Computers & Geosciences 84 (2015) 86–95

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

An ontological system for interoperable spatial generalisation in biodiversity monitoring

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ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form
14 June 2015
Accepted 24 August 2015
Available online 28 August 2015

Keywords:
Remote sensing
Spatial reclassification
Generalisation
Nature conservation
NATURA 2000
OWL2

ABSTRACT

Semantic heterogeneity remains a barrier to data comparability and standardisation of results in different fields of spatial research. Because of its thematic complexity, differing acquisition methods and national nomenclatures, interoperability of biodiversity monitoring information is especially difficult. Since data collection methods and interpretation manuals broadly vary there is a need for automatised, objective methodologies for the generation of comparable data-sets. Ontology-based applications offer vast opportunities in data management and standardisation. This study examines two data-sets of protected heathlands in Germany and Belgium which are based on remote sensing image classification and semantically formalised in an OWL2 ontology. The proposed methodology uses semantic relations of the two data-sets, which are (semi-)automatically derived from remote sensing imagery, to generate objective and comparable information about the status of protected areas by utilising kernel-based spatial reclassification. This automatised method suggests a generalisation approach, which is able to generate delineation of Special Areas of Conservation (SAC) of the European biodiversity Natura 2000 network. Furthermore, it is able to transfer generalisation rules between areas surveyed with varying acquisition methods in different countries by taking into account automated inference of the underlying semantics. The generalisation results were compared with the manual delineation of terrestrial monitoring. For the different habitats in the two sites an accuracy of above 70% was detected. However, it has to be highlighted that the delineation of the ground-truth data inherits a high degree of uncertainty, which is discussed in this study.

1. Introduction

Reducing biodiversity loss is a key global environmental challenge and is addressed by a variety of global, national, and regional initiatives (Butchart et al., 2010). To properly assess progress made in retaining the existing biodiversity, advanced measuring and monitoring systems are needed (Magurran et al., 2010). Although there are a number of differently scaled monitoring programs, comparing acquired data is a crucial but often neglected task. The European Habitats Directive (Council Directive 92/43/EEC, 1992) was established to provide a consistent and comprehensive basis for biodiversity monitoring and nature conservation activities. The so-called Natura 2000 network collects this information as reports produced by each member state every six years. Due to the federal structure of the European Union and the differences in data delivery approaches of the various nature conservation authorities there is a high demand for innovative technical solutions to realise a comparable, comprehensive monitoring program.

Generally, information about biodiversity can be gained by field mapping, species modelling, and remote sensing. Various publications have highlighted the benefits of remote sensing in conservation biology and demonstrated standardisation of monitoring results and hence transferability is possible. Yet, even for the remote sensing-based mapping of the Natura 2000 areas, various methods of deriving nature conservation data (semi-)automatically (Thoonen et al., 2010; Bock et al., 2005; Frick and Weyer, 2005; Vanden Borre et al., 2011; Schuster et al., 2011; Corbane et al., 2015) are available. It is necessary to generate applications that are able to use the produced information to generate interoperable and therefore comparable outcomes. International decision-makers rely on the comparability of this kind of information to evaluate policy options. Since remote sensing-based products in the field of Natura 2000 monitoring are usually generated for local or regional purposes and produced with a range of sensors, image processing methodologies and nomenclatures; thematic harmonisation of this spatial information is crucial for international policy-making (Arvor et al., 2013; Schmeller et al., 2014).

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http://dx.doi.org/10.1016/j.cageo.2015.08.006
0098-3004/

Classes derived by remote sensing are often based on indicators (e.g. the Normalised Difference Vegetation Index (NDVI), homogeneity, biomass, etc.) (Buck et al., 2015) which have to be restructured to vegetation or habitat classes defined in regulations (as is the case for the Habitats Directive). However, there is often a data mismatch between what administrative classes represent and the information contained in a remote sensing signal. To give an example: using a remote sensing signal we can accurately differentiate between open soil, heath, and grassland. However, in a certain combination (percentage) and spatial proximity, these three components form a heathland habitat according to the habitats directive. To automatically aggregate this class, a spatial reclassification is needed.

This work proposes a spatial reclassification approach, which is able to extend existing generalisation methods (Thoonen et al., 2010; van der Kwast et al., 2011) by using semantic relations and inference to generate comparability of the outcomes of different regions with regard to its content. It represents a further enhancement and detailed evaluation of the methodology developed by Nieland et al. (2014). This procedure is independent from classification approaches and sensors and can therefore be applied to data from multiple input sources to generate interoperable data-sets.

The main objectives of this paper are to:

- propose a kernel reclassification algorithm that is able to generalise remote sensing classification results to Natura 2000 habitats and show its functionality and applicability,
- give a practical example of semantic mediation and interoperability of geo-spatial data in the field of remote sensing-based biodiversity monitoring by combining spatial reclassification with ontology-based data handling.

2. Related work

The utilisation of ontological reasoning for interoperable data management is an increasingly accepted method in the field of geo-spatial research. This refers mainly to applications, which use shared conceptualisations to generate comparability of categories included in different data models (Durbha et al., 2009; Buccella et al., 2009; Lutz et al., 2009; Visser et al., 2002). Ontologies can be used to facilitate information exchange between different components of workflows (Van Zyl et al., 2012; Zhao et al., 2009), as a bridge between different data structures (Nieland et al., 2015; Kavouras et al., 2005), nomenclatures or databases (Martino and Albertoni, 2011) or as a basis to advance retrieval (Visser et al., 2002) and discovery (Stock et al., 2013) of information. An overview of recent usage of ontologies in GIScience is given in Table 1.

In the field of remote sensing, ontologies have been applied by using observations (Andrés et al., 2013; Belgiu et al., 2014; Forestier et al., 2013; di Sciascio et al., 2013) as a basis for further reasoning. This so-called observation-driven geo-ontology engineering approach (Janowicz, 2012; Couclelis, 2010) uses ontological primitives (concepts in the ontology that cannot be further reduced) that can be derived from observations. Semantic descriptions of categories can be further conceptualised by taking into account these primitives in a bottom-up approach and then assigned to upper level ontologies to foster a broader interoperability. This technique therefore allows semantic diversity of categories and local formalisation without giving up comprehensive interoperability. Although there are promising approaches in ontology-based classification there are, until now, very few applications (Lutz et al., 2009) that make use of its possibilities for improving interoperability. Previously the way to compare remote sensing classification results was to have remote sensing experts manually map the classified categories. In order to cope with the constantly increasing amounts of data and remote sensing classifications, there is a need for automatised methods that are able to generate comparable data. This is especially needed for supranational and international treaties and obligations. Spatial Reclassification Kernels (SPARK) have been developed for remote sensing-based classification of heterogeneous categories in the urban environment (Barnsley and Barr, 1996). This methodology has been adapted for use in the field of habitat mapping as it properly deals with between-class spectral confusion and within-class spectral variation of especially very high resolution satellite data (Keramitsoglou et al., 2005; Kobler et al., 2006). It has already been used to generalise biodiversity indicators to habitat patches (Thoonen et al., 2010).

3. Method

This section illustrates the developed methodology of generalising remote sensing classification results to Natura 2000 habitat patches. It furthermore highlights the possibility of developing an application, which is able to interact with a Web Ontology Language (OWL2) ontology to produce fully interoperable results. By taking advantage of the underlying semantics, the application is able to use the logic and relations of the given class descriptions to generate comparable Natura 2000 habitats throughout different regions and classification approaches.

Table 1
Fields of ontological research in GIScience and exemplary publications.

Research field	Area of application	References
Remote sensing	Agent-based image analysis for remote-sensing data	Hofmann et al. (2015)
	Detection of building types from airborne laser scanning	Belgiu et al. (2014)
	Coastal image interpretation	Forestier et al. (2013)
	Classification of high resolution satellite imagery	Andres et al. (2012)
		di Sciascio et al. (2013)
Interoperability of geo-spatial data	Matchmaking using similarity measures	Kavouras et al. (2005)
		Hess et al. (2007),
		Schwering and Raubal (2005)
	Matchmaking through reasoning	Durbha et al. (2009)
		Cruz and Sunna (2008)
		Nieland et al. (2015)
Workflow management	Wildfire detection generic/theoretical description	Van Zyl et al. (2012)
		Zhao et al. (2009)
Data discovery and retrieval	Environmental impact of port extension	Stock et al. (2013)
	Transfer of land-cover products	Visser et al. (2002)