Automatic Interpretation of Raster-Based Topographic Maps by Means of Queries

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Key words: Map Interpretation, Pattern Recognition, Query Language, Fuzzy Sets, Template Matching, Knowledge Base.

ABSTRACT

This paper presents approaches and results of a project in the field of pattern recognition and automatic interpretation of topographic maps. The aim of this project is to obtain multiple information and structured objects from digital raster-based topographic maps using a query language. Thus, an approach how to query objects or other information directly from raster data is required. Query languages, well known by handling data in databases, can acquire data in a well-structured way (e.g. SQL = structured query language), which will now be adapted in the field of raster data manipulations. If queries on raster data images, e.g. topographic maps, are implemented, several methods and approaches of raster data acquisition have to be combined to provide the results of the queried desires. Therefore template matching strategies, the use of fuzzy logic, and other approaches of data acquisition will be combined in order to obtain a hybrid system, which can be driven by query languages. The results of queries can be visualized in the maps. This paper summarizes the research of several Ph.D. thesis of Swiss Federal Institute of Technology (ETH) in Zurich.

ZUSAMMENFASSUNG

Diese Arbeit präsentiert Ansätze und Ergebnisse eines Projektes der kartografischen Mustererkennung bzw. Interpretation kartografischer Dokumente. Mit Hilfe einer Abfragesprache (Query Language) wird versucht, Informationen und strukturierte Objekte aus topografischen Karten in Rasterdatenform zu gewinnen. Hierzu muss ein Weg gefunden werden, wie möglichst direkt Objekte und andere Information aus Rasterdaten abgefragt werden kann. Hier wird gezeigt, wie Abfragesprachen, die bereits aus der Datenbankanwendung bekannt sind, auch im Bereich der Rasterdatenverarbeitung eingesetzt werden können. Hierzu müssen verschiedene Methoden der rasterbasierten Datenerfassung kombiniert so werden, dass sie den Anforderungen der Abfragetechnik entsprechen. Der Einsatz von Template-Matching-Strategien, von Fuzzy-Logik und anderen Ansätzen ermöglicht in ihrer Kombination ein hybrides Mustererkennungssystem, welches durch Abfragen steuerbar ist. Dabei können die Resultate zusätzlich direkt in der Karte visualisiert werden. Die hier vorgestellte Arbeit fasst mehrere Dissertationen an der ETH Zürich zusammen.

RESUME

Le projet décrit dans la présente publication a pour but d’automatiser l’interprétation d’images cartographiques en utilisant les méthodes du traitement d’images. Il s’agit d’identifier et d’extraire des informations et des objets structurés en employant un langage d’interrogation (Query Language). Pour atteindre ce résultat il a été nécessaire de développer une méthodologie applicable à l’analyse directe de données raster. Dans le cadre de la recherche il a été possible de démontrer que les langages d’interrogation connus dans le domaine des bases de données sont tout à fait indiqués pour l’analyse d’images raster. Le but a pu être atteint en combinant une variété de méthodes de traitement d’images, qui ont été adaptées pour satisfaire les exigences du langage d’interrogation. L'utilisation de procédés de comparaison d'images (Template Matching), de la logique floue ainsi que d’autres méthodes a permis de réaliser un système d’analyse hybride qui peut être piloté en posant des questions. Les réponses du système peuvent par la suite être visualisées directement dans l’image cartographique. La recherche décrite dans la présente publication rassemble les résultats obtenus dans plusieurs thèses de doctorat de l’école polytechnique fédérale de Zurich.

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1. INTRODUCTION

Geographical Information System (GIS) is nowadays a key technology to handle spatial data [*Burrough and McDonnell (1998)*]. In order to acquire spatial information belonging to GIS the automatic interpretation of topographic maps is required. Maps, which can easily be scanned in higher resolutions, consist of important and accurate spatial information. However, this spatial information is only given implicitly due to the raster data nature. Pattern recognition and image processing methods based on raster data are relevant to acquire explicit spatial information belonging to GIS. We want to interpret automatically topographic maps in order to obtain this structured information.

Therefore the nature of raster data must be remembered. Thus, methods of querying raster data structures mainly depend on the difficulties of raster data enhancement. We will give a short description of raster data and their enhancement in Chapter 2. In order to propose an interpretation method based on topographic maps we give a short overview of concepts of cartographic pattern recognition (Chap. 3). There are some specifics concerning recognition methods due to the interpretation of special documents, namely of maps.

Further, the use of queries in the field of raster data enhancement is a rather new approach. Queries are firstly implemented in other fields (Chap. 4). Our approach of using queries in order to recognize raster data structures or objects, proposed in Chapter 5, is a hybrid system that consists of several raster data interpretation and manipulation strategies driven by queries. Because queries are often fuzzily formulated, and because they are in general free of tuning parameters, we intend to implement some strategy by means of fuzzy technologies. The paper will be concluded by a short outlook of obtained results.

2. RASTER DATA AND THEIR ENHANCEMENT

Raster data consist of a structure and an amount of information. The structure is given by the raster dividing a two-dimensional area in little elements we call pixels (pixel = picture elements). Each pixel has got an address to which it can be queried and its content provides in general pixel-related information. Therefore the administration of raster data, especially raster based images or graphics can be achieved by arrays in which each field corresponds to one pixel of the whole raster table. Though the administration of raster-based images is simple, there are several disadvantages of raster data.

Raster data are in general “unintelligent” (*Bill und Fritsch (1994)*, p.28f.), that means that each information is only pixel-related. Objects, contours, lines and symbols are heavily fragmented by the raster, the information of geometric and topological features is mainly lost, reduced or summarized to the raster-compatible information, and between the pixels there is no other geometric and topological relation than the neighbourhood from one pixel to the other in certain discrete directions of the raster table. In raster data we cannot recognize objects directly. We must compare pixels which are standing together, and similar information among these pixels provides segments that may be interpreted as one object.

Thus, main tasks of raster data enhancement are pattern or object recognition. Objects and features must be recognized by a combination of both information of certain pixel regions and their (unfortunately) weak topological and geometric relationships. The recognition task should provide objects or structures built by an amount of picture elements. Some extraction of features, e.g. the extraction of contours, may be done by simple procedural methods like filtering [*Göpfert (1991), Haberäcker (1995)*].

For more complex features and objects we need a knowledge base. Here the knowledge on the features and objects is saved in lists, files, or templates, and a knowledge based recognition system will detect by means of collecting or interpretation of information and matching. Template matching is one strategy in order to detect or recognize pattern or objects, however the objects and pattern must not heavily be blurred. The knowledge base of template matching strategies is the template itself, which is given as pre-information. During the matching process, the template is matched with raster image samples. By means of evaluating values the correlation between template and image sample provides the information whether the image sample could be interpreted as similar with the template or not.

3. CONCEPTS OF CARTOGRAPHIC PATTERN RECOGNITION

The field of pattern recognition is rather large: There are applications in document analysis, in target or benchmark detection, in contour extraction, and other tasks of information acquisition and analysis. They can be distinguished by both the method and the source of data. Cartographic pattern recognition belongs to the field of document analysis, and the related documents (i.e. the data source) are maps. Maps themselves are written by means of a system of graphic symbols and signatures [*Hake und Grünreich (1994)*] that encodes geographical information. The map legend is the key we are using to understand and decode the map’s symbols and the geo-related information that is hidden behind them.

Among the approaches of cartographic pattern recognition we can separate into two groups: The exclusively raster-based pattern recognition techniques (raster-based interpretation) and the mainly vector-based recognition techniques after a preliminary raster-vector conversation process (vector-based interpretation).

3.1 Raster-Based Map Interpretation Approaches

The main tasks are matching strategies in order to recognize objects and structures whose geometry is well-known, segmentation strategies in order to classify the image or to build objects by means of radiometric features or by means of morphologic manipulations (dilatation and erosion), and other raster-based feature extractions. For example, the concept of *Samet and Soffer (1994)* is a legend driven interpretation method working with matching strategies. On the other hand, classification, segmentation, and feature extraction approaches can be found in *Brügelmann (1998)*. Further *Chhabra (1996)*, *Stengele (1993, 1995)*, *Frischknecht and Kanani (1997)*, and *Frischknecht et al. (1998)* have mainly proposed raster-based strategies of cartographic pattern recognition.

3.2 Vector-Based Map Interpretation Approaches

In contrary to raster-based map interpretation, for a vector-based method the given raster data are firstly converted into vector data. By means of raster-vector conversation methods geometric prototypes like points, line elements, polylines and area shapes are obtained. The task of vector-based interpretation methods is to increase spatial information by combining these geometric prototypes to more complex objects and by investigating their meaning. The advantage of these vector-based methods is the independency of the raster-structure. Especially for finding lines, vector-based approaches work more efficiently than raster-based approaches. Some mainly vector-based approaches can be found in *Chhabra (1996)* and *Mayer (1996)*. A method using both raster-based and vector-based approaches is proposed by *Pierrot Deseilligny et al. (1997).*

4. QUERIES AND QUERY LANGUAGES

4.1 Definition and Application Fields

Queries are formulated desires used to analyze data, or to obtain data from certain data sources. Thus, queries allow obtaining specific information from data. They are formulated by means of keywords and a redundancy-free grammar whose are lent on human way of formulating desires. A query language is the whole system which consists of all possible keywords and the grammar that explains the use and combination of keywords in order to get queries.

Following the definition of *Samet*: "*A query language is a high-level computer language which is preliminarily oriented towards the retrieval of data held in files or databases.*" [cit. *Samet (1981)*], query languages have firstly been developed in the area of databases or files. They are used to manipulate or to acquire structured information held in databases. Nowadays, the Structured Query Language (SQL) is a standard of database-querying tools.

Instead of databases, raster-based images can be used as source of information where query languages can work on. In 1995, the language GISQL allowed querying of spatial vector data [*Costagliola et al. (1995)*]. Approaches towards the use of raster data or even raster images querying can be found since 1998, for example the language RasQL [*Widmann and Baumann (1998)*], the use of queries for the spatial analyses by *Lin and Huang (1999)*, and the query language RaQueL [*Frischknecht (1999)*, see also Chap. 5].

4.2 Advantages of Queries

The use of queries in order to obtain information has several advantages we are going to point out:

- Queries allow a quick formulation of desire.
- Query languages have keywords based on human languages. Therefore they are user-friendly.
- Query languages use a simple grammar; therefore they are user-understandable. The grammar is based on the human grammar and well structured.
- Query languages need only a small vocabulary of keywords.
- Query languages are formulated without setting parameters. Thus, information whose attributes (as setting parameters) are similar, but not identical, can be queried in the same query.

In general, queries are a useful information acquisition tool based on the human way of desiring.

4.3 Fuzzy Querying

By using human-like keywords for querying information we often use fuzzily formulated queries. For example, obtaining information, which is “beautiful”, “cold”, or “similar to something” contains fuzzily formulated desires. This requires new strategies of querying with respect to the fuzziness there enclosed. On the other side, the result of queries may be fuzzy. If our data source is an image and if we intend to query all objects from the image whose appearance are like a certain well-known object, its visualization on the image is blurred by the brightness and shadows, even the segmentation (separating fore- and background) of the desired object is rather difficult. Therefore methods of fuzzy logic and the use of fuzzy sets, firstly introduced by *Zadeh (1965)*, should be implemented here. Some approaches on fuzzy queries can be found in *Wang (1994).*

5. REALIZATION OF A QUERYING TOOL FOR RASTER DATA

5.1 The Two Concepts of Querying Raster Data

We intend to transfer the idea of querying information towards the field of raster data enhancement and interpretation. Obtaining information from raster data will now be made by means of queries. Thus, there are two concepts how to realize a raster-based query language: The idea of the indirect method, proposed by *Frischknecht (1999)* is querying features of objects that are firstly extracted from the image. After segmentation and object generation by means of radiometric features, we have got a list of segmented objects. To each object we compute features like area, perimeter, compactness, and a lot of others. For to extract objects of an object class an ideal combination of features is required to identify them in the image. After selection in the object-related feature database which has done by means of queries, we can visualize the selected objects in the image. The functionality of the query language is the same we use in databases, and its keywords are followed by the principle of SQL (structured query languages) we know from working in databases. This is the method we call indirect because the selection will be done in the object-related feature database, and not in the image itself (Fig. 1).

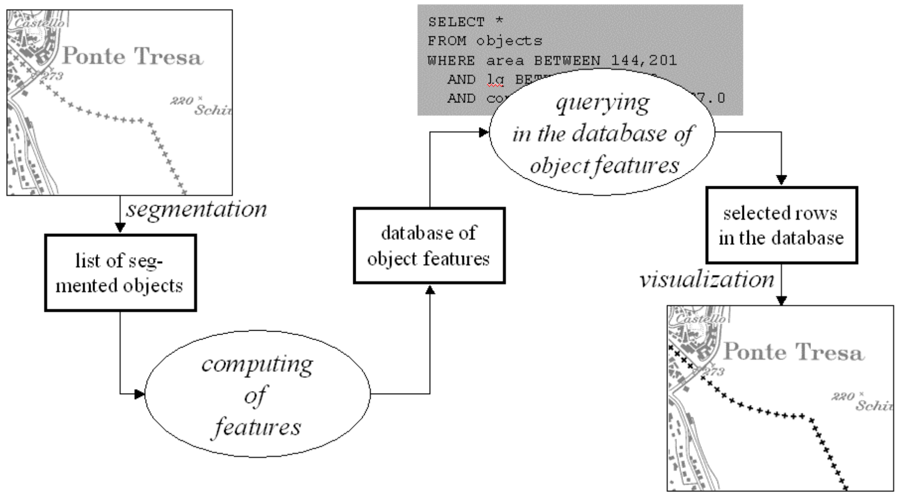

Fig. 1: Querying of Raster Data by Means of an Object Feature Database (Indirect Method)

This indirect method consists of the following advantages: the querying result is unambiguous due to the selection of rows in the database. Further selections from selected or unselected objects are also possible [*Frischknecht (1999)*], and due to the structure of common databases the querying process is rather fast. However, the definition of objects collected in the databases depends highly on the segmentation and image classification strategy. We cannot query structures laying only in part of objects or extending over more than one object. The segmentation strategy determines the database of objects and thus, the querying result highly depends on this separation into objects.

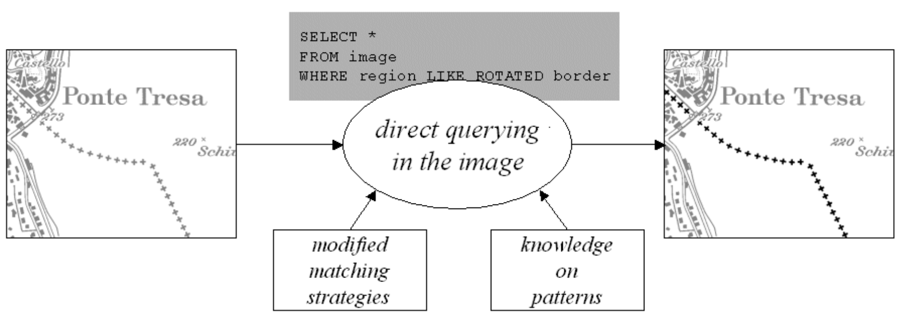

Fig. 2: Direct Querying in the Image by Means of Matching Strategies (Direct Method)

The other method we call direct querying method does not depend on the object segmentation strategies. Modified image matching strategies based on knowledge concerning geometrical and topologic features of objects allow us to query raster data structures in a direct way. Thus, we do not segment the image, we do not obtain objects from the image, and we could query raster data structures consisting of object parts or even of more than one usually segmented object. For example, the character of the little “i” consists of two object segments, but may be queried as one raster data structure because the dot of the “i” has a fix relation to the body of this character. For to implement a direct querying method we need matching functions of higher performance. In cartographic documents that we are usually using template matching strategies provide a large field of algorithms we can use to build a query tool. That is why most signatures, characters and symbols do not vary in this kind of documents. Their geometrical and topologic appearance is well known and well declared in the map's legend that provides a knowledge base of patterns (Fig. 2). The direct method is more time-consuming than the indirect method due to the implemented matching tools. Therefore matching strategies have to be modified [*Graeff (2001*)].

5.2 Realization of Raster Data Querying Language

A query language is a high-level language, and its keywords have to be defined. In both methods we follow the formulation we know well from SQL (structured query languages). Thus, queries begin by a SELECT-statement, followed by the indication of data source in the FROM-part and the data- or information-selecting WHERE-part.

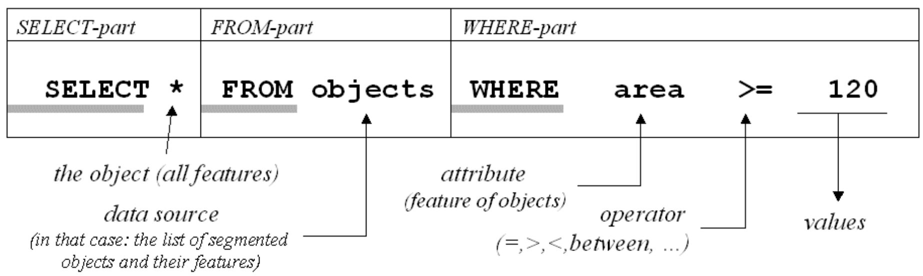

Fig. 3: The Usage of Queries in the Indirect Method

In the indirect methods the functionality of the raster-based language RaQueL, which has been developed by *Frischknecht (1999)*, follows exactly the functionality of SQL in databases. However, after the query is executed, the result is not given as a table of data but directly visualized in the map. All selected objects are shown in red colour. The data source is the databases of object features we have to create preliminarily. Among the object features we use as attributes, RaQueL computes area, perimeter, compactness, size parameters, orientation parameters (main axes) and a lot of other geometric features, which are mainly independent of the raster structure. The values are in general numbers (integers, floats) or Boolean expressions. Thus, the operators for comparing attributes with values are the mathematical ones (Fig. 3).

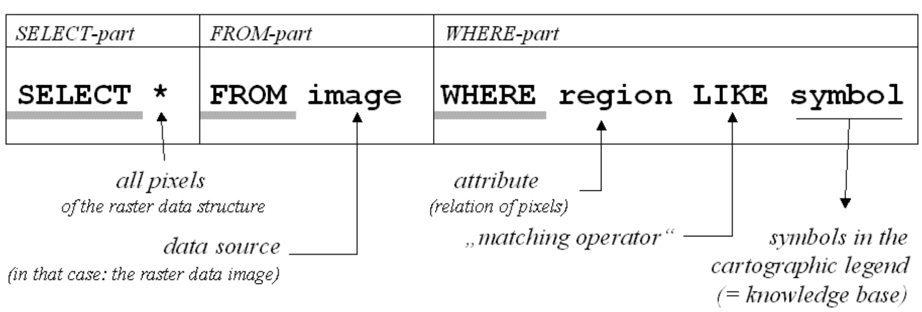

Fig. 4: The Usage of Queries in the Direct Method

In the direct querying methods we have no database derived from the image. The queried raster data structure is itself the value we count on. The attribute is then called "region" because raster data structures are given as certain regions of the image. Further, instead of exactly comparing mathematical operators we use different matching operators (Fig. 4). The choice of the matching operator indicates the fuzziness we hold on. Among the matching operators we have developed four operators with various degree of fuzziness, especially various reaches of sizes and orientations (Tab. 1).

Because raster-based image structures with the same (semantic) meaning are not exactly represented as the pattern of the legend, the matching operators must be few fuzzy. In cartographic documents there are a lot of signatures, which are placed in only one orientation or size, and others with different sizes and orientations. Among the signatures with different sizes and/or orientations, the orientation varies continuously but the sizes are merely staggered in few possible sizes.

Operator	***matching task***
LIKE	*pattern in only one size and only one orientation*
LIKE ROTATED	*pattern in only one size, but all possible orientations*
SIMILAR	*pattern in all possible sizes, but non rotated*
SIMILAR ROTATED	*pattern in all possible sizes and orientations*

Tab. 1: Operators of Direct Querying

The operator "LIKE" represents a matching operator where templates with the standard size and the standard orientation (0°) are used (Fig. 5). Queries formulated with "SIMILAR" implicate all possible sizes, and the addition "ROTATED" implicates querying in all possible orientations. Though the orientations can vary continuously, steps of 5° are introduced. Practical experiences with fuzzily defined templates have shown that orientations between the 5°-steps will be well detected due to the fuzzy working matching strategy.

5.3 Requirements for a Raster-Based Querying Tool

Due to the difficulties of raster data enhancement we have pointed out in Chap. 2, the matching strategy we intend to implement has to be modified. On the one side signatures in cartographic documents are rather similar, that means that deformations of geometrical and topologic features are small, on the other hand, matching strategies are often too exact. The principle of template matching is to compare pixel by pixel between template we take from the map's legend, and an image sample. Few pixels laying on the contour line of a raster-based object usually do not change the object's meaning but the same amount of mislaying pixels that are locally concentrated may change the object's meaning heavily.

Another difficulty is the fact that matching shown as comparing pixel by pixel is a rather time-consuming process. Due to all these three main disadvantages we have developed a new approach of matching and enclosed it in a hybrid matching system [*Graeff (2001)*].

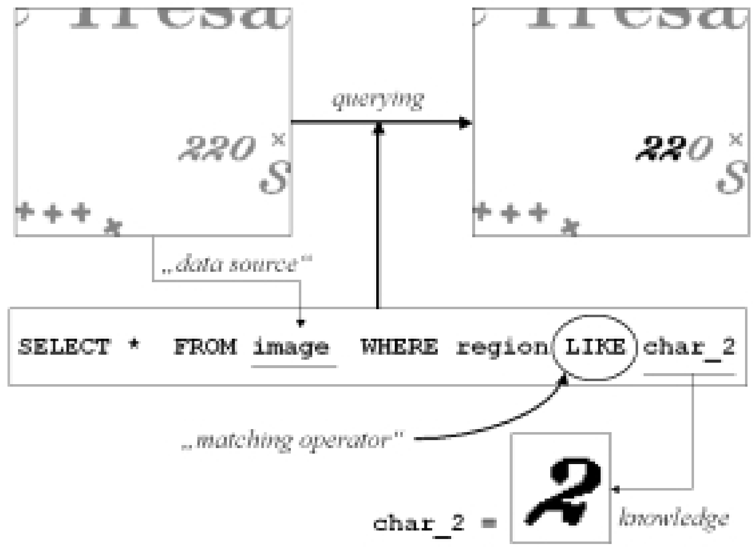

Fig. 5.: Querying of Well-known Patterns from a Raster-based Image.

Firstly a composition of structural points is checked (for to accelerate the first matching all over the image), then, after aborting most image samples a fuzzy template is matched with the remaining image regions: Separated in regions of different significance of both fore- and background accessory, the image samples is matched with respect to more and less essential structures of the template, especially with respect to the contour blurring. The third step of the hybrid matching strategy is a last check among similar alternatives. That is why the detection of some signatures succumbs to confusion with other signatures whose geometrical features are rather similar but whose meanings are different (Fig. 6).

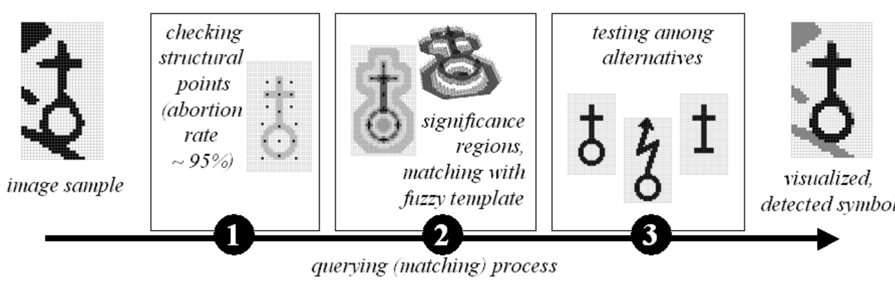

Fig. 6: Diagram of the Hybrid Querying (Matching) Method.

Only if exact positions are required (e.g. detecting and measuring benchmarks of the map) an exact parameter estimation concerning position and orientation parameters provides more exact coordinates of raster data structures. However, for the simple recognition task exact coordinates are not required.

6. CONCLUSION

In this paper several approaches for querying structured information from scanned topographic maps are presented. The first way how to query information from scanned map requires an object database generation. In this database features can be queried and the selected objects are then visualized. Thus, the image is represented by the database, and the querying method is the same we know from SQL concerning databases. The other approach of raster data querying is more direct: A highly modified matching strategy has been modified in order to drive it by queries.

The indirect method (querying via database) has been developed by *Frischknecht (1999)* and its results make it suitable for a user-friendly analyzing tool of cartographic maps. The only disadvantage is the segmentation of objects but the queries are executed as fast as in common databases. In the current Ph.D. thesis we are implementing the direct method of querying raster-based structures. The researches of *Stengele (1995)*, in which template matching strategies have been modified, and further additions by *Graeff (2001)* provide a tool of raster object querying with rather high speed and utmost high efficiency. The reduction of computing time in the matching process comes to less than 1%, and the reliability of the detection amounts to more than 98%. Thus, the legend's symbols of a whole Swiss topographic map (1:25,000), scanned by 20 lines/mm, whose size comes to 14,000 x 9,600 pixels, can be recognized in about one hour (depending on the amount of symbols), due to the modifications in the matching strategy. The use of query languages, the rather high recognition rates, and the highly reduced matching time make the proposed hybrid method of directly querying suitable for a wide range of applications in the automatic map interpretation.

REFERENCES

Burrough, P.A. and R.A. McDonnell (1998) : Principles of Geographical Information Systems. Oxford University Press.

Brügelmann, R. (1998) : Analyse gescannter Karten. In: *Bähr, H.-P. und T. Vögtle (Hrsg.) (1998) : Digitale Bildverarbeitung. Anwendungen in Photogrammetrie, Kartographie und Fernerkundung. Heidelberg, Wichmann, 3. Auflage*, S. 69-107 (ebd. Kap. 5.1).

Chhabra, A.K. (1997) : Graphic Symbol Recognition: An Overview. In: *LNCS 1389, Berlin, Springer*, pp. 68-79.

Costagliola, G.; G. Tortora; and M. Tucci (1995) : GISQL – A Query Language Interpreter for Geographical Information Systems. In: *Spaccapietra, S. and R. Jain (eds.) (1995) : Visual Database Systems 3, Chapman&Hall*, pp. 275-286.

Frischknecht, S. and E. Kanani (1997) : Automatic Interpretation of Scanned Topographic Maps: A Raster-Based Approach. In: *LNCS 1389, Berlin, Springer*, pp. 207-220.

Frischknecht, S.; E. Kanani; and A. Carosio (1998) : A Raster Based Approach for the Automatic Interpretation of Topographic Maps. *ISPRS Commission III Symposium, ISPRS Vol. 32, Part 3/1, Object Recognition and Scene Classification from Multispectral and Multisensor Pixels, Columbos/Ohio, 6.-10.7.1998.*

Frischknecht, S. (1999) : Eine Abfragesprache für die Geometrie von Rasterelementen für die rasterorientierte Kartographische Mustererkennung und Datenanalyse. *Mitteilungen Nr. 69 des IGP an der ETH Zürich.*

Göpfert, W. (1991) : Raumbezogene Informationssysteme. Karlsruhe, Wichmann.

Graeff, B. (2001) : Querying Raster Data Structures – Probabilistic and Non-probabilistic Approaches On Knowledge Based Template Matching Methods. In: *Proc. IAG, Budapest.*

Haberäcker, P. (1995) : Praxis der Digitalen Bildverarbeitung und Mustererkennung. München, Hanser.

Hake, G. und D. Grünreich (1994) : Kartographie. Berlin, New York, De Gruyter, 1994.

Lin, H. and B. Huang (1999) : Vector-Raster Interoperation: A Spatial Query Language Approach. In: *Geomatica Vol. 53, no. 3*, pp. 307-316.

Mayer, H. (1996) : Using Real World Knowledge for the Automatic Acquisition of GIS Objects from Scanned Maps. In: *GIS 2/1996*, pp. 14-20.

Pierrot Deseiligny, M.; R. Mariani; J. Labiche; and R. Mullot (1997) : Topographic Maps Automatic Interpretation : Some Proposed Strategies. In: *LNCS 1389, Berlin, Springer*, pp. 175-193.

Samet, P.A. (1981) : Query Languages. An Unified Approach. British Computer Society Monographs in Informatics.

Samet, H. and A. Soffer (1994) : A Legend-Driven Geographic Symbol Recognition System. In: *Proceedings IAPR Pattern Recognition and Neural Networks, Vol. II, Jerusalem*, pp. 350-355.

Stengele, R.E. (1993) : Kartographische Mustererkennung durch Template Matching. *Bericht Nr. 230 des Instituts für Geodäsie und Photogrammetrie an der Eidgenössischen Technischen Hochschule Zürich.*

Stengele, R.E. (1995) : Kartographische Mustererkennung. Rasterorientierte Verfahren zur Erfassung von Geo-Informationen. *Mitteilungen Nr. 54 des IGP an der ETH Zürich.*

Wang, F. (1994) : Towards a Natural Language User Interface: An Approach of Fuzzy Query. In: *International Journal of Geographical Information Systems, Vol. 8, No. 2,* pp. 143-162.

Widmann, N. and P. Baumann (1998) : Towards Comprehensive Database Support for GeoScientific Raster Data. In: *Proceedings of the ACM-GIS 97, Las Vegas, Nevada, USA, November 1997.*

Zadeh, L.A. (1965) : Fuzzy Sets. In: *Information and Control 8*, pp. 338-353.