Forming and Utilizing Communication between Two Spatial Representations at Different Scales – A Demonstration

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Abstract

The research development of interoperability of Geographic Information Systems (GIS) enhances the potential of cooperation between existing representations of spatial information. Many representations are separately developed for technical or substantial reasons. Each representation is typically based on a different semantic model and a geographic model, and the information detailed in it reflects the real world by a population of similar, yet non-identical, objects. In the frame of the multiple-representation domain, principles and methods are developed for the purpose of forming communication and sharing information between separate representations of spatial information. The current research practically demonstrates setting up a system that includes two representations in vector format of planimetric information at different scales. The original representation data was translated into a

common language by converting it into one GIS environment. A model that depicts the connection between semantic and geometric models of the representations was constructed, and finally the connection between the objects contained in them was individually defined. This communication then allows simultaneous bi-directional work with the information contained in them. It is possible to select objects of one representation, while matching objects in the second representation are immediately selected. This potential allows performing the mutual analyses between the representations: objects selected in one representation constitute a basis for spatial queries, in which the results in the second representation are produced. In this way the user can benefit from the advantages involved in each of the representations: easy orientation of the contained information regarding the extensive area in the small scale, as well as obtaining the detailed and accurate information which is maintained in the large scale. In the frame of the research, an operation of manual matching between objects of different representations was applied, including handling of partial matching relations, without which the functionality of communication between the representations would be limited and would not render the satisfactory results. This potential enables to operate in the right manner, even when the spatial reality in the real world was defined as objects of different geometric slicing in any of the representations.

1. Introduction

A section of the real world is usually represented in a number of separate digital representations, which are different from one another. The representations may differ in their scale, their central theme of the information, their time and their method of formation. The domain of multiple representations focuses on the principles of simultaneous use of a number of spatial representations of the same area, in order to produce most efficiently the information contained in all the representations together.

Multi-scales is a sub-domain of multiple representations, which are focusing on representations of a given area, when each of them reflects the information in a different scale. Scale is an alternative concept in the digital world to resolution and accuracy level of spatial information [17]. The smaller the scale is, the more can be observed, analyzed and it is possible to simultaneously manage a more extensive area in a screen or printed page type “window”. The larger the scale is, the smaller is the area that can be observed in the “window”, which impairs the perception of the context between the information observed to its environment. On the other hand, the detailed and accurate level of the information in the large scale is higher than in the small scale. The properties aforementioned, justify the need for integrated work with multiple-scale information: comprehensive overview and managing in a smaller scale, in conjunction with details and accuracy in the larger scale.

This paper presents a system that includes two connected representations that enable efficient operations, such as simultaneous selection and query. The user can select an object or objects of one scale, and the object, or objects are immediately selected in the other. Similarly, the user can perform a spatial query, which is based on objects that appear in one scale, and the query is processed on the other, and the requested results are produced from the information in that scale.

The presented system does not purport to be comprehensive in its essence. The research approach was to manually produce a bi-representation spatial information system in a given area, implement mutual analysis functions of the data sets, and gain knowledge regarding the efficiency produced by it and the aspects and problems that have to be addressed in building a more extensive system.

In section 2, background is offered regarding the research development in the multiple-representation domain in the last decade. Furthermore, a preliminary review is presented of the aspects of semantic matching and geometric matching between separate representations, which were studied in the researches conducted up to now. The process of designing and building a bi-representation system is described in section 3: the research data, converging the separate representations into a common language, building a matching model between them and forming a detailed connection between the objects contained in them. Section 4 demonstrates the application of the developed system: simultaneous selection and investigation of the information in the two connected representations. This section also presents the limitation, which derives from addressing the matching between whole objects only, and the adequate solution offered in this research, by developing a mechanism that also addresses partial matching between objects. The discussion performed in section 5 deals with principal topics, which were studied in the course of developing the system presented in the research and the results obtained by its implementations. Section 6 presents a short summary of the current research innovations and introduces the topics, which have to be further studied, so as to enable future non-restrictive multiple-representation system applications.

2. Background

Multiple representation of spatial geographic information is a well-known approach from the time when most of the information was supplied in the form of printed-paper maps. It was always necessary to use information regarding the same area at different levels of scale, theme or at different times. The digital era opens the opportunity for new options of realizing the need in the multiple representations of the geographic information, in an efficient and powerful manner. Many examples exist of multiple representations of geographic information in the internet sites (e.g., [14], [15], [18]), which allows to skip between various scales and different themes. However, the multiple representations of the geographic information is still under development [11], and the application of the geographic information systems is currently manifested in change of display during change of scale, yet not in the real connection between the objects in the separate representations.

Multiple representations were explicitly defined in research initiatives at the end of the 80’s [2], [3]. In this frame, emphasis was especially placed on a system that contains a group of representations, when each is formed by a generalization process of the previous one. Forming the representations begins with a basic representation at a large scale which was produced in detailed mapping operations. The advantage of this approach lies in the fact that matching between objects in the “successive” representations is recorded in the system during the course of the generalization process, since the objects of a certain scale are formed as a result of a defined transformation of the objects in representation of a larger scale.

During the 90’s the study of multiple-representation topic was extended in different directions. The need arose for forming connection between separate representations through detailed matching procedures between objects [23], [24], [6], [7], [8], [9], [25], [28]. The progress of the study, regarding the topic of topological relations between matching objects in various representations [5], [4], opened the road for developing automatic matching processes for multiple-representation systems [12], [13], [20]. These approaches mainly concentrate on the geometry of the objects – assuming that the objects are matching semantically.

Another study associated with the multiple representations is the development of uniform standards for transferring spatial information between various environments (e.g., [26]). These standards allow adapting various representations to an environment of common data structure. In this situation, it is easier to design and construct a multiple-representation system and perform detailed matching processes between the objects. In recent years another important step forward has been conducted in this direction in the frame of initiatives of formulating a uniform set of rules for defining objects, properties and actions for spatial geographic information [21], [10]. Designing various work environments with internal application of the uniform set of rules, will enable interoperability in the world of spatial geographic information. Databases and applications will be able to share data sets, a property that will transform them to an ideal environment for developing multiple-representation systems. In this case, there is no need to adapt representations to one environment. It will be possible to set up systems in the global network that will contain the information regarding the connection between the various and separate GISs, and each such GIS will function as representation in a global multiple-representation system. However, in order for the research to materialize the aforementioned vision, the basic problems, which have to be handled in order to set up a simple multiple-representation system, must first be solved.

In order to gain the full potential of the multiple-representation system, which is presented in the vector format, the connection between the matching entities in each of the representations should be documented in it. For the purpose of defining this detailed connection, the connection between the models, on which the representations are based, have to be formulated. The model of each representation principally describes the two components of the information: Semantics and geometry. Therefore, it is first essential to define matching between the semantic description and the geometric description of the information in the two representations.

Matching between semantic models of two representations requires common analysis of the models for the purpose of identifying the matching objects [19], [22], [12]. The relations between object types may be in any one of the levels: *1:0*, *1:1*, *1:n*, *1:m*, or *n:m* (***n*** is the types of features in the small scale and ***m*** in the large scale). There is no one set of rule that will produce total semantic matching between any pair of models. Any two representations must specifically undergo the process due to the uniqueness of each matching between two models. However, a directive process, which, on the one hand, is assisted by a predetermined set of rules and, on the other hand, relies on human decisions regarding matching between the object types in the representations, will significantly shorten the matching operation of the semantic models of the two representations [22].

The more dissimilar the scale of the two representations is, the more cases of semantic matching of the *1:0*, *1:m*, *1:n* or *n:m* type will occur. For example, ***n*** object types that describe a road in small scale: polyline object of a road center line type, polyline object of road shoulder type, may correspond to ***m*** types of objects in the large scale: polygon object of a road lane type, polygon object of a traffic island type, polygon object of a sidewalk type.

Matching between geometric models of two representations should cover various aspects. Following are a number of the important ones:

1) Maintaining matching states between spatial objects types: point - point, point - line, point - polygon, line - line, line – polygon, polygon – polygon.

2) Matching can be at different levels of mutuality:

   - Complete matching: the object in the two representations is at a fully matching state.
   - Partial matching: The object in one representation is contained / contains / partially coincides with the object in the second representation.

3) Similar to semantic matching, there can also exist geometric matching between a combination of objects of different amounts in any one of the representations, in the following relations: *1:0*, *1:1*, *1:n*, *1:m* or *n:m*.

The matching processes between objects in the various spatial representations are “processing abundant”. Throughout the years various approaches to automation of these processes have been presented, the purpose of which was to shorten the performance time and the degree of human intervention. Good matching between the models of the representation renders the matching processes efficient. There are a number of different approaches of performance: Matching between whole objects only [23], matching between a combination of whole object groups [28] and also matching that enables to explicitly define partial matching between objects of different representations [6], [9].

The matching processes between the representations, similarly to the generalization processes of representations, are still at the stage of research and development, and have not reached a state of automatic comprehensive implementation. Therefore, the matching processes constitute a bottleneck in setting up the multiple-representation systems of vector spatial information. There is a link between the development in the spatial generalization domain – forming new representation out of the existing one, to development of solutions of matching processes – forming connection between two existing representations. For logical reasons, most effort is invested in advancing the research and development in the spatial generalization domain [16], following which, progress was also made in the research and development of the matching processes between the representations. The more advanced the automation of the matching processes is, the easier it will be to set up multi-scale GISs, or form connections between separate GISs, which store spatial information of a different scale.

3. Designing and constructing the bi-representation system

This section describes the main stages in setting up a bi-representation system in the current research. At first, the research data will be presented, with the formation of one system in which the two representations are separately defined, yet in a uniform data structure. Next, will be described the semantic matching model and the geometric matching model between the representations, that constitute a basis of communication between the representations. Finally, this section describes the process of forming the detailed connection between the objects in the two representations, based on manual matching, whose results are documented in the system.

3.1 The research data

The test area, demonstrated in figure 1, includes a part of the village Vimbuch and its adjacent neighborhood in the south-western part of Germany. The data were retrieved from the two national geographic databases of Germany: one representation was retrieved from ATKIS database (hereafter: "Small Scale Representation"), and the other from ALK database (hereafter: "Large Scale Representation"). Semantically, the objects in each representation were divided into few categories, which only roughly correspond to ATKIS and ALK original categories.

The small scale representation data were collected mainly from cartographic sources of a scale of approx. 1:25,000. The database describes general planimetric information. In the data sample, which was retrieved for the purpose of the research, spatial entities, composed of polylines and polygons, were included. Semantically, the objects were divided into three categories:

> Transportation – roads, paths and bridges (130 objects represented as polylines).
>
> Water – ditches and streams (5 objects represented as polylines).
>
> Land areas – classified according to use (97 objects represented as polygons).

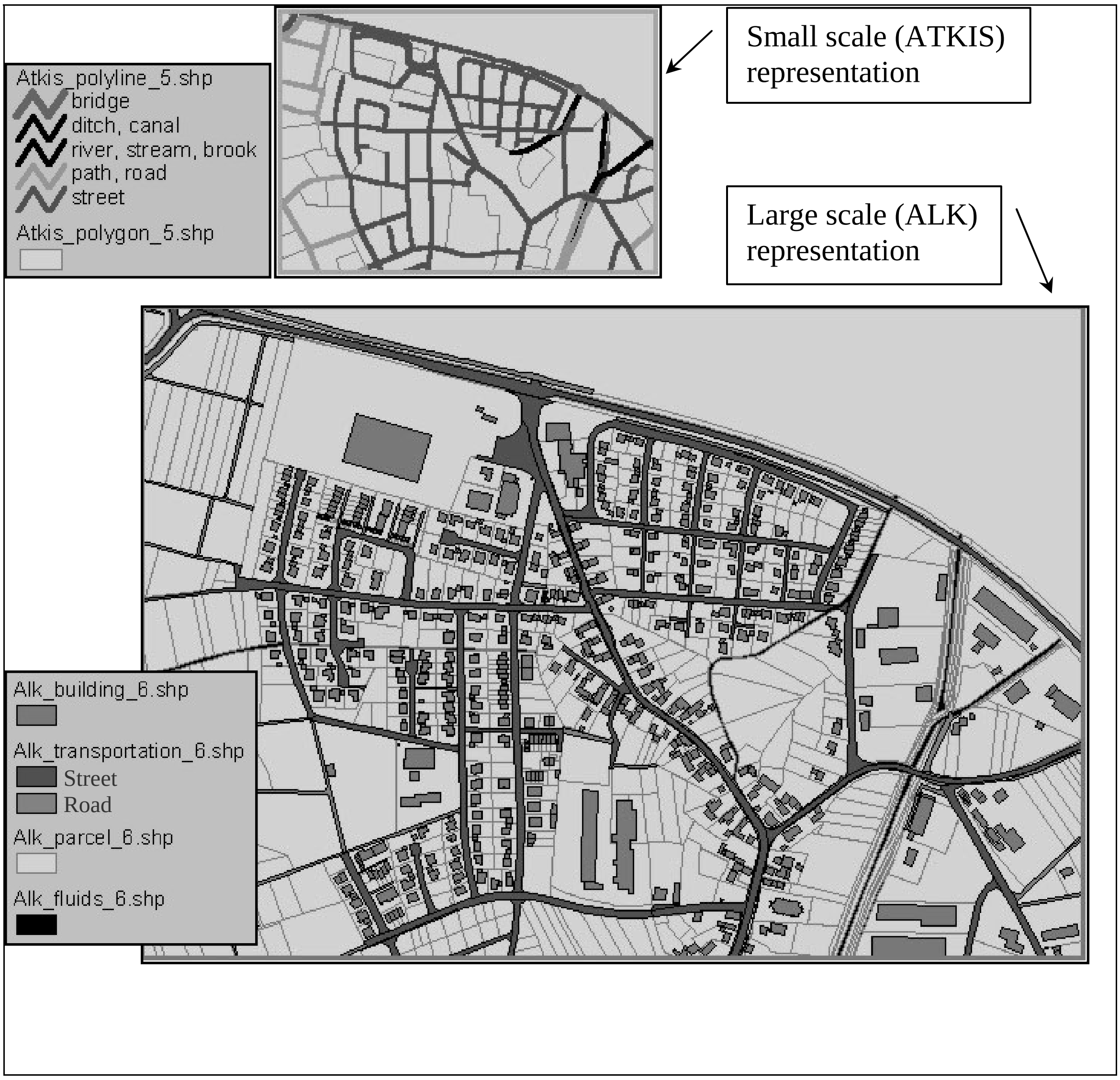


Figure 1: The research data: overview of the two representations and their legends.

The large scale representation data were collected from cartographic sources of scales from 1:500 to 1:2,500. The database describes general planimetric information on cadastral background. In the data sample, retrieved for the purpose of the research, spatial entities of polygon type only, were included. Semantically the objects were divided into four categories:

- Transportation – roads, paths, sidewalks, etc. (92 objects).
- Water – ditches and streams (12 objects).
- Land parcels – classified according to use (721 objects).
- buildings – classified according to use (825 objects).

3.2 Joining the separate representations into one system

The data that were converted from the original format in which they were saved in the databases ATKIS and ALK into the Shape format of the ArcView application (ESRI), in which the research was materialized. During conversion the semantic and geometric properties of the objects in any one of the representations were maximally maintained. In this state each of the two representations were defined as a “view” in a bi-representation system. Each semantic category in the original database turned into a “layer” in the view of the appropriate representation. The fact that the representation data were transformed into a joint geometric format, allowed a logic connection between the data in the next stage.

In order to examine the semantic and geometric relation between the representations, they had to be defined in one joint view, by overlaying the data, which was possible, as they are acquired in one common reference system. In this situation, all the information appears in an identical scale, it is possible to focus on an object or a number of objects from one representation and visually inspect the specified relation with the object or objects that are adjacent in the other representation. This fact assists in constructing a model (scheme), which matches between the semantic and the geometric models of the representations.

3.3 Constructing the matching model between the representations

The first stage in forming the connection between the representations is by determining the degree of matching between their semantic models.

It was discovered that determining the compatibility in the category level is sufficient, thus there is no need to define the compatibility in the sub-category or the single object level. Accordingly, for each category in one representation a matching category or categories was determined in the second, as demonstrated in figure 2.

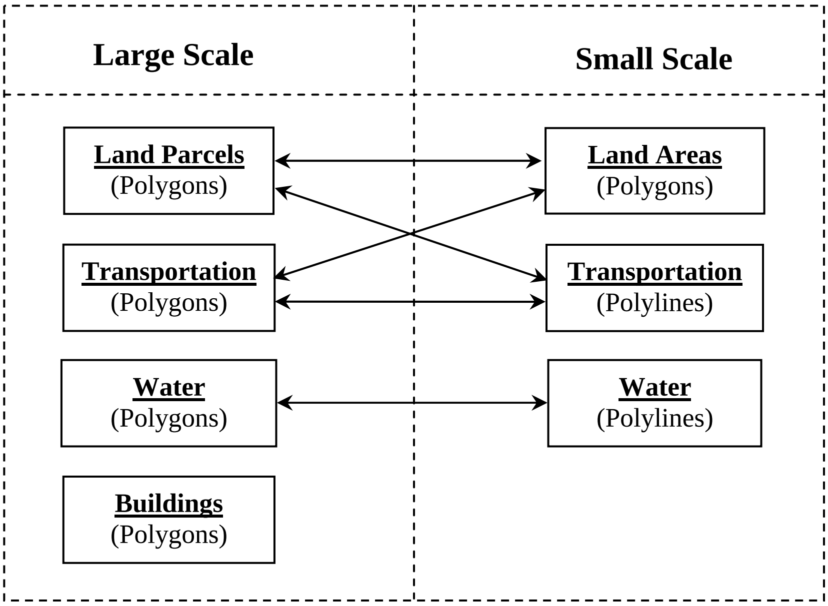


Figure 2: Semantic matching between categories of objects.

The categories of {land areas/land parcels} and {transportation} maintain a relation of *2:2*. The category of water in the two representations maintains a mutual relation of *1:1*. The category of large scale buildings does not directly correspond with any smaller scale category; however, connection may be performed via another category of a large scale category, i.e., any building that is located on a large scale land parcel is connected to the small scale land area. The semantic matching schema, above demonstrated, was chosen according to the objectives of the system as defined in the present research. There is no one matching schema that is correct: If the system objectives change, the matching schema may also have to be changed, so that it may efficiently serve the new objectives.

The second stage in forming the connection between the representations was by determining the matching between their geometric models. According to the specified in the previous section, it was necessary to relate to three main factors:

(a) *The types of the matching objects*. In the system that was experimented in this research, only two states of matching between the object types existed –

(1) matching between a polyline object to a polygonal object; and

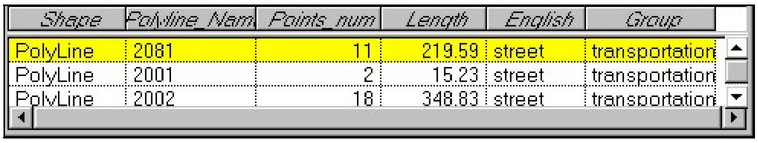
(2) matching between two polygonal objects.

(b) *Manifestation of matching between objects as a whole, or also in states of partial matching*. In the first part of the research (detailed description of the two stages of the research will follow) one form of geometric matching between the objects was defined – matching a whole object to a whole object (even if matching in practice was partial); yet at the second part of the research, another matching form was defined – explicit partial matching between objects.

(c) *The quantitative relation between matching objects in each representation*. The quantitative relations between objects in geometric matching relations in the two representations are: *1:0, 1:1, 1:m, 1:n, n:m* (***n*** of small scale and ***m*** of large scale).

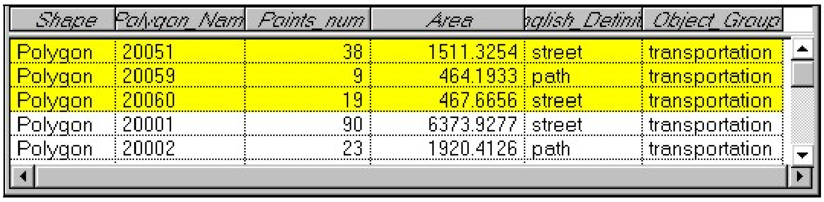
3.4 Forming a detailed connection between the objects in the two representations

The detailed connection between the objects was manually defined by means of a joint view in which the two representations were graphically presented together (see example in figure 4). The operator manually selects one object in a small scale representation and its matching objects in the large scale. The selection is done while maintaining the rules of the semantic and geometric matching model between the representations. At this stage the operator implements a software function that is activated by a button in the user interface of the bi-representation system. The function registers into the connection table one record (relation *1:1*) or a number of records (relation *1:m*). There are two fields in each record: The object identification (ID) in the large scale and the ID of the matching object in the small scale. Relations of the type of *1:n*, or *n:m* are indirectly documented in the table, when the small scale object matching is performed separately ***n*** times with ***1*** or ***m*** objects of the large scale. An example of the connection table structure is depicted in figure Figure 3.



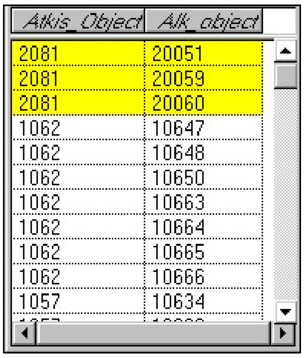
Shape	Polyline_Nam	Points_num	Length	English	Group
PolyLine	2081	11	219.59	street	transportation
PolyLine	2001	2	15.23	street	transportation
PolyLine	2002	18	348.83	street	transportation

(A) Part of the attribute table of the small scale representation



Shape	Polygon_Nam	Points_num	Area	nglish_Defini	Object_Group
Polygon	20051	38	1511.3254	street	transportation
Polygon	20059	9	464.1933	path	transportation
Polygon	20060	19	467.6656	street	transportation
Polygon	20001	90	6373.9277	street	transportation
Polygon	20002	23	1920.4126	path	transportation

(B) Part of the attribute table of the large scale representation



Atkis_Object	Alk_object
2081	20051
2081	20059
2081	20060
1062	10647
1062	10648
1062	10650
1062	10663
1062	10664
1062	10665
1062	10666
1057	10634

(C) The corresponding part of the connection table

Figure 3: The highlighted rows in tables (A) and (B) corresponds to the matching objects, depicted in figure 8a. The matching situation is registered in the connection table (C), using the IDs ("names") of the objects.

The small scale representation consists of 232 objects. The large scale representation consists of 1615 objects, of which 825 pertain to the three categories that were joined with the information in the large scale representation (i.e., not buildings). At the end of the process of forming the detailed connection between the objects, the connection table included 917 records. 107 objects of the small scale at a matching state "to many" objects (2 or more) of the large scale representation. 37 objects of the large scale are at a matching state "to many" objects of the small scale representation.

In the first stage of the research, from the mutual geometric matching level aspect, matching was defined in whole between every two corresponding objects; i.e., even if the two objects corresponded partially, yet explicitly, it was not indicated in the connection mechanism, which is based on the table above demonstrated. For example, in the large scale, the main street in the village is described by one long polygon approximately extending in the north to south direction, however, the same street is represented in the small scale by nine successive polyline objects (see figure 3). In this case, nine records appear on the connection table, and the spatial information that specifies which part of the single polygon is covered by any one of the polylines, is not documented. This connection method has advantages, such as simplicity and promptness of reaction, and disadvantages manifested in incomplete demonstration of the relation between objects in the representations. These drawbacks led to the development of another connection method in the second stage of the research.

Figure 4: The main street in the village: one large scale polygon corresponding to nine successive polyline objects in a small scale.

The case presented in the above example, shows that there are cases in which the small scale, the more generalized, require more objects to represent one spatial entity (a street) of large scale. This phenomenon is caused due to the fact that the street network is presented in small scale by polyline objects that are topologically organized as a planar graph. That is, in any transportation junction where two or more street polylines meet, a topologic node is defined, that constitutes an end point to all the polylines. On the other hand, a street network is represented in the large scale as strings of polygons touching each other, but sampled with a weak relation to their functioning as a transportation network. Therefore, transportation junctions are not expressed, in many cases, as topological nodes, and thus a long polygon, which is "uninterrupted" by transportation junctions, can be produced. The cause of this phenomenon is that these matching objects were sampled under a system of different considerations in small scale and in large scale.

The state of matching the objects in the categories of land areas and parcels is opposite of the state described regarding matching objects in the transportation categories in the two representations. Here, in most cases, one land area of small scale corresponds to a small or large number of land parcels of large scale (example in figure 4). Most of the connection table describes the matching relations between objects that pertain to the categories of land areas and parcels. In a great number of cases, there was only partial matching between the objects.

In figure 4 a joint view of the two representations, depicts the relation between one land area of small scale (marked in light color) covering a group of land parcels of large scale. 10 parcels are fully included in the land area (complete matching on their part), 5 parcels which intersect the land area are identified as partially matching with the land area. By means of cartographic considerations, out of the partial matchings, four parcels were marked as matching, while the one at the top-right corner of the group was not marked as such. Therefore, in this example a total of 14 new records were added to the connection table.

Figure 5: A joint view of the two representations: one land area object of the small scale representation covers a number of parcel objects of the large scale representation.

In the connection table between the matching objects of the two representations afore described, the information about the connection between the representations is stored, however, it is not suitable to the current operation of applications. A user who wishes to select objects or perform a simultaneous spatial analysis of objects in the two representations, expects a prompt reaction from the system. Simple access to the connection table, as afore described, in real time, and search in one representation for matching counterparts in the second representation will be very time consuming, since it requires reviewing all the records for the answer. In order to expedite obtaining the answer of object matching between the representations in real time, a different data structure, which documents matching between the objects, was defined in the main memory. When the bi-representation system is reset, a one-time pass is performed on the permanent connection table. During this pass, the data structure in the main memory generates a group of direct pointers to the matching objects in the second representation, for each object in every representation. This mechanism allows real time speedy reaction of simultaneous operations with matching objects of the two representations in the system. Future research should be conducted to suggest advanced and efficient methods to store and apply the matching relations defined between objects in different spatial representations.

4. Using the bi-representation system

In the previous sections, setting up the system, which includes two representations of spatial information in a given area was described, when the matching objects are mutually connected. In the bi-representation system, four new operations were defined, when each is realized through a software function and implemented through the user interface. Following are their descriptions:

1. The user selects one or more objects, in the small scale representation. The appropriate function implementation produces the selection of the matching objects in the large scale, while zooming in the relevant area in this representation.

   Figure 5, demonstrates the object selection of a road type, and produces the matching object selection in the large scale (*1:1* relation). In figure 6 the object selection of a land area type produces the selection of a matching parcel group in the large scale (*1:m* relation).

Figure 6: Simultaneous selection of road type object in the two representations.

Figure 7: Object selection of a land area type in the small scale produces the selection of a matching parcel group in the large scale.

2. The user selects one or more objects in the small scale representation. Implementing the appropriate function opens a window, which allows it to define the spatial query regarding objects of the large scale representation, which maintain a desirable spatial relation with the objects that were selected in the small scale. The query is performed in

four stages: (a) the user selects one or more objects of the small scale, (b) in this scale, a desirable spatial relation is defined for objects of the large scale, (c) the objects matching to the selection in stage ***a*** are selected in the large scale, (d) in this scale, the objects that maintain the desired spatial relation with the objects that were chosen in stage ***c*** are selected. All types of spatial relations that are provided by the underlying system (ArcView) are fully exploited here.

Examples of queries that can be performed in this operation:

- Find the parcels in the large scale that are touching the road or path selected in the small scale (see figure 11 in section 4.1).
- Find the buildings in the large scale that appear at a distance that does not exceed 50 m from the road or path selected in the small scale (see figure 12 in section 4.1).
- Find the roads or paths in the large scale, which are adjacent to the land area that was selected in the small scale.
- Find the buildings in the large scale whose centers are in the land area selected in the small scale.

The following two operations are identical in the essence to operations (1), (2). However, they operate in the opposite way: the user selects objects of large scale representation, and obtains the result in the small scale representation.

3. The user selects one or more objects in the large scale representation. Implementing the appropriate function produces the selection of the matching objects in the small scale, while focusing on the relevant area in this representation.

   In figure 7, the parcel type object selection produces the selection of the matching land area object. The land area that was selected in the small scale is the one that contains the parcel in the large scale at which the user pointed.

Figure 7 The land area that was selected in the small scale is the one that contains the parcel in the large scale at which the user pointed.

4. The user selects one or more objects of large scale representation. Implementing the appropriate functions opens a window which enables him to define a spatial query regarding objects in the small scale representation, which maintain a desired spatial relation with the selected objects in the large scale representation (see sub-stages in operation 2 above).

   Examples of queries that can be performed in this operation:

- Find the roads or paths in the small scale that are adjacent to the land area which contains the land parcel that was selected in the large scale.

- Find the land areas in the small scale in which at least part of their area resides in a distance less than 100 m from a stream or ditch that were selected in the large scale.

- Find the land areas in the small scale adjacent to a road or path that was selected in the large scale.

Out of the four operations, afore described, it was discovered that the first two are more useful. By selecting or performing a query, the operation direction from the small scale to the large scale is the more efficient and needed in the bi-representation system. This direction expresses the advantage of easy orientation in an extensive area of a small scale, thus enabling quick zooming in on a certain target area, and obtain detailed and accurate results regarding this area in the large scale. The third and fourth operations, where the direction is from the large scale to the small scale, are less required during work with the system. The third operation mainly offers an answer to the query “where is a small information item of the large scale in relation to the extensive and generalized information of the small scale?” The fourth operation is found less applicable than the others, since the results obtained in the small scale regarding the queries asked in the large scale, supply poorer information than that obtained for the same query in the large scale itself. However, sometimes it is efficient, as the above examples have demonstrated.

The main disadvantage of the system functioning whose development in the research has so far been demonstrated, is lack of consideration for partial matching between objects in the two representations. In most cases, even when the geometric matching was small, the objects were marked as matching, without any explicit indication regarding the state of the partial matching. For this reason, in many cases, insufficient results were obtained for the mutual query and selection operations between the representations. Consequently, selecting an object in one scale may lead to selection of objects in the second scale, which actually match the original object, yet their coverage area may be significantly different from its coverage area. The results of the query pertaining to this object will be erroneous, as they will also include reference to parts of objects, which are not matching with the original object. Examples of such states can be seen in figures *8a* and *9a*. In these states, it is preferable for the user to receive results of higher geometric matching between the representation, as demonstrated in figures *8b* and *9b*.

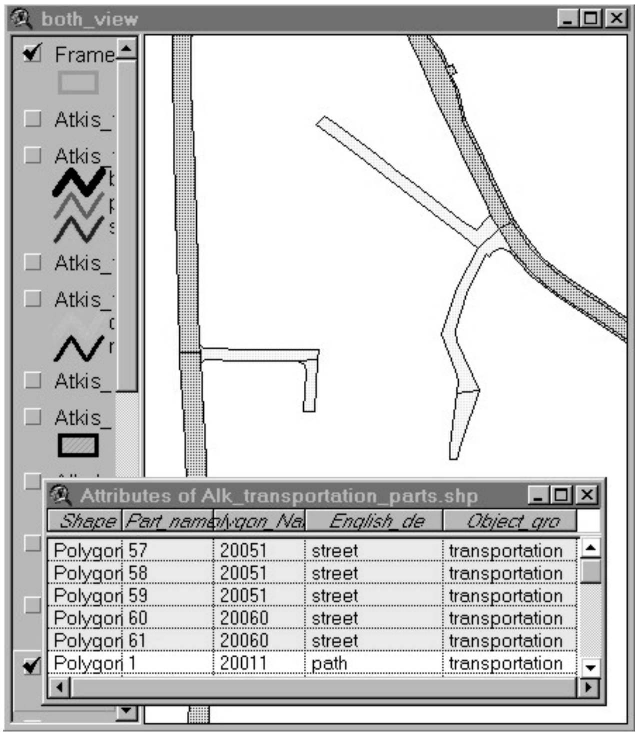
4.1 Design and application of a bi-representation system that includes consideration of partial matching between objects

In order to overcome the drawbacks of the bi-representation system, which was developed in the first stage of the research, the capability of the system to cope with partial matching between objects was extended. For that purpose, states of partial geometric matching, both in their existence, as well as the geometric description of the matching state, were explicitly defined in the system.

For practical considerations, the principles developed in the second stage were demonstrated only in the direction of operation from small to large scale; i.e., when a selection of objects is performed in small scale, matching objects and object parts of large scale are selected, so that a very similar spatial coverage of objects in the two representations, is obtained.

Realizing the reference to the object parts in the data structure of the system was performed in a number of stages. As before, matching was defined while visually inspecting the spatial information of the two representations in one joint view. However, now that it was identified in the large scale, an object that maintains partial matching with an object or objects of small scale, is copied to a separate layer, in which only the object parts were defined. In a manual editing operation the object was divided into a number of separate parts, according to its matching state. The division of an existing object was performed by ***split operations*** on the graphical representation of the object in the joint view. The ***split lines*** were defined by the operator, considering the geometric relation of the edited object with the corresponding small scale object (using the View/Edit tools of ArcView). In practice, a layer of *object parts*, for each layer that exists in the large scale, was generated. An example of a small section of the transportation object parts layer is depicted in figure 102. Objects that are shown in figure *8a* in their original shape were decomposed to parts which function as independent objects. A field in the attribute table of the object parts layer store the information about the ID of the original object. Only the relevant object parts were used to produce the result shown in figure *8b*.

As indicated in section 3.1, the objects of the large scale are of the polygon type only, while in the small scale, part of the objects are of polyline type and others of the polygon type. Since the object partition was performed in the large scale only, it was always manifested by dividing one polygon into smaller polygons.



Shape	Part_name	olygon_Na	English_de	Object_gro
Polygon	57	20051	street	transportation
Polygon	58	20051	street	transportation
Polygon	59	20051	street	transportation
Polygon	60	20060	street	transportation
Polygon	61	20060	street	transportation
Polygon	1	20011	path	transportation

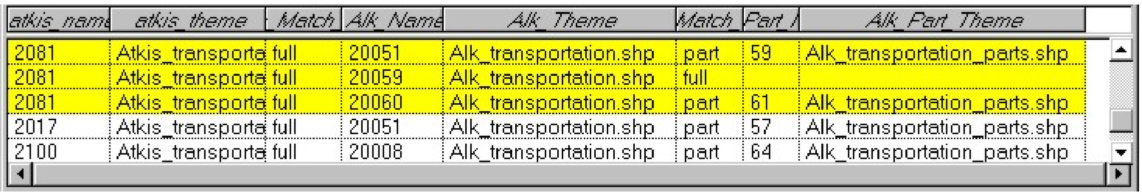
Figure 8: Section of the transportation object parts layer and the corresponding section of its attribute table. Only two of the object parts, which appear in light color at the graphic view and dark color in the table, participate in the selection operation depicted in figure *8b*.

The connection table, in which the matching relations between the two representations are recorded, differs from the table served for that purpose in the first stage of the research (part C of figure 101), and each record consists of 10 fields, so that 5 fields depict the matching state in any of the scales:

1. The object ID, unique in the layer;
2. The name of the layer in which the object is defined;
3. The matching state of the object: *complete* (full) or *partial*;

4. The object part ID, unique in the layer of the object parts;
5. Name of the layer in which the object part is defined.

Fields (4) and (5) are filled if field (3) shows that matching is defined regarding only part of the object. An example of the connection table is shown in figure 103. Fields (4) and (5) do not exist for the small scale because the partial matching mechanism was applied only in the direction of operation from small to large scale in the current research.



atkis_name	atkis_theme	Match	Alk_Name	Alk_Theme	Match	Part_I	Alk_Part_Theme
2081	Atkis_transporta	full	20051	Alk_transportation.shp	part	59	Alk_transportation_parts.shp
2081	Atkis_transporta	full	20059	Alk_transportation.shp	full		
2081	Atkis_transporta	full	20060	Alk_transportation.shp	part	61	Alk_transportation_parts.shp
2017	Atkis_transporta	full	20051	Alk_transportation.shp	part	57	Alk_transportation_parts.shp
2100	Atkis_transporta	full	20008	Alk_transportation.shp	part	64	Alk_transportation_parts.shp

Figure 9: A section of the connection table that consider partial matching between objects in the small scale representation (three left fields) and the large scale representation (five right fields). The highlighted rows register the matching depicted in figure *8b*.

In the second stage a simultaneous selection or a simultaneous query of the two representations can also be performed by means of the four operations depicted in the first stage. Nevertheless, when the direction of operation is from small to large scale, the system relates to states of partial matching in an appropriate way; i.e., when selecting an object or objects of the small scale, which partially correspond to objects of large scale, only object parts of that scale will be selected in practice, and not the objects as a whole.

When selecting an object or a group of objects in the small scale, an indirect process of selecting the matching information in the large scale is performed. A temporary layer is defined in the bi-representation system, into which the matching features of the large scale are collected. The data gathering for one simultaneous selection is performed according to the process in algorithm 1. Identification of corresponding objects in the algorithm is based on the data stored in the afore described connection table.

The object gathering that was accumulated in the temporary layer facilitates the performance of operations parallel to those described in the first stage of the research: (1) simultaneous selection from small to large scale, (2) simultaneous query from small to large scale. Results of high level of correctness are obtained for these operations, since the geometric matching between the selected information in the two representations is significantly higher than that obtained in the first stage of the research.

Figures *8b* and *9b* demonstrate how reference to partial matching between objects produces more correct and efficient results than those obtained in figures *8a* and *9a*, in which no such reference exists. Selecting two object parts and one whole object, as in figure *8b*, instead of the whole three objects, as selected in figure *8a*, demonstrates a more correct geometric polygonal representation in the large scale of a polyline type feature that was selected in the small scale. Selecting the three object parts, in figure *9b*, rather than three whole objects, as selected in figure *9a*, demonstrates a more correct geometric representation in the large scale of a polygon type feature, which was selected in the small scale.

Algorithm 1 Data gathering for simultaneous selection, with reference to partial matching, in direction from the small scale to the large scale.

```
Begin the simultaneous selection process;
    For any one of the objects that were selected in the small scale:
        For any one of the objects that correspond to that object in the large scale:
            If matching is complete:
                Create a copy of the object as a whole from the original layer and
                define it in the temporary layer;
            Else, if matching is partial:
                Create a copy of the object part from the appropriate part layer and
                define it in the temporary layer;
            End if;
        Terminate handling the object in large scale;
    Terminate handling the object in small scale;
End the simultaneous selection process;
```

Figure 8a Simultaneous selection of road type object in the two representations without reference to partial matching.

Figure 8b Simultaneous selection of road type object in the two representations with reference to partial matching.

Figure 9a Selection of a land area object in the small scale produces the selection of the matching parcel group in the large scale, without reference to partial matching.

Figure 9b Selection of a land area object in the small scale produces the selection of the matching object parts of parcel type in the large scale.

Figures 10-12 demonstrate the results of the bi-representation system operations, in which reference is maintained to the partial matching of the objects. Operations of selection and query are performed in the small scale representation and the results are obtained in the large scale representation. Figure 10 depicts the selection of a track, in small scale, consisting of eleven road-type objects. As a result a matching track in the large scale, consisting of twelve object parts, was selected. In figure 11 the following query result is demonstrated: find the parcels in the large scale adjacent to the road-type polyline object that was selected in the small scale. It is apparent that in the first stage three object parts of the large scale that correspond to the road in the small scale were selected: the part which corresponds to the road polygon (which in its original definition extends in whole along the village, as shown in figure 3), and two parts of sidewalk polygons on both sides of the road. In practice, in the second stage the spatial query was performed in the large scale, and that was where the parcels, touching the sidewalks, were actually found. Figure 12 demonstrates the result of the following query: Find the buildings in the large scale, which are at a distance of up to 50 m from a road-type polyline object, that was selected in the small scale (the same object as the query in figure 11). In the first stage, the same three object parts of the large scale were selected as in the previous query. In the second stage a spatial query in the larger scale was performed: each building that is partly or wholly at a distance of 50 m form the circumscribing boundary, which is co-joined from the three object parts - one road and two sidewalks - is included in the query results. All the three operations that were demonstrated in figures 10-12, produced satisfactory results from the user of bi-representation system stand point. The results that would have been obtained in a system, which does not relate to partial matching states of such examples (as depicted in figures 8,9) , would produce unsatisfactory and inapplicable results.

Figure 10 Selection of a track consisting of eleven road-type objects in the small scale produces a selection of a matching track consisting of twelve object parts in the large scale.

Figure 11 Results of the query: "find the parcels in the large scale adjacent to the road-type polyline object that was selected in the small scale."

Figure 12 Results of the query: "find the buildings in the large scale, which are at a distance of up to 50 m. from a road-type polyline object, that was selected in the small scale."

5. **Discussion**

This section deals with a number of aspects of a multiple-representation system of geographic information that were studied in the course of the current research. These aspects demonstrate significant topics to be considered in setting up and applying other multiple-representation systems.

Two types of matching between objects in the bi-representation system can be distinguished; longitudinal matching (figures 3, 5, 8, 10) and non-longitudinal matching (figures 4, 6, 7, 9). Longitudinal matching is obtained when matching exists between features of elongated character in the two representations, thus it will be more prevalent with features of the transportation category or the water category. In the present research data the longitudinal matching is most prevalent between polyline features of small scale and polygon features of large scale (all the examples of figures 3, 5, 8, 10), but it also exists between features represented by elongated polygons in both scales. The drawback of disregarding the partial matching was especially expressed by objects of longitudinal matching, and less with objects of non-longitudinal matching.

The longitudinal matching is expressed in two forms of partial matching: parallel matching and serial matching. In figures 11, 12, for example, the road that served as basis for performing the query in the small scale, corresponds longitudinally to the three parallel polygons: one road and two sidewalks attached to it. The other lines, which represent that road in small scale (see figure 3), correspond longitudinally-serially to the various parts of the central polygon, which represents that road in the large scale, usually by parallel matching with parts of the sidewalks adjacent to the road. In these cases, the road and the sidewalks in the large scale were cut in parallel groups, in order to define matching with the polyline objects representing the road in the small scale.

Dividing the objects into parts allows, from a technical aspect, to refer to matching states of one-to-many or many-to-many, as if the matching states were one-to-one. For example, for a matching state of many-to-many between two groups of objects in two representations, each object, that maintains matching with more than one object in the second group, is divided into parts. For each of the objects or the object parts that are obtained at the end of the process, there is a one-to-one matching with an object or object part in the second group. In the present research, object parts were only formed in the large scale representation, therefore, the states of one (in the small scale) to many (in the large scale) were left in the system.

As afore described, the connection between the two representations was constructed in a manual matching process, which was based on the fact that the two representations were defined in the same terrestrial reference system. Thus it was possible to present them in a common view and mark the matching objects and the object parts. An important aspect is the fact that after the matching was defined and connection was made between the two representations of spatial representation, the reference system of one or two of the representations can be modified, without affecting the functionality of the system. The mutual pointing between the representations is based on a semantic and geographic connection between the objects, rather than their absolute location. As long as the topological relations are maintained within each representation, the correctness of the definition of the connection between the representations will not be altered.

6. Summary and future research

The present research demonstrates design, construction and application of a system that includes two representations of geographic information, that describes in different scales the same area. The representations were connected in such a way that facilitates using them in an integrative manner.

The main topics handled in this research are as following:

- Matching between the semantic models of the representations;
- Matching between the geometric models of the representations;
- Detailed matching between objects and object parts in each representation;
- Defining an information storing mechanism of the connection between the objects in the two representations;
- Defining the functionality of bi-directional simultaneous spatial selection of objects between the two representations;
- Defining the functionality of performing bi-directionally spatial queries, in which the query is defined in one representation, and the results produced by the information appear in the second representation.

The connection of the two representations is the key to the wider or more developed version of the multiple representations in various environments.

The example in this research demonstrated that there is a great deal of practical potential in connecting important, yet separate, pairs of representations. Many users wish to simultaneously utilize the information included in them:

- GIS representations of various scales (different levels of generalization, resolution and accuracy);
- GIS representations with different topical emphasis;
- GIS representations of various update level (and thus having the possibility for the automatic propagation of updates).

The principles, which served to set up the system in this research, demonstrate solutions that may serve as a basis for the development of more complex multiple representation systems. However, it is clear that developing such systems will require much more research that will address the topic in a comprehensive way. Some of the aspects that need to be studied:

- Multiple representations in systems contain a number of representations (more than two).
- Models for documentation of the matching between semantic and geometric models of representations.
- Integrating metadata of different representations to assist the definition of the connection between their data models.

- Extending the research to developing methods for detailed matching of spatial information between existing representations.
- Defining the methods for the matching definition when the representations are generated one out of the other in a generalization process.
- Integrate automatic matching procedures, especially for the automation of partial matching.
- Developing automation methods of dividing objects to parts, to allow flexible and correct definition of spatial information matching in the representations.
- Models for describing the established connections between representations in systems or networks.
- Assimilating the research achievements in the standardization and interoperability domains of spatial geographic information in frame of the research and development of multiple-representation systems.

The importance and benefit of the multiple representation topic, in general, and the multiple representation in various scales, in particular, is demonstrated in a practical way in this article. In a world in which sharing of digital information through global and local computer networks is becoming a powerful tool, development and application of vector multiple-representation systems is a natural step forward. Multiple representations enhances the potential to utilize the existing information by allowing the user to integrate a number of geographic databases in the course of his work, thus jointly facilitating much more information and options, than each of them separately.

References

1. P.H. Burrough and R.A. McDonnell. Principles of Geographical Information Systems, Oxford University Press, 1998.
2. B.P. Buttenfield. “Multiple Representations,” Closing report, NCGIA Research Initiative 3; Dep. of Geography, SUNY, Buffalo, New York, 1993.
3. B.P. Buttenfield and J.S. DeLotto. “Multiple Representations,” Scientific report for the specialist meeting, NCGIA Research Initiative 3; Dep. of Geography, SUNY, Buffalo, New York, 1989.
4. M.J. Egenhofer and E. Clementini. “Evaluating inconsistencies among multiple representations,” Sixth International Symposium on Spatial Data Handling, Edinburgh, 901-920, 1994.
5. M.J. Egenhofer and D.M. Mark. “Modeling conceptual neighborhoods of topological line-region relations,” International Journal of Geographical Information Systems, 9(5):555-565, 1995.

6. Y. Gabay and Y. Doytsher. “Automatic adjustment of line maps,” in Proceedings of GIS/LIS'94, Phoenix, Arizona, 333-341, 1994.
7. Y. Gabay and Y. Doytsher. “Automatic feature correction in merging of line maps,” in Proceedings of the 1995 ACSM-ASPRS Annual Convention, Charlotte, North Carolina, Vol. 2, 404-410, 1995.
8. Y. Gabay. Relative Correlation of Geographic Information Layers, Doctoral thesis (in Hebrew), Technion - Israel Institute of Technology, Haifa, Israel, 1996.
9. Y. Gabay and Y. Doytsher. “An approach to matching lines in partly similar engineering maps,” *Geomatica*, 54(3), 297-310, 2000.
10. M.F. Goodchild, M.J. Egenhofer and R. Fegeas (compiled by). “Interoperating GISs,” Report of a Specialist Meeting held under the auspices of the Varenius Project, NCGIA, Santa Barbara, California, 1997.
11. C.B. Jones. Geographical Information Systems and Computer Cartography, Longman, 1997.
12. C.B. Jones, D.B. Kidner, L.Q. Lou, G.L. Bundy and J.M. Ware. “Database design for a multi-scale spatial information system,” International Journal of Geographical Information Systems, 10(8), 901-920, 1996.
13. D.B. Kidner and C.B. Jones. “Considerations for the design of a multiple representation GIS,” In Proceedings of AutoCarto 11, Minneapolis, Minnesota, 197-207, 1993.
14. Maporama, http://www.maporama.com, 2001.
15. MapQuest, http://www.mapquest.com, 2001.

16. R.B. McMaster and K.S. Shea. Generalization in Digital Cartography, Association of American Geographers, Washington D.C., 1992.
17. J.C. Muller. “Optimum point density and compaction rates for the representation of geographic lines,” In Proceedings of AutoCarto 8, Baltimore, Maryland, 1987.
18. National Geographic, MapMachine, http://www.nationalgeographic.com/maps/, 2001.
19. T.L. Nyerges. “Schema integration analysis for the development of GIS databases,” International Journal of Geographical Information Systems, 3(2), 153-183, 1989.
20. P. Van Oosterom and V. Schenkelaars. “The development of an interactive multi-scale GIS,” International Journal of Geographical Information Systems, 2(3), 217-228, 1995.
21. Open GIS Consortium (OGC), http://www.opengis.org/, 2001.
22. M.A. Rodriguez, M.J. Egenhofer and R.D. Rugg. “Assessing semantic similarities among geospatial feature class definitions,” Interop 99’, Zurich, Lecture Notes in Computer Science, Vol. 1580, 901-920, Springer-Verlag, 1999.
23. A.J. Saalfeld. “Conflation - automated map compilation,” International Journal of Geographical Information Systems, 2(3), 217-228, 1988.
24. A.J. Saalfeld. “Conflation: automated map compilation,” Report of the Computer Vision Laboratory, Center of Automation Research, University of Maryland, College Park, Maryland, 1993.

25. M. Sester, K.-H. Anders and V. Walter. “Linking objects of different spatial data sets by integration and aggregation,” GeoInformatica, 2(4), 335-358, 1998.
26. Spatial Data Transfer Standard (SDTS), http://mcmcweb.er.usgs.gov/sdts/, 2001.
27. G. Vosselman. Relational Matching, Springer-Verlag, Berlin, 1992.
28. V. Walter and D. Fritsch. “Matching spatial data sets: a statistical approach,” International Journal of Geographical Information Science, 13(5), 445-473, 1999.
29. M.F Worboys. GIS – A Computing Perspective, Taylor & Francis, 1995.