Something more abstract seems likely to be necessary for a general account of the ecology of the human world.

In their latest work, Smith and Varzi (2002) extend their previous work on niches introducing the dynamic aspect of life. They focused mainly on movement and its influence on the definition of the boundaries of a niche. They introduce a theory of token environments that is a first step towards a general theory of causally relevant spatial volumes.

6 Some Open Questions

In light of the fact that we are concerned to describe the integration and differentiation of ecological ontologies, we suggest that analysis of ecological systems from this point of view may be helpful in identifying the ecologically relevant points of connection and discrimination among alternative ontologies. Specifically, it is a question whether or not the integration of two or more ecological ontologies furthers ecological analysis by showing how a function described by one of the ontologies is carried out.

Moreover, there is the important possibility that an ontology resulting from the integration of two or more prior ecological ontologies might possess emergent ecological characteristics (recursions not found in any of the source ontologies). On the other hand, an integration of two or more non-ecological ontologies might (because it possesses emergent recursions) be ecological. These kinds of complementarities – in which the whole is greater than the sum of its parts – would be of particular interest in light of the subject matter of the ontologies we propose to investigate.

Briefly, some of the possibilities we wish to explore in light of the foregoing considerations are as follows:

1. Development of a metric in terms of which we can examine the similarities and differences among ecological ontologies in terms of geometrical patterns of recursion. Recognition of similarities and differences would be important for guiding the integration and dis-integration of ontologies.

2. Development of a metric for distinguishing the degree to which an ontology is ecological (characterized by recursion). This might be significant in discriminating perspectives in terms of their grasp of ecological issues.

3. Development of an account of meaning of nodes in an ecological ontological network in terms of the relations (roles) that specify the nodes in question.

4. One of the most interesting characteristics of an ecological system is that it is neither entirely open, nor entirely closed. It retains what coherence and continuity it possesses by virtue of its recursive character. That characteristic enables it to assimilate new components into its structure and to accommodate its structure to novelty without being destroyed by it. An analysis of the capacity of ecological systems to assimilate and accommodate to a constantly perturbing environment would be crucial for the representation of an ecological ontology.

It is clear that an exploration of the geometry of ecological ontologies and their combinations would be both interesting and important for the computational representation of information about ecological systems. Further, the essentially temporal nature of ecological ontologies may complement the already existing work dealing with spatial ontologies (Fonseca, 2001), and, as such, constitute an important step in the development of a theory of ontologies.

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