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ORIGINAL ARTICLE

Two-Dimensional Topology Structure between Vector Layers in GIS

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ABSTRACT: Queries in Spatial databases, such as Geographic Information Systems, are often based upon the relationships among spatial objects. Unfortunately, currently used GIS software do not support complete topological structures. As such, answering topological queries is time consuming, if not impossible. In this paper, the 9-intersection model is implemented using ActiveX and Dynamic Link Library (DLL) Technologies. The main characteristic of this package is to create complete topological relationships between 2D objects in a GIS environment. Results of the test have shown the superiority of the proposed structure versus current commercial GIS software.

Keywords: Topological Relationships, 9-Intersection Model, Logical Operations, Topological Queries, Spatial Queries

INTRODUCTION

Queries in Spatial databases, such as Geographic Information Systems, image databases, or CAD/CAM systems, are often based upon the relationships among spatial objects. For example, in geographic applications typical spatial queries is "Retrieve all cities which are within 50 kilometres of the interstate highway" and typical topological queries is "Find all highways in the province adjacent to City X." Spatial relations are the basis of many queries that Geographic Information Systems (GISs) perform, as such the topological relations deserves a focused attention from GIS researchers. Current commercial query languages do not sufficiently support such queries, because these languages provide only tools to compare equality or order of simple data types, such as integers or strings. The incorporation of spatial relationships over spatial domains into the syntax of a spatial query language is an essential extension beyond the power of traditional query languages.

There are three aspects for geometry of features:

- Position and orientation can be expressed with respect to a spatial reference or coordinate system. The position of each point will then be represented by a coordinate pair. The orientation of sides can be expressed by their angles with respect to (one of) the coordinate axes.
- The shape and size of geometric figures can be expressed without any reference to a coordinate system. These metric aspects can be derived from the length of the sides of the figures and from the angles between their sides. This information is invariant under changes of the reference system, i.e. coordinate transformations.
- The topological relationships between the objects can be described without reference to their position, orientation, shape and size. These are relationships like: 'inside', 'adjacent to', 'intersect', etc. Topological relationships are invariant under all continuous transformations of the coordinate systems and continuous deformations (Figure 1).

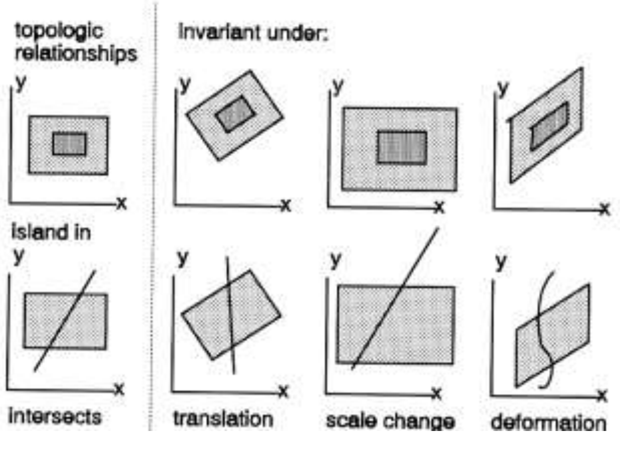

Figure 1: Examples of invariant topological relationships.

Three classes of spatial relationships are discriminated which are based upon different spatial

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concepts (Examples are terms like neighbour and disjoint):

- Spatial order and strict order relationships rely upon the definition of order and strict order, respectively. In general, each order relation has a converse relationship. For example, behind and its converse in-front-of.
- Metric relationships exploit the existence of measurements, such as distances and directions.
- Topological relationships are invariant under topological transformations, such as translation, scaling, and rotation.

Three different formal approaches exist for the definition of spatial relationships. The first one is based upon distance and direction in combination with the logical connectors AND, OR, and NOT. This approach has two severe deficiencies: (1) It is not possible to model inclusion or containment, unless 'negative' distances are introduced. (2) The lack of appropriate computer numbering systems for geometric applications impedes the immediate application of coordinate geometry and distance-based formalisms for spatial relationships. The secondary approach is based on the representation of spatial data in the form of point sets. Binary relationships are described by comparing the 'points' of two objects with conventional set operators, such as equal, and less than or equal. A serious deficiency inherent to the point sets approach is that only a subset of topological relationships is covered with this formalism. While equality, inclusion, and intersection can be described, the point set model does not provide the necessary power to define neighbourhood relationships.

The third approach is based on the intersection of the boundary, interior, and exterior of two objects to be compared and distinguishes only between "empty" and "non-empty" intersection (The 9-intersection model). This method is superior to the other two formalisms because it describes topological relations by purely topological properties.

The 4-intersection and 9-intersection are two comprehensive models for binary topological spatial relations and applies to objects of type region, line, and point. The 4-intersection model characterizes the topological relation between two point sets, A and B, by the set intersections of A's interior (A^0), and boundary (∂A) with the interior, and boundary of B.

The 9-intersection model

The 9-intersection model characterizes the topological relation between two point sets, A and B, by the set intersections of A's interior (A^0), boundary (∂A), and exterior (A^-) with the interior, boundary, and exterior of B (Eq. 1).

$$R_X(A,B) = \begin{pmatrix} \partial A \cap \partial B & \partial A \cap {}^o B & \partial A \cap B^- \\ {}^o A \cap \partial B & {}^o A \cap {}^o B & {}^o A \cap B^- \\ A^- \cap \partial B & A^- \cap {}^o B & A^- \cap B^- \end{pmatrix} \quad (1)$$

Hence, the 9-intersection model is better than the 4-intersection model in perfectly expressing the topological relationships between two objects. In 9-intersection model with each of these nine intersections being empty (0) or non-empty (1), the model distinguishes 512 different topological relations between two point sets, some of which cannot be realized, depending on the dimensions of the objects and the dimensions of their embedding space (for example r000). The possible relations are represented in table 1.

Table 1: The possible relations between 2D features.

Type of intersection	Number of possible relations
Region-Region	10
Region-Line	19
Region-Point	3
Line-Line	33
Line-Point	3
Point-Point	2

Some of the possible topological relationships between 2D features are represented in Figure 2. The relations will be presented by a binary code which can then be converted to a decimal number. To obtain the binary codes a 9-field tuple is defined as follows:

$$R_X(A,B) = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} = \begin{pmatrix} r_{11} & r_{22} & r_{21} & r_{12} & r_{33} & r_{13} & r_{23} & r_{31} & r_{32} \end{pmatrix}$$

$$r = r_{11} \times 2^8 + r_{22} \times 2^7 + r_{21} \times 2^6 + \cdots r_{32} \times 2^0$$

For example:

r119:

$$\begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \end{pmatrix}$$

$$\Rightarrow 0 \times 2^8 + 0 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 119$$

Figure 2: The possible topological relationships between 2D features is shown in Figure 2 as A, B, C and D parts

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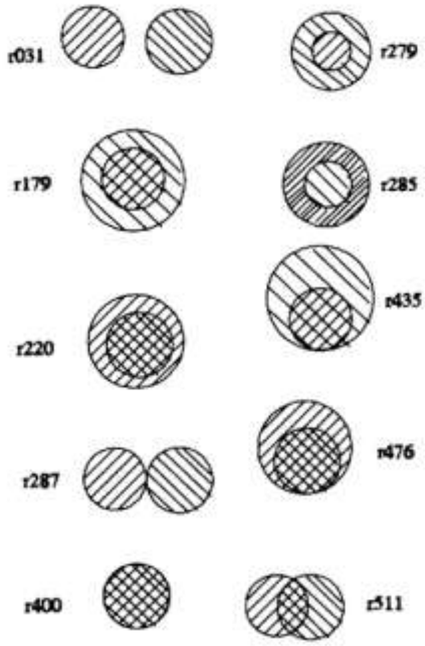

Fig.2, A: Topological relationships between two region objects.

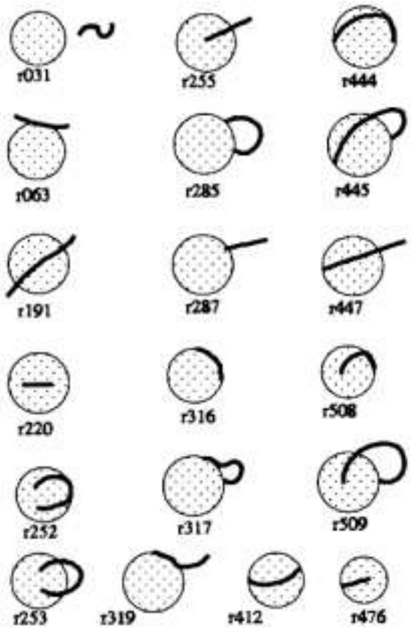

Fig.2, B: Topological relationships between region and line objects.

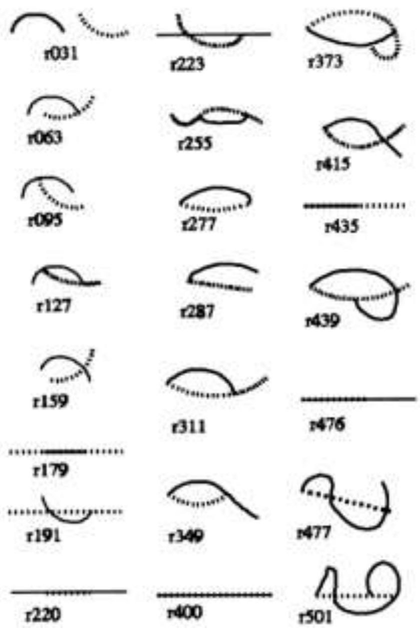

Fig.2, C: Topological relationships between two line objects.

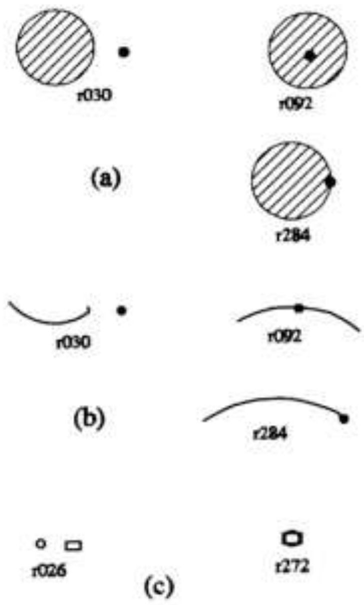

Fig.2, D: Topological relationships between (a) region and point objects, (b) line and point objects, (c) two point objects.

IMPLEMENTATION

To use the 9-intersection model in GIS, a software package has been designed and implemented. The implementation flowchart and the applied interface for the software are represented in Figures 3, 4, respectively.

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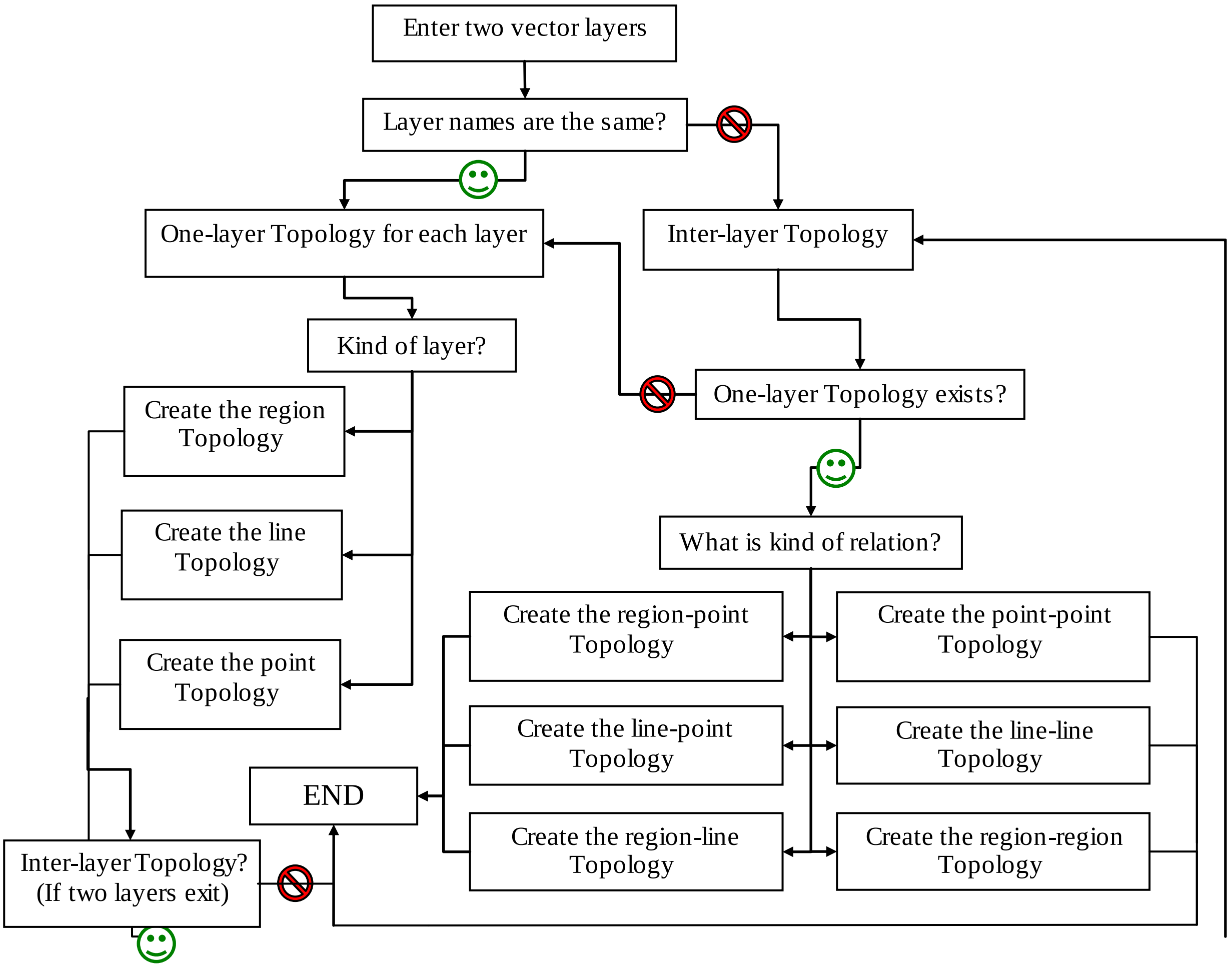


Figure 3: The flow-diagram of the written software.

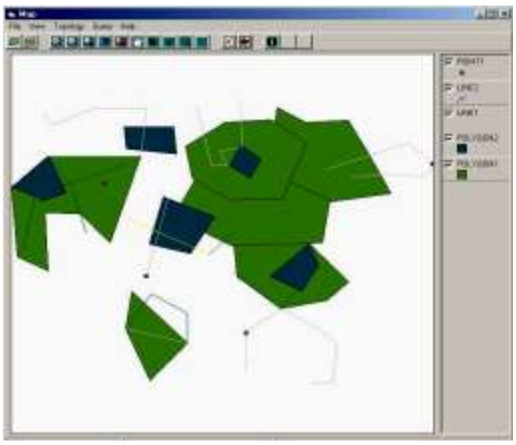
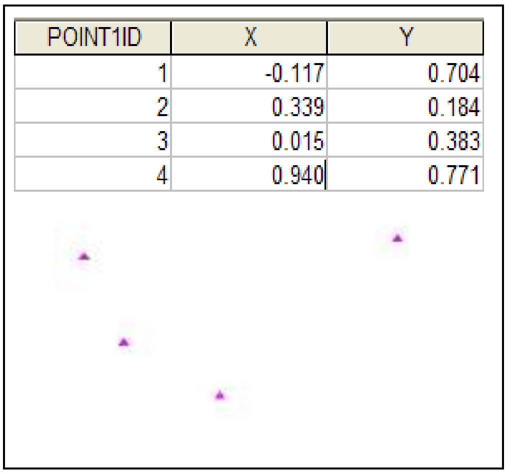


Figure 4: The interface of the software.



POINT1ID	X	Y
1	-0.117	0.704
2	0.339	0.184
3	0.015	0.383
4	0.940	0.771

Figure 5: One-layer topology for point.

One – layer topology

Point topology: By running the software, three fields are added to an attributes table. These three fields contain "Pointed", "X", and "Y" as coordinates. An instance of the result for this status has been represented in Figure 5.

Line topology: Once the software ran, four fields are added to an attributes table. These fields contain "Lined", "From node", "Ton ode", and "Length". The instance of running software for this case has been represented in Figure 6.

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LINE2ID	FROMNODE	TONODE	LLENGTH
1	1	2	0.361
2	3	4	0.388
3	5	6	0.291
4	7	8	0.381
5	6	9	0.113
6	10	11	0.119
7	11	12	0.181
8	11	13	0.198
9	14	11	0.316

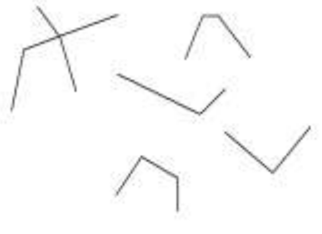
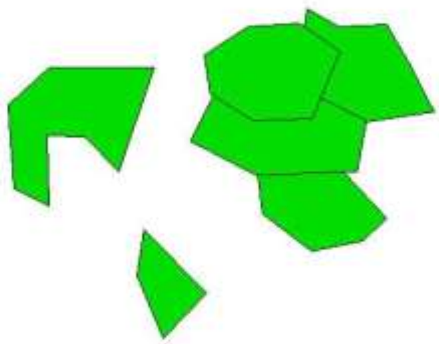


Figure 6: One-layer topology for line.

Region topology: Running the software, creates an additional table i.e. three fields contain "Polygon nod", "Perimeter", and "Area", are added to an attributes table and one new table that contains three fields for representing topological relations. An instance of running software for this status has been represented in Figure 7.

POLYGON1ID	AAREA	PPERIMETER
1	0.081	1.074
2	0.076	1.309
3	0.065	1.204
4	0.058	0.964
5	0.029	0.764
6	0.094	1.583



POLYGON1ID	POLYGON1	RELATION
1	2	r287
1	3	r287
2	3	r287
2	4	r287

Figure 7: One-layer topology for polygon.

Inter-layers topology

Inter-layers topology is described in 6 statuses as point-point, point-line, point-polygon, line-line, line-polygon, and polygon-polygon. In all of these cases and using the one-layer topology, one new table is created. This new table represents topology between two layers. The instances of running software for these statuses have been represented in Figure 8, 9, 10.

LINE1ID	LINE2ID	RELATION
1	3	r159
2	4	r277
3	2	r159
6	6	r287

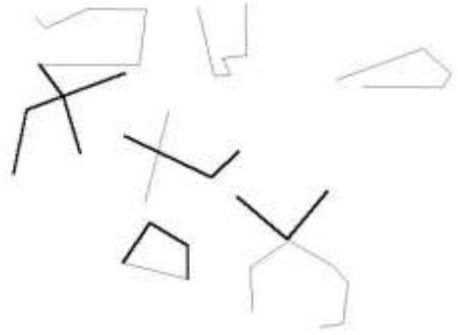


Figure 8: Inter-layer topology for line-line.

LINE1ID	POLYGON1ID	RELATION
4	1	r191
5	3	r253
3	4	r063
2	5	r412
6	6	r319

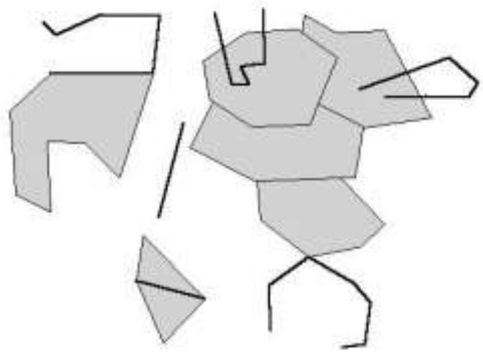


Figure 9: Inter-layer topology for line-polygon.

POLYGON1ID	POLYGON2ID	RELATION
1	1	r220
4	2	r476
6	3	r476
2	4	r511

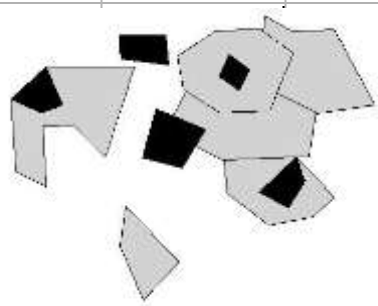


Figure 10: Inter-layer topology for polygon-polygon.

CONCLUSION

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Topological queries are posed frequently once a GIS is used. They require the information about the relationships between two spatial objects. Currently used software lacks the capability of presenting a complete topological structure. Recognizing this problem, the paper aimed at delving on the design and implementation of a complete topological structure. A comprehensive review of the methods that can create such a structure has been presented in this paper. The methods are scientifically assessed. With the use of practical examples, the paper is then revealed the results of running prepared software for creating a complete 2D topological structure.

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