SEMANTIC NETS FOR OBJECT-ORIENTED LAND COVER MaPPING: a preliminary example

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ABSTRACT:

GEOBIA approach shows a high potential for land cover mapping on very high spatial resolution images. However, the map's quality often depends too much on i) the remote sensing expert knowledge of the land cover classes to be mapped, ii) the remote sensing methods employed and iii) the remote sensing processing software capabilities. In this paper, we argue that knowledge representation techniques such as semantic nets can be used to share and aggregate knowledge of thematic experts (such as ecologists) and remote sensing experts in order to develop enhanced image processing methods guided by domain expert's knowledge. We first asked ecologists to describe an olive grove, seen as a geographic entity belonging to the real-world. Then, we asked remote sensing experts to propose a derived methodology to map olive groves (seen as geographic objects representing geographic entities) on very high spatial resolution images based on the ecologists definition of an olive grove. We built a complete semantic net describing both point-of-views and discuss conceptual issues and perspectives linked to both descriptions.

1. INTRODUCTION

The remote sensing community is evolving rapidly. The launch of new satellites has been accompanied by enhanced sensors, including multi-spectral, hyperspectral and radar with increasingly high spatial and temporal resolutions. Access to the satellite images has been improved by the evolution of web services such as data portals by which data is disseminated rapidly at no cost to end users. As increasingly sophisticated satellite images are becoming available, new processing techniques are also needed to process the data and extract meaningful parameters from them. For example, limitations in pixel-based techniques for classifying very high spatial resolution images have resulted in the development of object-oriented analysis techniques (Blaschke and Strobl, 2001). The object-oriented approach is now considered as a paradigm shift in remote sensing and has formed a new discipline: Geographic Object-Based Image Analysis (GEOBIA, Hay and Castilla, 2008). New software, such as eCognition Developer® 8 (commercial software), InterImage (Costa et al., 2007) and OrfeoToolBox (http://www.orfeo-toolbox.org/otb/), have been designed to support remote sensing experts in their image analysis using the GEOBIA approach.

This evolution has broadened the spectrum of remote sensing applications (see the nine Societal Benefit Areas defined by the Group on Earth Observation - GEO) and highlighted new research issues, such as the production of standardized products. Various environmental parameters measured by remote sensing satellites, such as topographic height, vegetation productivity, precipitation, and Sea Surface Temperature (SST) are now provided, through GEOSS (Global Earth Observation System of Systems), to the scientific community… However, a major issue remains in conceiving an automatic and consistent approach to land cover mapping. Few land cover maps, based on medium to low resolution images, are produced, for example the GLOBCOVER global land cover initiative produced with MERIS/ENVISAT images (ESA, 2008). High resolution images are also used for land cover mapping in projects such as Corine Land cover and Urban Atlas in Europe or TerraClass in Amazonia (INPE) but the processes are not fully automated.

Currently, remote sensing experts are working on GEOBIA techniques for producing very high resolution land cover maps. Such approach based on the application of a knowledge-driven process considering various object features such as shape, texture and context, additionally to the spectral signature leads to very high quality maps. However, the map's quality depends on the remote sensing expert's knowledge regarding i) the land cover classes to be mapped, ii) the remote sensing attributes and thresholds used to map a defined class (which are usually identified through a trial-and-error process), and iii) the software used. Since the map's quality depends on the skill of the analyst, the process cannot be considered as repeatable and robust and consequently, is not compliant with the requirements for producing standardized products. In summary, GEOBIA shows a high potential for land cover mapping but inconsistency in the interpretation of very high resolution remote sensing images, depending on the skill of the analyst, remains an issue.

In this paper, we argue that a way to solve this issue consists in formalizing the expert-knowledge in order to deduce the optimal processes to be applied on remote sensing images. Knowledge representation techniques such as semantic nets can help in formalizing expert-knowledge. Knowledge representation is an area of artificial intelligence research aimed at representing knowledge in symbols to facilitate inferencing from those knowledge elements, thereby creating new elements of knowledge. Semantic nets, defined as directed acyclic graphs consisting of nodes (representing concepts) and edges in between (representing relationships between concepts), can be considered as useful techniques to represent knowledge (Growe, 1999).

We introduce an example to show semantic nets can be built for land cover class description and consequent mapping. The land cover class that serves as an example is that of an "olive grove". The method is based on a conceptualization phase for describing a land cover class of interest from different point-of-views (from ecology and from remote sensing). We discuss how both approaches are complementary and can lead to a complete description of a land cover class linking domain expert-knowledge to remote sensing.

The method will be used within the FP7-SPACE-2010.1.1-04 project titled BIOdiverity Multi-Source Monitoring System: from Space TO Species (BIO_SOS), The project aims to develop a pre-operational automatic multi-modular system to provide a reliable long term biodiversity monitoring service at high to very high-spatial resolution within Natura 2000 and their surrounding areas. The proposed system will be based on expert knowledge driven learning techniques (i.e. deductive learning). Expert ecologists are providing the 3D description of both LC and Habitat class description for several study areas belonging to different environmental zones (www.biosos.eu).

2. METHOD

Our work intends to be highly interdisciplinary in that we aim to share and aggregate knowledge from diverse domains in order to achieve a better classification process. Thus, this work has been carried out during a meeting involving experts from various areas:

- Ecologists who are the final users of the land cover maps and who have the knowledge on what they expect from remote sensing images
- Remote sensing experts specialized in very high resolution images processing with GEOBIA analysis
- Computer scientists specialized in knowledge representation techniques.

We first asked ecologists to express their knowledge on olive groves. Then, we asked remote sensing experts to analyze the ecologist's description in order to build an object-oriented methodology to detect olive groves on a very-high resolution image. The ecologist description and the remote sensing methodology were then merged in order to create a complete semantic net linking ecology knowledge to remote sensing processes. Computer scientists built the corresponding semantic nets based on the UML (Unified Modeling Language) formalism.

2.1 Land cover class description from the ecologist point-of-view

In order to assist ecologists in expressing their knowledge, we conceptualized the olive grove land cover description according to the methodology proposed by Couclelis (2010). Couclelis identified a semantic hierarchy that an expert follows for describing an object of discourse, i.e. a land cover class. It consists in seven levels used to describe a Geographic Information Constructs (GIC). These seven levels are a "semantic contraction which corresponds to an orderly procedure for draining the ontological system of semantic in a stepwise fashion as one moves from the more complex to the simpler levels" (Couclelis, 2010).

The seven levels are summarized below (for a more detailed description, the reader is invited to read Couclelis, 2010):

- **Level 7: Purpose.** The purpose of a GIC is the reason why the user is interested in mapping the land cover. For instance, one may be interested in mapping olive groves in Italy in the context of habitat mapping or estimate of agricultural production.
- **Level 6: Spatial function.** Spatial function serves purposes, for example, in expressing why mapping olive groves in Italy is relevant to monitor biodiversity.
- **Level 5: Composite Geographic Information Constructs**. The constitution of the land cover of interest is described at this level. It can be composed of disconnected and heterogeneous parts. For instance, an urban area is composed of buildings and roads.
- **Level 4: Simple Geographic Information Constructs.** Spatially-connected and homogeneous objects are categorized as independent objects or as parts of composite objects. For instance, a road is a simple object that is part of an urban area.
- **Level 3: Similarities.** At this level, the ability to identify and name objects is lost. The identity of objects is now based on their measurable properties (geometry, topology, etc). For instance, all roads in an urban area can be identified by a similar property such as their linear shape. However, it is not sufficient to detect linear objects to claim they are roads.
- **Level 2: Observables.** Objects can only be described based on a qualitative observation. The properties

cannot be measured any more. For instance, a photo-interpreter sees lines in an image but is not able to qualify them by a semantic (road) or a numeric value (length).

- **Level 1: Existence.** It refers to the ability to observe an object at a particular granule of space and time. For instance, lines observed on a 1km spatial resolution NOAA-AVHRR image cannot correspond to roads whereas same roads can be observed on 2.5m SPOT images.

Using such a semantic hierarchy for describing GIC offers an important advantage that is expressing the way domain-experts reflect on an object (i.e. a land cover class) by identifying i) why we want to map a land cover class (levels 7-6), ii) the thematic concepts we associate with the object of interest (levels 5-4), iii) the semantic, non-spatial (is a, part of), spatial (topological and not-topological) and temporal relations between these concepts (levels 5-4) and iv) the properties of the concepts and relations (levels 3-2).

2.2 Land cover mapping by remote sensing experts

The second step of the methodology consisted in asking remote sensing experts to describe the object-based image analysis process they would apply to map an olive grove based on very high spatial resolution images and ancillary maps (if updated), such as cadastral maps for mapping the field boundaries. However, in order to understand how the remote sensing experts can define an image processing methodology based on expert-knowledge, it is necessary to introduce a few conceptual issues linking both point-of-views of a same geographical element, i.e. an olive grove.

Theoretically, the semantic hierarchy introduced in section 2.1 allows different domain-experts to describe several different views of the same element. In that sense, an ecologist and a remote sensing expert should be able to describe the same land cover class based on the same method at the same scale (granularity). However, it is important to consider that both experts are not talking about the same thing: ecologists are describing geographic entities, while remote sensing experts are mapping geographic objects.

The concepts associated with geographic entities and geographic objects are different but are related nonetheless. Entities refer to the real-world phenomena, while objects refer to the digital world (Mark, 1993). In that context, a geographic entity is a component of the real-world characterized by attributes which are assigned attribute values. A geographic object is a bounded geographic region that can be identified, on a remote sensing image for example, for a period of time as the referent of a geographic term, i.e. a land cover class or a tree. It is noteworthy that geographic objects tend to be representations of geographic entities, but there is no identity between them (Castilla and Hay, 2008). Indeed, there is an important distinction between fiat objects created by spatial analysis and real-world entities to which these fiat objects are supposed to correspond (Câmara et al., 2001). In other words, an “olive grove” geographic object is not the vegetation itself, but rather a representation of this vegetation which would be characterized by different properties. For example, an olive grove might be described by its color, height, size, variety, phenological cycle, yield and spatial distribution whereas its image representation will be described by its texture, spectral signature etc. Finally, in order to identify geographic objects, remote sensing experts need first to extract image objects. An image object is defined as a discrete region of a digital image that is internally coherent and different from its surroundings (Castilla and Hay, 2008). So the goal of a remote sensing expert is to find relevant image attributes for classifying image objects and turn them into geographic objects.

Thus, in the example of the olive grove description, the semantic net built from ecologist's knowledge actually refers to the description of an "olive grove" geographic entity while the image process proposed by remote sensing experts refers to the description of an "olive grove" geographic object. The issue then consists in identifying the links between both descriptions in order to build a complete semantic net based on a shared and aggregated knowledge from ecology and remote sensing experts.

3. APPLICATION

3.1 Ecologist point-of-view

The olive grove is here considered as the object of discourse of an ecologist whose purpose (level 7) is to map habitats in Italy in order to capture the agricultural practices and their effect on biodiversity (level 6).

An olive grove is defined by ecologists as a cultivated orchard composed of olive trees. Fields usually have a geometric shape. Olive trees are identified by various properties such as leaf type (broadleaved), phenology (evergreen), height (from 2 to 4 m), biomass, crown size (usually more than 2 m) and crown shape (circular) Moreover, in olive groves, trees are regularly planted, arranged in orthogonal rows and the distance between trees varies between 10 and 20 m. Trees are surrounded by an herbaceous layer and/or bare soil depending on the farming practices and seasonality.

Based on this definition, we can conclude that olive groves are composite geographic information constructs (level 5) composed of olive trees and a land surface, both of them being considered as simple geographic information constructs (level 4). The olive grove is characterized by object-specific properties such as its shape (geometric) and its spatial structure (generally orthogonal rows). Here we redefined the shape as polygon and the spatial structure as point ordinated, as proposed by Provencher and Dubois (2007). The simple geographic information constructs (olive trees) are related to the olive grove by internal relations, such as the arrangement of trees inside the field which can be specified by a “disjoint” topological relation (with a specified distance varying between 10 and 20 m).

Each simple geographic information construct then has its own specific object properties and internal relations. For instance, olive trees and land surface are linked by topological relations such as “surrounded by” or “inside” (olive trees are surrounded by land surface). An olive tree can be described by object properties such as height, crown size and biomass which are measurable properties (level 3), or phenology, crown shape and leaf type, which are non-measurable properties (level 2). The land surface can also be described as being either soil and/or grass..

Based on this description, we built the UML diagram introduced in figure 1 (upper part).

3.2 Remote sensing point-of-view

The olive grove description made by ecologists was then analysed by remote sensing experts in order to propose an expert knowledge image process for mapping olive groves on very high spatial resolution images. The experts first identified the main concepts linked with the olive grove description. An olive grove is described as a cultivated area, being consequently included in cadastral maps. The geographic object representing an olive grove is a composite geographic information construct (level 5) composed of olive trees (as image core object) surrounded by soil, grass or shadow (as image context object). It must be denoted that the concept of shadow, though not included in the ecological definition of an olive grove, appears in the remote-sensing point-of-view, since the latter is derived based on the image perspective.

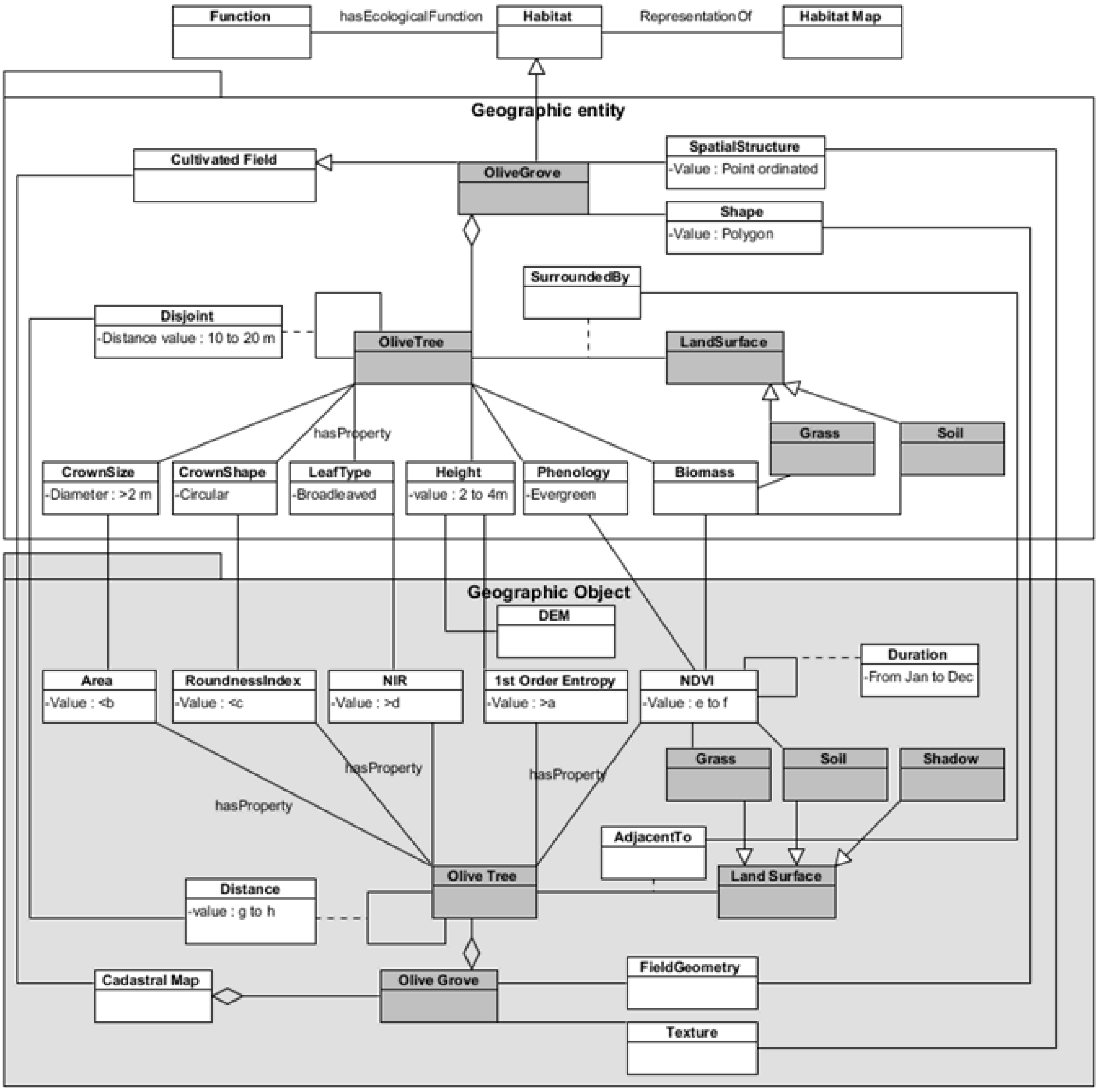

Figure 1. Top part: Semantic net description of an olive grove (as a geographic entity) by ecologist experts. Bottom part: Remote sensing decision rules for classifying olive groves (as geographic objects) in very high spatial resolution images. Arrows represent “is-a” relations, Diamond links represent “Part-Of” relations. Grey boxes represent simple and composite geographic information Constructs (in top) and corresponding simple and composite geographic objects (in bottom). (a, b, c, d, e, f, g and h are thresholds, some of them are expressed in pixels).

At this step, the remote sensing experts have identified the geographic objects (simple objects: olive trees, soil, grass and shadow; and composite objects: cultivated areas) they intend to detect in order to map an olive grove. Thus the first question to solve is: what would be the maximum spatial resolution that would allow mapping the simple geographic objects? Due to the fact that the minimal measure mentioned is 2 m (minimal crown size of an olive tree), the optimal spatial resolution must be at a metric scale, i.e. Quickbird image (2.4 m) or WorldView-2 image (1.84 m) for example. The second question then is, supposing such data is available, what image attributes can serve for delineating and classifying image objects. Here, remote sensing experts proposed the use of a series of measures to support image segmentation and classification, i.e. the Normalized Difference Vegetation Index (NDVI) as an indicator of biomass in order to discriminate vegetated from non-vegetated areas. All processes were developed on the Trimble eCognition software (http://www.ecognition.com/).

Vegetation height would be ideally monitored by LIDAR imagery. However, such data being of quite difficult access (especially due to cost limitations), experts proposed the use of a texture index, i.e. the 1st order entropy applied on the green band computed on very high spatial resolution multi-spectral images, for monitoring variation in vegetation height and thus discriminating low from high vegetation. Moreover, trees can be discriminated by object properties such as round shape (Roundness index) and area of the crown. A high threshold should be chosen for the crown size to take also into consideration cases where trees are adjacent to neighbouring trees (distance between tree crowns is very small) so that they are seen as a single object in the image, which in real-world is an aggregation of single trees. The leaf type can be monitored based on the Near-Infrared band and the canopy shape which is more spherical in the broadleaved whereas conical in the needleleaved species. Furthermore, the phenology property mentioned by ecologists (e.g., evergreen) can be observed by multi-temporal measures of leaf presence and productivity. One can then observe the NDVI values at both dates (usually one in summer and another in winter) to indicate if the vegetation is evergreen. Apparently, the vegetation phenology can be represented through temporal relations in the semantic net.

In addition, spatial relations can also be integrated to improve the process. The ecological definition of the olive grove implies spatial relations between the trees, i.e. their in-between distance is approximately 10 to 20 m. From the remote sensing experts point-of-view the tree objects are adjacent to land surface objects, i.e. soil, grass or shadow, and the center-to-center distance between trees can be measured in pixels.

Moreover, once the simple objects have been mapped and their relations observed, it is also possible to study the properties of the composite objects, i.e. the olive grove. Experts proposed to use additional context-sensitive features to observe the spatial arrangement of the trees inside the olive grove and the compactness index to check object's geometry. Finally, the cadastral map is used to ensure that olive groves are only located inside the cultivated areas.

Based on this process description, we built the corresponding UML semantic net representing the remote sensing expert point-of-view (Fig. 1; bottom part).

4. CONCLUSION

We consider that knowledge representation techniques such as semantic nets can assist the experts from different domains in structuring their knowledge so that it can be shared and aggregated in order to enhance information retrieval from remote sensing images. Our preliminary experience will be used to map olive groves in a study area in Italy on Quickbird and Worldview-2 images applying a GEOBIA approach on eCognition with the attributes proposed in this study and thresholds defined by a trial-and-error process. From a conceptual perspective, our main conclusions and perspectives are:

- The gap between ecologist and remote sensing experts point-of-views is an opportunity to improve the remote sensing process for classification.

- Whereas ecologists described the land cover class according to the semantic hierarchy proposed by Couclelis (2010), i.e. going from objects to field properties, the remote sensing experts process images using field properties contained in pixels to detect and classify image objects. In a sense, ecologists are deconstructing a Geographic Information Construct while remote sensing experts re-construct it in the image.

- This work needs to be improved using controlled vocabularies in order to ensure a better interaction amongst disciplines and guide experts when describing the semantic nets. For example, ecological concepts inspired from the LCCS (Land Cover Classification System; http://www.glcn.org/ont_2_en.jsp) could be useful. Moreover, terms used for the description of spatial (Clementini et al. 1993) and temporal (Allen 1983) relationships must be consistently applied as well as, for example, "structure" and "texture" concepts (Provencher and Dubois 2007).

- Finally, we intend to implement the UML semantic nets through ontologies to allow further automatic reasoning on objects extracted from remote sensing data (Gruber, 1995; Fonseca et al., 2002). This will enhance the transferability of the method to ontologies used in other scientific disciplines, such as ecology (Madin et al., 2008) or hydrogeology (Tripathi and Babaie, 2008).

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