New methods for semantic and geometric integration of geoscientific data sets with ATKIS – applied to geo-objects from geology and soil science

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1 Overview

Although in geoscientific applications the topography of the Earth surface and thus topographic data sets constitute a common base for most related data sets, discrepancies and even disagreements often arise when inspecting one and the same object in different data sets. This is visible when superimposing different data sets of identical objects in reality. The reason is that the different data sets are typically based on different data models and have been collected for different purposes. Thus, different aspects of reality are important and have consequently been mapped. Also, different sensors are being used, data acquisition takes place at different dates, data representation differs (for example in terms of vector or raster data), and so does the resolution and the quality of the data. Data integration is a big issue today, when more and more digital data sets are being collected and made available – also in the “Geotechnologien-Programm” the improved access and use of data is an important and crucial aspect.

Due to the heterogeneity of the data it is complicated and sometimes even impossible to handle them in a coherent manner. In some cases this even leads to new data acquisition. The integration of inhomogeneous data is therefore becoming more and more important. The benefits of an integration are:

- To use the stored data for various purposes and applications. The information which is not contained in one data base, can be taken from another one.
- To complete and enhance the data bases thematically. For instance from the integration of a data set with another one new thematic information can be derived.
- To automatically verify the stored data regarding their quality, to correct them or to improve their accuracy.

Basically, this means that new data acquisition – typically the most expensive part of spatial analysis tasks – can be largely reduced and is only required if no data are available or changes in the reality have occurred. Consequently, a considerable saving of cost and labour is obtained by adding significant value to the existing data.

The work undertaken in the proposed project aims at providing methods which can be used by different applications for an integrated use of data of different sources. The integration will be treated on the basis of the combination of general data types (vector-vector, raster-vector), and will be conducted in three sub-projects.

1.1 Project director, co-operation partners

The project will be undertaken in a co-operation of three institutes of the University Hanover, together with the Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt, as well as the Niedersächsiches Landesamt für Bodenordnung (NLfB) in Hannover.

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Main contractors are the Institutes of the University:

- Institut für Kartographie und Geoinformatik (ikg), Prof. Dr.-Ing. Monika Sester, Dipl.-Ing. Guido von Gösseln, project management
- Institut für Photogrammetrie und GeoInformation (IPI), Prof. Dr.-Ing. Christian Heipke, Dipl.-Ing. Matthias Butenuth
- Institut für Informationssysteme, Fachgebiet Datenbanksysteme, Prof. Dr. Udo Lipeck, Dipl.-Inform. Sascha Klopp, Dipl.-Inform. Daniela Mantel.

Co-operation Partners:

- BKG: Dr.-Ing. Heinrich Jochemczyk (official geo-data)
- NLfB: Dr. Horst Preuß (thematic information systems)
- NLfB: Dr. Henning Bombien (geology),
- NLfB: Dr. Jan Sbresny (soil science).

In close co-operation among the partners new concepts and methods for data integration will be developed and tested. The co-operation is particularly important during the first project phase, when the characteristics and semantics of the objects of interest are defined. At a later stage the developed techniques will be evaluated by the co-operation partners, and if possible they will be integrated in their daily production work flow. Thus, the scientific research and development is verified by means of applications relevant for practical work.

1.2 Project goal and conceptual aspects

In this project the following data sets will be integrated: geo-scientific digital vector data sets Geological Map (GK) as well as Soil Science Map (BK), topographic geo base data (Basis-DLM) from ATKIS (Authoritative Topographic-Cartographic Information System) of the State Surveying Authorities, as well as aerial imagery in digital form.

The **objectives of this project** are

(1) The development of techniques for the integration of the digital Soil Science Map and the digital Geological Map of the State Geological Survey with the Basis-DLM.
(2) The automated enhancement of the digital Soil Science Map by information of current aerial images, also in combination with the ATKIS Basis-DLM.
(3) The access to these integrated data sets in a federated spatial data base.

These objectives lead on the one hand to two sub-projects in which the problems of the particular data combination on the basis of specific tasks will be focused on. On the other hand, in the third project general techniques for the integration of databases will be developed. The objects and data types dealt with in the sub-projects are general enough to be transferable to further related problems.

Due to the common spatial reference a transformation of geological and soil science data onto the ATKIS Basis-DLM or an orthophoto is in principle possible with relatively simple techniques such as overlay. In this project, however, the aim is to achieve an **object-related data integration** which will allow for the exchange of data stemming from different sources, different representations and structures, and thus will establish a base for performing combined, integrated analyses.

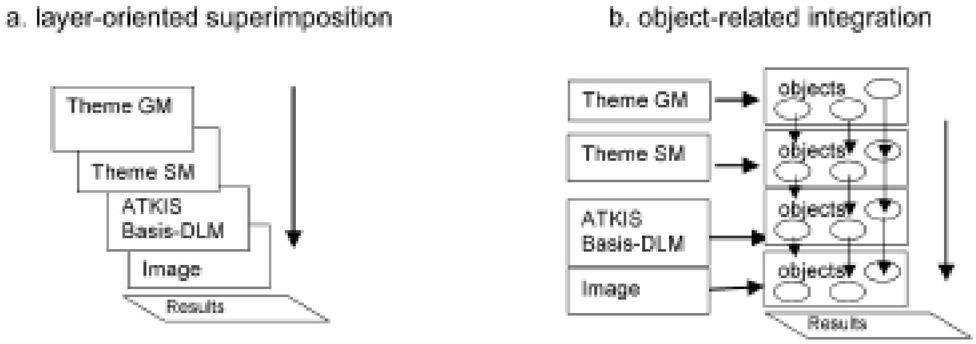

Figure 1: Comparison of different data integration techniques

For the object-related integration the corresponding objects in the different data sets have to be identified. Once these correspondences are established, various possibilities for information exchange between the data arise:

- Integrated access on data sets: after integration, processes like queries, adaptations or updates can be performed based on the established links.
- Adaptation and transfer of geometry: after matching two representations are available for each object in the reality. If the different objects were collected with different accuracy, a new combined geometry can be created, which takes the original accuracies into consideration. In this way the data with lower accuracy can be adapted to data of higher accuracy.
- Adaptation and transfer of thematic information: the thematic characteristics derived from the particular descriptions can be exchanged. This leads to a refinement and enrichment of the data sets.

The advantage of such possibilities for information exchange will be explored and proven in close collaboration with the project partners of the geo-scientific arena.

1.3 Combination of the results

The results of the three sub-projects lead to an enrichment of the relevant data sets. This information can be used by all project partners. For example, one can imagine to use first the ATKIS-information for the interpretation of a given vegetation phenomenon in the images, and to subsequently extract the corresponding geological information, which may provide evidence about the sub-surface characteristics. Thus, the integration of all available data sources can lead to new results. The federated data base will allow for the integrated analysis of all available information.

2 Integration of different vector data

In the first sub-project, carried out at the Institut für Kartographie und Geoinformatik (ikg) of the University Hanover in co-operation with the NLfB and BKG, techniques for the matching of objects of the basis data set ATKIS on the one hand, and the digital Soil Science Map and the digital Geological Map on the other hand will be developed. This allows for the explicit and direct linking of geo-scientific base data to the ATKIS-data. Such a link is so far only implicitly given and established by the fact, that the geo-scientific data is originally acquired based on the topographic maps.

This interrelation can be made explicit by identifying common objects in both data sets. First of all, it has to be defined on a object class level. Based on a semantic correspondence, individual objects be matched later on can. For instance, for the integration of the Soil Science Map and ATKIS, the object class "water" is relevant, as it is represented in both data sets (cf. Figure 2, right). Furthermore, roads are important, as they form the natural and artificial border of the land utilization. Overlaying the three different maps reveal different kinds of objects that are candidates for the matching methods. Certain areas of the soil science map show the same geometry as objects in the geological map (Figure 2, left). In the first phase of the project, the possibly corresponding object classes have to be identified.

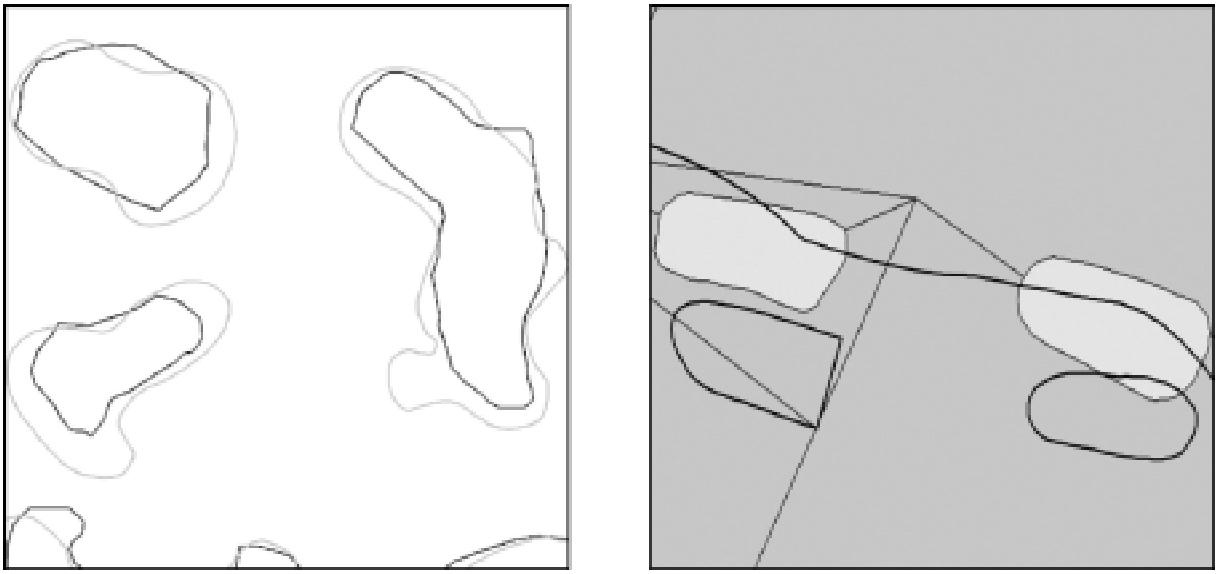

Figure 2: Overlay of the different vector data-sets: *left-image:* soil science map and geological map, *right image:* soil science map, ATKIS and selected object "water" in ATKIS

First investigations show that the ATKIS objects which will be the main target for the first research will be "water", "settlements", "streets" and "borders", as well as the objects which show fairly the same geometry in the geological and the soil science map. In the next step there will be a comparison of the three data-sets with focus on these four object classes.

The matching can be divided into the following two steps:

1. *Matching, i.e. the identification of corresponding individual objects using semantic-geometrical matching algorithms*: A mutual linking of the objects already allows for a multitude of options, like the exchange of attributes.

2. *Integration of the linked objects by harmonization of geometry and thematic information*: In this way, ONE consistent object geometry can be obtained. The harmonization is based on transformations that will take the accuracy of the original data into account. The result of the adjustment is a new, common, object geometry as well as quality measures with respect to the transformation. This adaptation requires knowledge about the relative significance of the objects as well as their accuracies. The generation of the common geometry can be achieved in different ways:
   - The object of the theme A has a higher importance or accuracy, respectively, so that the object of theme B will be adapted.

- The importance or accuracy values of the respective objects are given – the new object geometry is gained as "weighted mean" of the two original geometries.

Matching techniques will be developed exemplarily for important object types in the given data sets.

2.1 A brief description of the international state-of-the-art in vector data integration

The matching problem can be solved in different ways. One of the first approaches of matching vector data sets of different sources – also named as conflation [Lynch and Saalfeld 1985] - was carried out by the Bureau of Census in Washington DC [Saalfeld 1988]: the census data were integrated with data of the United States Geological Survey (USGS) with the objective of improving the quality, eliminating errors, as well as exchanging attributes. In Geodesy and Geoinformatics often geometric features like form and position of the objects are used [Gabay and Doytsher 1994]. If, however, unknown transformation between the data sets have occurred, or no unique matching candidates can be found, also binary object characteristics, i. e. relations, have to be applied in order to constrain the search process [Walter 1997]. Integration problems arise on the one hand in the domain of the integration of heterogeneous data, on the other hand they are also investigated when data of different scales have to be combined [van Wijngaarden et al. 1997, Badard 1999]. Devogele et al. [1998] analyse the theoretical discrepancies of different data sets and present potential solutions.

It can be summarized, that up to now integration approaches were primarily investigated for the integration of artificial objects like buildings and roads – natural objects like rivers or borders of vegetation are missing up to now. These objects are representing a special challenge, as the fuzziness of their boundaries plays a decisive role.

3 Integration of raster and vector data

3.1 Project goals

The goal of this project, being carried out at the Institute of Photogrammetry and GeoInformation (IPI) together with NLfB and BKG is to automatically enhance the applicability of the digital Soil Science Map by integrating it with information of up-to-date aerial images for the following two geo-scientific problems:

1. *Derivation of field boundaries:* Field boundaries are important for various soil science problems. Furthermore, this information is also required in other areas, like in the agricultural sector. The field boundaries – as far as they are visible in the images – will be extracted automatically. In this task particularly the geometric information of the field boundaries in form of polygons is of importance. Additional attributes may also be collected.
2. *Derivation of wind erosion obstacles:* Wind erosion obstacles (hedges, rows of trees, groves etc.) are relevant for the determination of the potential damage of an area caused by wind. These obstacles will be identified in the images by automatic processes. Furthermore, the

information about the height and possibly also about the permeability will be extracted for every obstacle.

Generally, the combined use of raster and vector data plays an important part in the geosciences for the registration, validation, updating and visualisation of objects of the Earth surface. An important aspect is the refinement of existing vector data sets by objects that have been extracted from aerial images. At NLfB, primarily black-and-white aerial imagery from the State Survey Authorities and corresponding orthophotos are being used for such tasks at present. An important challenge with regard to research is the automatic extraction of the objects of interest incl. the corresponding attributes from these images using techniques from image analysis based on suitable semantic scene models. In this way the information implicitly contained in the images is made explicit and is thus available for object-related geo-scientific analyses.

According to the state-of-the-art in image analysis the use of constraints by introducing prior information taken from the combination of different data sources is an essential element for the stabilisation of the process. In the context of the project the prior information comes from ALKIS, ATKIS Basis-DLM and the digital Soil Science Map in form of an initial scene description. This information is helpful for image analysis, e. g. the field boundaries frequently are parallel to parcel and land use boundaries and/or to the road network. The same applies to wind erosion obstacles, which are often located in parallel or at a right angle to topographic objects and to the border of vegetation areas. Figure 3 shows an orthoimage (left) and the desired results (right): Field boundaries are depicted in black lines, wind erosion obstacles in white lines.

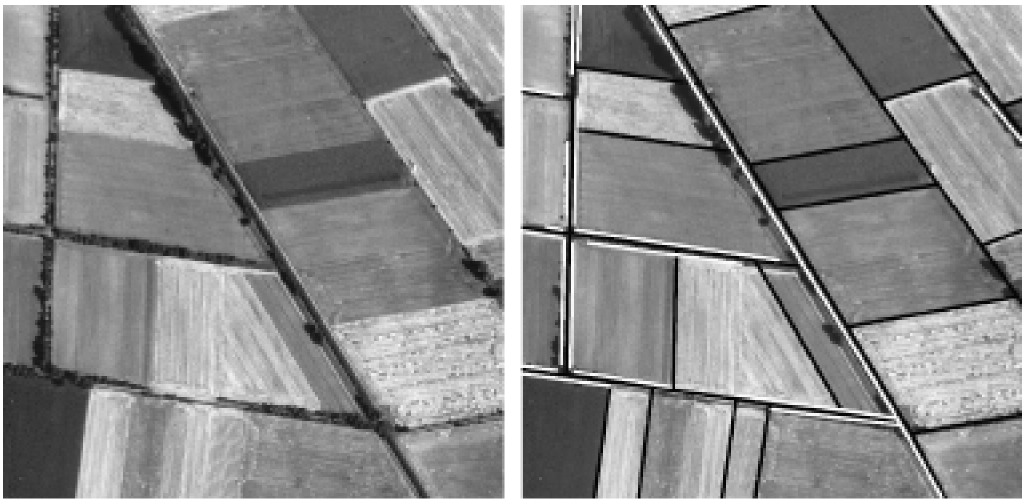

Figure 3: Example of the project results: Extracted field boundaries (black lines) and wind erosion obstacles (white lines). Note that these results have been acquired manually, the goal of the project is to automate this acquisition process as far as possible

Up to now, both the field boundaries and the wind erosion obstacles are manually acquired at NLfB and are subsequently imported into the existing vector data sets. This task is carried out partly at an interactive workstation based on the aerial imagery, and partly in the field. The data thus acquired as well as further base and thematic data (price per km^2, land use, ground topography as well as the main wind direction) are being used as input for simulations which provide as result among other things an assessment of the wind erosion danger for each field (e.g. Thiermann et. al. 2002).

The time-consuming, manual data acquisition for such tasks will be complemented by an automated process in the context of this project and thus become more effective. In this process data integration plays an important role in two ways: (1) During the construction of the semantic scene model the prior vector information (ALKIS, ATKIS, digital Soil Science Map) has to be integrated with the objects to be extracted from the aerial imagery, where the description of the latter is restricted by the observability of the corresponding attributes and the relations, (2) the process of image analysis provides the necessary pre-processing of the raster data as well as the connection between the objects extracted from the aerial image and the existing vector data.

3.2 A brief description of the state-of-the-art in integration of raster and vector data

Latest developments in research in image analysis for topographic applications is brought together in [Baltsavias et. al. 2001]. According to this reference knowledge-based methods represent a very promising approach [Niemann et. al. 1990; Liedtke et. al. 2001]. As far as applications are concerned a multitude of successful approaches for the automatic extraction of man-made single objects like buildings or roads exist [see Mayer 1998 for an overview]. For the extraction of vegetation objects from high resolution images approaches have only been presented recently [e. g. Borgefors et. al. 1999, Heipke et. al. 2000, Pakzad 2001, Straub et. al. 2001], prior work mostly uses multi-spectral-classification. A significant limitation of nearly all known techniques constitutes the focus on one object class only, see also the corresponding statements in [Stilla et. al., 1998].

Work on the use of vector data of a Geographic Information System (GIS) as prior information of a scene are documented at several references. Only a few approaches [Bordes et. al. 1996, Quint, 1997, de Gunst and Vosselman 1997], which again deal with man-made objects only, use this prior information for the generation of incremental hypotheses. A paper, interesting with regard to the extraction of field boundaries intended for this project, has been presented by Löcherbach [1998], who reports on the refinement of topologically correct field boundaries.

In summary, one may say, that there is a demand for research and development in automatic image analyses. In particular in the area of vegetation there is still insufficient literature and success. It is a shortcoming of many approaches, that existing prior knowledge, often available in the form of vector data, is not adequately integrated into image analysis at this stage [see also Baltsavias 2002]. Work in the current project aims at overcoming these limitations by properly representing and integrating prior knowledge into image analysis.

4 Federated spatial database

The third subproject aims at designing and implementing a “federated“ spatial database that discloses the given heterogeneous data together with their relationships after they have been united. Therefore, general methods for database federation have to be specialized and adapted to the integration of spatial databases. Additionally, new methods have to be developed for object-wise database integration, in particular for identifying related spatial objects from separate data sources.

4.1 State of the art

In order to couple heterogeneous databases, at first so-called multi-database architectures had been discussed for loose coupling, but then so-called *federated databases* have been proposed and investigated to support a closer coupling. A systematic and comprehensive treatment of that subject can be found, e.g., in [Conrad 1997].

Federated databases allow integrating existing autonomous and (with respect to modeling and contents) heterogeneous databases via a common database interface. This so-called *federation service* refers to a global database schema that has been designed by integrating the participating local schemas. Local applications remain unchanged, but additional global applications can be developed with an integrated view on the data.

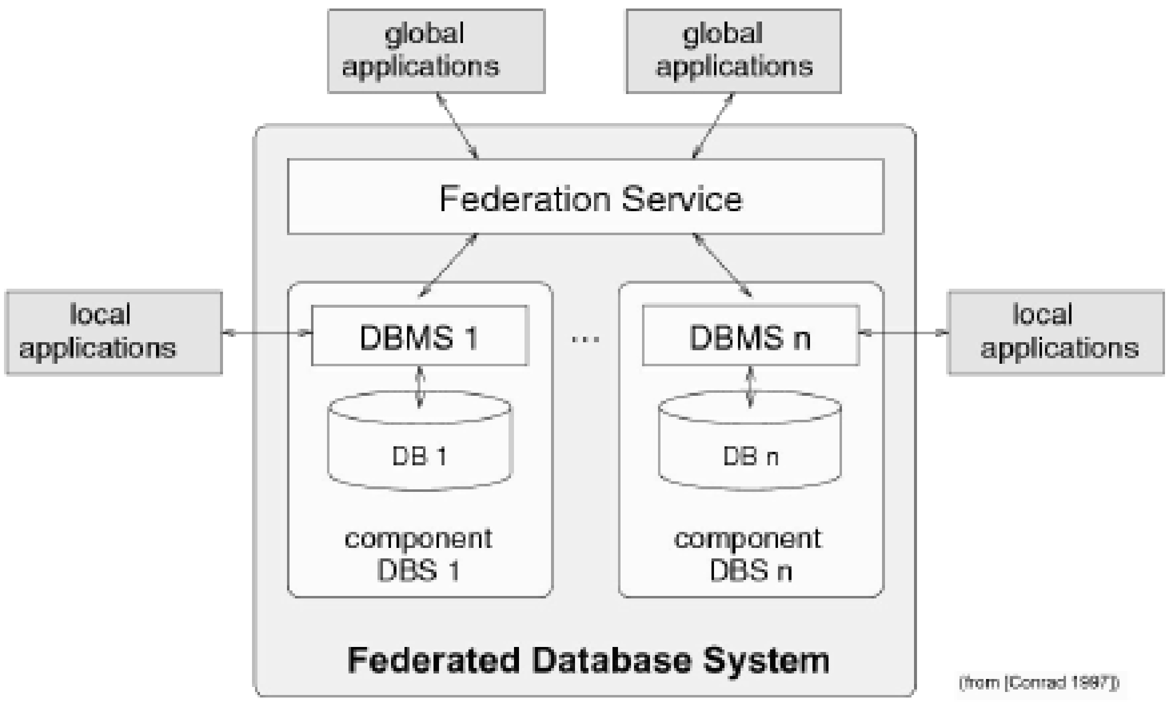

Figure 4: Federated Database System

For schema integration, a broad spectrum of methods has been investigated in the literature. Typically corresponding object types have to be detected and merged on the schema level, after conflicts (on names, structures, extensions, etc.) have been detected and resolved. On the instance level, however, such methods either expect implicit unique assignments between “identical” objects (e.g., based on a world-wide numbering schema like ISBN for books) or treat objects from different sources to be different. More sophisticated correspondence relationships are usually not considered when identifying objects.

There are first proposals for query languages (usually extensions of SQL) that respect specific needs of federated databases, for instance, the “multi-database language” SchemaSQL [Lakshaman et al. 1996] or the “federation query language” FraQL [Sattler et al. 2000]. They introduce language features for transforming different structures or for reconciling attribute values of already identified objects (e.g., for producing a uniform notation of bibliographic book data).

Whereas there is a lot of work on spatial databases (for surveys compare, e.g., [Günther 1998], [Rigaux et al. 2002]), requirements of spatial data on database federation have hardly been investigated; exceptions are [Devogele et al. 1998] and [Laurini 1998]. At least, there is a standardized representation of vector data types according to the OpenGIS consortium [OpenGIS 1999].

The authors have already gathered some experience in processing data of the kinds required in this project by means of an object-relational database. Such a database offers extensions for spatial (vectorized) data and allows for own extension development, as it might be needed for, e.g., raster data or raster/vector combinations. In particular, modeling, importing and processing data from cartography and from soil science have already been realized within the Oracle database management system (plus Spatial cartridge) [Kleiner et al. 2000; Pfau et al. 2000]; it was shown how to specify and implement arbitrary queries and computation methods. Thus, a flexible database environment can be utilized as a starting point for modeling and prototyping the federation service, before in later project phases dedicated GIS interfaces will be connected.

4.2 Project goals

By utilizing assignments and unification rules between corresponding objects as developed in the other two subprojects, this subproject will design and prototypically realize an integrated access to the given heterogeneous data sets according to the paradigm of federated databases.

First of all, the different kinds of correspondence relations between objects and/or between object parts have to modelled : direct structural assignments like 1:1, 1:n or n:m relations have to be considered as well as various instances of thematic and geometric similarity. There may even be alternative potential assignments being valid with different degrees of probability.

For the applications at hand, we can on the one hand expect true identification relationships between composed objects of the same type, for instance, between subsections or subareas of water objects which “belong to the same object in the real world”, and which can be found by methods matching complete geometries. On the other hand, it will be necessary to establish more general correspondence relationships, for instance, which topographic objects and which soil areas “share boundaries” (in order to propagate exact topographic boundaries to soil maps); here, methods for partial and multiple matching will be needed.

At least for identified objects stemming from several sources, conflict resolution rules have to be specified for the joint attributes; geometries, for instance, might be taken from the topographic model being the more precise source.

Then queries to corresponding databases (including import and export tasks) have to be supported which can utilize such object assignments by asking for thematic and geometric properties of the respective corresponding objects. As far as objects can be identified, queries should be supported that need not refer to such objects assignments explicitly. This will require appropriate extensions of the database language SQL by language features, which allow a unified access to objects of different data sources along correspondence relationships and conflict resolutions. Of course, not only thematic operators (like alphanumeric comparisons), but also geometric operators on spatial datatypes must be adapted.

Later, updates that are propagated along correspondence relationships according to pre-specified rules have to be supported as well.

Due to the federation paradigm, the original databases keep their autonomy – as can be expected in practice since separate agencies are responsible for topographic and soil/geologic maps. The databases, however, will be disclosed by a federation service that acts like a database with an integrated global schema – it does not copy the original databases, but it imports queried extracts into a spatial working database of its own.

This federation requires design of an integrated database schema for the involved databases including object assignments, matching methods, conflict resolution rules, and update rules. Then the working database can be realized such that it stores not only extracts according to the unified schema, but also correspondence relations between objects together with their kind and degree of validity, and the resolved attributes of identified objects. Additionally, it serves as a method base for import, matching, conflict resolution, and update procedures.

Expensive spatial operations, like, e.g., boundary matching on entire maps, will need dedicated optimizations by means of precomputed data like, e.g., topological relations, and specialized index structures. Fortunately, object-relational databases like Oracle 9i are extensible also with respect to such physical optimizations.

4.3 Interfaces

To exchange data between the data sources and the federation service or, more general, between the project partners, system independent tools and object-structured views for accessing and delivering information are desirable.

Here, the XML standard fits as an exchange language [Abiteboul et al. 2000] that can be specialized to the considered data by joint conventions to be specified in the meta description language XML Schema. The latter can also serve as an instrument for communicating and unifying the semantic object models of the subprojects. The OpenGIS-GML can be used as the sublanguage to exchange geometric data.

To specify the (global) database tasks preceding XML-based data exchange, Java-based web interfaces to the underlying object-relational database will be developed. These have to control the import of XML data into the federation service and the export of XML data from that service as well as ad-hoc queries and updates. How to automatically generate object-structured XML data from object-relational spatial databases has been studied in [Kleiner und Lipeck, 2001a/b].

5 Literature

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