Model Driven Approach for Accessing Distributed Spatial Data Using Web Services - Demonstrated for Cross-Border GIS Applications

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Key words: Model Driven Approach, OGC Web Services, Schema Translation, Spatial Data Infrastructures

SUMMARY

The paper addresses current research issues in the field of interoperability of heterogeneous GI systems. Special emphasis is placed on heterogeneity at the level of conceptual data models. This problem is discussed in the context of cross-border web-based GIS applications which involve the combination of spatial data on the same type of real world objects from different countries. Existing approaches for setting up such cross-border web-based GIS applications using both raster and vector data are discussed. A new concept of a Model Driven Approach for accessing distributed, heterogeneous spatial data using web services currently being developed in a joint research of the Eidgenössische Technische Hochschule Zürich and the Technische Universität München is presented, based on the fundamentals of Service Oriented Architectures (SOA) and the Model Driven Approach (MDA). The Lake Constance region serves as cross-border test area for this project using topographic vector data from Germany and Switzerland.

ZUSAMMENFASSUNG

Der vorliegende Beitrag beschäftigt sich mit aktuellen Forschungsfragen im Bereich der Interoperabilität heterogener GI Systeme. Die Heterogenität auf der Ebene der konzeptionellen Datenmodelle steht dabei im Mittelpunkt. Dieses Problem wird im Kontext grenzüberschreitender web-basierter GIS Anwendungen erörtert, die eine Kombination von Geodaten über die gleiche Art von Realwelt-Objekten aus verschiedenen Ländern beinhalten. Bestehende Ansätze zum Aufbau solcher grenzüberschreitender web-basierter GIS Anwendungen sowohl unter Verwendung von Raster- als auch Vektordaten werden diskutiert. Vorgestellt wird ein neues Konzept für einen modellbasierten Ansatz für den web-basierten Zugriff auf verteilte, heterogene Geodaten, das derzeit in einem gemeinsamen Forschungsprojekt von der Eidgenössischen Technischen Hochschule Zürich und der Technischen Universität München entwickelt wird, basierend auf den Grundlagen der service-orientierten Architekturen (SOA) und des modellbasierten Ansatzes (MDA). Die Bodenseeregion dient als Testgebiet für das Projekt, in dem topographische Vektordaten aus Deutschland und der Schweiz verwendet werden.

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1. INTRODUCTION

Spatial Data Infrastructures (SDI) on regional, national and international levels are currently one of the top items on the GI agenda. Fast, easy access as well as efficient and sustainable usage and combination of distributed, heterogeneous spatial information across the borders of vendor systems, disciplines, sectors and countries have become more important than ever and are also stipulated in the directive for an Infrastructure for Spatial Information in Europe (INSPIRE). To achieve these goals, a number of obstacles have to be overcome, one of the biggest being the data's heterogeneity at the level of data models and semantics. This problem is currently not sufficiently addressed by GI standardisation and becomes particularly evident in cross-border web-based GIS applications, where heterogeneous data from sources in different countries need to be harmonised so that they can be combined seamlessly and consistently.

Data harmonisation is also a key aspect of INSPIRE, but "INSPIRE does not require Member States to change the format of their spatial data holdings; instead, Member States can provide interfaces that transform heterogeneous data to a uniform model" (COM 2004). Thus the focus is not on full harmonisation of the underlying data models, but rather on achieving interoperability in a service-oriented architecture (SOA), e.g. by using web services for translating between different data models.

In existing web services for spatial data, as standardised by the Open Geospatial Consortium (OGC) (e.g. Web Feature Service), the *syntactic* heterogeneity is dealt with by encapsulating the internal structures of heterogeneous GI-systems using standardised interfaces. The internal structures, i.e. also the data models are hidden from the user. On the one hand, hiding the data model from the user leads to an ad hoc easy-to-use access to spatial information. On the other hand, the problem of *semantic* heterogeneity, is not solved by existing services. To allow for semantic interoperability by translating between different data models in OGC Web Services (OWS), the latter have to be enhanced by adapting concepts of schema translation / semantic translation based on the Model Driven Approach (MDA). This very issue is addressed in an ongoing research project which is presented in section 3 of this paper.

In section 2 we start by describing criteria according to which different approaches to set up cross-border web-based GIS applications can be classified. Out of the many possible combinations of these criteria three selected case studies are illustrated. After describing shortcomings of the existing approaches, the new concept of a Model Driven Approach for accessing distributed spatial data using web services is explained in section 3.

2. EXISTING APPROACHES FOR CROSS-BORDER WEB-BASED GIS APPLICATIONS

2.1 Classification Criteria

Approaches for setting up cross-border web-based GIS applications can e.g. be classified according to the criteria listed in table 1, with several options for the implementation of each of the criteria.

Classification Criteria	**Options**
source data type	- raster - vector (graphic-oriented or object-structured)
target data type	- raster - vector (graphic-oriented or object-structured)
system configuration	- distributed system - centralised system
coupling	- no direct coupling of systems at all - “ad hoc” (loosely coupled) - “hard-wired” (closely coupled)
client system	- web client (thick or thin) - desktop GIS
data harmonisation	- no harmonisation at all - harmonisation of spatial reference system - harmonisation of geometry - harmonisation of symbolisation - harmonisation of data models
vendor independence	- vendor independent (standards based) - vendor specific (proprietary)

Table 1: classification criteria for cross-border web—based GIS applications

The possible combinations of options result in a whole variety of different system architectures. In section 2.2, three typical combinations have been selected as case studies for setting up cross-border web-based GIS applications

2.2 Case studies

2.2.1 Harmonisation and Integration of raster data into a central data store

The case study described here is specified by the following combination of options:

Classification Criteria	Options
source data type	- raster
target data type	- raster
system configuration	- centralised system
coupling	- no direct coupling at all
client system	- web client (thin)
data harmonisation	- harmonisation of spatial reference system - harmonisation of geometry - harmonisation of symbolisation
vendor independence	- vendor specific (proprietary)

Table 2: combination of options for the case study "harmonisation and integration of raster data into a central data store" exemplified by "Bodensee-Geodatenpool" (data pool for the Lake Constance region)

Integrating raster data into a central data store (see figure 1) can be seen as the least complex case for setting up a cross-border GIS application.

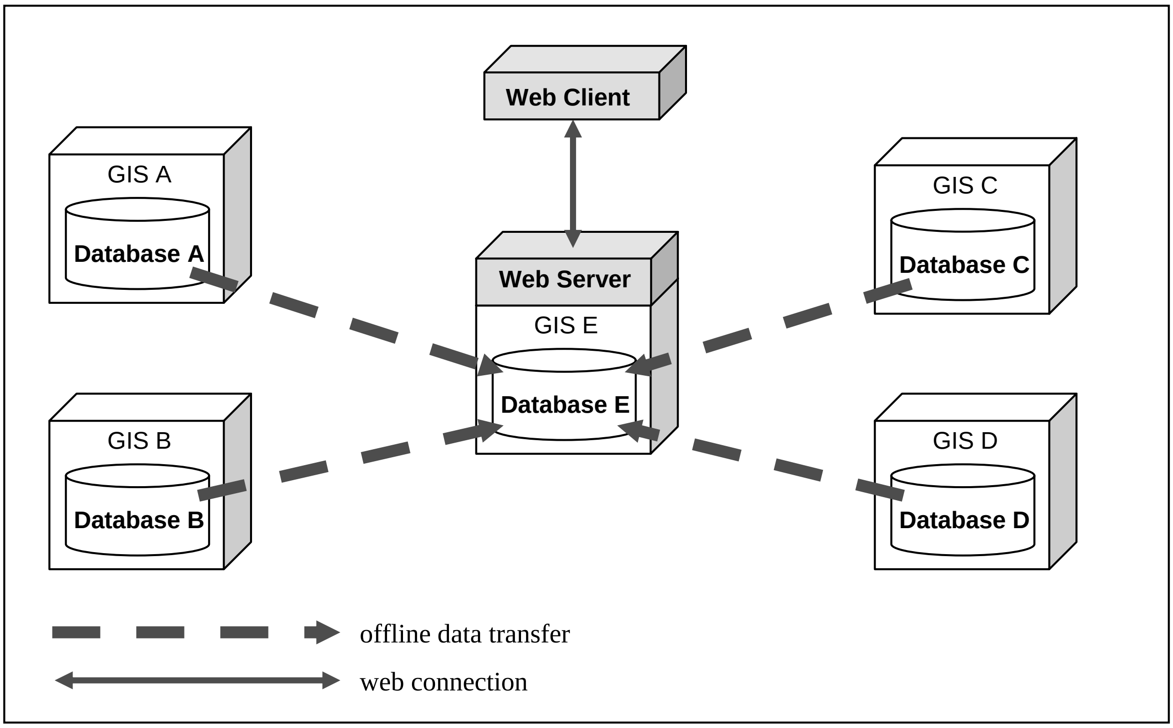

Figure 1 integrating raster or vector data into a centralised data store

The “Bodensee-Geodatenpool” (data pool for the Lake Constance region), a project carried out by the federal mapping agencies of Switzerland and Austria and the German state mapping agencies of Bavaria and Baden-Württemberg can serve as an example. In the project’s first step, raster data (digital topographic maps in the scale 1:50.000) from Switzerland, Austria and Germany were integrated into a seamless raster data set (see Fig. 1). The data sets of the different mapping agencies were rather similar concerning their structure (thematic layers) as well as symbolisation, but were based on different spatial reference systems (SRS).
To create a seamless cross-border data set, the source data had to be harmonised by transforming it from the different SRS to the ETRS89 / UTM 32 and by graphically retouching boundary lines and symbolisation in the overlapping areas at state boundaries. A web-based viewer was designed as a thin client, which requests maps from a java-based server. Next steps will include the integration of digital orthophotos, digital terrain models and vector data of administrative boundaries. (Gläßl et al. 2006; Steudle 2006).

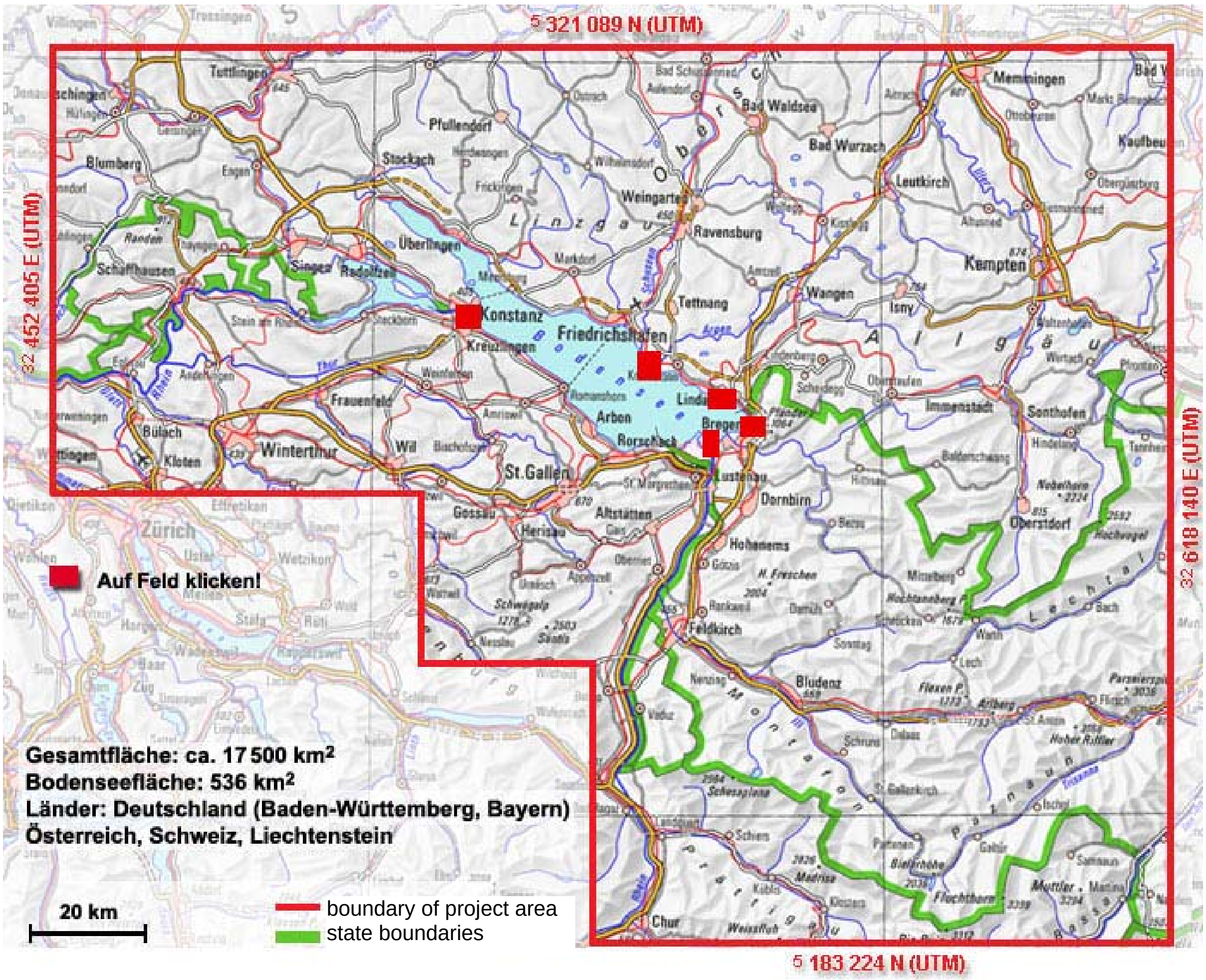

Figure 2: Project area of the “Bodensee-Geodatenpool” (based on Gläßl et al. 2006)

2.2.2 Harmonisation and Integration of vector data into a central data store

Integrating vector data into a centralised data store can be seen as the traditional approach to combining distributed, heterogeneous spatial databases. The basic architecture of a web-based cross-border GIS application that relies on a centralised data store is shown in figure 1. Although the general data flow is the same as for raster data (see section 2.2.1) the integration process is more complex. Basically there are three levels of complexity which are illustrated in the following using data of administrative boundaries from Switzerland and Germany as an example.

- *Graphic-oriented integration with harmonisation of data formats*: Provided that the vector data of the Swiss and German administrative boundaries exist in graphic-oriented vector formats like DXF or SVG, they can be integrated in a centralised data store using import filters that support these formats. As the data in this case doesn't provide information on the underlying data models (e.g. different semantics), the user only can visually interpret the images of the Swiss and German data sets. The service provider in charge of data integration only can perform a harmonisation of SRS and / or symbolisation but has no possibility of performing more complex tasks. In principle the capabilities of the graphic-oriented vector approach concerning spatial analysis are comparable with the raster approach described in section 2.2.1.

- *Object-structured integration with harmonisation of data formats*: If the Swiss and German source data are available in object-structured data formats *(e.g. ESRI Shape files, OGC GML)* they can be integrated into one centralised data store provided that import filters harmonising the data formats are available. If data is imported without harmonisation of the underlying data models, the user can again visually interpret the data like in the first case. In addition to that, the user can access the alphanumeric information that comes with the geometry in order to perform analysis and interpret the data's semantics. The user can e.g. see that there are four types of administrative areas in the Swiss data ("Land", "Kanton", "Bezirk" and "Gemeinde") and five types in the German data ("Nationalstaat", "Bundesland", "Regierungsbezirk", "Kreis" and "Kommunales Gebiet"). As the data models are not harmonised, building queries that involve both source data sets is awkward. If a user for example wants to find municipalities in Germany that share a border with municipalities in Switzerland, he has to explicitly state the terms "Gemeinde" and "Kommunales Gebiet" in the query in order to get features from both sides of the border.

- *Object-structured integration with harmonisation of data models:* To generate a data set which is consistent and seamless concerning the data's content, the user has to harmonise the underlying data models e.g. by defining relations between equivalent constructs in the different models (e.g. the Swiss "Kommunales Gebiet" and the German "Gemeinde"). There are different approaches for achieving this (e.g. conversion engines like FME or the model-driven data transfer), which are described in section 3.1. A prerequisite for a model-driven data transfer is, that the data's *conceptual* models (i.e. information about the structuring in classes and the corresponding attributes) have to be described in an exact, formal and machine readable way using a conceptual schema language (CSL). Once the data models have been harmonised, queries in cross-border regions are facilitated.

2.2.3 Distributed system using OGC Web Services

Classification Criteria	Options
source data type	- raster - vector (graphic-oriented or object-structured)
target data type	- raster - vector (graphic-oriented or object-structured)
system configuration	- distributed system
coupling	- “ad hoc” (loosely coupled) - “hard-wired” (closely coupled)
client system	- web client (thick or thin) - desktop GIS
data harmonisation	- no harmonisation at all - harmonisation of spatial reference system - harmonisation of symbolisation
vendor independence	- vendor independent (standards based)

Table 3: combination of options for the case study "distributed systems using OGC Web Services"

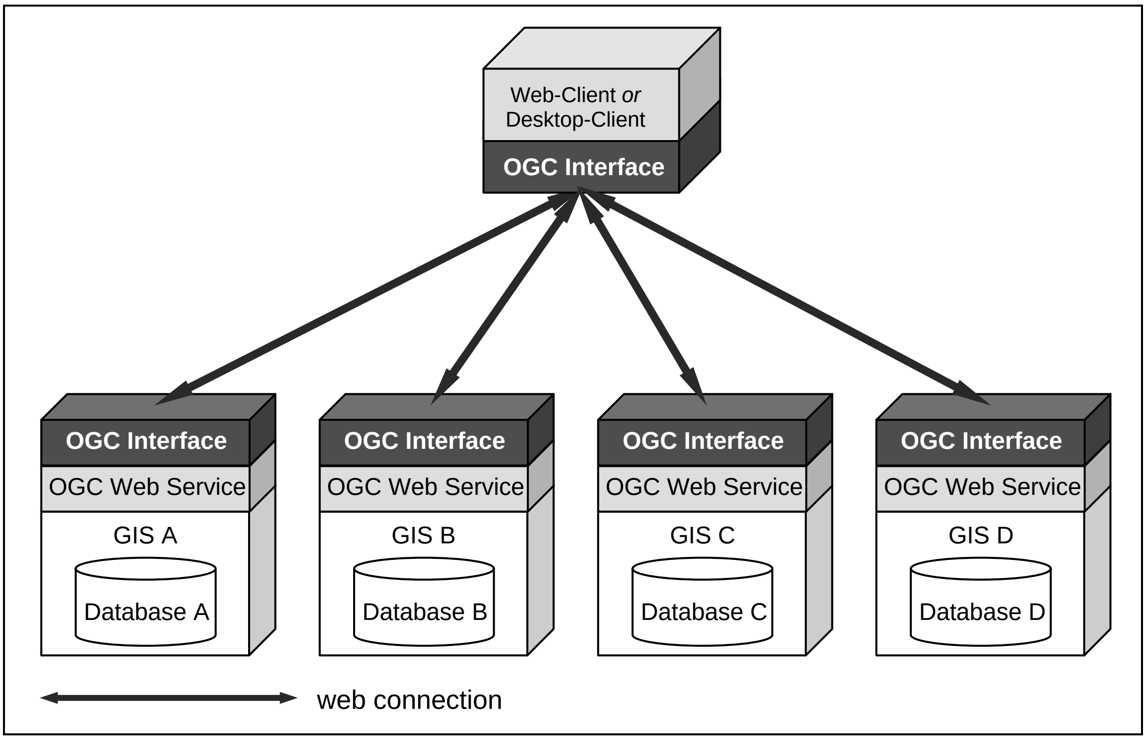

Figure 3: Distributed system using OGC Web Services

In this approach the data is not integrated into one target system, but remains in the source systems, where the data is captured and maintained. The systems can be coupled "ad hoc" via the internet in a Service Oriented Architecture (SOA) (see section 3.1). A user just places requests via his client and receives responses from the web services made available by service providers (see Fig. 2). The complexity of the source systems' internal structures is encapsulated by the service and thus not visible to the user. The encapsulation facilitates an interoperable access to the data across different vendor systems, provided the web services use standardised interfaces. In the field of GIS, the OGC specifies such interfaces. Services using those interfaces are referred to as OGC Web Services.

The graphic-oriented Web Map Service (WMS) (OGC 2006) facilitating online display of maps or the Web Feature Service (WFS) (OGC 2005) facilitating access to object-structured spatial data and (within limits) analysis and manipulation of the data. A WMS may serve raster or graphic-oriented vector data (e.g. in the SVG format), a WFS serves vector data in GML. In a distributed system using OGC Web Services, heterogeneous data from the different systems can - to a certain extent - be harmonised concerning their SRS and concerning their symbolisation. Coordinate transformation capabilities are either provided by WMS / WFS instances or by a Web Coordinate Transformation Service (WCTS). Map symbolisation can be harmonised using the Styled Layer Descriptor (SLD) specification (OGC 2002). The user can access the service e.g. via a web-client or use the service as data source for a desktop-GIS.

OGC Web Services can be used to build a cross-border GIS application as proposed by Jaenicke (2003) for the region Bavarian Forest National Park (Germany) / Sumava National Park (Czech Republic) and by Riecken et al. (2003) for the Northrine Westfalia (Germany) / Netherlands region. In these cases, data from both sides of the border are made accessible via WMS.

In such a cross-border scenario the data's heterogeneity at the level of data models and semantics becomes particularly evident. This problem is not addressed by current OGC specifications, which do not support harmonisation of data models and semantics. As far as cross-border queries are concerned, using WFS for example results in equivalent potentials and limitations as the vector data integration approach "*Object-structured integration with harmonisation of data formats*" described in section 2.2.2. These shortcomings are discussed further in the following section, based on the experiences of the Technische Universität München in evaluating and applying OGC Web Services (e.g. Donaubauer 2004; Donaubauer 2005).

2.3 Shortcomings of the existing approaches

The integration of data from different source systems – be it raster or vector data - into a central data store is often a time-consuming and technically demanding process requiring expert knowledge. Where necessary, the data has to be converted from different source data formats into a format readable by the target system. In the case of integrating vector data, the format conversion tends to be more complex than in the case of raster data. Format conversions are also often lossy. Different format conversion engines (e.g. FME or CITRA) can assist in the process of integrating data, but they also require expert knowledge. The model-driven data transfer as described in section 3.1 can help to automate the integration process, provided the data's conceptual models are described in a conceptual schema language (CSL) and rules for automatically deriving a transfer format from the conceptual model as well as processing engines which are able to read and write the transfer format are available. If this is not the case, and the user has no access to a machine-readable description of the data models, the user can only "manually" harmonise some aspects of the data like symbolisation, geometry (e.g. "retouching" to match boundaries of two adjacent data sets) and, if applicable, grouping into different layers, etc. Integrating data from different source systems into a central data store also implies redundant data storage in the majority of cases. The data user only accesses a "copy" of the original data and not the original data itself. To maintain a certain degree of up-to-dateness, the process of data integration has to be repeated in certain time intervals. Nevertheless, data integration can be a practicable approach for data which changes only within long time intervals.

The approach of using OGC Web Services in a distributed system offers advantages concerning some of the aspects discussed above, as it e.g. saves the effort of data integration and facilitates access to original data instead of data copies that are possibly outdated. However, it still has a number of shortcomings concerning practicability, functionality and acceptance (Donaubauer 2005). Issues of inconsistency between different types of OGC Web Services and between different versions of one OGC specifications arise when trying to combine different OGC Web Services. Tests carried out at the Technische Universität München also showed the limitations of distribution and modularity. Under certain conditions answering a spatial question (e.g. "Which land parcels are adjacent to water bodies and are owned by municipality X?") based on distributed data storage and distributed processing is less efficient than retrieving the same information from an integrated database. Today's adopted OGC specifications facilitate more or less simple mostly read-only web applications, but there is still a lack of analysis functionality (e.g. metric queries or polygon overlays creating new features from a given set of features). Concerning acceptance, data providers are often still apprehensive about allowing online access to their data via the internet. The absence of security and access control concepts in the existing adopted OGC specifications are often named as a mayor cause for this.

The key shortcoming as seen from the cross-border interoperability point of view taken in this paper comes along with the very principle of the OGC Web Services approach, which is dealing with the heterogeneity by encapsulating the internal structures of heterogeneous GI-systems using standardised interfaces. The internal structures of the systems are hidden from the user. On the one hand this is of course advantageous, because it allows for *syntactic interoperability* of systems. On the other hand an OGC Web Service also hides the conceptual schema of the spatial data encapsulated by the service. This information however is needed when it comes to facilitate *semantic interoperability*, e.g. by translating between the different schemas.

3. MODEL DRIVEN APPROACH FOR ACCESSING DISTRIBUTED SPATIAL DATA USING WEB SERVICES

3.1 The fundamentals of SOA, MDA and schema translation

Service Oriented Architectures (SOA) and the Model Driven Approach (MDA) are both common concepts in software development.

The term SOA describes a concept for a system architecture that provides functionality through services in a network, e.g. the web. The components in a SOA are in most cases distributed and heterogeneous and can be coupled loosely, which makes them reusable. Service requests and responses can be stringed together (referred to as "service chaining") to represent complex processes. The functionality provided by the service can be accessed via standardised interfaces that encapsulate the internal structures of the underlying system and thus facilitates interoperability between the systems (Straub 2005).

The main principle of the Model Driven Approach (MDA) in software development is designing a precise model for the software to be developed, which can be used to generate the actual executable software components by automatical transformation. The main goal of the MDA is to facilitate the design and implementation of platform-independent software components (Straub 2005).

The MDA can also be applied to data transfer between systems. The approaches for transferring data range form the relatively simple format-based data transfer to the powerful model-driven data transfer. In the latter, additional information e.g. on the conceptual model of the data can be transferred together with the data, whereas in the first approach only the transfer format of the data is described. To facilitate a model-driven data exchange, the data's conceptual models (i.e. information about the structuring in classes and the corresponding attributes) have to be described in an exact, formal and machine readable way using a conceptual schema language (CSL) (e.g. the Unified Modeling Language UML) and rules for automatically deriving a transfer format from the conceptual schema as well as processing engines which are able to read and write the transfer format have to be available.

Processes and techniques required to transparently view and query data from multiple data sources that provide data on the same types of real world objects in different data models as one uniform data source are described using a number of more or less similar terms such as "model integration", "model transformation", "model mapping", "model translation", "schema integration", "schema transformation", "schema mapping" or "schema translation". etc. Different disciplines dealing with this subject-matter use different terminology, but still not always in a consistent way. A distinction between the terms "model" and "schema" is sometimes made by defining a "schema" as a conceptual model expressed by a conceptual schema language. In Geographic Information Science, "schema translation" seems to have established itself as the most commonly used term. In general Information Science the process of translating from one data model (schema) to another and vice versa is referred to as schema transformation whereas the combination of different schemas into a new schema is referred to as schema integration. The term schema mapping describes a set of rules and techniques that establishes relationships between equivalent constructs of the different schemas.

Schema integration approaches can be classified according to the following criteria:

- Level of abstraction: Schema integration can be performed on different levels of abstraction (conceptual, logical, physical level). Schema integration on conceptual level is platform independent whereas approaches on logical and physical levels are platform specific.
- Orientation: Schema integration can be performed either horizontally (between different schemas on one level of abstraction) or vertically (between different schemas on different levels of abstraction).
- Level of automation: Schema integration can be performed on different levels of automation as far as the mapping between entities in different schemas is concerned. Normally the mapping is carried out by hand but there are also some approaches for matching schemas automatically often involving ontologies.

3.2 Existing approaches of schema translation in web services

Schema translations are identified as a key interoperability issue in international SDI-related initiatives and projects such as INSPIRE, RISE and EuroSpec. However, no detailed specifications concerning type and level of the translations or tools for executing them have been made yet. In a number of international projects, e.g. OGC GOS-TP (OGC 2003a; OGC 2003b), GiMoDig (Sarjakoski and Lehto 2004) and SDIGER (Orlova and Bejar 2005), web services are used to translate horizontally between different schemas (e.g. translating road data from a national schema to a common schema) and prototypes of so-called “translating WFS” have been implemented.

All the translations implemented in the above mentioned projects were executed on the logical level (e.g. using Xquery or XSLT). Translation between different conceptual schemas and the definition of a language to express these translations were identified as future fields of research. The project *md*WFS (see section3.3) aims at tackling these fields and facilitating translations on the conceptual level.

3.3 The project ***md*WFS**

With the goal of simplifying the usage of distributed, heterogeneous spatial data, the Technische Universität München (TUM) and the Eidgenoessische Technische Hochschule Zürich (ETH) have teamed up in the research project „Model driven approach for accessing distributed spatial data using web services - demonstrated for cross-border GIS applications” (*md*WFS), funded by the Bundesamt für Kartographie und Geodäsie (German Federal Agency for Cartography and Geodesy) and the Swisstopo (Swiss Federal Office of Topography).

The project started in 2006 with a first phase in which the possibilities and limitations of the two above mentioned approaches „OGC Web Services" and „model-driven data transfer" are evaluated. The feasibility of combining the two approaches is assessed including a specification of prerequisites for such a combination.

In phase two (2007) a prototype of a model-driven Web Feature Service (*md*WFS) is to be designed and implemented. The concepts of model-driven data transfer, schema translation and semantic translation will be adapted for a Web Feature Service. This also includes the implementation of a formalism for conceptual descriptions of schema translations. Thus schema translations on a conceptual level using web services will be facilitated.
This implies that the underlying schemas of the data served by the WFS are described in an exact, formal way, using a CSL. The project's test data (Swiss and German topographic vector data of the Bodensee region) meet these demands. The data model of the Swiss mapping authorities' data is described in the textual CSL INTERLIS, the data model of the German mapping authorities, the AFIS-ALKIS-ATKIS reference model, is described in UML. The workflow of the *md*WFS can be illustrated using the following scenario: An EU agency requests data (e.g. on administrative boundaries) from the German mapping authority which runs a *md*WFS. The description of the German data schema is delivered as a response to a DescribeFeatureType request. The user then formulates mapping rules (or loads previously defined mapping rules for this translation) between the German schema and the EU schema. The translation is executed in the *md*WFS, using the mapping rules and the description of the target schema. Thus the data from the German source system can be delivered to the user in the EU agency in the desired EU target schema.

The *md*WFS will surmount the shortcomings of existing OGC Web Services regarding *semantic* interoperability. The following table lists the classification criteria of the new approach for setting up cross-border web-based GIS applications. The option that distinguishes a *md*WFS from existing OGC Web Services is written in *italics*. The general system architecture is identical with the one depicted in figure 3.

Classification Criteria	**Options**
source data type	- vector (object-structured)
target data type	- vector (object-structured)
system configuration	- distributed system - centralised system
coupling	- "ad hoc" (loosely coupled) - "hard-wired" (closely coupled)
client system	- web client (thick or thin) - desktop GIS
data harmonisation	- harmonisation of spatial reference system - harmonisation of symbolisation - *harmonisation of data model*
vendor independence	- vendor independent (standards based)

Table 4: combination of options for a system based on *md*WFS

4. CONCLUSIONS AND FUTURE WORK

A number of approaches for setting up cross-border web-based GIS application using both raster and vector data already exist. The project *md*WFS aims at overcoming some of the key shortcomings of these existing approaches.

The following aspects are seen as the main advantages of the approach in the *md*WFS project (translations on the conceptual level) over the existing approaches described in section 3.2 (translations at the logical or format level):

- The possibility of formulating mapping rules on the conceptual level e.g. by graphically assigning classes of the source schema to classes of the target schema (possibly aided by a graphical user interface) can simplify the access to schema translation for users.
- The model-driven platform-independent approach makes it possible to deliver data in the user's target schema instead of merely delivering the data in the desired transfer format. It also improves the maintainability for mapping rules. When changes occur in either the source schema or the target schema, the mapping rules can be modified on the conceptual level and the respective new transfer formats can be derived automatically.

Detailed prerequisites for the feasibility of a *md*WFS and a *md*WFS prototype will be delivered in the course of the project.

A language for the conceptual description of schema translations is currently being developed at the ETH. Existing approaches in general Information Science, such as the newly published OMG MOF 2.0 Query/View/Transformation Specification are currently evaluated. Further research has to be done in the field of semantic interoperability, taking into account related work in the ontology field (Gnägi et al. 2006).

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Activities: president of the "Runder Tisch GIS e.V." at the Technische Universität München, member of the WG 2 "Geoinformation und Geodatenmanagement" of the German Association of Surveying (DVW), member of the editorial advisory board of the journal "GIS"

Florian Straub

Academic experience: 2005 master's degree in Informatics (M.Sc.) from the Technische Universität München , 2003 degree in Computer Science (Dipl.-Inf., FH) from the Munich University of Applied Sciences

Work experience: 2000-2005 self-employed software developer (design and implementation of OGC Web Services)

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