CHANGE DETECTION AND INTEGRATION OF TOPOGRAPHIC UPDATES FROM ATKIS TO GEOSCIENTIFIC DATA SETS

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KEY WORDS: Cartography, Geology, Soil, Integration, Change Detection, Update, Correction

ABSTRACT:

Solving geoscientific tasks and questions is often performed using a set of different data sets. Single data sets mostly cannot offer all information which is needed, therefore data integration is used to enrich the data set with the missing information. Data integration offers additional benefits like verification and change detection, as well as the possibility of propagating updates from one data set to another. In the last years analogue maps from geology and soil-science have been digitised and stored in data base systems. Superimposing them with the German digital topographic map ATKIS reveals disturbing discrepancies in geometry and semantic. This inhibits the common usage of these geoscientific and topographic data sets. Performing the propagation of updates and the harmonisation of semantic and geometric differences is required but can not be performed manually due to the high demand on human and financial resources. Therefore, new methods for semantic and geometric integration are required to enable the automatic performance of the integration process. After an introduction into the problem area, the paper focuses on the geometric integration of the data sets, with focus on the merging of segmented objects and the usage of the iterative closest point algorithm (ICP) to enhance the matching process. At the end of this paper the intersection process and the evaluation of the resulting polygons will be descriped, followed by an outlook on future work.

1. INTRODUCTION

Data from different data sources is usually involved when geoscientific or environmental problems have to be solved. The advantage of using different sources offering "the best of all worlds" can be a disadvantage at the same time.

Despite the fact that all geoscientific data sets containing topographic information rely on the same source, the earth surface, they show significant differences due to different acquisition methods, formats and thematic focus, different sensors, level of generalisation, and even different interpretation of a human operator. Sometimes new acquisition is therefore needed to create a single homogenous data set.

Another problem which occurs while working with different data sets is the problem of temporal consistency:

Even if the data sets originally are related to the same objects, different update cycles in the different thematic data sets lead to significant discrepancies. Observing this problem it is obvious that harmonisation, change detection and updating of different data sets is necessary to ensure consistency, but hardly practicable when performed manual.

In a project of the German Ministry of Education and Research under the headline "GEOTECHNOLOGIEN", a research group at the University of Hannover, consisting of three institutes from surveying and computer science is dealing with the problem of data integration, applied to data sets from topography, geology and soil science. The project deals with different aspects of data integration, namely integration of different vector data sets, integration of vector and raster data, as well as providing an underlying data structure in terms of a federated data base, allowing a separate, autonomous storage of the data, however linked and integrated by adapted reconciliation functions for analysis and queries on the different data sets (Sester et al., 2003).

In the paper, there will be a concentration on the work of the Institute of Cartography and Geoinformatics (ikg), namely the semantic and geometric integration of vector data: Methods for the automatic integration, change detection and update between data sets of different origin will be developed – with a focus on the above mentioned data set. Here, we will focus on the geometric

aspects, namely the merging of segmented objects and the adaptation of the geometry by using a rigid transformation, followed by a mere intersection and evaluation of the resulting elements.
In this project the German digital topographic data set (ATKIS) can be chosen as reference, therefore the geometry of the geoscientific maps will be adapted without using constraints regarding accuracy or actuality so far. The approach, however, will be extended in the near future, to also take the relative accuracy and importance of the objects to be integrated into account.

2. RELATED WORK

Data integration is being investigated with different focus: on the one hand, data of different sources is integrated for a common data analysis in order to derive new knowledge.
Secondly, data can be integrated and fused for mutual benefit: (Walter & Fritsch, 1999) present an approach that fuses two different data sets with road information with the aim of mutually exchanging attributes of the two data sets involved. The integration of vector data and raster data is being investigated in the partner project with the aim of enriching a 2D-vector data set with 3D-information (Butenuth & Heipke, 2003). It is also popular in the domain of 3D-city modelling, where 2D-groundplans from buildings and 3D-surface models are fused, e.g. (Brenner, 2000). Data integration or data matching is also needed for update purposes, e.g. when a data provider has to deliver up-to-date information details to his customers (Badard, 1999).
Integration can be used for data registration, when one data set is spatially referenced and the other has to be aligned to it (Sester et al., 1998). A conceptual framework for the integration of geographic data sets, based on a domain ontology and surveying rules, was developed for update propagation between topographic data sets (Uitermark, 2001).
Finally, data integration is needed for the generation of Multiple Resolution Data Bases (MRDB); in this case objects of different geometric and thematic resolution have to be fused (Mantel, 2002).

3. USED DATA SETS

For the research in the GEOTECHNOLOGIEN project three data sets are used: the topographic data set ATKIS, the geological map and the soil-science map, all at a scale of 1:25000. When going from analogue to digital maps, new possibilities for data handling and analysis appear: basically, the combination of different data sets in a geo-information system (GIS) is enabled.
Simple superimposition of different data sets already reveals visible differences (Fig. 1). These differences can be explained by comparing the creation of the geological, the soil-science map and ATKIS (Goesseln & Sester, 2003).
As for ATKIS the topography is the main thematic focus, for the geo-scientific maps it is either geology or soil science – however they are related to the underlying topography. The connection between the data sets has been achieved by copying the thematic information from topographic to the geo-scientific maps at that point of time the geological or soil-science information is collected.

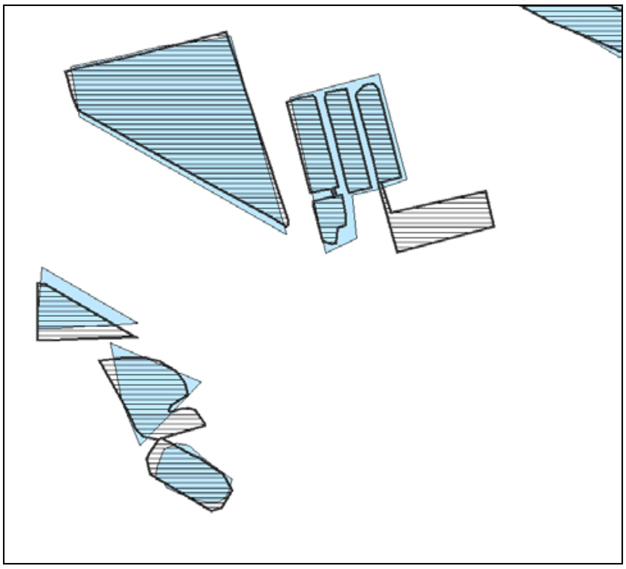


Fig. 1 : Simple superimposition of ATKIS (dark border, hatched) and geological map GK 25 (solid fill).

While the geological content of these data sets will keep its actuality for decades, the topographic information in these maps do not: In general, topographic updates are not integrated unless new geological information has to be inserted in these data sets.
The update period of the feature classes in ATKIS varies from one year up to three months – in general, 10% of the objects have to be updated per year (LGN 2003).
These differences in acquisition, creation and updating lead to discrepancies, making these data sets difficult to integrate. The amount of financial and human resources which is needed for the removal of these discrepancies can hardly be afforded. Therefore, new methods are required

which offer an automatic or semi-automatic process capable of detecting and removing the differences between these data sets and supporting a human operator in this process.
In order to identify changes in the data sets and update the changes, the following steps are needed: identification of corresponding objects in the different data sets, classification of possible changes, and finally update of the changes.

4. DATA INTEGRATION

4.1 Semantic Integration

Firstly, semantic differences between these data sets must be described to avoid comparing "apples and oranges".
Enabling the adaptation of updates from one data set to another leads to the problem of integration of heterogeneous data sets. There are four different types of data integration types defined (Walter & Fritsch, 1999).
Integration of data sets :

- I.: stemming from the same data source with unequal updating periods,
- II.: represented in the same data model, but acquired by different operators,
- III.: stored in similar, but not identical data models,
- IV.: from heterogeneous sources which differ in data modelling, scale, thematic content, …

The integrational part to be performed in this project could be categorized as type IV.
In the first phase of this project, the topographic feature class "water areas" has been chosen as a candidate for developing and testing, because of the existence of this topographic element in all data sets. To ensure a correct and fully automatic process, the detection of changes and the correct linking between semantic partners is a must.
In later stages, other topographic feature classes will be examined with respect to their relations between the data sets. In this way, a model for the semantic harmonization will be set up.

4.2 Geometric Integration

Following the semantic integration, differences in geometric representation have to be identified and removed. Geological and soil-science maps are single-layered data sets which consist only of polygons with attribute tables, while ATKIS is a multi-layered data-structure with objects of all geometric types, namely points, lines and polygons, together with attribute tables. At this point of time the first attempts of integration have been performed on the feature-class "water". The different data models used in ATKIS and the geoscientific data sets are resulting in more discrepancies in the geometric representation requiring a harmonisation procedure before the establishing of links between corresponding objects could be done.

4.2.1 Harmonisation

Water objects in ATKIS are represented in two different ways: Water areas and rivers exceeding a certain width are represented as polygons. Thinner rivers are digitised as lines and are assigned additional attributes, referring to some classified ranges of widths.

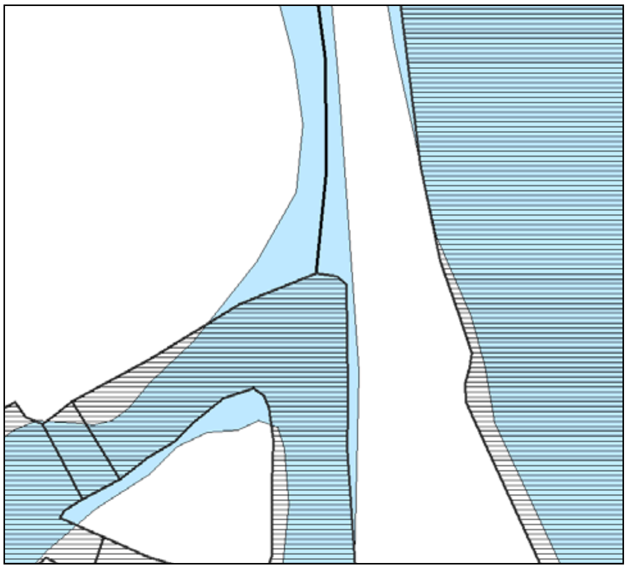


Fig. 2 : Different representations of water-areas in digital maps. River in ATKIS represented as line (dark line) and polygon (hatched area), and as polygon (solid fill) in the geoscientific map.

The representation of water objects in the geo-scientific maps is always a polygon (Fig. 2).
These differences have to be adjusted before integration starts. For the first implementation a simple buffer algorithm has been chosen, using the line representation from ATKIS as centre line and the width attribute. This enables the operator to compare the polygon from ATKIS and the water object from the geo-scientific maps using the mere intersection.

Another problem is the representation of grouped objects in different maps. For a group of water objects, e.g. a group of ponds, the representation in the different data sets could either be a group of objects with the same or a different number of objects, or even a single generalised object. Finally, also objects can be present in one data set and not represented in the other. All these considerations lead to the following relation cardinalities that have to be integrated: 1:1, 1:0, 1:n, and n:m.

4.2.2 Merging of segmented objects

In spite of the fact that the geometry of the objects stored in the geoscientific data sets arises from the same topography, the representation of the same "real-world" object differs between the reference and the geoscientific data sets.

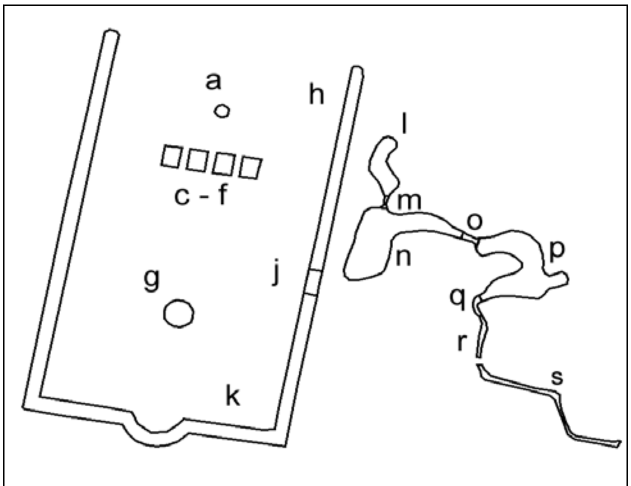
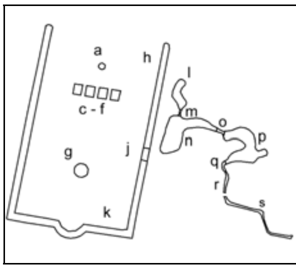


Fig. 3 : Segmented objects from the reference data set ATKIS.

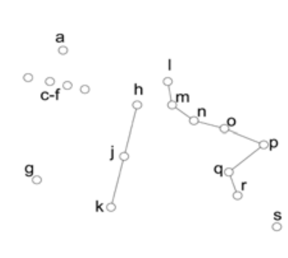
Not only shape, size and orientation of the partners to be integrated differ. Due to the diversity in digitisation they differ in the number and geometry of segments (Fig. 3).
Investigation for corresponding partners between the ATKIS and the geoscientific data sets at this point of time, would lead not only to unsatisfying results but to relation errors. Therefore, a merging of the segments must be performed to ensure the correct investigation of relations.
Assuming a segmented object is nothing else than a special kind of a network, single segments could be taken as nodes and the relation "is a neighbour of" will be modelled as the connecting edge between two adjacent segments (Fig. 4).



	a	b	c	d	e	f	g	h	j	k	l	m	n	o	p	q	r	s
a	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
h	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
j	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
k	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
l	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
o	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
p	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
r	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Fig. 4 : Segmented objects (left), represented in a matrix with each direct (one step) neighbour link (right)

The implementation of the neighbourhood criteria which has been chosen for this project is the examination of a definite distance between the points of both polygons. If the distance between two points falls below the definite distance, two polygons are considered adjacent.
The result of every revision is stored in an adjacency matrix (A). An adjacency matrix is used in computational geometry for the description of a graph structure like a traffic network. The dimension of the matrix is equal to the number of nodes (i.e. objects) in the data set. Every value inside the matrix (a_{ij}) represents the connection between two nodes (n_i ; n_j). The matrix will be symmetric if every connection in the network is bi-directional (de Lange, 2002).
Implementation becomes easier due to the symmetry of the matrix. Therefore, the tested polygons must not be stored in an additional list to check whether a connection between two objects has already been tested.
The first polygon in the data set is tested against all polygons from 2 to n, following the second polygon against 3..n and so on. After all combinations have been tested, the upper half of the matrix is copied to the lower half. The resulting matrix is showing every adjacency relation in the data set.
But thinking of the polygons as nodes in a network only the connections which could be travelled with one step are represented. The multiplication of A with itself (A^2) will show every connection which could be reached within two steps. The next multiplication (A^3) reveals all three step possibilities, but not the previous connections.
A matrix showing all possible connections is the goal. This could be done by adding up the identity matrix to A (A+I) before multiplication.
With every multiplication ($(A+I)^N$) the matrix shows all (1..n) connections, the multiplication must be repeated until no more cells have been changed from 0 to a higher value.



	a	b	c	d	e	f	g	h	j	k	l	m	n	o	p	q	r	s
a	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
h	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
j	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
k	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
l	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
m	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
n	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
o	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
p	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
q	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
r	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Fig. 5 : Objects from data set represented as graph structure (left), found groups in matrix (right).

Every object group fulfilling the neighbourhood criteria could be easily detected from the resulting matrix. The row rank of the resulting matrix is equivalent to the number of objects or object groups. After the removal of linear-dependencies (e.g. double represented rows) and rows with only one entry on the main diagonal axis, the resulting rows are representing the groups in the data set (Fig. 5).

This implementation showed very good results with the project data sets. Using an larger point distance, even object groups could be detected. Following the merging union of segments belonging to a "single object" the identification of similar objects could be performed. Alternatively, we can use a breadth search procedure for finding the object clusters. In order to define the neighbourhood using a fixed threshold, a triangulation of the objects reveals possible neighbours. A parameter free approach to identify clusters is based on an hierarchy of neighbourhood graphs [Anders 2003].

5. CHANGE DETECTION

Objects which have been selected through semantic and geometric integration and have been considered as a matching pair will be investigated for change detection. A simple intersection of corresponding objects is used for the change detection. Yet, the mentioned differences may cause even more problems which are visible as discrepancies in position, scale and shape. These discrepancies will lead to unsatisfying results using a mere intersection and make the evaluation of the resulting elements almost impossible (see Fig. 6).

Therefore firstly, a local transformation will be applied, leading to a better geometric correspondence of the objects. To this end, the iterative closest point (ICP) algorithm has been implemented to achieve the best fitting between the objects from ATKIS and the geo-scientific elements using a rigid transformation.

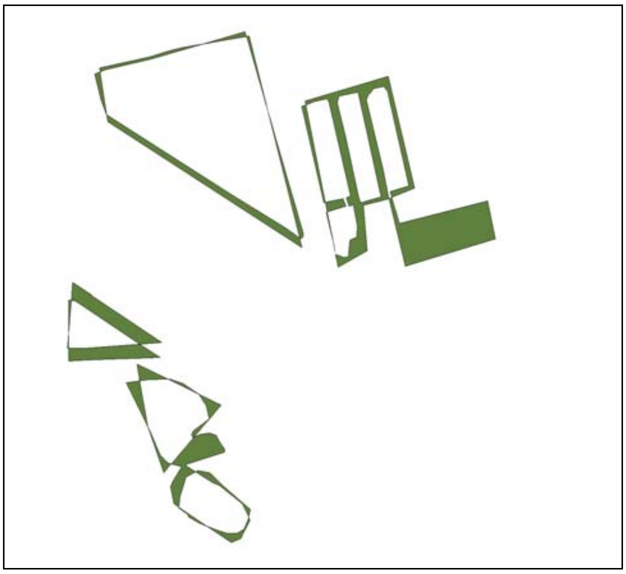


Fig. 6 : Resulting overlapping segments from mere intersection showing geometric differences between water bodies in the German digital topographic map (ATKIS) and in the geological map.

5.1 Iterative closest point algorithm (ICP)

In our first approach, objects from ATKIS are considered as reference due to their higher geometric accuracy, and the objects from the geoscientific datasets are optimally fitted to the ATKIS objects.

The ICP algorithm which has been developed by (Besl & McKay, 1992) to match three-dimensional objects using a 7 parameter transformation. In this case the problem is reduced to a 2D problem which requires 4 parameters (position, scale, orientation).

The implementation places points (railing points) with a fixed distance on the contours of the reference and the corresponding geoscientific object (so called fitter). For every railing point on the fitter the closest railing point from the reference object is selected. These pairs are taken as an input value for a similarity transformation (Helmert-transformation) achieving four new parameters as result. These results are fed again into the process and the whole process is repeated iteratively.

The transformation parameters are evaluated after every calculation; the iteration stops if no more variation in the four parameters occur.

At the end of the process the best fit between the objects using the given transformation is achieved, and a link between corresponding objects in the different data set is established (Fig. 7). Evaluating the transformation parameters allows to classify and characterize the quality of the matching: in the ideal case, the scale parameter should be close to 1; also rotation and translation should not be too large – assuming, that the registration of the data sets is good.

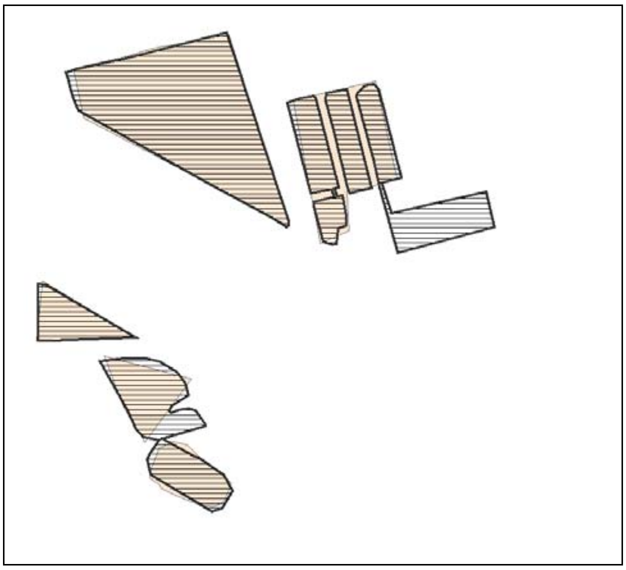


Fig. 7: Simple superimposition of water bodies in ATKIS (dark border, hatched) and geological map GK 25 (solid fill) after the application of the ICP-algorithm (compare to Fig. 1).

If an even more accurate correspondence between the data sets is needed, specific geometric reconciliation functions for the exact adaptation of the geometry have to be implemented. The idea is that for that purpose, the individual shapes of the objects will be geometrically adjusted: depending on the relative accuracies of the original objects, an “intermediate” geometry will be calculated. This will be achieved using a least squares adjustment process, where observations in terms of differences in shape will be introduced as a functional model – the stochastic model will describe the accuracies of the original shapes. This process then will lead to a local adaptation of the individual corresponding objects, but also of their local environment. Too large discrepancies of the shape boundaries will be considered as outliers and can be treated in the subsequent overlay and analysis step.

5.2 Intersection and segment evaluation

Following these steps, intersecting objects for a proper change detection will lead into a more promising result (Fig. 8) as simple intersection (Fig. 6). This analysis and the classification into different change situations is a semantic problem and will be conducted in close collaboration with experts from geology and soil science, who are also partners in the project.

At this time of the project three different classes have been identified: the intersection segments can be classified according to their respective classifications in the original data sets in:

- Type I : Area is defined as water area in both maps, no adaptation required,
- Type II : Area in data set B has been any type of soil, but is defined as water-area in the master data set A; therefore the attribute of classification will be changed in the geoscientific map (data set B),
- Type III : Area in data set B has been water-area, but is now updated, therefore a new soil-classification is required.

While Type I and II require only geometric corrections and can be handled automatically, Type III needs more of the operators attention.
A topographic object, which is represented in ATKIS, but not in the geoscientific map (1:0 or n:0), would be integrated to the geoscientific data set and handled as Type II. For example, comparing Fig. 6 and Fig. 8: there has been a L-shaped object in the upper right corner which disappeared through segment evaluation. This object represented a water area in the ATKIS data set. Therefore it was more actual than the area definition stored in the geoscientific map. So it was integrated into the geoscientific map as water area regarding the higher actuality of the reference data set (ATKIS). This decision has been done automatically. An object which is still represented in the geoscientific map, but not longer present in ATKIS (0:1 or n:0) would be removed. Depending on the area size of the resulting non-attributed area, it will receive the same soil-definition like the surrounding neighbourhood using the nearest-neighbour criteria, if it is smaller than a definite threshold. An area bigger than the given threshold will appear in the resulting visualisation of the detected changes and would be handled as Type III (Fig. 8). To avoid the integration of sliver polygons, there will be an enhancement of the filtering in the next step. Together with the area, the shape of the resulting segment will be evaluated, this will avoid the integration of large objects which are only the results of geometric discrepancies and must not be taken into account.

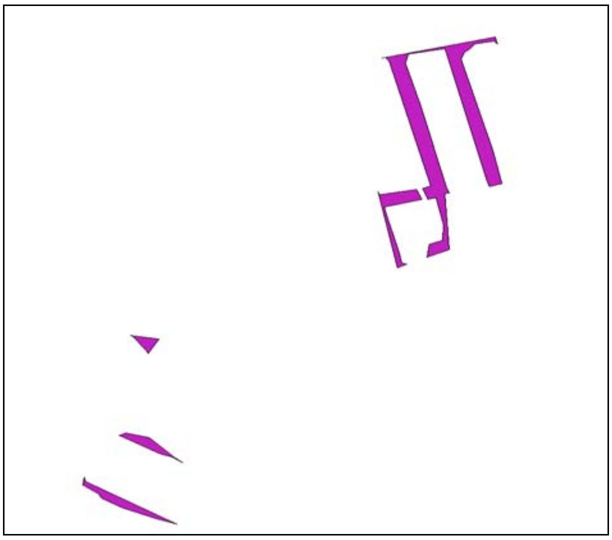


Fig. 8 : Visualisation of changes between topographic content from ATKIS and geological map, after applying ICP algorithm and area-threshold filtering.

Developing methods for handling water objects, there are many situations a Type III segment can occur. Due to different natural effects like desiccation or man-made rerouting of a river bed, water areas have been changed in shape or they even disappeared from the face of the environment.
After an actual topographic description is no longer available, there is no up to date process or method to derive a new soil definition automatically. As there are different ways an water area can disappear, there are different natural (e.g. erosion) or man-made (e.g. refill) processes which have influence to the new soil type. This new soil type could not be derived automatically, but there are different proposals which could be offered to the user by the software.
An area-threshold which has to be defined in the near future together with the experts from geology and soil-science will be applied to remove Type III segments which occur due to geometric discrepancies.
As a result a visualisation will be produced showing all the areas where an automatically evaluation of the soil situation could not be derived or only a proposal could be delivered and manual "field work" must be performed (Fig. 8).
The visualisation of Type III segments will reduce the amount of human resources needed to detect the topographic changes between the geoscientific data sets and ATKIS.
It is expected, that a high degree of automation can be achieved with this process. In some situations there will be an automatically generated suggestion from the algorithm, however the expertise of a human operator will still be mandatory in some cases in order to commit or propose another solution.

6. CONCLUSION AND OUTLOOK

In this paper the ongoing research on semantic and geometric integration has been presented. The selection of the topographic element water, the automatic merging of the segmented objects and the use of the ICP-algorithm showed very good results.
In the near future the semantic catalogue will be expanded to cover all topographic elements which are represented in each of the three data sets, german digital topographic map (ATKIS) and the geoscientific maps from geology and soil-science. The introduction of punctual and linear elements will enhance the process of geometric integration, because at this point of the project only polygons are evaluated.
Due to the fact that only linked objects are changed and adjusted geometrically during the integration, their neighborhood remains unchanged. Therefore, these objects have to be transformed accordingly.
In our case the ATKIS objects have been selected, as they have also been the basis for the capture of the geoscientific data sets and due to the fact that they represent a standard of topographic data sets in Germany which offers higher geometric quality. To ensure the possibility of adapting the whole process to other data sets, there will be investigations conducted to integrate a weighted geometry between two objects, taking the accuracy of each object into account.
The software prototype will be used as test bed to derive the different parameters and matching algorithms. The automatic merging of objects is already implemented as a standard feature in modern GIS application. But at this time the implementation of the integration process is a stand-alone application which is not bound to a special software package. Therefore this implementation, using adjacency matrices, offers the best possibilities in method testing and threshold evaluation.
Additional discussions with the external geo-scientific partners will ensure the creation of a fully-functional and automatic process.

ACKNOWLEDGEMENTS

This work is part of the GEOTECHNOLOGIEN project funded by the Federal Ministry for

Education and Research (BMBF) and the German Research Council (DFG) under contract 03F0374A.

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