Automating the Semantic Annotation of Geodata

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Abstract. The ability to represent geospatial semantics is of great importance when building geospatial applications for the web. It will not only enhance discovery and retrieval of geographic information, but it will also enable its translation and reuse in contexts other than the original one. We propose a method for automating the semantic annotation of geodata based on spatial characteristics and suggest applying spatial analysis methods for extracting information useful for the annotation process. The approach is illustrated by a case study on annotating data sources containing representations of floodplains.

1. Introduction

The pattern of geographic information utilization has shifted from monolithic expert systems (GIS) towards the distributed computing environments of Spatial Data Infrastructures (SDIs). Two implications arise from this: 1) The number of users with access to geographic information increases as well as the variation in the users' experiences, viewpoints and information needs, and 2) geographical datasets that were once produced for a specific purpose and used only within the same organisation are now accessible for a broad and heterogeneous user community. Interoperability for the setup of SDIs has been supported by the Open Geospatial Consortium (OGC) with a series of syntactic interface specifications, establishing protocols for the components exchanging geospatial information [1]. However, challenges remain in supporting the crucial tasks of discovery and retrieval of information sources that meet the user's needs. Metadata standards for the description of geodata exist as well as catalogue services to search them. But these do not account for the fact that the conceptualisations governing the different implementations have been constrained in different ways [2], causing semantic heterogeneity during discovery and retrieval [3].

Currently, the only explicit information available about geodata are database schemas and natural language entries in metadata documents. Since the semantics of these local resources is not machine-readable, it cannot be shared with other systems. What is lacking is a formal and explicit representation of the semantics in order to achieve semantic interoperability within an SDI [1]. While the standardization efforts of the OGC concentrate on syntactic interoperability, the semantic web initiative has brought the semantic issues of information processing into perspective [4]. It seems promising to adopt the developments around the semantic web like the Web Ontology

Language (OWL) and the Semantic Web Rule Language (SWRL) in order to approach semantic interoperability in geospatial web applications. Visions, architectures, and applications of this cross-fertilization of geospatial and semantic web technology are cumulating in the notion of a *Geospatial Semantic Web* [5-8].

In [9] we have presented an approach for automating the semantic annotation of geodata. The work concentrated on the role of spatial relations for extracting implicit instance level information. In this paper we refine that approach by exploring the use of semantic web technologies for the semantic representation layer.

Fig. 1 gives an outline of the semantic annotation process. Starting point are ontologies that have been specified for (more or less) homogeneous information communities (e.g. hydrology, geology, landscape ecology, transport planning, flood management). The ontology is supplemented by a set of rules that provide directions for the information extraction process. In our case, the sources for information extraction are spatial information objects that are stored in a spatial database. We can thus use, among others, spatial analysis methods in the extraction process. This has several advantages compared to textual or schema analysis, which will be discussed later. The result of the information extraction process is made explicit by establishing a reference to the corresponding concepts in the ontology. Depending o the ontological view that is imposed on the dataset, the resulting semantic representation will reflect the particular needs of the corresponding user community.

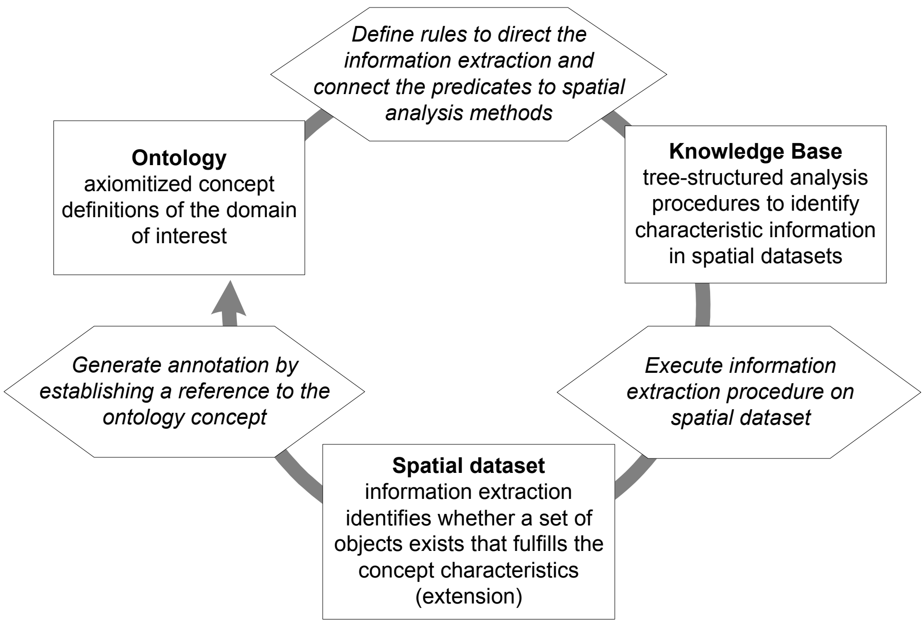

Fig. 1. Outline of the approach for automating the semantic annotation of geodata.

In section 2, we argument why explicit semantic annotations of geodata are needed in today's SDIs. In section 3 some background on geodata, which is the subject to annotation, is given. Section 4 discusses geospatial ontologies, which constitute the semantic representation layer. In section 5, we illustrate the general idea by conducting a walk-through the annotation process for floodplains. Finally, we discuss the approach and point to future work.

2. Motivation: Realizing Ontology-based Discovery, Retrieval and Translation of Geographic Information in SDIs

Emergent Spatial Data Infrastructures enable access to geodata for a broad user community. In such open and heterogeneous environments, semantic interoperability is crucial for searching data sources and evaluating their content. In this section we give some background on SDIs, point out the most evident semantic problems during data discovery, retrieval, and translation and show in what respect the availability of explicit semantic representations could improve usability.

2.1. Spatial Data Infrastructures

Geographic information systems (GIS) are expert systems for the collection, management, analysis, modelling and visualizing of geographic information. Spatial Data Infrastructures (SDI) have evolved out of the expansion of geographic information systems (GIS) into a distributed and cooperative environment, not only from a technical perspective (advances in network technologies) but also taking into account cooperation policies among different organizations (public or private), and at different levels (local, regional, national or global) [10].

The main components of SDIs are geographic information (GI) services providing access to geospatial data and geoprocessing capabilities. Acknowledging the role of interfaces for distributed computing in the GIS area, the Open Geospatial Consortium (OGC) identified the interface of software components as the key ingredient of GIS technology that needed standardization in order to achieve interoperability [11]. The result is a series of syntactic interface specifications, establishing protocols for components exchanging geospatial information.

Today, most of the digital geospatial information resides in databases and files. The definition of the Geography Markup Language (GML) [12] as an open, vendor-neutral XML encoding for the definition of geospatial application schemas and objects increases the ability of organizations to share geographic information. But still, users of these data need information on what they mean. So far, the only explicit information available are the attribute names of the database schema and the metadata entries in natural language. This leads to semantic heterogeneity problems at different levels. At each of these levels, it can inhibit tasks that are essential to the success of SDIs.

- At the *metadata* level, semantic heterogeneity impedes the *discovery of geographic information*;

- at the *schema* level, semantic heterogeneity impedes the *retrieval of geographic information*; and
- at the *data content* level, semantic heterogeneity impedes the *interpretation and integration of geographic information*.

Discovery

In an SDI context, clients and data sources are usually arbitrarily distributed in large networks and unaware of each other. In such a scenario, missing or insufficient documentation makes it difficult or even impossible for users to discover data sets and to assess whether a given data set is useful for their tasks. Catalogues are used to solve these problems, which makes them a fundamental part of SDIs. They allow a client to search for spatial resources available on servers that are unknown to the client and fit the client's needs. The effectiveness of a catalogue query highly depends on the methods implemented for discovering relevant information in the registered metadata. Even though the use of thesauri and natural language processing techniques (e.g. [13]) might increase the semantic relevance of search results, keyword-based search is inherently restricted by the ambiguities of natural language. As a result, keyword-based search can have low recall if different terminology is used and/or low precision if terms are homonymous or because of their limited possibilities to express complex queries [14].

Retrieval

Once an appropriate data source has been discovered, it can be accessed through a standardized interface like a Web Feature Service (WFS) [15]. While the service can be queried for the schema of a data source, a requester might still run into trouble when formulating a query filter if the property names are not intuitively interpretable. Also, when the retrieved data are to be consumed by another service (e.g. in a composite service chain) they might have to be mapped from the providing service's (source) schema into the consuming service's (target) schema.

Translation

Problems can also occur when interpreting the content of data, in particular if the semantics of values depend on some reference system (e.g. units of measure or a classification system). For example, it is difficult to interpret a value correctly, if the unit of measure is not given. Problems can also occur when classification systems (e.g. for rock, soil, or vegetation types) are used. They can differ between information communities (e.g. between geology and soil science), but also within *one* information community when the vocabulary used by the information community changes over time. The resulting heterogeneities present serious problems when several datasets using different classification schemes are to be represented in a common map, interpreted by a user or combined for analysis. Likewise, the data integration task within a composite service chain requires the detection and elimination of semantic heterogeneities, e.g. transformations of values between different units of measure.

2.2. Approach to Overcome Semantic Heterogeneity Problems in SDIs

Ontologies can be applied for making the semantics of geospatial data sources explicit and enable automated semantic matchmaking. As shown in [3, 16] the integration of the matchmaking capability into SDIs overcomes some of the semantic heterogeneity problems in GI discovery and retrieval. Their applicability for semantic translation has been shown in [17, 18].

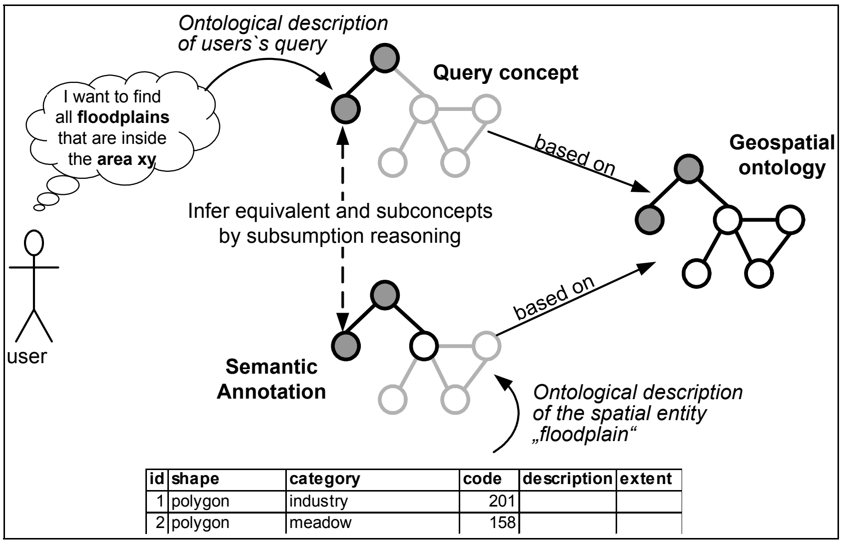

Fig. 2. Semantic annotation and semantic matchmaking based on a shared geospatial ontology.

However, in order for this approach to become widely accepted in the GI community it is essential to provide methods and tools that support the user in generating formal semantic annotations. So far, no automated method for the semantic annotation of geodata exists. It remains a laborious task and data providers who are no ontology engineering specialists will neither be willing nor capable to perform it.

3. Subject of Semantic Annotation: Geodata

Subject of semantic annotation are spatial information objects that are stored in spatial databases. They can be analysed with spatial processing methods, as we can calculate e.g. properties like shape or altitude and relations like topology or distance. Applying spatial analysis methods for information extraction avoids problems of semantic heterogeneities encountered with textual (symbol) analysis, which is obviously restricted by the ambiguities of natural language.

A *geoobject* is spatially referenced relative to the earth surface. It can be distinguished from other geoobjects according to its geometry (spatial location), topology (spatial relationships with other geoobjects), thematic domain (relevant, subject-related characteristics), and dynamics (temporal changes). *Geoinformation* is the geometrical, topological, thematic and dynamic description of the geoobject with emphasis on those aspects with particular meaning for its study within a particular academic discipline. *Geodata* (spatial data) are formal descriptions of geoinformation in the form of digits and characters, suitable for computer processing [19].

There are two paradigms for modelling geoinformation. The entity view stresses individual objects with well determined boundaries and attributes. In the entity view the world consists of exactly definable and delimitable individuals. Each object occupies space and has properties. Objects may consist of parts and sub-parts. Basic geographical objects are the point, the line (a set of linked points), and the polygon (a set of linked lines, or contiguous points). Their properties are described by tuples of attributes measured on nominal, ordinal, interval or rational scales [2].

In the continuous field view every point in space can be characterized in terms of a set of attributes (e.g. terrain use, elevation, average annual rainfall, soil texture, etc.). Each attribute is measured on an appropriate nominal, ordinal or ration scale. It is assumed that most properties vary smoothly and gradually, so that attribute values at unsampled locations can be determined by interpolation [2]. Thus, depending on the data modeller's viewpoint, real world phenomena can be approximated either by exact geographic datatypes which are termed "objects" or by smooth, continuous "fields".

In our work on semantic annotation we concentrate on data stored as objects.

4. Semantic Representation Layer: Geospatial Ontology

Different user groups have different abstractions and descriptions of the real world, depending on their application field. This specific world view is also termed the user's *context* or the *universe of discourse*. The context of a user determines the conceptualizations used to describe specific information units. This includes not only the domain specific vocabulary, but also the relationships and rules that hold between these concepts, constituting a *conceptual model*. User groups that share, at least part of the time, common abstractions, metadata, and spatial feature definitions are termed Geographic Information Communities (GIC) [20].

Information system ontologies can be built to reflect the conceptualisations of a specific GIC, and thus specifying a particular application context and resolution of representation. According to Guarino [21], an ontology refers to "an engineering artefact, constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary words". The closer this theory corresponds to the human concepts about a domain, the more useful an ontology will be [1].

Ontology is mainly concerned with *intension.* The intension of a concept is the set of characteristics (formalised with axioms in the ontology) which are shared by everything to which it applies. This set of objects that the concept refers to is its *extension*. Obviously, it is impossible to capture a concept's complete intension with the axioms in an ontology; we can only give a partial account of it. For example, part of the intension of a *motorbike road* is (something like) “a road with a high twisting grade”. This characterization of the concept *motorbike road* provides direction by which its extension in a particular database (i.e. the set of road objects that has a high twisting grade) can be identified. Two concepts might have the same extension. But this does not imply that they are identical. Their intension can be quite different. For example, road objects can be seen as connections between two locations in a navigation system, but also as man-made barriers that intersect habitats in an environmental impact assessment.

We usually suppose that the intension of a concept determines its extension. The strategy for semantic annotation of spatial objects thus is to decide whether or not each object belongs to the concept by analysing whether or not it has the characteristic relations and properties. In the geospatial domain, relations among spatial entities are often as important as the entities themselves [22]. In geospatial ontologies spatial relations and spatial properties thus play an important role for characterizing the concepts [9]. For example, “Floodplains are *adjacent to* Rivers”, “Beaches *touch* Seas”, “Channels are *straight* Waterways”, and “Barriers *intersect* Biotopes”.

5. Approach for Automating the Semantic Annotation of Geodata

To illustrate our approach for automating the semantic annotation of geodata, we will use the example of annotating floodplains introduced in [9].

Floodplains are crucial elements for the task of flood management. They serve as a natural water retention area after a river broke its banks during a flooding event. If sufficient area along the river banks has the function of a floodplain, some of the river’s water load will “naturally” be absorbed and the flooding event will be less critical for populated areas that lie further downstream. Floodplains can be looked at from several different perspectives: “To define a floodplain depends somewhat on the goals in mind. As a topographic category it is quite flat and lies adjacent to a stream; geomorphologically, it is a landform composed primarily of unconsolidated depositional material derived from sediments being transported by the related stream; hydrologically, it is best defined as a landform subject to periodic flooding by a parent stream. A combination of these [characteristics] perhaps comprises the essential criteria for defining the floodplain" [23].

5.1. Walk-Through the Annotation Process

First we need a formalised account of the concept floodplain (section 5.2). This needs to be implemented with an adequate representation language. In our case, we have chosen to use OWL, as this is a recommended W3C standard to exchange ontologies on the web. The concept definition then has to be supplemented by a rule that gives direction on how a floodplain is identified. The spatial predicates in the rule will then be connected to spatial processing methods (section 5.3). The subsequent extraction process thus is “controlled” in the sense that the system will analyse the dataset by looking explicitly for the concepts defined in the ontology (rather than performing an “uncontrolled” search for arbitrary patterns in the dataset). The process can be depicted as a decision tree, e.g. the system identifies a spatial object *L* as a floodplain if *L* fulfils the following criteria:

- *L* is a region (polygon)
- *L* is adjacent to a river
- *L* is flat

For each spatial relation, the corresponding spatial analysis method will be applied on the geodataset to be annotated (*AnnoDS*). If the dataset does not comprise sufficient information to conduct the analyses, it will be necessary to include further information sources in the information extraction process. For example, to identify all x in the dataset that are “adjacent to some river”, a reference dataset (*RefDS*) with the well-known geometry of all rivers in the respective area might be required. This role could be fulfilled by the national topographic map; other reference datasets needed may include a Digital Elevation Model (DEM) for calculating e.g. slope and altitude of unknown spatial entities.

Those spatial entities that meet the characteristics of floodplains are stored as the result of this analysis step. The analysis process moves along the decision tree until only those objects are left, which comprise all the characteristics of a floodplain.

The result of the automated process will be presented to the users for verification. They will also be asked for additional information if necessary. In the end, the system will generate the semantic annotation by establishing a reference to the ontology concept *floodplain.*

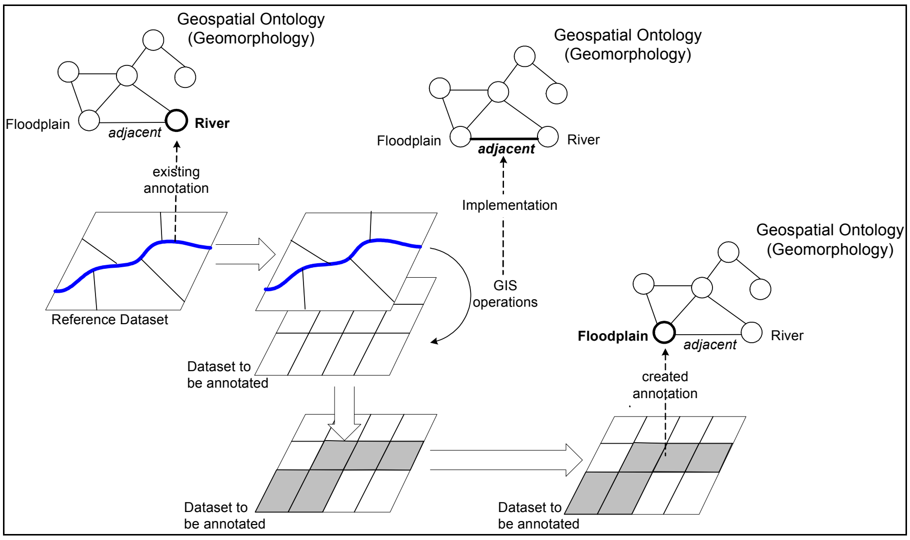

Fig. 3. Procedure for (semi-) automated annotation of geodata [9].

In the following sections we give a detailed account of how the spatial characteristics of a floodplain are formalized in a geospatial concept definition and we give an example of how a spatial analysis algorithm for implementing a spatial relation is specified.

5.2. Formalization and Implementation

One of the characteristics that distinguish *floodplains* from a *meadow* relies in the spatial relation of lying *adjacent* to a river. Such characteristic relations have to be identified by a domain expert during the ontology modelling process. In the following, we illustrate how these can be used for formally defining the *floodplain* concept.

$$\forall x\ (\mathtt{Floodplain}(x) \Leftrightarrow \mathtt{Region}(x) \wedge \mathtt{HasSlope}(x,\ \mathtt{Flat}) \wedge \exists y\ [\mathtt{River}(y) \wedge \mathtt{Adjacent}(x,\ y)]) \tag{1}$$

Formula (1) states that all floodplains are regions that are flat and adjacent to a river and that all such regions are floodplains. With this simple example we want to illustrate our approach to semantic annotation. By no means does this definition give a satisfactory definition of a floodplain. We have left out other spatial characteristics like the difference of altitude between the river and the floodplain, which should not exceed a certain threshold value. We have also not taken into account its non-spatial characteristics (e.g. being subject to periodic flooding, being composed of sediments).

The selection of the ontology representation language should be based on the inference mechanisms needed by the application that uses the ontology. For achieving semantic interoperability in web service environments, crucial requirements regarding the representation language are the availability of a reasoning engine, the ability to scale up with the requirements of web applications, and the expressiveness to meet the ontology engineering criteria [24]. Considering these requirements, OWL-DL in combination with SWRL has been our choice for a first prototypical implementation.

The implementation of the *floodplain* definition with the Web Ontology Language (OWL) [25] is depicted in Fig. 4.

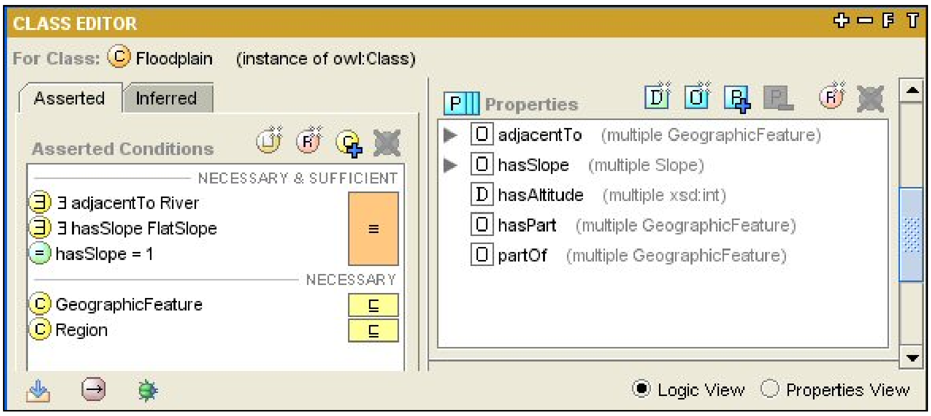

Fig. 4. Implementation of the *floodplain* concept in OWL with the ontology editor Protégé 3.1.1 (http://protege.stanford.edu/).

In formula (2) the corresponding Semantic Web Rule Language (SWRL) notation is given. SWRL extends the set of OWL axioms to include Horn-like rules. It thus enables Horn-like rules to be combined with an OWL knowledge base [26]. The rule stated in formula (2) gives directions on the conditions that must be fulfilled in order to have something classified as *floodplain*.

```
Region(?x) ∧ River(?y) ∧ adjacentTo(?x, ?y) ∧
hasSlope(?x, FlatSlope)  →  Floodplain(?x)                    (2)
```

5.3. Spatial Analysis Methods

The association of relations in the ontology with spatial analysis methods can be done in different ways. An analysis method can be associated as a "black box" containing the spatial relation it implements. This has the advantage that the description of the method and thus the association with the spatial relation in the ontology is simple. However, this also means that the implementation of the spatial relation is not transparent to the user. It can be assumed that there are always a number of different possible implementations for one spatial relation, especially if one takes into account more "fuzzy" relations like *side by side* instead of only precisely defined ones like *meet* [27].

We therefore reject the possibility to represent the implementation as a "black box" in favour of representing the analysis methods based on primitive operations defined in the ISO 19100 series of standards and specifications of the Open Geospatial Consortium (OGC). This strategy provides flexibility for adjusting the semantics of spatial relations in different application domains by changing the underlying implementation (e.g. *adjacent* could also be implemented using other primitives). Moreover, this implementation, and thus the semantic interpretation of a spatial relation remain transparent to the user.

One possibility on how to implement *adjacent to* in a sequence of spatial analysis steps is depicted in Fig. 5.

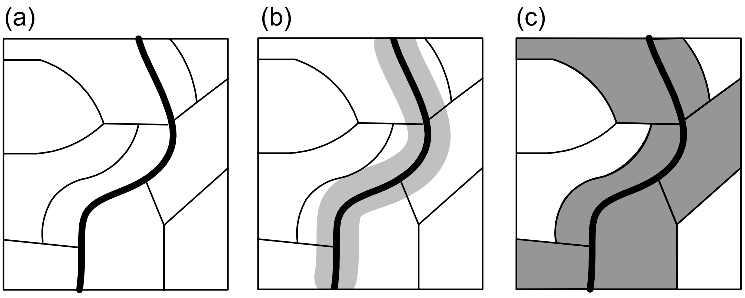

Fig. 5. Spatial analysis steps associated with the spatial relation *adjacent to* (a river): In (a) the river object is selected, in (b) a buffer is generated, and in (c) the objects intersecting the buffer are selected as being "adjacent to the river" [9].

The algorithm that contains the spatial analysis steps involved in calculating *adjacent to*, can be based on the following specifications and standards:

- The *Web Feature Service (WFS) Implementation Specification* [15] defines the *GetFeature* operation for selecting features of a particular feature type.

- In *ISO 19109 "Rules for Application Schema"* [28] states that the geometric characteristics of a feature are described by one or more *spatial attributes* whose values are given by a geometric object (GM_Object) or a topological object (TP_Object). We introduce the *geometry* attribute to refer to the geometric representation of a feature.
- *ISO 19107 "Spatial Schema"* [29] defines the notions of GM_Object and TP_Object and a number of operations that can be applied to them. In our example, we use the *buffer* operation, which returns a buffer polygon, and the *intersects* operation, which returns a boolean value to indicate whether two geometries intersect.

The resulting algorithm is made up of the following sequence:

```
select all features from Dataset where featureType = River
create empty set A
for each selected feature f
    A.add(f.geometry.buffer(d : Distance))
create empty set B
for each feature g in A
    for each feature h Dataset
      if (g.geometry.intersects(h.geometry))
        B.add(h)
return B
```

6. Discussion and Future Work

The ability to represent geospatial semantics is of great importance when building geospatial applications for the web. It will not only enhance discovery, retrieval and translation of geographic information, but it will also enable its reuse in other contexts than the original one. We propose a method for automating the semantic annotation of geodata based on spatial characteristics and suggest applying spatial analysis methods for extracting information useful for the annotation process. Compared to knowledge extraction techniques like string-based attribute analysis, the calculation of spatial characteristics remains independent from the textual description of geographic objects and their attributes. This has the advantage that semantic heterogeneity problems inherent in the processing of natural language are avoided.

We are aware that a fully automated process is out of scope. We have planned to refine the approach to combine spatial analyses with the analysis of non-spatial attributes. Hopefully, this combination will eventually lead to reasonable results in the annotation process with only little need for supervision.

At this stage of the work two fundamental questions still remain. One is related to the vagueness, uncertainty, and levels of granularity, which are fundamental to geospatial information. It will be necessary to account for vagueness during the information extraction process. We have to accept the risk of being wrong part of the time and move away from the constraining model of binary or simple discrete logic to a more flexible continuous system that allows the ideas of class overlap, partial membership of a set and the concept of partial truths that we use in everyday speech [30].

The second question refers to the strategy for establishing the reference between the geodata and the ontology, i.e. how the semantic annotation will be realised. After having identified entities within a geodatabase that belong to a category, there are two possibilities of how to annotate them. On the one hand, we could introduce a new category into the geodatabase and establish a direct link. This could eventually lead to very complex database schemas. Also, each time entities are added or deleted, the whole annotation process would have to be repeated for updating. On the other hand, we could provide the concept alignment in the metadata without providing a direct link to the identified entities. Thus, it is declared that the specified information exists, but for its identification in the dataset the calculation has to be performed again.

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