AUTOMATED DIGITAL MAP DESCRIPTION FOR GENERALIZATION

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ABSTRACT

The present article describes an approach to map generalization based on automatic map description. This approach is focused on the identification of the errors (inconsistencies) originated by the generalization. Map description is attempt to represent the relationships (invariants) that not change after the generalization by a set of description operators. The inconsistencies are identified by comparing the description of the map prior to and after generalization. The identified inconsistencies are corrected using local generalization parameters. This process can be iteratively repeated until all inconsistencies are corrected. The resulting map without inconsistencies indicates that the map's semantics is preserved after the generalization. Examples and results of the proposed approach are presented for the case of study of hydrological networks.

KEY WORDS

Automatic Generalization, Digital Map Description, Spatial Properties, Spatial Semantics.

1 INTRODUCTION

Over the recent years, digital cartography has been facing major changes in at least three ways: (a) the map making process has been supported by facilities of collecting and maintaining data and by supporting map design by means of computer graphics; (2) in the consequence of the former, Geographic Information Systems (GIS) have been developed to integrate the processes of data acquisition, manipulation, and representation; and (3) the process of description and understanding of maps is being explored to gain insight in the ways humans perceive and construct the surrounding geographic world through maps [1].

Cartographic map generalization is the process of designing maps overly detailed geographic data. Automation of cartographic generalization is a problem of primary importance in computer cartography. First, automatic cartographic tools allow us decreasing cost and time necessary to produce maps. Automation of generalization requires that the cartographic tools be able to find 'where' and 'how' to generalize. The 'where' depends on the capacity of analysis: the system should be able to identify which objects do not respect the specifications. The 'how' depends on the existence of procedural knowledge and consists of rules that connect generalization conflicts with algorithms supposed to solve such conflicts [2].

Thus, this approach attempts to answer these questions. The 'where' is focused on identifying the inconsistencies and solving spatial conflicts, wich can be generated by the generalization. The 'how' is focused on modifying and establishing the parameters of the generalization functions to solve the inconsistencies.

The generalization problem is not completely solved universally due to the great number of existing case of studies. Erroneously, map generalization has in the past been seen as a set of geometric manipulations. It is true that generalization manifests itself as manipulation of geometry, but it is fundamentally driven by the need to convey specific meaning with respect to a particular map purpose [3].

Projects developed in [4] and [5] use a constraint based on approaches to map generalization, that is constraints control the map generalization process. A constraint denotes "a design specification to which solutions should adhere" [6], that allows considering both the user's needs and mapping principles such as minimal dimensions. In this approach the constraints are considered the invariants. These are used to specify the spatial object relationships that should be preserved in the generalized map.

In digital map generalization (in the interactive and automatic environment), certain spatial inconsistencies are generated. These inconsistencies represent topological and logical errors of spatial object systems; therefore, some relationships among objects that should be invariant are not completed.

The map description process can be used to reflect the map structure. Thus, the description of digital maps allows evaluating certain aspects in a simple manner prior to and after generalization, in other words, to evaluate a set of generalization constraints.

The basic difference between the alternative herein presented and other the state-of-the-art systems is as follows:

- Method to represent some map semantic invariants,
- Evaluation method to qualify generalized data, and
- Mechanism that makes possible to parameterize appropriately generalization functions.

The present article is organized as follows: in Section 2, properties of spatial objects (PSO) are described; in the next section, we present map description as tool of map generalization, showing the process employed to make the generalization. Section 4 presents the preliminary results, and finally, Section 5 contains our conclusions.

2 PROPERTIES OF SPATIAL OBJECTS (PSO)

All objects presented in maps show a land situation. This land situation is composed by thematics. The set of objects with the same primitives of representation (point, arc, and polygon) consist of a thematic (T_i) such as populations, roads, etc., wich represents a spatial object system (S_i).

$$\exists i = 1,\dots,n;\ T_i \cong S_i \ \text{(where} \cong \text{denotes equivalence)} \qquad (1)$$

An object system can be composed by a single layer, although spatial object system such as populations is composed of a few layers (possibly three, including punctual (O_p), linear (O_l), and area layers(O_a) that in this case are a group of three spatial object systems).

$$T_i = (So_p \cup So_l \cup So_a)_i;\ i = 1,\dots,n \qquad (2)$$

The properties of spatial objects (P_s), are defined by relations (R) and attributes (A).

$$P_{S\,i} = (A \cup R)_i;\ i = 1,\dots,n \qquad (3)$$

According to the nature of the property, it is possible to distinguish the following (Figure 1):

- Locational properties (λ). These properties are related to the position of spatial objects. The position is represented by numeric values of coordinates.
- Geometric properties (γ). These properties depend on some computation of distance (e.g. area, perimeter, and length). Their values are typically numeric.
- Topological properties (τ).These properties can be described without reference to their position, orientation, shape and size. A relationship can only be topologic when it is preserved under geometric transformations (translation, rotation, and scaling). It is generally represented by nominal values. For example, intersect, inside, adjacent.
- Directional properties (δ), when they concern the orientation (e.g., north, northeast, and so on). It is generally a directional feature that is represented by means of nominal values.
- Logical properties (*l*), when certain objects have a greater relative importance or combinations of properties that depends on the human expertise (e.g. faraway-west).

Each object system has a particular set of properties: {locational, directional, topological, geometrical and logical}. This set of properties is important for spatial data manipulations and semantic data representation.

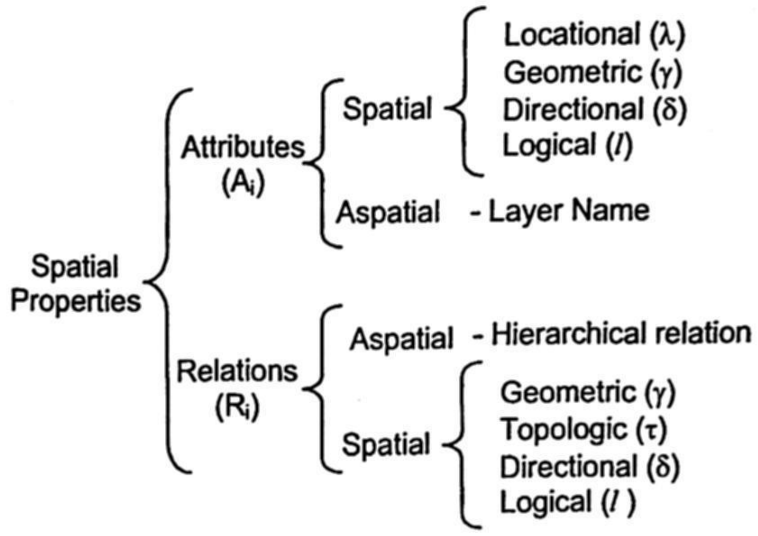

Figure 1. Taxonomy of spatial properties

The relations can be divided into two categories: intrinsic and extrinsic; *intrinsic* (R_I) represent the relationships among objects of the same spatial object system. On the other hand, *extrinsic* relations (R_E) describe the relationships among different spatial object systems.

$$R_{Si} = (R_I \cup R_E)_i;\ i = 1,\dots,n. \qquad (4)$$

Note that, properties denominated *semantic invariants* exist. These represent the essential properties of spatial patterns that do not change in scale. For instance:

- Altitude in which any hydrological network starts is greater than the altitude where it finishes.
- A population at the right side of the river.

The set of semantic invariants (I) is a subset of the set of properties.

$$I_{S\,i} \subset P_{S\,i};\ i = 1,\dots,n \qquad (5)$$

The map definition is "a conventionalized image of geographical reality, representing selected *features* or *characteristics*, resulting from the creative effort of its author's execution of choices, and thus designed for use when spatial *relationships* are of primary relevance" [7]. Considering this definition we can observe that characteristics and relations play a primordial role in map processing. Attributes and relations define the map processing. Attributes and relations define the map structure. Any change, in the *characteristics* or *relations* modifies the map structure, this means that it is not the same map. While, the *content* of the set of spatial properties reflects the situation represented in a map, according to the map purpose.

The map semantics can be defined by the set of spatial properties, composed by *relationships* and *attributes*, which define the characteristics of the geographical information. That is the *spatial semantics* of a map is equivalent, in certain sense, to the content of set of PSO that has a map.

For instance, any topographic map has a particular group of spatial objects system with specific properties, these properties defines that it is topographic map, in other words, define its semantics. After any processing of map, it should preserve the essential properties.

3 MAP DESCRIPTION AS TOOL OF MAP GENERALIZATION

Description of spatial object systems represented in a map facilitates the task of finding some properties and relationships among objects. Certain properties are characteristics for certain spatial data layers and some properties are invariants in all scales. Additionally, it is possible to find relationships among different spatial data layers. Map Description represents a map using the relationships between the spatial objects and attempts to obtain the description as better as possible. The description should preserve the spatial semantics.

The map description allows representing properties of spatial data by means of *operators*. This proposal is focused on the identification of inconsistencies originated by generalization. The inconsistencies are relations that do not respect the semantic invariants. They represent an error in generalized map. These are identified by comparing map description prior to and after generalization.

3.1 MAP DESCRIPTION

The description process allows consideration of many spatial object systems. In nature, diverse configurations exist, wich contain objects of different types, as the case of a hydrological network. For this case, the objects (i.e., rivers) can be represented by lines or areas depending on scale. They are always connected with other elements of the network and related with other thematic.

To describe a topographic map, a set of operators can be used. Operators should involve each possible relationship (geometric, topological, directional, and logical). These operators should be consistent so that they can allow describing spatial object systems appropriately. In addition, operators should be as basic as possible; at the same time, an operator should be applicable to the most of existing case of studies and use the invariants.

Certain spatial objects have more accurate than the others and they can be used as a means to initiate map objects description. In Table 1, we list some operators and their meaning and description.

Table 1. Map description operators

Operator	Meaning	Type	Domain	
			Type	Values
ArctoPnt (A,P)	Relation between arc A and point P	Geometrical	Numerical	[0...CELL size]
PlytoPnt (A,P)	Relation between Polygon A and point P	Topological	Boolean	{true, false}
ArctoArc1 (B,A)	Relation between arc A and arc B	Topological	Nominal	{connected, not connected}
ArctoArc2 (A,B)	Relation between arc A and arc B	Logical	Nominal	{Nearly perpendicular, Nearly parallel}
ArctoPnt3 (A,B)	Relation between arc A and point B	Logical	Nominal	{N,NNW,NW, WNW,W,WSW, SW,SSW,S,SW, S,SSE,SE,ESE, E,NE,NE,NNE}

Figure 2 shows a fragment of topographic map (1:50,000). The relationships between these objects are described by description operators. The operators applied for this map as follows (see Table 1 for the definition of operators):

Description Cell: 15
{
ArctoPnt1(LFOR, Mine2) = 800mu1,
ArctoPnt1(River8, Mine2) = 50mu,
ArctoArc1(LFOR, River 8) = Not connected,
ArctoArc2(LFOR, Highway1) = Nearly perpendicular,
ArctoArc2(River 8, Contour4) = Nearly perpendicular,
ArctoPnt3(River2, Population1) = N,
...
}

In this description, the group of operators is referred to an object that has the more exact coordinates. The Largest First Order River (LFOR) is obtained using the algorithm CLAJER [8]. The map description process is detailed explained in [9].

1 Map units, e.g. meters.

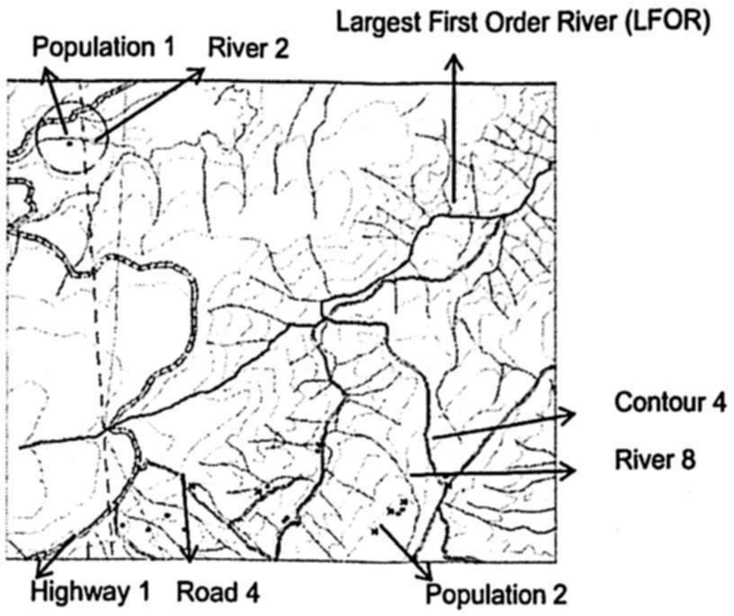

Figure 2. Fragment of topographic map

3.2 MAP GENERALIZATION

The core of the generalization process is based on our capacity to develop (and to master) measures able to describe geographical information as well as possible. These measures replace the analytical capacity of a cartographer, who detects that a situation is not correct and who is able to change it while preserving its main properties. Measures are used to detect conflicts as well as the information and properties that should be preserved during the process [2]. In this article the comparison of Map Description is used as a measure to detect and solve conflicts originated by the generalization.

During the generalization many properties of a map are manipulated principally by topological and geometrical operations, but some PSO should be preserved (invariants). The preserved properties should represent the particular aspects of the map structure (avoiding inconsistencies) in other words: the map *semantics* should be preserved.

3.3 GENERALIZATION BASED ON MAP DESCRIPTION

In this section, we describe a generalization method as tool of map description. This method consists of three functional stages: (1) Map Description, (2) Map Generalization and (3) Verification (Figure 3).

Map Description generates a description of relationships between the objects that compose a map by means of operators. (See Section 3.1)

Map Generalization is manipulated by Generalization Functions. These functions are composed by generalization operators [11].

Verification is the stage that evaluates the generalization process.

This method uses a source map (S_M) and a generalized map (G_M). Description of the map source (D_S) and of generalized map (D_G) are generated. The Verification will be made comparing D_S and D_G (See Figure 3). Verification allows evaluating the structure of generalized map identifying inconsistencies. This will be used to feeding back parameters to Map Generalization. This process can be iteratively repeated until all inconsistencies are resolved. The target map (T_M) without inconsistencies indicates that the map's *semantics* is preserved after the generalization (See Figure 4).

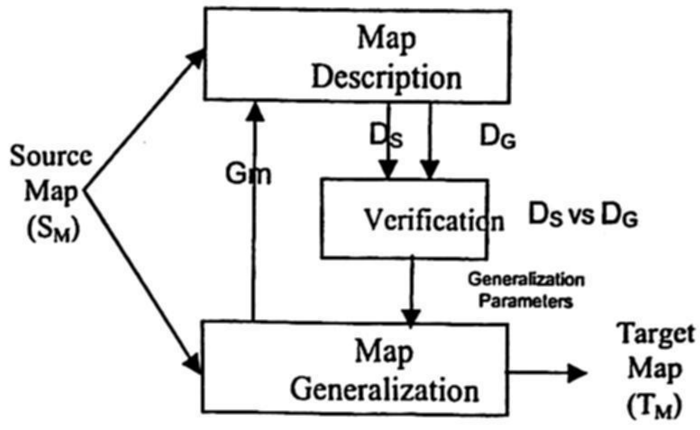

Figure 3. Generalization based on map description.

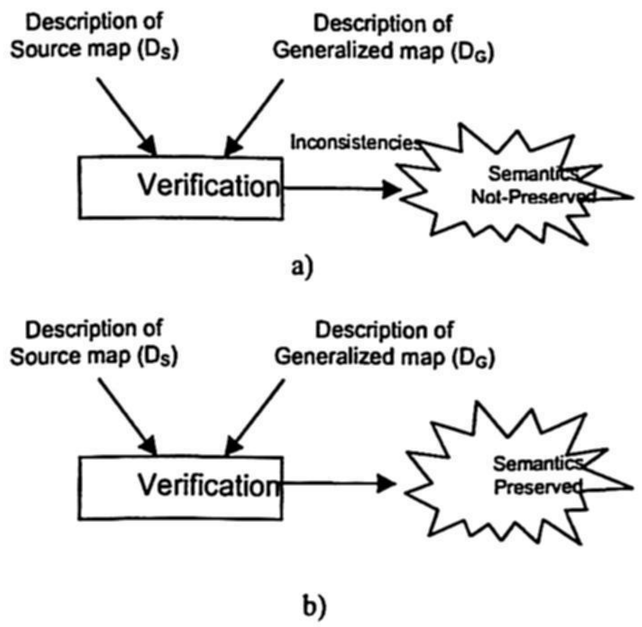

Figure 4. Verification to identify inconsistencies: a) Not satisfactory Generalization, b) Satisfactory Generalization

The results of verification that can be obtained are the following : *Equal, Different* and *Equivalent* (see Table 2).

Table 2. Results of Verification

Case	Verification (D_S vs D_G)	Meaning
Oa = Oa	Equal	Invariant respected
Oa ≠ Ob	Different	Inconsistency
Oa ≅ Ob	Equivalent	Invariant respected (in certain cases)

- *Equal:* This is obtained when the value of both operators is the same. It is representing that the *invariant* has been preserved (Figure 5).

- *Different:* This represent that the operator value is not the same in D_S and D_G. Then it is representing an *inconsistency*. The map structure is modified (See Figure 5b).

- *Equivalent:* This represent that the operator value is not the same in D_S and D_G, however in certain cases of study it is acceptable. The equivalent values not represent an inconistencies since they do not break the structure of the map. For instance; Figure 5c shows that the value ArctoPnt1 = NNE is accepted as equivalent. However, in Figure 5d, ArctoPnt1 = NW and it is not accepted as equivalent value. This situation represents an *inconsistency*. To define the equivalence, it is necessary to define threshold values. These values depend on the context and the subject domain.

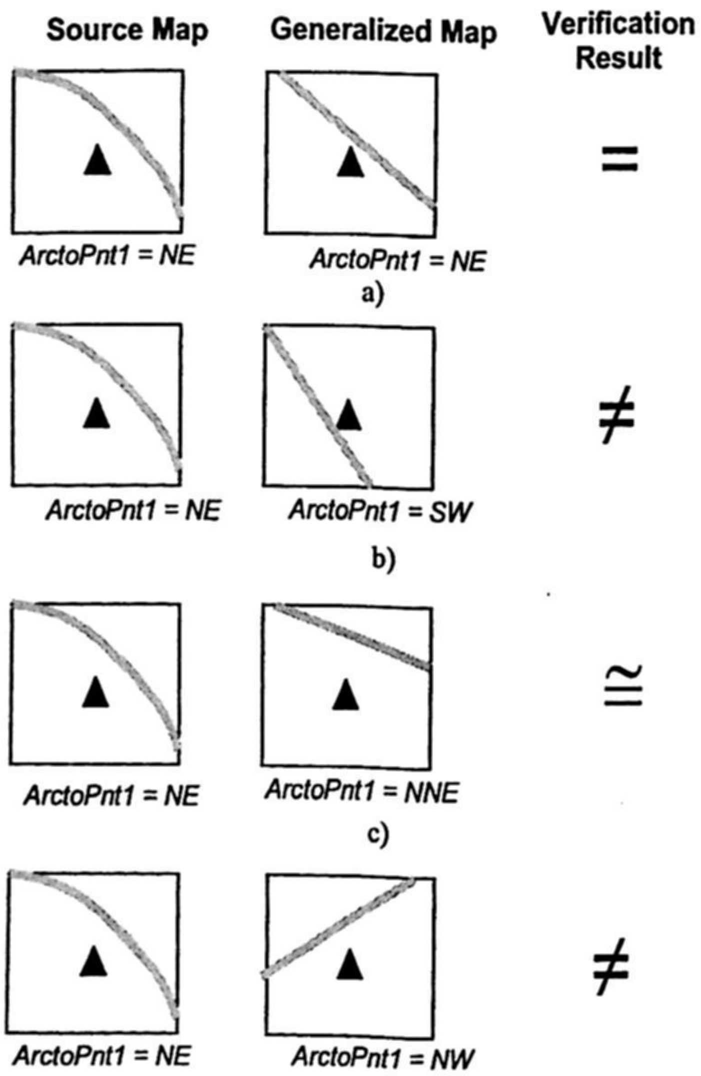

Figure 5. Results of verification: a) Equal, b) Different, c) Equivalent d) Different.

The identified inconsistencies are solved using local generalization parameters. These parameters will be matching to the specific situation. For instance; applying different tolerances in diverse parts of the arc, in other words, they are not necessarily the global parameters and the criteria of generalization, but are useful.

This method is useful because if parameters appropriately parameterize functions, inconsistencies generated by the generalization process can be resolved. For instance; in topographic data subject domain, one of possible set of parameters can be arc curvatures, number of vertices, arc intersections, etc.

4. PRELIMINARY RESULTS

Figures 6 and 7 show the simulations of generalization for hydrological network using as source the topographic map presented in Figure 2. In Figure 6, we use the generalization method developed in [8]. It can clearly be observed that in the original data, "Population 1" (surrounded by a circle) is at the north of "River 2" (Figure 2). In Figure 6 after the generalization this "Population" is at the south of the river, which is an *inconsistency*. The inconsistency is solved (Figure 7), because now the population is at the correct position with respect to the river.

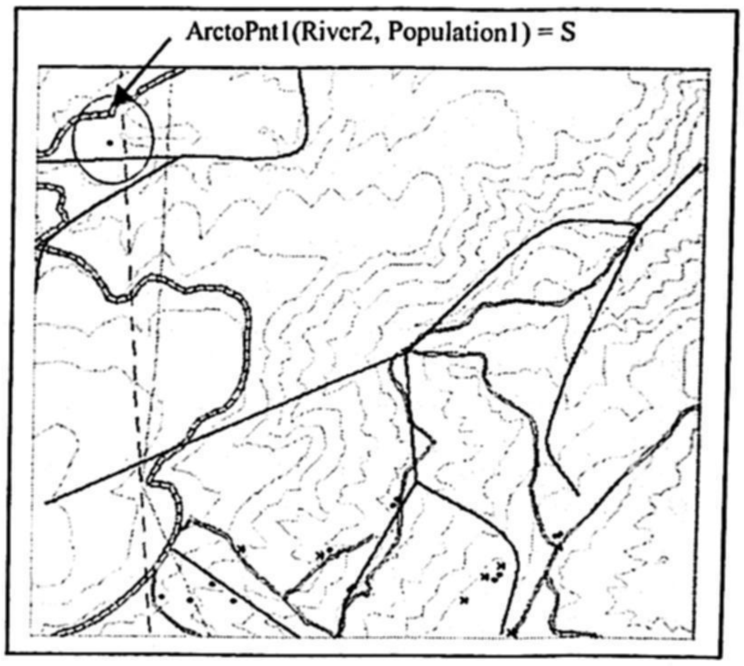

Figure 6. Generalization with inconsistencies

To correct the map inconsistency we used the position of the point (population) with respect to the river. On the other hand, a wide linear object was ill-parameterized and its shape is not appropriate to the scale (Figure 6). We corrected this inconsistency, using the curvature of the corresponding arcs (geometrical properties). The generalized object now seems more appropriate to the map scale (Figure 7). Thus, the data have more aesthetical quality.

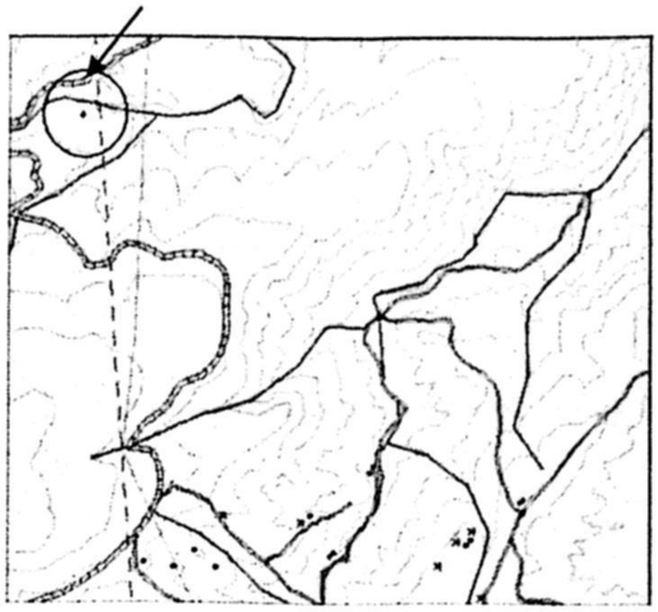

Figure 7. Generalization without inconsistencies

6. CONCLUSIONS

Automatic generalization is a Geomatics area that has attracted much attention during last few decades. A method herein presented provides an alternative to identify and solve certain conflicts in map generalization. Relationships between spatial objects allow solving inconsistencies generated by the generalization process. Map description enlarges the field of action of generalization operators because they can be parameterized in an appropriate manner, depending on the applications.

The main characteristics that provide the methodology herein presented are:

1. This proposal attempts to detect the map semantics by means of the elimination of inconsistencies.
2. Data analysis on the whole, not isolated data layers, but generalizing spatial object system that interact with other spatial object system;
3. Use of techniques that allow evaluating data after generalization;
4. Use of Properties of Spatial Object to describe spatial systems;
5. Auxiliary to parameterize functions that manipulate spatial data, in particular generalization functions;
6. Possibility to modify and incorporate new functions and properties.

The challenging tasks in generalization are to solve inconsistencies generated during the generalization process. Thus, it is necessary to carry out a methodology of general application to the great amount of cases of studies and to preserve inherent *spatial semantics* for each spatial object system. Developing our proposal, it is possible to solve partially some problems originated from the generalization.

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REFERENCES

[1] B. Berendt, T. Barkowsky, Freksa, C., Kelter, S. Spatial Representation with Aspect Maps. In: C. Freksa, C. Habel, K. F. Wender (Eds.), *Spatial Cognition – An Interdisciplinary Approach to Representing and Processing Spatial Knowledge.* (Ed.: Springer-Verlag, 1998).

[2] A. Ruas, Spatial Analysis and Agent Principles to Automate Generalisation Process. In: Levachkine, S.,Ruas, A., Bodansky, E. (eds.), *eProceedings of the International Workshop on Semantic Processing of Spatial Data (GEOPRO 2002)*, 33-4 December 2002, Mexico City, Mexico (2002) (CD ISBN: 970-18-8521-X).

[3] S. Lamy, A. Ruas, Y. Demazeu, M. Jackson, W. Mackaness, and R. Weibel, The Application of Agents in Automated Map Generalisation, *Proceedings of 19th International Cartographic Conference*, Ottawa, Canada (1999). http://agent.ign.fr/public/ica/paper.pdf

[4] A. Ruas, Modele de generalization de donnees geographiques a base de contraints et d'autonomie, Ph.D. thesis, Universite de Marne-la-Vallee, 1999. (in French) ftp://ftp.ign.fr/ign/COGIT/THESES/

[5] M. Galanda, Modelling Constraints for Polygon Generalization, *International Cartographic Association (ICA), Map Generalization Workshop Paris 2003, Paris,France* (2003). http://www.geo.unizh.ch/ICA/docs/paris2003/papers03.html

[6] R. Weibel and G. Dutton, Constraint-based Automated Map Generalization, *Proceedings 8th International Symposium on Spatial Data Handling*, Vancouver, Canada (1998) 214–224.

[7] T. Kanakubo, 'On the definition of "map", "cartography" and "cartographer" by Dr Christopher Board, chairman of the ICA working group on cartographic definitions', *Map-Journal of the Japan Cartographers Association*, (33) 3, 1993, 27-28.

[8] M. Moreno, La Generalización Automática de la Información Geográfica Multiescala, M.S. Thesis, Centre for Computing Research, National Polytechnic Institute, Mexico City, Mexico, 2001. http://geo.cic.ipn.mx (in Spanish).

[9] M. Moreno, Map Description as Intelligent Tool of Generalization. In: Levachkine, S.,Ruas, A., Bodansky, E. (eds.), *eProceedings of the International Workshop on Semantic Processing of Spatial Data (GEOPRO 2002)*, 33-4 December 2002, Mexico City, Mexico (2002) (CD ISBN: 970-18-8521-X).

[10] M. Bobzien and D. Morgenstern, Abstracting and Formalizing Model Generalization, *International Cartographic Association (ICA), Map Generalization Workshop Paris 2003.*