Photogrammetrie • Fernerkundung • Geoinformation 6/2003, S. 451–461, 2 figs.

Ontologies for Intelligent Search and Semantic Translation in Spatial Data Infrastructures

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Keywords: Spatial Data, Spatial Data Infrastructure (SDI), Geodata-Infrastructure (GDI), semantic interoperability, Geoservices

Zusammenfassung: *Ontologien für die intelligente Suche und semantische Übersetzung in Geodaten-Infrastrukturen*. Die zurzeit existierenden und diskutierten Ansätze von Geodateninfrastrukturen liefern Verfahren zur Überwindung der syntaktischen Heterogenität zwischen verteilten Daten und Diensten. Allerdings existieren keine Ansätze, die das Problem der semantischen Heterogenität lösen. In diesem Artikel wird ein Anwendungsfall eines Informationssystems aus dem Bereich des Katastrophen-Managements diskutiert, der den Nutzen von Geodateninfrastrukturen deutlich macht. Die hier auftretenden semantischen Heterogenitäts-Probleme werden dabei genauer analysiert und Lösungsansätze aufgezeigt, wie sie zur Zeit in dem Forschungsprojekt *„Semantische Interoperabilität mittels Geodiensten (meanInGs)" für den GI-Bereich entwickelt werden*.

Summary: Currently existing or discussed approaches of spatial data infrastructures (SDIs) provide solutions to common problems caused by syntactic heterogeneity of distributed data and services. Nevertheless, these approaches do not solve the issue of semantic heterogeneity. In this paper, we present a use case from the area of disaster management, which illustrates the benefits of employing a state-of-the-art SDI. The use case also points out several semantic heterogeneity problems that need to be solved. We analyse these problems and present approaches to their solution, which are currently developed in the research project *Semantic Interoperability by means of Geoservices (meanInGs)*.

1 Introduction

The problem of syntactic heterogeneity among geographic datasets emerged as a result of native data formats and the development of monolithic and proprietary systems. The World Wide Web (WWW) supplies the basic infrastructure for the distributed use and multiple exploitation of data and systems (*systems interoperability*). Geoinformation technology standards developed by the OpenGIS Consortium (OGC) and the International Organization for Standardization (ISO) provide the basis for syntactic interoperability and cataloguing of geographic data and geographic information (GI) services. Spatial data infrastructures (SDIs) like GDI[1]-NRW (KUHN et al. 2001, BERNARD & STREIT 2002) show what can be accomplished by this approach, but also raise challenging interoperability issues (BERNARD et al. 2003). Although SDIs provide the basis for syntactic interoperability the usability of information that is created in one context is often of limited use in other contexts. One important reason for this is *semantic heterogeneity*.

[1] GDI: Geodata-Infrastructure

1432-8364/03/2003/0451 $ 2.75

It is the goal of the research project *Semantic Interoperability by means of Geoservices (meanInGs)* to overcome the problems resulting from semantic heterogeneities in SDIs. The first step is to identify and analyse existing problems caused by semantic heterogeneity in several real-world use cases. Based on the results of this analysis the project will focus on developing methods for overcoming these problems during service discovery, composition and execution within SDIs. The viability of the developed approaches will be illustrated by prototypically implementing web services for intelligent search and semantic translation and by applying them to the use cases. This paper will describe the semantic problems that can occur in SDIs based on a real-world use case and point out possible approaches for their solution that will be elaborated in the *meanInGs* project.

The remainder of the article is structured as follows. In section 2 a use case for applying an SDI in the field of disaster management is depicted and the major problems associated with the distributed processing of geographic information are pointed out. Section 3 introduces the relevant (technical) background on SDIs and illustrates what happens „behind the scenes" in the use case. In section 4 an in-depth analysis of the semantic problems occurring in the use case is given. Section 5 sketches the main ideas that are to be employed in the project to solve these problems. We conclude the paper with summarising our findings and by sketching a road map for future research in section 6.

2 Using SDIs in Disaster Management – a Use Case

Disasters like floods, oil spills or wildfires are events where space and time are crucial. Thus, the acquisition, processing and analysis of geographic information is vital for disaster management. GI services can be used as a key technology to compile ad hoc the necessary information for decision makers.

In the area of disaster management well-informed decision making is essential. In order for the decision makers to invoke reasonable measures, often the most up-to-date information about a specific region is required. It is not sufficient to rely on data that have been collected, pre-processed and converted over a long period of time. Rather, it is necessary to deploy data directly or shortly after they have been collected or measured. However, the required information is generally distributed over several institutions, and therefore often represented heterogeneously in syntax and semantics.

The following scenario illustrates the benefits and problems of an SDI approach that uses distributed nearly real-time data in the context of a use case for disaster management.

2.1 *Detection of Flooded Areas*

In August 2002 extreme flooding occurred in large parts of central Europe, especially along the Elbe river in Eastern Germany (Fig. 1). This event showed the benefits of an effective and fast-working information system (LANCELLE 2002, SCHMIDT 2002). An overview of the present situation in the disaster area and predicted future scenarios can make a crucial contribution to avert further damages.

Fig. 1: Catchment area of the Elbe river.

The main actor in our scenario is a disaster manager who wants to get an overview of the Elbe river catchment indicating the areas which are currently flooded and those which are most susceptible to flooding (*flooding hazard areas*) within the next 24 hours based on current water-level measurements, remotely sensed data and a very simple evaluation model to make forecasts on flooding based on empirical hydrological data.

The disaster manager accesses a web-based risk assessment service that acts as a client to other services. It can produce maps of the catchment area showing the water levels for a certain point in time and/or highlighting potential flooding hazard areas.

In the service's user interface the manager selects a certain area of interest in the Elbe catchment area and chooses between the options of displaying the current (or past) situation(s) and estimating flooding hazard areas.

- *Displaying the current or past situation(s).* For this option the manager also has to choose between different periods of time (e. g. current situation or several past situations). Based on the input parameters the system generates a map displaying the water levels not only for the measurement points but for the entire Elbe catchment river network. By zooming and panning, the user can visually explore the situation in the area of interest.
- *Estimating flooding hazard areas.* In this option remote sensing data and methods are used in addition. These can play a crucial role in disaster management as they allow fast and objective assessment of the situation in a large area of interest (in this case in the whole river catchment area). Based on an estimation model the service displays the areas which are potentially at high risk together with the water levels in a map.

How all this is achieved within an SDI, which services and data sets are involved and what actually goes on „behind the scenes" is described in more detail in section 3.3.

2.2 *Problems Caused by Semantic Heterogeneity*

In order to provide the needed geoinformation for the described scenario a number of data sources are necessary. These data are highly distributed, as the Elbe river not only crosses international borders, but also those of seven German federal states. Thus, it can be expected that the structure and content of the data provided on water level measurements, river network etc. differs significantly.

Multiple factors have lead to these diverse developments in terms of data structures in the different administrative areas of the Elbe catchment. The most important reason for structural heterogeneities is the fact that most data have been gathered for a very specific purpose. In order to use the data, the modelling and therefore the syntax and the meaning of the data is adapted to specific applications.

We assume that the syntactic problems can be tackled by using approaches that already exist or are currently discussed in the context of SDIs. The technical details of these approaches for the use case together with the relevant background on SDIs is given in section 3.

The fact that the data to be processed in the use case originate from multiple information communities results not only in heterogeneous formats, but also problems caused by semantic heterogeneity[2].

For example, different terms can refer to the same kind of information in different data sets. Contrary, it is also possible that different data sets use the same term for referring to different kinds of information.

Such semantic heterogeneity problems can cause serious conflicts during the discovery of suitable data sources (Lutz et al. 2003). For example, a service whose task is described as 'classifying flooded areas in satellite images' might not be found when

[2] We assume here for simplicity reasons, that the same problems occur when dealing with distributed services. The specifics of dealing with semantic heterogeneity of services is outside the scope of this paper.

searching for a 'classification service' for 'remotely sensed data'.

Semantic heterogeneity can also affect the processing and analysis steps. For example, an analysis service might expect 'quality information' and does not accept the 'oxygen content' offered by a data source.

These problems are further analysed in section 3.3.

3 Principles and Components of SDIs

This section gives an overview on the motivations for building SDIs, their main components and on the role of standards within SDI development. It also describes in detail what happens „behind the scenes" in the use case depicted in section 2.1.

3.1 *Motivation and Aims*

A main motivation for setting up spatial data infrastructure (SDIs) is to make the work with geodata more efficient (McKee 2000, Nebert 2001). This is motivated by problems that occur with conventional GIS technology and geographic data sets.

Two major problems are that data sets exist in a plethora of different data formats and that they are often not (sufficiently) documented:

- Datasets in different formats often have to be converted in order to be used in a different system. This problem is usually tackled by providing data in commonly used vendor formats or vendor-neutral data exchange formats like GML (OGC 2003a). In the case of frequently changing data such as water level measurements, however, the conversion of the data has to be automated as manual conversion is not feasible.
- Missing or insufficient documentation makes it difficult or even impossible for outside users to discover data sets and to assess whether a given data set is useful for their tasks.

The development of SDIs addresses these problems. SDIs are based on the assumption that it is usually not the data a user is interested in, but a piece of information that can be generated using the data[3]. Therefore SDIs are based on geographic information (GI) services that implement standardised service interfaces. Through these services distributed geographic data can be accessed and processed across administrative and organisational boundaries. Also, data and services can be accessed in an ad-hoc manner. As a result geographic data sets and the GI services using them can be created and maintained locally which leads to increased quality (e. g. timeliness) and efficiency. Also, SDIs can be easily extended to include new services and/or data sets.

3.2 *Components of SDIs*

The main (physical) components of an SDI are GI services, geographic data and catalogues providing metadata on the data and services.

Following the definition of (Groot & McLaughlin 2000) SDIs also contain the institutional, organisational, technological and economic resources that support the development and maintenance of the SDI and their geographic information. However, these issues will not be addressed here.

3.2.1 GI Services

Interoperability is a key requirement for SDIs. It is defined as „the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units" (ISO/TC-211 & OGC 2002).

In order for two services (e. g. a web map client and a web map service) to interoperate

[3] When seeing SDIs as providing information (e.g. a computed shortest path between two locations) rather than raw data they should better be called spatial information infrastructures. However, we will stick with the term spatial data infrastructure in this paper as it seems to be well established internationally.

they have to be *interface and service interoperable*. This means they have to agree on the set of services offered by the entities of the two systems and the interfaces to them (ISO/IEC 1996).

The standardisation of these interfaces is an important feature of SDIs because it allows the classification of services in well-known service types that provide the behaviour specified by the interface. Thus, standardisation makes it possible to connect arbitrary service instances as long as they are of a well-known service type. In the geospatial domain, there are mainly two standardisation efforts to enable interoperability in distributed systems: the ISO Technical Committee (TC) 211, which develops the 19100 series of standards, and the OpenGIS Consortium (OGC).

The OGC has developed an architectural framework for geospatial services on the Web platform (OGC 2003c). It specifies the scope, objectives and behaviour of a system and its functional components. It identifies behaviour and properties that are common to all such services, but also allows extensibility for specific services and service types.

In so-called *testbeds* implementation specifications for several service types have been developed, e. g.:

- Web Map Service (WMS) (OGC 2002c) for producing digital maps; and
- Web Feature Service (WFS) (OGC 2002b) and Geographic Markup Language (GML) (OGC 2003a) for accessing XML-encoded geographic data.

A complete list of approved, candidate and planned OGC implementation specifications can be found at *http://www.opengis.org/pressrm/summaries/20010911.TS.SpecOver.htm*.

Knowing these specifications, a service consumer that is aware of the location of a service provider can connect to the service over the Web and invoke its operations.

3.2.2 Catalogues and Metadata

Catalogues are a fundamental part of SDIs and become relevant in scenarios where clients and services are arbitrarily distributed (in large networks) and unaware of each other. A catalogue's task is to allow a client (service consumer) to find and access resources (data and services) available on servers (service providers) that are unknown to the client and fit the client's needs. Service providers offer particular data access and geoprocessing (data manipulation) services. Both types of spatial resources are described by metadata.

The catalogue itself consists of the metadata and the operations working on these metadata. In general each service provider has to register (publish) its offerings by means of metadata to a catalogue to enable accessibility. A catalogue may also collect metadata from known service providers (pull). In addition to these registration functions a catalogue provides „librarian functions" (discovery, browsing, querying) for service consumers.

The structure, entities and element sets of the metadata entries in a catalogue are determined by a *metadata schema*. For geographic data, there are several standards for metadata schemas, the most prominent being FGDC (FGDC 1998) and ISO 19115 (ISO/TC-211 2003).

Both standards also contain guidelines to develop *metadata profiles* to allow its customisation for specific user groups. The resulting heterogeneity leads to problems when querying and interpreting search results of different distributed catalogues, and is further aggravated by the fact that different user groups may use different vocabularies to describe their datasets and services.

3.2.3 Geographic Data

An SDI also contains a number of vector or raster data sets, e. g. a river network, water level measurement points and satellite images for the use case described in section 2.1. These data sets are provided through geographic model/information management services. e. g. OGC Web Feature Services (WFS) (OGC 2002b).

It is currently discussed, e. g. in the context of developing the *Infrastructure for*

Spatial Information in Europe (INSPIRE), whether so-called *core, framework* or *reference data sets* are to be part of the underlying infrastructure and what they are to contain (BARR 2003, LUZET 2003). These basic data sets are meant to provide a frame of reference for all datasets for more specialised applications.

3.3 *The Use Case – „Behind the Scenes"*

With the relevant background on the technical aspects of SDIs we can now have another, more detailed look at the use case presented in section 2.1 and disclose what happens „behind the scenes". In order to produce the maps depicting the current situation or an estimate for future scenarios a number of data sources and GI web services are necessary.

For estimating the current water levels along the Elbe river, all up-to-date measurements available have to be evaluated. Some important providers of these data are *Bundesanstalt für Gewässerkunde (BfG)*[4], *Wasser- und Schifffahrtsverwaltung des Bundes (WSV)*[5] and *Niedersächsischer Landesbetrieb für Wasserwirtschaft und Küstenschutz* (NLWK)[6]. Further providers supply data on different sites and/or on different measurements at the same site.

For our scenario we assume that all these providers make their data available through standardised interfaces, e. g. through WFS or Sensor Collection Services (SCS)[7], in a standardised format, e. g. GML or O&M (OGC 2003b).

In order to obtain information on the water levels for a whole stream section a model has to inter- and extrapolate the discrete (point) water level measurements provided by the WFSs or SCSs. The model for assessing the susceptibility of a river segment to flooding and for classifying it according to risk levels will be kept simple within the scope of the project. Of course, these could later be replaced with more sophisticated models that would be necessary for accurate estimations. We assume that both the interpolation model and risk assessment are also implemented as web services.

The remote sensing data used in the scenario are provided through a SCS or Web Coverage Service (WCS) (OGC 2002a). In order for these data to be useful in our scenario, they have to be classified automatically. Currently, there are no approaches to provide interoperable services for automatic image classification. It is therefore one of the primary goals of the *meanInGS* project to implement a working prototype of such a service.

All pre-processing steps that have to be performed to prepare the image for a classification (e. g. georectifying, filtering) are not considered in the first step. The data provided are already pre-processed. At a later stage, some of these procedures might be provided as OGC compliant services as well, so raw image data can be evaluated, too.

Finally, the results returned by the services described above are integrated into a single map in a WMS.

Fig. 2 shows the data sources and services used in the use case and the data flow between them.

4 Semantic Problems in SDIs

When establishing a flexible, generic system such as the time-critical disaster management from our use case, some syntactic and semantic problems occur and have to be solved. Unfortunately, the SDI approaches described in the previous section only address the syntactic interoperability of services by defining interfaces and communication (markup) languages.

However, semantic problems such as those described in section 2.2 remain be-

[4] http://www.bafg.de
[5] http://www.elwis.de/gewaesserkunde/Wasserstaende/Wasserstaende_start.php?target=1&gw=ELBE
[6] http://www.nlwk.de
[7] A SCS can be seen as specialized WFS for accessing observations and measurements (O&M) documents. Its specification is still work in progress and is not yet publicly available.

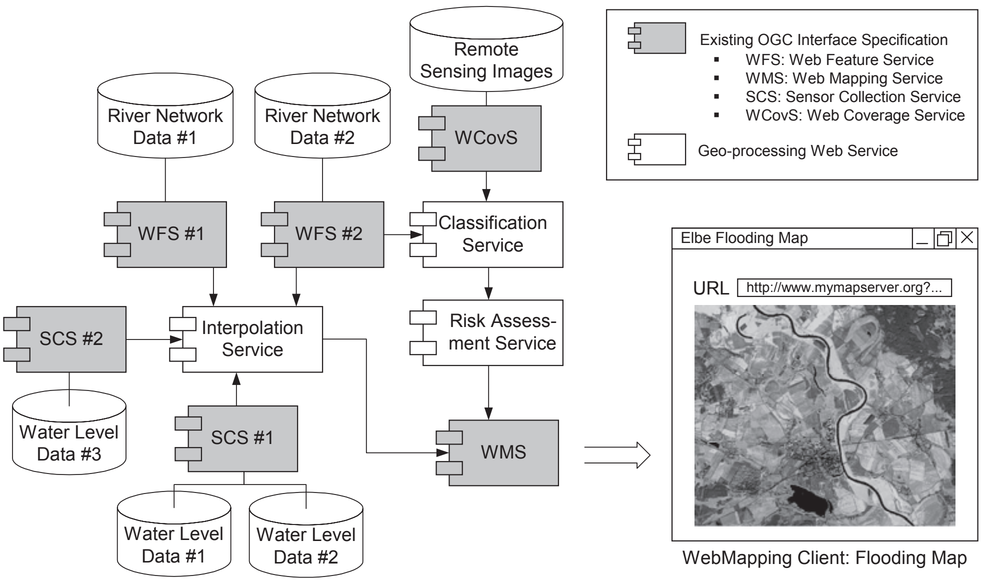

Fig. 2: Data and services in the use case.

cause the data to be processed are provided by members of various information communities. This makes it difficult to correctly interpret the data and extract the included information.

In the presented use case, unclarity and ambiguity result from heterogeneous terminology and different spatial and temporal resolutions. In the following, we will concentrate on terminological aspects of semantic interoperability; further details on the specific demands of spatial and temporal information can be found in (Vögele et al. 2003) and (Hübner 2003), respectively.

In the following sections, we will analyse the examples for semantic heterogeneity presented in section 2.2 in more detail. The major problems in terms of semantic interoperability occur on three levels of data interpretation which correspond to three different steps of communication within SDIs:

- metadata interpretation
- data interpretation
- (meta)data fusion

We will give short examples for these issues in order to illustrate their meanings and the circumstances under which they appear. In section 5 we will describe how to meet these problems with our approach of using ontologies for intelligent search, semantic translation and semantic integration.

4.1 *Metadata Interpretation*

The data representing water levels of the Elbe originate from different providers such as the WSV, the NLWK and the BfG (section 3.3).

The WSV annotate their data with the term „Pegel“ (which can mean both „gauge“ or „water level“), while the NLWK use the term „Wasserstand“ („water level“). For humans, it is not difficult to see that both terms are to refer to water levels, especially in the known context of rivers. In contrast, for a computer there is no coherence between the terms – it would not even assume any kind of similarity – and the terms are treated as being totally different.

Even worse than differing metadata are missing metadata. For example, the BfG provide data in a raw form without any annotations:

...
04. 06. 2003; 00:45; 138.00;
04. 06. 2003; 01:00; 138.00;
04. 06. 2003; 01:15; 138.00;
04. 06. 2003; 01:30; 138.00;
04. 06. 2003; 01:45; 137.00;
...

Knowing the context of information (water levels of the river Elbe), humans will interpret the data as date, time, and level separated by semicolons. Without knowledge of the domain and without any metadata it is impossible for machines to work with the included (but hidden) facts.

4.2 *Data Interpretation*

In addition to sensor data, the use case also utilises spatial data describing the Elbe's catchment area. These data include land cover information, which is exceptionally important to the correct classification of flooded areas by the remote sensing service. There exist various vocabularies for land cover classification. Some of these are standardised and widely used, e. g. ATKIS (AdV-Arbeitsgruppe ATKIS 2002) or CORINE (EEA 2000), while others are created by the data providers themselves. Rivers belong to the class „Stream courses" in CORINE but can be called differently in other nomenclatures.

This is an example for problems that appear when interpreting data. These kind of problems are very similar to the problems that appear with metadata as described above: in the last section the terms used to describe the attribute types (in relational databases: the column headings) are ambiguous, in this section the terms used as attributes itself (in relational databases: the cell values) are ambiguous.

4.3 *(Meta)Data Fusion*

A third kind of problem can be derived from the two above: when data from different sources have to be combined and integrated into a single collection, ambiguities regarding metadata interpretation and data interpretation have to be overcome. Therefore in the result

- each field of the annotated metadata must own an explicitly defined vocabulary, and
- it must be absolutely clear from which vocabulary the terms in the data itself are taken.

In both cases it is obviously useful to choose one of the involved vocabularies, whose terms can remain unchanged, while all terms coming from a different vocabulary have to be translated. This leads to the field of semantic translation (section 5.3).

4.4 *Remote Sensing*

Additionally, the integration of remotely sensed data by implementing a new service for automatic classification is associated with significant semantic problems. Crucial issues in the context of image classification are the definition of appropriate class structures (nomenclatures), which have to be described very precisely, as well as rule networks to assign the correct classes to the image objects.

5 Intelligent Search and Semantic Translation in SDIs

This chapter focuses on two main tasks in the context of spatial data infrastructures: the search for services with wanted characteristics, and the translation of metadata and data.

The first task is indispensable when building dynamic chains from services that are distributed over the internet and described by metadata. The second task allows the use of data from different information communities. As already mentioned in the last section, the problems that occur with both tasks are quite similar; in the following we will show that they can be overcome with the same technologies and methods.

5.1 *Ontologies*

In our approach ontologies act as the basis for both search and translation. We orient to the definition of (Gruber 1995) who described an ontology as a formal and explicit specification of a conceptualisation. A *conceptualisation* refers to an abstract model of how people think about a real thing in the world. *Explicit specification* means that the concepts and relations of this abstract model have been given explicit names and definitions. *Formal* means that the definition of a term is written down in a formal language with well-understood properties; very often this is a logic-based language. The main advantage of using a language of this kind is the avoidance of ambiguities of concepts.

The problems described in the previous chapter result from the fact that the terms from a certain vocabulary (e. g. that used in a catalogue) are just words with an *implicit* meaning (for humans), but without an *explicit* meaning (which machines are able to understand). Therefore we propose the usage of concepts that are clearly defined by ontologies to circumvent the ambiguities that otherwise emerge.

This has several significant advantages. First, it becomes possible to translate a term (i. e. a concept) from one vocabulary (i. e. one ontology) into a term from another vocabulary. When two terms are found to be equal because they are specified by the same definition, this is called a „mapping“: one concept is mapped onto another.

Secondly, ontologies can be used to derive super-concept and sub-concept relationships. Terminological reasoning engines can automatically construct hierarchies of concepts by examining their definitions. This makes it possible to „translate“ a superordinate, general term into one or more subordinate, more specific terms, which can even come from different vocabularies – as long as these vocabularies are built up on the same basic definitions.

Further in-depth information about ontologies and their general use for knowledge representation, semantic translation and semantic integration can be found in (Wache et al. 2001).

5.2 *Intelligent Search*

The searching tasks in our use case can be divided into two fields: the search for services and the search for data. Both depend on descriptions by „rich“ metadata which take their content from catalogues. In our approach the catalogues are in fact ontologies with clearly defined concepts.

The usage of such enhanced catalogues makes it possible to search for e. g. ‘quality information’ of ‘water bodies’ and find the ‘oxygen content’ of the ‘river Elbe’ (search for data).

In the same way it is possible to search for e. g. a ‘classification service’ for ‘remotely sensed data’ and find a service for ‘classifying flooded areas in satellite images’ (search for services).

Although the services and data in these examples have been described by totally different words, the search engine is able to detected the super- and sub-concept relationships and presents more and better results. Therefore we call this technology „intelligent search“. Accordingly we call a catalogue service, which was extended in a similar way, „intelligent catalogue service“.

5.3 *Translation of (Meta)Data*

Ontologies can also be used to overcome the problems that have been identified with data or metadata fusion.

Since the presented use case has to create maps from various German federal states, the services involved have to deal with data on different levels of granularity. This includes for example very finely differentiated as well as very coarsely graduated land classification schemes.

When a service is to generate a consistent map of the Elbe river, it has to translate all the encountered land cover types into terms from a single classification scheme, normally from the coarsest scheme. As the terms are explicitly defined concepts, reasoning engines are able to find super- and sub-concept relationships. Thus, the very exact classification „Stream courses“ can be translated to the more general term „Continental

Waters". This procedure is called „translation by re-classification".

6 Conclusions and Future Work

We have presented a use case from the area of disaster management that illustrates the benefits of employing state-of-the-art spatial data infrastructures. The approaches that already exist or are currently discussed in the context of SDIs can solve problems caused by syntactic heterogeneity. However, the presented use case also demonstrates that a number of semantic heterogeneity problems remain to be solved.

We have sketched an approach for addressing these remaining problems that makes use of ontologies for intelligent search, semantic translation and semantic integration. It is the goal of the *meanInGs* project to further develop this approach and to prototypically implement services for intelligent search and semantic translations. In order to do so, a number of open research questions have to be addressed, e. g.:

- What are the specifics of dealing with heterogeneous service rather than data sets?
- How can the presented approach for intelligent searching be integrated with existing data and service catalogues?
- How can the presented approach for semantic translation be implemented as a web service?
- How can services for analysis and processing be combined with such a semantic translation service?

We believe that by addressing these questions the *meanInGs* project will provide valuable results on the way to enabling the level of interoperability that is required for next-generation distributed geoprocessing and analysis.

Acknowledgements

The work presented in this paper has been supported by the German Ministry for Education and Science as part of the GEOTECHNOLOGIEN program (grant number 03F0369A) and can be referenced as publication no. GEOTECH-33.

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Manuskript eingereicht: Juli 2003
Angenommen: August 2003