Coordination of Different Map Themes using Cartographic Relations

Boedecker, M.,
Roonstraße 16, 95028 Hof, Germany, E-mail: mboedecker@gmx.de

Abstract
In cartography the coordination of different map themes is directly linked to map generalization (Imhof, 1972). That means a good generalization result can only be achieved by a reasonable coordination of participated map themes and their associated generalization operations and algorithms. In the field of automated map generalization there exist only a few research papers (e.g. Gaffuri, 2006 and Monnot et al., 2007a) where a simultaneous generalization and coordination has been implemented. The objective of this paper is to investigate a generic set of cartographic relations which could exist between different map themes and to prove how they can be used for cartographic coordination. One approach to define and recognize cartographic relations during generalization is data enrichment (Neun, 2007). Following this approach an auxiliary data structure was used to implement a simultaneous generalization of "rivers" and "borders". This simple test case shows how cartographic relations can support the coordination of different map themes.

1. Geographic Context and Coordination

To reach a good generalization result geographic objects should never be treated one by one. In fact cartographic generalization should always consider the geographic context of an object (Lee, 2004). Cartographic coordination is a common method to preserve geographic context during generalization. That means cartographers always try to recognize and preserve significant relations between existing map objects or map themes. The following example of Weibel and Dutton (1998) shows what happens if geographic context will be ignored during generalization and how coordination can help to preserve important relations between different map themes. Figure 1a shows a simple geographic situation with roads and a group of small lakes. To fulfil the cartographic constraint of "minimum size" the lakes could simply aggregate together without considering the roads. When doing so a cartographic conflict will arise. While the roads firstly route around the lakes, one road is now crossing the new generalized lake (Figure 1b). To avoid this conflict the coordination of roads and lakes is necessary. In this case roads could be seen as a natural barrier to prevent the aggregation of small sized lakes (see Figure 1c). This kind of geographic relation must be described and recognized during the generalization process. Therefore a transfer of structural and cartographic knowledge from a cartographers mind to a generalization system is required.

2. Cartographic Relations

As mentioned above the preservation of significant relations between geographic objects is one of the most important cartographic tasks during generalization. To describe geographic relations the term relations is often used in current literature (e.g. in Bobzien et al., 2006, Neun and Steiniger, 2005 and Steiniger and Weibel, 2007). Considering the scale and actuality of a map, a differentiation in horizontal, vertical and update relations occurs.

Figure 1: Example for dependent map themes (according to Weibel and Dutton, 1998)

Horizontal relations describe relations between geographic objects at the same scale (e.g. the distance between two buildings in a map). Vertical relations describe relations between geographic objects at different scales (e.g. deformation of a building before and after generalisation). Update relations describe relations between geographic objects over time. This means that geographic objects can be added, deleted or changed during an update process of larger scale maps which cause again changes to the geographic context in derived scales. According to Haldimann (2008) cartographic relations can also be expressed as mathematical relations, which could support a later formalization. Binary relations exist between two geographic objects (a, b). They can either exist as heterogeneous relations ($R \subseteq A \times B$) among objects of two sets, e.g. the relation among a house and a road, where set A contains all houses and set B contains all roads. Or they exist as homogeneous relations ($R \subseteq A \times A$) between objects of one set A, e.g. the relation between two houses, where set A contains all houses. These examples can also be adapted for n-ary relations among geographic objects of one set ($R \subseteq A_n$) or many sets ($R \subseteq A_1 \times \ldots \times A_n$). Furthermore Haldimann classifies relations according to their regional influence into local, regional and global relations. While global relations are valid for a complete map and can be defined before generalization, regional and local relations need to be recognized and analysed during generalisation on object level. In the following the term relation will be replaced by the term cartographic relation according to Steiniger and Weibel (2007). Cartographic relations are interacting with measures and constraints. They represent together with generalization algorithms the fundamental parts of a generalization system (see Figure 2). Measures help to detect and describe cartographic relations and can be used to describe constraints (e.g. minimum size). Constraints in turn monitor cartographic relations and cartographic relations enforce constraints by controlling generalization algorithms. Following this a cartographic relation can be used to transfer cartographic knowledge to a generalization system and to coordinate different map themes.

3. Developing Cartographic Relations

While cartographic relations could be a key to a useful coordination, the development of cartographic relations should be the first step. The objective of this paper is to develop a collection of important cartographic relations to increase the quality of simultaneous generalization to an acceptable standard level. The development of cartographic relations follows the classification of Steiniger and Weibel (2007). It is divided into geometric, topological, statistical and semantic relations. To achieve a manageable number of generic and important relations, the set of possible map themes will be reduced to the geometric primitives point, line and polygon. Furthermore structural relations are not included, because they are strongly bounded to special map themes. The starting point for a cartographic relation is always a cartographic conflict followed by a cartographic constraint. The developed cartographic relations are presented below and summarized in table 1.

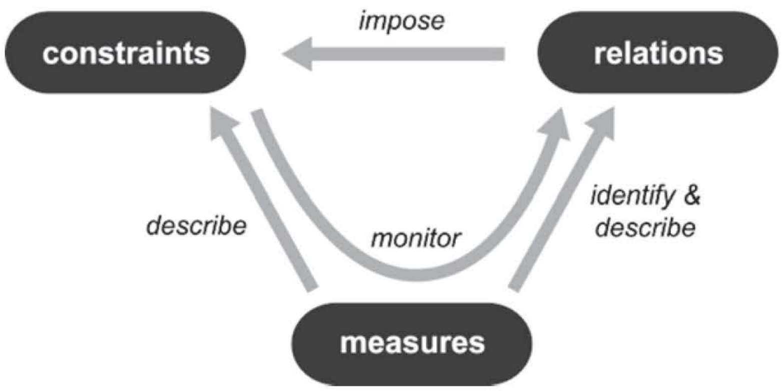
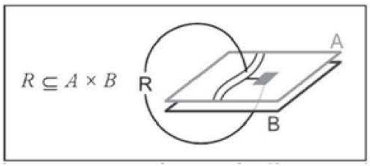


Figure 2: Interaction of constraints, measures and relations in a generalization system (according to Steiniger and Weibel, 2007)

3.1 Geometric Relations

3.1.1 Minimum distance

Cartographic conflict: Changes in geometry or symbolization can cause an undershooting of minimum distance during generalization. Not only between objects of one map theme but also between objects of different map themes. The conflict can occur between disjoint objects and overlapped objects. Cartographic constraint: The minimum distance between two disjoint objects or outlines of overlapping objects of different map themes must be preserved during generalization (see also Gaffuri, 2005). If one of the participated objects would be removed during generalization the constraint gets invalid. Cartographic relation: The relation exists between two objects of different map themes. It compares the distances of objects with a required minimum distance. Set A contains an object of one map theme and set B contains an object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization and a minimum distance must be defined before generalization.



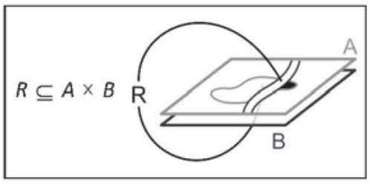
Benefit: This relation can be used to describe and analyze the minimum distance between two objects of different map themes. Due to the different combinations of geometries there exist two main use cases:

1. Analysis of minimum distance between two disjoint objects
2. Analysis of minimum distance between two overlapping objects

If a measured distance between two objects falls below a required minimal distance the relation should activate a generalization algorithm (e.g. displacement, removal) to fulfil the cartographic constraint.

3.1.2 Minimum size

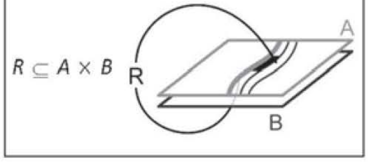
Cartographic conflict: Changes in geometry or symbolization can cause an undershooting of minimum size during generalization. Overlapping map themes can result in rest-areas and gaps which are undershooting the minimum size. Cartographic constraint: The minimum size of resulting rest-areas and gaps between overlapping objects of different map themes must be preserved during generalization. If one of the participated objects would be removed during generalization the constraint gets invalid. Cartographic relation: The relation exists between two objects of different map themes. It compares the size of gaps and rest-areas with a required minimum size. Set A contains an object of one map theme and set B contains an object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization and a minimum size must be defined before generalization.



Benefit: This relation can be used to analyze the minimum size of rest-areas and gaps of two objects belonging to different map themes. If a measured size of rest-areas or gaps falls below a required minimum size the relation should activate a suitable generalization algorithm (e.g. displacement, enhancement) to fulfil the cartographic constraint.

3.1.3 Parallelism

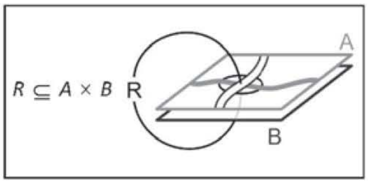
Cartographic conflict: The separated generalization of different map themes can cause the violation of relevant parallelism between two objects. Cartographic constraint: The parallelism between objects of different map themes must be preserved during generalization (see also Weibel, 1996 and Bertin, 1974). If one of the participated objects would be removed during generalization the constraint gets invalid. Cartographic relation: The relation exists between two objects of different map themes. It describes the distance relation of two objects and checks if a significant parallelism exists. Set A contains an object of one map theme and set B contains a nearby and disjoint object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization and a parallelism threshold must be defined before generalization.



Benefit: This relation can be used to analyze the parallelism between two objects of different map themes. The relation should coordinate generalization operations in a way that it preserves significant parallelism.

3.1.4 Intersection angle

Cartographic conflict: A cartographic conflict exists if intersection angles between objects of different map themes will be strongly manipulated during generalization. Cartographic constraint: The intersection angles between overlapping objects of different map themes must be preserved during generalization (see also Bertin, 1974 and Harrie, 1999). If one of the participated objects would be removed during generalization the constraint gets invalid. Cartographic relation: The relation exists between two intersecting objects of different map themes. It describes the angles, which exist at intersection points of both objects. Set A contains an object of one map theme and set B contains an intersecting object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization and a manipulation threshold for intersection angles must be defined before generalization.



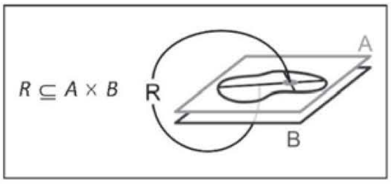
Benefit: This relation can be used to analyze the intersection angels of two intersecting objects of different map themes. The relation should coordinate generalization operations in a way that it preserves the recognized intersection angles as good as possible.

3.1.5 Relative position

Cartographic conflict: A cartographic conflict exists if the relative position of two objects belonging to different map themes strongly changed during generalization.

Cartographic constraint: The relative position between objects of different map themes must be preserved during generalization (see also Weibel, 1996, SGK, 2002 and Bertin, 1974). If one of the participated objects would be removed during generalization the constraint gets invalid.

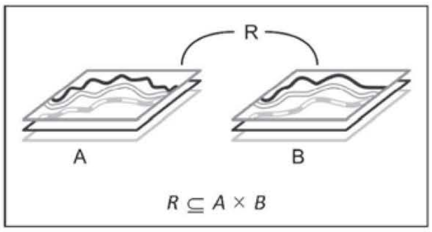
Cartographic Relation: The relation exists between two intersecting objects of different map themes. It describes the relative position between two objects. Set A contains an object of one map theme and set B contains an object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization.



Benefit: This relation can be used to analyze the relative position between two objects of different map themes. The relation should coordinate generalization operations in a way that it preserves the recognized relative position as good as possible.

3.1.6 Deformation

Cartographic conflict: A cartographic conflict exists if the degree of deformation among different map themes differs too much. Cartographic constraint: The geometric deformation of different map themes must remain well-balanced during generalization in comparison to each other. In other words that means the degree of generalization must be equal (Hölzel, 1967). Cartographic relation: The relation exists between different map themes before and after generalization. It describes the ratio of deformation among different map themes. Every element in set A contains geometries of a map theme before generalization and every element in set B contains geometries of a map theme after generalization. The relation is classified as vertical and global. Deformation-Ratios must be calculated after generalization and deformation thresholds need to be defined before generalization.

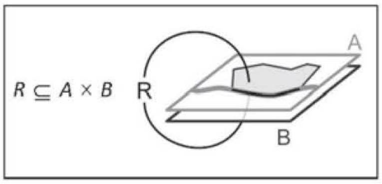


Benefit: This relation can be used to analyze the quality of a generalization result. It can be used to determine the deformation of each map theme and to compare the degree of deformation for each map theme with another one. If there is a high difference between the participated map themes, the parameters of generalization algorithms must be adjusted.

3.2 Topological Relations

3.2.1 Intersection Types

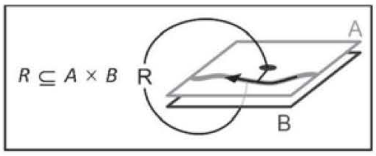
Cartographic conflict: A cartographic conflict exists if intersection types between objects of different map themes will not be preserved during generalization. Cartographic constraint: The different types of intersection between objects of different map themes must be preserved during generalization (see also Weibel, 1996 and AGENT, 1998). If one of the participated objects would be removed during the generalization process the constraint gets invalid. Cartographic relation: The relation exists between two objects of different map themes. It describes the relation of intersection between two objects. Set A contains an object of one map theme and set B contains an intersecting object of another map theme. The relation is classified as horizontal and local. It must be recognized during generalization.



Benefit: This relation can be used to analyze the intersection types between two objects of different map themes. The determined relations can be used to preserve the topological consistency while executing generalization operations.

3.2.2 Left and right side

Cartographic conflict: A cartographic conflict exists if objects of a map theme (e.g. trees or houses) are placed left or right to a line object (e.g. road or river) before generalization and change their position in relation to the line object after generalization. Cartographic constraint: The left and right side relation between objects of one map theme to a line object of another map theme must be preserved during generalization (see also AGENT, 1998). If one of the participated objects would be removed during generalization the constraint gets invalid. Cartographic relation: The relation exists between two objects of different map themes. It describes the left and right side relation of an object in relation to a line object. Set A contains an object of one map theme and set B contains an object of another map theme and must be a line geometry. The relation is classified as horizontal and local. It must be recognized during generalization.

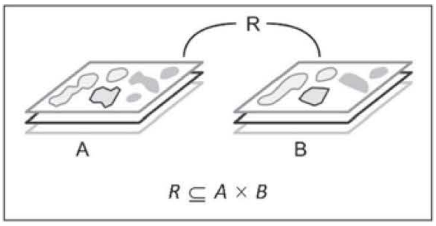


Benefit: This relation can be used to analyze if an object lies on the left or the right side of a line object. Both objects belong to different map themes. The relation can be used to preserve the relative position during generalization process controlling the participated generalization algorithms.

3.3 Statistical Relations

3.3.1 Size- and Quantity-Ratio

Cartographic conflict: A cartographic conflict exists, if the size- and quantity-ratio between different map themes before and after generalization differs too much. Cartographic constraint: The size- and quantity-ratio between different map themes must be preserved during generalization (see also Weibel, 1996). If one of the participated map themes would be removed during generalization the constraint gets invalid for this map theme. Cartographic relation: The relation describes the size- and quantity-ratio between different map themes. Set A contains all objects of the involved map themes before generalization and set B contains all objects of the involved map themes after generalization. In this case one element of set A or B is equivalent to a collection of objects belonging to one map theme. The relation is classified as vertical and global. Size- and Quantity-Ratios must be calculated after generalization.

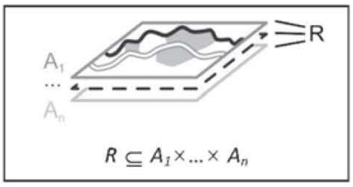


Benefit: This relation can be used to analyze the size- and quantity-ratio between different map themes before and after generalization. The relation can be used to evaluate the generalization result.

3.4 Semantic Relations

3.4.1 Priority of edge treatment

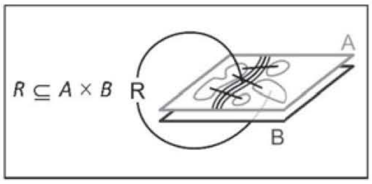
Cartographic conflict: A cartographic conflict exists if two objects share the same edge and the algorithms of the map theme with lower priority have been chosen during generalization. For example, rivers have naturally a direct geometrical influence to forest areas. That's why generalization algorithms of rivers should have a higher priority towards forest area algorithms and should be chosen for geometric simplification of a shared edge. Cartographic constraint: If two objects of two different map themes share an edge, the generalization algorithms used for this edge must belong to the map theme of higher treatment priority. (see also Weibel, 1996 and AGENT, 1998). If the dependent map themes would be removed during generalization the constraint gets invalid. The relation is classified as horizontal and global. Cartographic relation: The relation describes the treatment priority of all map themes belonging to a shared edge. Each of the sets A_1 to A_n corresponds to one map theme. Priorities of edge treatment must be defined before generalization.



Benefit: This relation can be used to select a suitable generalization algorithm for a shared edge depending on the treatment priority of all involved map themes.

3.4.2 Barriers

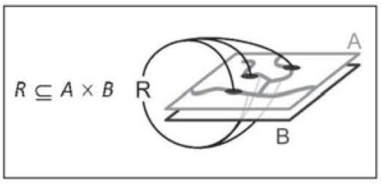
Cartographic conflict: A cartographic conflict exists if area objects are aggregated together despite semantic barriers. A group of lakes for example should not aggregate together if they are separated by a road. Cartographic constraint: If polygon objects of one map theme will be separated by barrier objects of a second map theme, then the separation must be preserved during the generalization process. If one of the participated barrier objects would be removed during the generalization process the constraint gets invalid. Cartographic relation: The relation exists between polygon objects of one map theme and barrier objects of another map theme. It describes if there exists a barrier between two polygon objects. Set A contains objects of a polygon class and set B contains barrier objects of a second map theme. The relation is classified as horizontal and global. Barriers must be defined before generalization.



Benefit: This relation can be used to analyze the existence of a barrier between two polygonal objects and can be used to control generalization operations. That means if there exists a barrier between two or more polygonal objects a merge operation should be avoid during generalization process.

3.4.3 Existence dependency

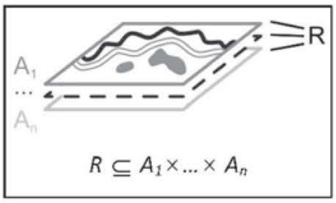
Cartographic conflict: In a map the existence of an object could be depend on a parent object of another map theme. A cartographic conflict exists if the dependent object will be preserved, while its parent object will be removed during generalization. Cartographic constraint: If there is an existence dependency between objects of two different map themes, child objects must be deleted if their belonging parent objects disappear during generalization. If one of the participated map themes would be removed during the generalization process the constraint gets invalid. Cartographic relation: The relation exists between objects of two map themes. It describes the existence relation of dependent objects to their parent objects. Set A contains dependent objects of one map theme and set B contains parent objects of another map theme. The relation is classified as horizontal and global. Existence dependencies must be defined before generalization.



Benefit: This relation can be used to control and initialize the elimination of child objects if their parent objects disappear during generalization.

3.4.4 Priority of position preservation

Cartographic conflict: A cartographic conflict exists if the priority of position preservation will be violated. For example, during generalization of topographic maps above all the position preservation of the traffic network is required. Cartographic constraint: The priority of position preservation must be maintained during simultaneous generalization of different map themes (see also SGK, 2002). Cartographic relation: The relation describes and compares position preservation priorities of all participated map themes. Each of the sets A_1 to A_n correspond to one map theme. The relation is classified as horizontal and global. Priorities of position preservation must be defined before generalization.



Benefit: This relation can be used to sequence position preservation priorities during generalization. By transferring these priorities from class level to object level, generalization operations and algorithms can be controlled to maintain their order.

4. Summary of Developed Cartographic Relations

Table 1 gives an overview of developed cartographic relations, their geometric domain and their classification into horizontal, vertical, local, regional and global relations. While the geometric domains can be used to identify generic relations between different map themes, their other characteristics can be used to define the point of application during generalization (Haldimann, 2008). The application of cartographic relations is ordered as follows: 1. horizontal/global, 2. horizontal/regional, 3. horizontal/local, 4. vertical/global, regional, local.

Table 1: Overview of developed cartographic relations

Cartographic Relation	Geometric Domain						Relation Property				
	PP	PL	PA	AA	AL	LL	H	V	L	R	G
Geometric Relations											
Minimum Distance, disjoint	x	x	x	x	x	x	x		X		
Minimum Distance, overlaps			x	x	x		x		X		
Minimum Size				x	x	x	x		X		
Parallelism				x	x	x	x		X		
Intersection Angle				x	x	x	x		X		
Relative Position, disjoint	x	x	x	x			x		X		
Relative Position, overlaps			x	x	x		x		X		
Deformation				x	x	x		x			x
Topological Relation											
IntersectionTypes (DE-9IM)											
Disjoint	x	x	x	x	x	x	x		X		
Touches		x	x	x	x	x	x		X		
Crosses					x	x	x		X		
Within		x	x	x	x	x	x		X		
Contains		x	x	x	x	x	x		X		
Overlaps				x		x	x		X		
Equals		x		x		x	x		X		
Intersects	x	x	x	x	x	x	x		X		
LeftandRight Side		x			x	x	x		X		
Statistical Relations											
Size- andQuantity-Ratio	x			x		x		x			x
SemanticRelations											
Priorityof Edge Treatment				x	x		x				x
Barriers				x	x		x				x
ExistenceDependency	x	x	x	x	x	x	x				x
Priorityof Position Preservation	x	x	x	x	x	x	x				x
P = Point, L = Line, A = Polygon, H = horizontal, V = vertical, L = local, R = regional, G = global											

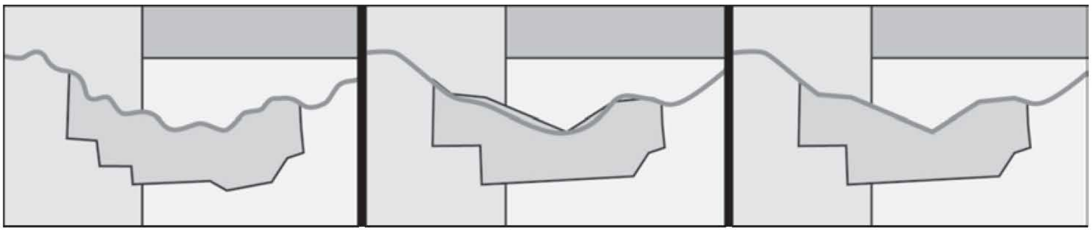
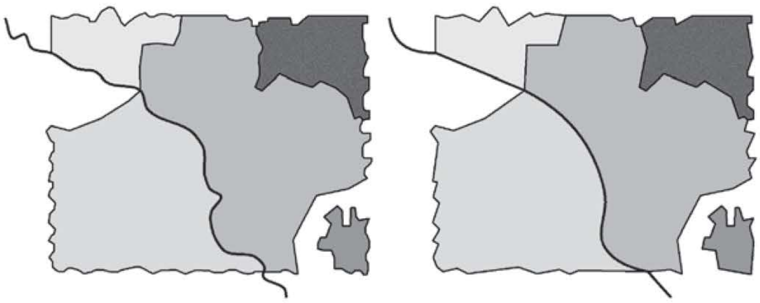


Figure 3: A Simple map scenario of rivers and borderlines showing the conflicts which should be solved by a suitable coordination



ITopologyGraph topoGraph = topo.Cache as ITopologyGraph

Figure 4: Application of cartographic relations in a small test area using ESRIs topology graph to maintain shared edges and to choose theme based algorithms

5. Exemplarily Application of Cartographic Relations

The application of cartographic relations has been implemented exemplarily as a simultaneous generalization of rivers and borders in a commercial GIS (ESRIs ArcGIS). Therefore a preselection of active relations has been chosen and prioritized. In the case of rivers and borders the relation of "intersection (touch)" and the relation of "priority of treatment" have been evaluated as significant. Both relations should avoid topological and semantic problems during the simultaneous generalization of river and border objects (Figure 3). The relation "priority of treatment" has been implemented directly in the code by defining dependent (borders) and independent (rivers) geometry parts. An implementation using priority parameters could also be possible. Especially if a simultaneous generalization of more than two map themes should be realized. The relation "intersection (touch)" has been implemented and detected by using an auxiliary data structure (ESRI topology graph) and has been used to control the different generalization algorithms of borders and rivers. The topology graph has been used to resolve the separated thematic map layers for analysis of geographic context. That means each topological edge has been checked for a relation to each map theme. If both map themes have been detected as a part of the edge then generalization parameters of the class with higher priority, in this case the map theme river, have been chosen. If only one relation to one map theme exist, then its algorithm would be used to generalize the edge.

6. Conclusion and Perspective

This paper shows how a generic set of cartographic relations could be developed using the geometric primitives point, line and polygon. Its usage could be shown by implementing two cartographic relations for simultaneous generalization of rivers and border polygons in a simplified thematic map. Literature study as well as the test implementation shows that data enrichment is an important method to describe, recognize and preserve cartographic relations during generalization. Furthermore it shows how cartographic relations can support the coordination of map themes during generalization. Two relations could be validated in a small test scenario. For all other cartographic relations a usage and relevance analysis needs to be done. The usage of ESRIs topology graph is limited to its edges and nodes. A better option to implement geometric and topologic relations could be the usage of triangulated structures (e.g. Delaunay triangulation) as some authors in the field of automatic generalization has shown before (e.g. Ruas and Plazanet, 1996, Hojolt, 2000 and Monnot et al., 2007b). This paper shows that there exists a set of generic cartographic relations which could be used to fill the knowledge gap for simultaneous generalization of different map themes.

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