METHODOLOGY FOR DEVELOPING A DATABASE OF GEOMETRIC PATTERNS TO BETTER SUPPORT ON-THE-FLY MAP GENERALIZATION

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Abstract

Cartographic generalization has been a research topic for more than thirty years. In spite of recent advances, a complete automation of this process still faces fundamental problems. Furthermore, recent needs such as web mapping and Spatial On-Line Analytical Processing (SOLAP) require geospatial data that are generated on-the-fly at any scale. This requires processing times and a degree of automation that today's automatic generalization algorithms cannot reach with all data types.
This paper presents the concept of geometric patterns and explains how they can be built and stored in a pattern database for further use in a map generalization process. Geometric patterns are typical shapes that are representative of several occurrences of a cartographic object class. They support simple operations such as rotation, translation or stretch and allow adapting them to the exact geometry of individual objects.

1. INTRODUCTION

The analysis of several geographic phenomena often requires data at various levels of abstraction. Hence, there is a need for the modeling of geographic information at different levels of abstraction [Muller et al. 1995]. With the arrival of new geomatics applications such as Webmapping and SOLAP [Rivest et al. 2001], the needs for multiscale data has become more pressing. The variety and the increasing number of users of these applications require the systems to be able to generate geospatial data according to the specific user's needs and upon request. But, it is not possible and imaginable to know a priori the needs of the users of these applications. A solution would be to have a large-scale geospatial database from which other smaller scales could be automatically generated. For that purpose, cartographic generalization is necessary. Besides, such applications are characterized by their dynamic and interactive nature and « this dynamic and interactive nature requires almost short response time. Consequently, the scale changes must be made in real time so requiring on-the-fly map generalization » [Weibel et al. 2002].

Cartographic generalization has been an important subject of research for more than thirty years. In spite of constant efforts, the generalization remains a semi-automatic process (even manual in certain cases) that leads to slow response times and production costs incompatible to the requirements of these new applications. Solutions based on multiple representations (RM) thus became an alternative to the on-the-fly map generalization. Typically, in a multiple representation database, the same territory can be associated to several geometric representations, each of them representing the territory at different scales. Explicit links, either between the various scales of the database or between the different representations of the same object can be sometimes create. To create the different scales necessary to build the database, semi-automatic or manual generalization processes are used. Moreover, the redundancy and the possible problems of incoherence between various representations, « the creation of multi-scales data base entails three types of problems: correspondence between various abstractions, correspondence between various instances of an object and the definition of matching process between objects » [Devogele et al. 1996].

To minimize the above multiple representation and automatic generalization problems, several approaches aiming at combining cartographic generalization and multiple representation appeared these last years [Cecconi et al. 2002; GiMoDig 2004]. [Cecconi et al. 2002] recommends to use a database containing a minimum of two scales. After a user request, the most appropriate scale is selected and refined using an on-the-fly generalization process if it is necessary. The [GiMoDig 2004] project proposes a generalization approach similar to the one proposed by [Cecconi et al. 2002] and includes an on-the-fly integration process. A philosophy that is common to these two approaches is that the less is the difference between the initial scale and the scale of the map which will be generated, the easier will be the generalization. Unfortunately, to benefit from the advantages of this approach, the difference between the scale of the initial map and the generated map must be small, which is not always the case.

Like the previous projects, the GEMURE project (MUltiple GEneralization and Representations for one-demand map production and delivery) also tackles the problem of on-the-fly map generalization. Within the framework of this project, we've proposed an approach based on the use of geometric patterns. Geometric patterns are objects with a representative shape common to several cartographic objects and that support simple operations such as orientation, displacement or stretch. These operations allow a single pattern to adapt itself to the geometry of several specific objects. So, instead of using algorithms to generalize a cartographic object, we choose a predefined geometric pattern, already stored in a pattern library database, make some adjustments if needed and replace the object by this geometric pattern for smaller scales

This paper aims at presenting the concept of geometric patterns and explaining how they can be built and stored in a pattern database for further use in the map generalization process. First, a formal description of geometric patterns is formulated. Then, the iterative processes of creating geometric patterns are presented. Throughout the paper, we present various results obtained from concrete experimentations on buildings from the Quebec City area, a city with a mixed architectural style: European and North American. Finally, the mechanism related to the selection of a geometric pattern and its association to a specific cartographic object is introduced

2. GEOMETRIC PATTERNS

2.1 Some geometric patterns concepts

In the daily life, it is possible to notice a recurrence of several phenomena from a time and\or space point of view. In all application domains, the idea of patterns is closely dependent to this recurrence and similarity. In spite of an abundance of recurring phenomena in our environment, it is only in the 70s that the pattern concept was credited [by the architect Alexander et al. 1977]. His widely-cited definition of pattern is:

> *« A pattern is a solution to a problem in a context where each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice ».*

In the 90s, the idea of the patterns was adopted in the computer science field under the name of "concept of design pattern", popularized by the Gang of four. In their book, Design Patterns: Elements of Reusable Object-Oriented Software, [Gamma et al. 1995] propose 23 design patterns, each of them allowing to resolve a recurring problem of object programming. This reuse of code allows increasing programmer's productivity.

In several domains, such as architecture and computer science, the main interest of the use of patterns is to simplify complex processes. This capacity of the pattern to simplify some processes and the abundance of recurring phenomena and structures in our geographic environment stimulated the interest of some researchers to introduce this pattern concept in geomatics and particularly in map generalization processes. Indeed, when viewing the map, the eye discerns patterns of shape, orientation, connectedness, density and distribution [Mackaness and Edwards 2002].

Besides, in spite of the potential associated to the use of patterns in geomatics, few works are today dedicated to this approach. Nevertheless, we know for many years that the Danish Mapping Agency uses a series of templates to represent farm building in 1: 50 000 scale [Regnauld 2002]. To automate the choice of these templates, [Rainsford and Mackaness 2002] proposes the use of matching algorithms in order to select templates that best characterizes a rural building. The concept of pattern as proposed in this paper innovates in several ways and was first described formally by Cardenas [2004]. The work of the first author to test this concept against buildings is presented for the first time. This has resulted in enrichments to the initial concept, and particularly into the presented methodology.

2.2 Geometric patterns and map generalisation

The existence of recurring geographic phenomena and the hierarchical organization of patterns allow them to be used in a map generalization process. Indeed, certain works evoke a hierarchical organization of patterns; it is the case of [Zacks and Tversky 2001]. For a cartographic object, this hierarchical structure especially appears when we browse through various levels of abstraction (e.g. by changing the scale of visualization). While passing from a large scale to a smaller scale, for the same object or a cluster of objects, we observe an evolution in the shape of several patterns. For example, a single building can have several forms going from a detailed shape to a simple rectangular shape. From a pattern perspective, we can define generalization as a set of transformations (from one pattern to another) in which certain partonomic qualities are preserved and others are disregarded: as a result of this process we see different patterns according to changes in scale or theme [Mackaness and Edwards 2002].

The main idea of the use of patterns in cartographic generalization is to have for each map object, several geometric patterns. Each geometric pattern corresponds to the object shape in a given level of abstraction. When the level of abstraction is modified, an object is replaced by a geometric pattern in order to generalize it, instead of using traditional generalization methods. Given the generic character of the pattern's geometry, a same pattern can be used several times and in various scales to represent various occurrences, every time with appropriate parameters for each occurrence. For example, in 1K scale, for a portion of the test area composed by 365 buildings, 30 % of buildings were associated to a single geometric pattern with a "L" shape form. .

Cardenas [2004] defines the geometric pattern as being a geometric object with typical geometric characteristics representative of a great number of occurrences of a cartographic object or a primitive and that is able to adapt itself to the geometry of these occurrences for various scales. The geometric pattern is composed of primitives. The primitive is the atomic, indivisible element that forms a geometric pattern. The shape of a geometric pattern depends largely on the shape of the various primitives which compose it, the number of primitives and the way these primitives are juxtaposed. There are two types of geometric patterns: simple geometric pattern composed of one or several instances of the same primitive; complex geometric pattern composed of other geometric patterns (simple or/and complex). This definition of geometric patterns is the base of the methodology which will be presented in this paper.

Even if it is possible to replace all the cartographic objects having a similar shape with the same geometric pattern, certain parameters (e.g. the position or the size of every object which will be replaced by the geometric pattern) are necessary in order to adapt the geometric pattern to each specific object. For example, two buildings having the same size and the same shape may be associated to the same geometric pattern but implemented using different positions and different orientations. For these reasons, the following manipulations are necessary to be able to replace a specific cartographic object by a geometric pattern:

- Displacement, to position the geometric pattern;
- Orientation, to orientate the geometric pattern;
- Stretch, to fit the geometric pattern size to the object size.

The simplicity of these operations makes the generalization process based on geometric patterns very powerful. For example, the delay to realize certain generalization operations such as an aggregation and a simplification is about 10 times superior to the time needed for adapting a geometric pattern. The experiment was realized on 2844 buildings situated in Quebec City and 0.4 seconds were enough to adjust all geometric patterns, compared to 3.9 seconds for traditional generalization operations. For this reason, it is possible to use this approach in on-the-fly map generalization processes.

3. METHODOLOGY FOR DEVELOPING THE GEOMETRIC PATTERNS DATABASE

The geometric patterns database creation can be divided in five major steps: the detection of the different patterns on a map, the choice of the primitives that will be used to construct the geometric patterns, the choice of the most detailed common patterns, the detailed geometric pattern construction, and the construction of derived geometric patterns for each detailed geometric pattern. In this paper, the term pattern will refer to the pattern of shape that can be detected in our environment, or on a map. The term geometric pattern will refer to the constructed geometric pattern that will be stored in the database and used during a generalization process.

3.1 Patterns detection

The aim of this phase is to make a brief inventory of the various patterns associated to a specific object class. This inventory also serves to determine if it is relevant to use geometric patterns for this specific object class. In theory, any object classes can aspire to use geometric patterns. But, the basic concept of the geometric pattern is that the occurrences must present geometric similarities in order to be able to create certain forms that can be easily used by a large number of occurrences. Therefore, it is important right from the start to determine the object classes for which it is relevant to use geometric patterns. This discrimination avoids the creation of a plethoric number of geometric patterns as we create only the essential geometric patterns. A large number of geometric patterns makes the geometric patterns database creation much more laborious and reduce the performance of the system.

The detection of the various patterns is realized by an expert, from the initial map of the selected area. The initial map is the source map from which the smallest scales will be generated using geometric patterns. Using the initial map, the various potential patterns are detected, by visually analyzing the various elements of the object class for which we want to create geometric patterns. A particular attention is accorded to the frequency of appearance of various shapes on the map. The inventory of the different repetitive forms and the estimation of their frequency allow discovering a posteriori the necessary geometric patterns. The geometric patterns that are not representative are eliminated. But the existence of many representative geometric patterns permits to consider this object class as a good candidate for the use of geometric patterns

There is no magic number to quantify the relevance of the use of geometric patterns for an object class. But it is clear that the best object class for the use of geometric pattern is the one allowing to replace a majority of its elements by a small number of geometric patterns and to cover a large scale range. That is why it is important to make statistics showing the number of times that each pattern appears. After having analyzed these statistical results, we can thus retain only the better patterns, those which present a high frequency of appearance.

Besides, before even this analysis phase, certain object classes can be excluded from the list of the best candidate classes for the use of geometric patterns. Indeed, analyses from the GEMURE project test area showed that the most suited object classes to the use of the geometric patterns are buildings, highway cloverleaves and cul-de-sacs. For example, more than 75 % of the test area buildings were replaced by geometric patterns in 1K scale. But this does not mean that the patterns are not applicable to other object classes.

To facilitate the pattern detection it is sometimes helpful to use maps at various levels of details. Certain objects which seem very different on a large-scale map can present the same pattern on a smaller scale. For example, the majority of buildings are represented by simple rectangles on a small scale map, though they are represented by detailed polygons on large-scale maps. The use of several levels of abstraction allows detecting patterns appearing only on smaller scales. In the absence of different scales of the same territory, it is more difficult to imagine the various forms than an object can have over several scales. In that case, good cartographic generalization knowledge is necessary.

For certain object classes, it is very difficult to have geometric patterns when we see the complete object geometry. For example, it is very difficult to detect a pattern for entire rivers or entire roads. On the other hand certain parts of these objects (eg. road’s cloverleaf) can present good patterns. For these objects, the patterns search must be made not only at the level of whole objects, but also at the level of object geometric primitive (the objects sections). For that, segmentation is sometimes necessary.

Moreover of determining if it is relevant to use the geometric patterns for a given object class, this phase also allows to have a good idea of geometric patterns necessary to represent the selected object class. The analysis of these various patterns will drive us in the geometric patterns construction phase.

3.2 Primitives choice

The basic element for the construction of a geometric pattern is a primitive. That is why, during the previous step (cf. 3.1.), the detected patterns are meticulously analyzed to detect the different primitives that compose them. For that purpose, every pattern must be considered as being a juxtaposition of several primary shapes as rectangles, circles or triangles. For example, the pattern of a building can be created from several instances of a rectangle connected together (figure 1). This object design as an arrangement of different components is now shared by several researchers in the field of shape recognition [Fortin and Rousseau 1992]. According to [Biederman 1987], 36 primary shapes called geon, are enough for representing objects of our environment.

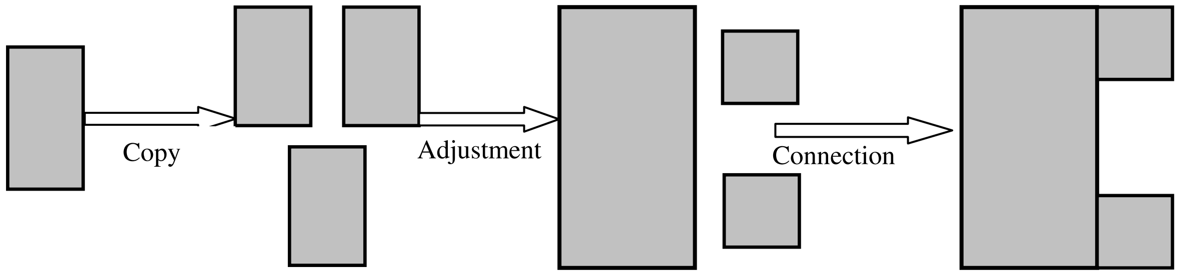

Figure 1 Buildings pattern composed by three instances of a rectangular primitive

The choice of the primitives shape is essential, because the shape of the geometric patterns which will be created and stored in the future database is strongly dependent on this choice. During the choice of the primitive, we must find, the balance between, on one side to have a restricted number of primitive, thus of geometric patterns and, on the other side, to adequately represent objects. Quantify the exact maximum number of primitives necessary to represent a given territory is not possible in our case. But, the 36 geons advanced by [Biederman 1987] seems to be plethoric in our case because geometric patterns are used in a context of cartographic generalization, which implies that they must be simpler than the objects they are meant to replace.

The number of primitives which will be used to create geometric patterns must be reduced to a minimum; otherwise it will lead to the creation of a phenomenal number of geometric patterns. For example, according to [Biederman 1987], by using 36 geons, we can create up to 157 million of objects. On the other hand, the representation potential of even a limited number of primitives is rather impressive. In fact, the various possible combinations between different primitive instances and operations applicable to each primitive instance (eg. change of orientation) allow to generate a large number of patterns. In our case, with six instances of a rectangular primitive, we can create 64 geometric patterns.

The choice of the primitives is closely related to the operations that can be applied on them. These pattern operations (applied on the entire pattern or on its primitives) must not allow to go from one primitive to another. If this case arises, a choice must be made to decide if we keep the primitive or the operation. For example if we have a rectangle and a square as primitive, it is impossible to keep the operation which allows changing the extension of the primitive. Using this operation, we can transform the square in a rectangle and inversely. Thus, the solution will be to take a more generic shape as primitive, for example an orthogonal parallelogram.

3.3 Choice of the most detailed common pattern

For each primitive retained during the previous phase (cf. 3.2), the most detailed common pattern must be defined from the detected pattern in the patterns detection phase (cf. 3.1). The most detailed common pattern is the pattern with the larger number of instances of primitive and from which we can build all derived patterns (formed by the same primitive) by deleting primitive instances. The most detailed common pattern can be seen as a union of the shapes of all patterns of its group. Figure 2 shows several patterns which were formed by the same primitive and the surrounded pattern is the most detailed common pattern of this group. The choice of the most detailed common pattern is a critical phase, because the size and the granularity of the database as well as the quality of generated data depend on this choice. It is about a balance between replacing the maximum number of map objects by fewer geometric patterns and covering a larger scale range with an acceptable degree of geometric accuracy. Indeed, a very detailed geometric pattern (with too many instances of primitive) would imply the creation of a larger number of derived geometric patterns resulting in a substantial increase of the patterns database size.

Some errors may arise during the patterns detection phase. To remedy to this kind of errors, the number of the instances of primitive of a pattern can be increased. For example, if our most detailed common pattern has 4 instances of the same primitive, we can choose a 6 instances pattern to have more flexibility. Raising the number of primitive's instances of the most detailed common pattern allows limiting the number of iterations during the geometric pattern's database creation. On the other hand, a substantial rise of the number of primitive instances can considerably increase the size of the database.

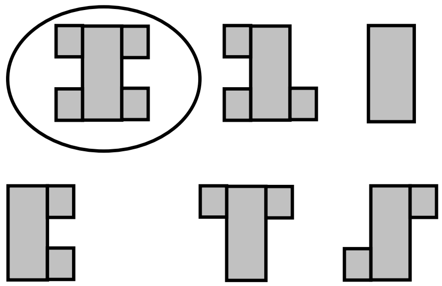

Figure 2 Group of patterns and its
most detailed common pattern

3.4 Initials geometric patterns creation

Each most detailed common pattern chosen during the previous phase (cf. 3.3.) is reproduced, using the patterns creation tools. The reproduced pattern is called the initial geometric pattern. Within the framework of the project GEMURE, tools which allow constructing geometric patterns were already created. These tools allow building geometric patterns from several instances of primitive. They also allow to perform several operations on the primitive such as changing the size, the anchoring points, the orientation of the primitive, etc. Geometric patterns are built by connecting several primitive instances. Figure 3.a shows a simple geometric pattern built from three instances of one rectangular primitive. But, an analysis of every most detailed common pattern is necessary to determine other parameters as the number of anchoring points, main and secondary primitives and the way these primitives are connected between them. For example, for the creation of the building geometric patterns, we can determine the number of secondary primitives connected on each main primitive side. Main primitive is the primitive on which secondary primitives are connected. . The creation of a geometric pattern begins with the creation of the main primitive. Afterward, various secondary primitives are connected. During the creation of the initial geometric pattern, an exact reproduction of the most detailed common pattern is not necessary because, the geometric pattern must be generic and manipulations are necessary to adapt it to a concrete map object.

Usually, for an object class that has been identified as relevant to the use of geometric patterns, the majority of its occurrences will be replaced by simple geometric patterns. However, these patterns may not be suited for more complex geometric objects that may be present in the object class. Complex geometric patterns must thus be used. The complex geometric patterns may be created in two ways: 1) by combining some primitives (instances of some primitives), 2) by combining already created geometric patterns. These geometric patterns can be simple and/or complex. Thus, the tools used for the simple geometric patterns creation are necessary. The figure 2.b shows a complex geometric pattern formed by an instance of a circular primitive and four instances of a square primitive.

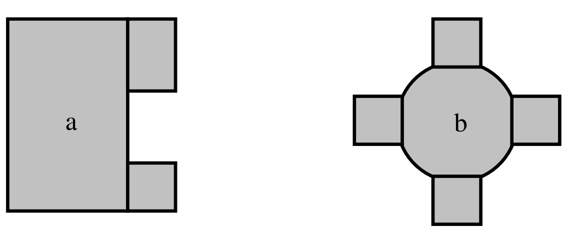

Figure 3 Two geometric patterns: a) simple geometric pattern;

b) complexe geometric pattern

3.5 Derived geometric patterns creation and the database creation

Besides operations such as rotation or displacement, which manipulate the entire pattern, they are also operations applicable to a primitive only. These operations allow to simplify the shape of a pattern and to fit it to the geometry of the object to be represented. The most important of these operations are:

- Elimination of a primitive;
- Combination of primitives;
- Change the primitive's size;
- Change the primitive's anchoring points;
- Change the primitive's orientation.

These operations are similar to that used during the generalization of 3D buildings described in [Thiemann 1999].

A derived geometric pattern is obtained by simplifying an initial geometric pattern. In theory, all these operations can be applied repeatedly to each initial geometric pattern, and then the generated derived geometric patterns can be stored in a database. But considering the important number of derived geometric patterns that can be generated with this approach (when applying all primitive operations) and the fact that some operations may be used on-the-fly, it is necessary to limit the number of operations that may be applied on initial geometric patterns when filling the database. Accordingly, only "elimination of a primitive" will be applied. For that purpose, the elimination of primitive is applied to the initial geometric pattern in an iterative way until we obtain the primitive that was used to build the pattern. For example, if we have an initial geometric pattern formed by instances of a rectangular primitive, the operation elimination of a primitive is applied repeatedly until we obtain rectangle. Only one instance of primitive is removed by iteration, and all possible configurations are obtained by permuting the remaining instances. When all derived geometric patterns of the same pattern are generated, the redundant patterns are deleted. Geometric patterns are also considered redundant when they can be obtained by rotating or by scaling an existing geometric pattern.

Each initial geometric pattern and its various derived geometric patterns are stored in a hierarchical tree (figure 4.) whose depth determines the number of primitive instances and consequently the level of detail of the pattern. The hierarchical structures are often used to store geographical data in order to minimize the redundancy and to facilitate the access ([Van Oosterom and Schenkelaars 1995]). Each geometric pattern (initial or derived) is linked to its children. These links forms the tree structure of geometric patterns. This tree structure facilitates the navigation through different levels of abstraction of the same pattern. So, for every map object, we can associate a geometric pattern (if this object can possess one). Also, we can indicate the path in the tree which allows accessing other derived geometric patterns. The choice of the associated geometric pattern and the tree's path depends on the shape of the object. Thus the geometric pattern tree (initial and derived geometric patterns) is a multiscale pattern which can represent different objects in different level of abstraction. So, the generalization using geometric patterns become a simple navigation through different hierarchical levels of the geometric patterns tree.

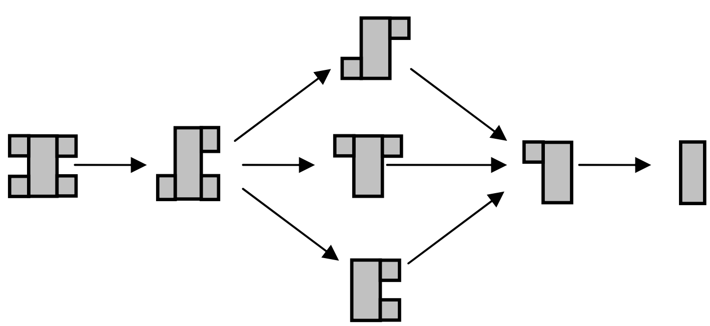

Figure 4 Tree structure of buildings geometric patterns

This research project is continuing towards efficient ways of coding in a unique data string the path or details of each pattern so it even becomes faster. We are also considering the inclusion of additional operations easy to implement in such a string (ex. collapse a primitive by half).

4. CONCLUSION

In this paper, we presented a five-step methodology to create a geometric patterns database. Geometric patterns are generic objects with geometrical basic characteristics used to replace map elements. This methodology allows creating at first one detailed geometric pattern (initial geometric pattern) for each pattern's primitive type. Other derived geometric patterns are generated by iterative simplification of the initial geometric pattern. Results are stored in a geometric patterns database using a tree structure. This methodology simplifies the process of building the geometric patterns database as, for each primitive type, only one geometric pattern is created.

The resulting database can be used in an on-the-fly map generalization process. So, for every map object (if this object can have a corresponding geometric pattern), we can create a link between this object and a geometric pattern. The underlying hierarchical structure allows the access to other derived geometric patterns from this cartographic object. All geometric patterns linked to a cartographic object constitute different shapes of this object, each shape corresponding to a different level of abstraction. Thus, instead of applying complex generalization algorithms when changing the level of abstraction, a corresponding geometric pattern is selected, adjusted and used to replace the object.

The geometric patterns stored in the database can also be used during a multi-scale database acquisition. So, instead of capturing different geometries of the same object, we can only capture the most detailed geometry and associate geometric patterns to provide the object with simplified geometries to be used at different levels of detail. Some researches towards this approach have already been initiated at the Centre for Research in Geomatics at Laval University.

Besides accelerating generalization processes, geometric patterns can also facilitate the data transit through the network. Indeed, in a client/server architecture, all the geometric patterns needed for the generalization of the user's map can be transferred only once to the client side. So, during the generalization processes, instead of transferring the results of the generalization (the generalized object obtained using traditional generalization algorithms or geometric patterns), we transfer only the parameters that will be used to adjust the geometric pattern. This would considerably decrease the volume of data transfer through the network.

One of the points that appear as a disadvantage of this approach is the amount of work required to create the database and to associate geometric patterns to the different map objects. However, this work is made only once and the results are useful several times and even for various territories. Also, certain stages of this methodology such as the pattern's detection can be automated. Future works will be centered on the automation of certain steps of this methodology and on the integration of traditional generalization methods to support the generalization of the objects that are not suited to the geometric patterns approach.

5. ACKNOWLEDGMENTS

The authors are grateful to the Canadian Network of excellence GEOIDE which made possible these works within the framework of the GEMURE project, as well as the following partners: Research and Development Defense Canada, Natural Resources Canada, Natural Resources, Fauna and Park Quebec, Intergraph.

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