

# GENERALIZATION PROCESS FOR URBAN CITY-BLOCK MAPS

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## 1 Abstract

A generalization engine based on a raster-vector structure (BCNRV) is presented in this paper. The generalization engine includes a toolbox based on selection, generalization, map algebra and mathematical morphology toolset operators. Using this generalization engine we have developed a generalization process for urban city block maps. The generalization engine has a high level of versatility. Therefore, the processes and solutions presented here are only a few among the many possible. Here we explain the way we have adjusted this process (operators and parameters), to include expert knowledge by means of a feedback process in order to generalize urban city-block maps in a semiautomatic way.

## 2 Introduction

Today the National Mapping Agencies of many countries are producing almost all of their maps via digital production. Nevertheless, significant problems still exist when we try to change the scale by applying an automatic generalization procedure, particularly for urban city block maps (Iribas, 2000).

Automatic generalization has been a subject of great research in cartography. It has been developed by public and private institutions: the National Oceanographic Administration Agency in USA (Clayton, 1986; Shea, 1988), the Institut Geographique National of France (Rousseau et al., 1994; Barrault, 1995; Plazanet, 1996), the Instituto Geográfico Nacional of Spain (Iribas, 1997), the National Centre of Geographic Analysis (Jasinski, 1990; Fico, 1992), the European Organization for Experimental Photogrammetric Research (OEEPE, 1994), the AGENT project (1997-2000) and many others.

Automatic generalization also tries to solve the problem of subjectivity in manual generalization. This subjectivity is due not only to the lack of a set of “universal” rules of generalization, but also the cartographic background and personal experience of every operator. Different results can also be obtained working with the same element, despite the fact that only one person has worked on it in all cases, because of the absence of repetitivity. On the other hand, due to the fact that the sequence of operations will be always the same, the digital procedure will always offer the same result if the data and the initial parameters are the same. Nevertheless, the cartographic and geographic knowledge on which manual generalization is based needs to be incorporated into the digital context, but there is a relative scarcity of available formalized cartographic knowledge (Weibel, 1995). In fact, this is one of the most complex difficulties that Cartography meets nowadays.

Urban areas are of great interest in cartography. They have three important characteristics: high population density, feature complexity and a high rate of change both in time and space. For this reason, cartographic processes like automatic actualization and generalization are critical when dealing with them.

Because of the complexity of urban areas, research on their automatic generalization is not as numerous as research on linear elements. There are two main model options for dealing with such generalization in digital mapping (Ureña, 2004; Ureña and Ariza, 2005a): vector and raster. The vector model is based on object representation by coordinates. In the vector model, points, lines and areas (polygons) are the units that carry information and support the generalization process. Within the vector perspective, the generalization of urban maps is complex because of the interdependence of objects and the semantic implications. Ruas and Mackaness (1997) present the philosophical elements involved in such a generalization. Cuenin (1972) shows a very practical point of view within a manual framework, Powitz (1993) presents an example of how to generalize within an automated framework, and OEEPE (1994) shows us the problems with commercial software applications.

The raster model is a space-primary data structure (Li and Su 1997) representing reality in terms of uniform, regular cells, which are usually rectangular or square. In the raster model objects and spatial relationships among them are

implicit (Ehlers 1991). Raster generalization is reasonably large as generalization is caused by a reduction in graphics space when a map scale becomes smaller. Nevertheless, raster generalization has received less attention than vector generalization, and most of the work on it is associated with remote sensing. Without any specific mention of Mathematical Morphology, the work of Monmonier (1983) shows one of the first applications of the erosion operator in a raster mode area generalization applied in cartography. For Monmonier (1983), raster generalization is more appropriate than vector for a land use or land cover data generalization because the raster model approach promotes the partitioning of thin or insignificant polygons and the growing or linking of others. Ureña and Ariza (2000) present an example of applying mathematical morphology to the generalization of area features with complex relations (city-blocks).

In this paper we present a model and a process for generalizing built-up areas which is developed on a hybrid raster-vector data model that we call BCNRV, which is also presented to this 22nd International Cartographic Conference (Ureña and Ariza, 2005). This model can be understood as a toolbox of logical and spatial operators that can be applied to the BCNRV to generalize urban areas. The starting point of the process is a set of built-up areas (vector model), which will be converted to raster model and enriched with a set of key attributes. The generalization takes place simultaneously using city-blocks (raster), streets (vector) and key attributes.

In the following section we present a review of different studies which give an understanding of the state of the art of this complex process and achievements. From all of these we have extracted some important issues that are taken into account for the development of our generalization engine. Next we present what we call the generalization engine which is the implemented workbench with operators that can be applied to a BCNRV. Later, a complete example of a generalization process is shown. Finally the main conclusions are stated.

### 3 State of the art

The recent years have been very fruitful, and many proposals, models, methods and examples dealing with the generalization of urban maps have appeared. In general, we can conclude that vector models have been increasing their complexity, that both methods have achieved great advances in generalization operators, particularly in shape simplification and object displacement, but that no method, neither raster nor vector, has achieved a successful solution. In the following paragraphs we briefly describe more interesting ideas for our issue of interest:

- Mackaness (1995): This work has great implications for the use of streets as important indexes of city-blocks. The main idea is to see cities as a set of relations among the transportation network (streets), urban morphology and spatial distribution on urban use. The structure of the city is constrained, but also constraining, because of the interaction among these elements.
- Jones, Bunday and Ware (1995): Here reality is divided into simplexes (triangles) that are derived by a Constrained Delaunay Triangulation. The triangular irregular network is stored in a Simplicial Data Structure that is used to implement some generalization operators: simplification, collapse, exaggeration and amalgamation.
- Hangoüet (1998): Some generalization operators are developed using Delaunay Triangulation or equal-area rectangles. Afterwards, the operator follows a categorical generalization which is achieved using a conversion to equal-area rectangles and a spatial redistribution of these objects. The process also includes elimination operators if conflict arises. The redistribution function is a self-generated lineal one, but is constrained by buildings whose orientations are different to that of their street.
- Regnauld (1998): Two interesting generalization operators are introduced, both of them based on relations among the objects within a Minimum Spanning Tree (MST):
  - a) Structuring: Reduces conflicts inside an urban island (city-block) using a displacement algorithm.
  - b) Amalgamation: Operates in two different ways. The first is based on the displacement of a small object towards an object of greater area. The displacement distance can be defined taking into account aesthetic criteria or minimum distance criteria. The second amalgamation operator is the filling of gaps among buildings; here convex hulls of objects are used.
- Ruas (1999): In a very comprehensive study Ruas proposes a new generalization method (subsequently inherited by Agent Project) in which the main phases are:
  - a. Enrichment of the objects database.

- b. Testing of some attributes of the objects against map specifications.
- c. Automatic proposal of one or more algorithms to solve the most important of possible conflicts.
- d. Calculation of new characteristics and repetition from step “b” until the desired accomplished agreement is reached.

Another important issue is the introduction of a three-level hierarchy: micro (level of single map elements), meso (first aggregation level micro objects), and macro (the general level of the map). Ruas applies the previous sequence to all micro objects using the constraints of the macro level. So this is a self-guided generalization process.

- Sester (2000): Two generalization operators are proposed:
  - a. Simplification of buildings: Reduces the perimeter detail based on maximum and minimum side distance.
  - b. Displacement operator: Is based on shape parameters (sides, angles and orientation), the minimum and critical distances (to discriminate between amalgamation and displacement), and position. These parameters are minimized using a least square adjustment. The weight of each value is defined in order to define the degree of agreement required.
- Agent Project (1997–2000): The main concept of this project is the Agent term. An Agent is briefly defined as a member or something that can solve a problem using teamwork. All the agents are micro, meso or macro (Ruas, 1999). In this classification macro agents trigger the activity of meso agents, and these trigger the activity of micro agents. When the triggered activity returns to its caller the map specifications are reached. Agent project is only concerned with meso and micro agents.
- Bader (2001): Energy minimization methods are used for feature displacement (lines and buildings).
- Monmonier (1983): One of the first studies that uses a raster model and is justified by its greater efficiency for semi-automatic areal generalization. Monmonier proposes an algorithm that maintains multiple classes by reducing the number of pixels. This reduction is based on a weighted average of the minicells (sets of pixels).
- Schylberg (1993): Here the use of three new operators in the raster model is proposed:
  - a. Amalgamation: A simplified version of aggregation operator that only handles area features.
  - b. Simplification: An operator that reduces details of area features.
  - c. Elimination: Algorithm to delete small or unsuitable features for the purpose of mapping.
- Su, Li y Lodwick (1997, 1998a y 1998b): Their work develops different method of generalization based on mathematical morphology. They propose elimination and aggregation (amalgamation) of areas by using opening and closing operations with circular shaped kernels whose size depends on scale reduction.

#### **4 The Generalization Engine**

Here we explain our generalization engine. This implements selection and generalization operators which are then applied to a generalization process. This process involves other aspects such as gestalt selection among urban features (city-blocks/buildings). These processes can only be handled using the Raster-Vector Cartographic Numeric Database (BCNRV).

Multiple operators have been developed and integrated into one program that we call the generalization engine. This is a workbench whose objective is to unify and simplify the testing process. We decided to use two different methods to implement this workbench:

1. Interactive method: User selects each operation and parameters and runs then one by one.
2. Virtual machine method: User programs in a plain language all parameters and runs this program (this operation can be used in normal run mode or in debug mode).

The generalization engine has four operator classes that define a toolset which allows the simulation of many cartographic operators:

1. Selection operators.
2. Generalization operators.
3. Map algebra operators.
4. Mathematical Morphology operators.

Following paragraphs briefly describe the toolset elements.

#### 4.1 Selection operators

The query processes are basic to select features. Multiple selection mechanisms have been developed in our generalization engine to simulate logics operators and simplify user's queries:

- a. Add to: Equal to logic O.
- b. Reselect: Equal to logic AND.
- c. Extract: Not needed, but implemented as a NOT AND (NAND).
- d. Invert selection: Equal to logic NOT of previous selections.

The above selections can also be applied in two ways:

1. For a given value interval: All objects whose values are between a defined maximum and minimum.
2. For a predefined number of objects from the whole: The percentage of objects which should comply with a given condition can be stated.

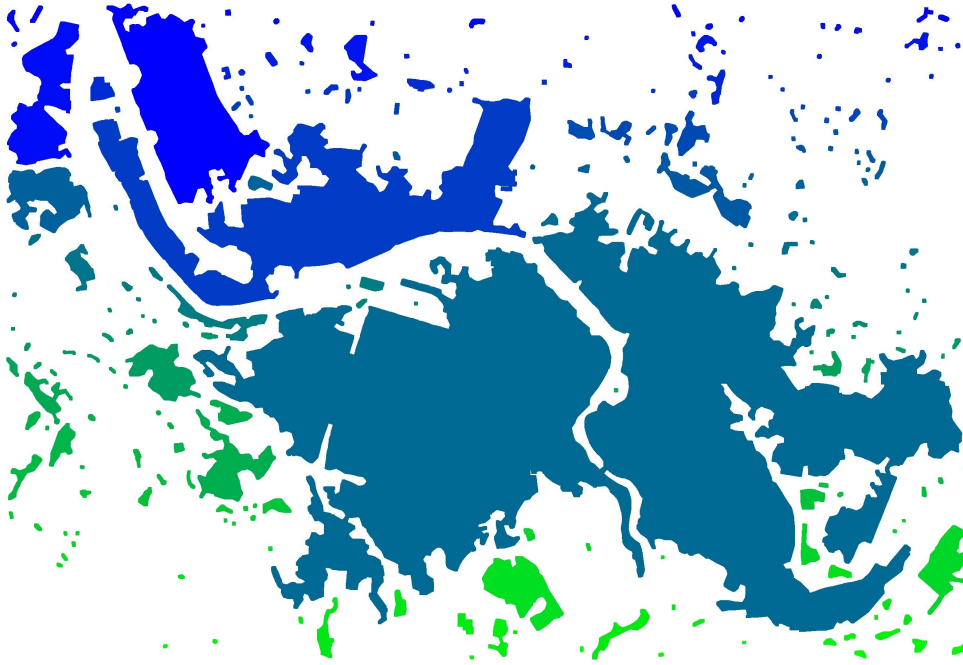
However, the above-mentioned selections are only based on the attributes of features (city-block/buildings, proximity networks, streets and lines of sight) from a BCNRV data set (see Ureña and Ariza 2005b). For that reason some spatial criteria has been added to extend selections to near objects, for example the selection of instances of the proximity network must erase streets that cross them, and conversely, a selection of instances of streets must erase the crossing proximity network.

#### 4.2 Generalization Operators

We have developed multiple generalization operators in the raster model to simulate those described by McMaster and Shea (1992):

- Amalgamation operator: Two amalgamation operators are implemented:
  1. Fusion of sides with distances less than a certain tolerance.
  2. Morphologic closing.

Also there is a special amalgamation operator which is applied to city zoning, joining and extracting all objects. The algorithm joins objects using distances, which is similar to vector amalgamation. The algorithm calculates all distances from perimeter pixels of one object to another, both of them in the same mesoblock. If this distance is less than the tolerance both pixels are joined. We call this solution an object extension (example shown in **Figure 1**).



**Figure 1. Example shows a complete use of amalgamation of zonified objects to the city of Bilbao. Each color represents a different zone.**

- Quasi-convex hull operator: This is an extreme case of the previous operator: the amalgamation operator is applied many times in order to achieve the quasi-convex hull. If we previously select a set of objects it is possible to create a segmentation or zonification of the city. This operator, when applied to a single object, develops a shape simplification algorithm.
- Erasing operator: Erases selected objects. The difference between this operator and other erasing operators is that they handle different objects. Therefore, if a street is erased here, two city-blocks/buildings are amalgamated and their topological relations erased. This implementation is based on the BCNRV structure proposed by Ureña and Ariza (2005b).
- Displacement operator: This operator has two approximations:
  - a. Mathematical Morphology approximation.
  - b. Basic approximation: A composition of erasing from the old position and rebuilding into the new position is used.
- Street rebuilding operator: This algorithm is exclusively raster. It is very similar to the paint option of an image editor (like paint brush). The size of the brush can be controlled so that we can reconstruct different widths.

### **4.3 Map algebra operators**

All the algebraic operators (addition, multiplication, and so on) have been included to be applied to raster images.

### **4.4 Mathematical Morphology operators.**

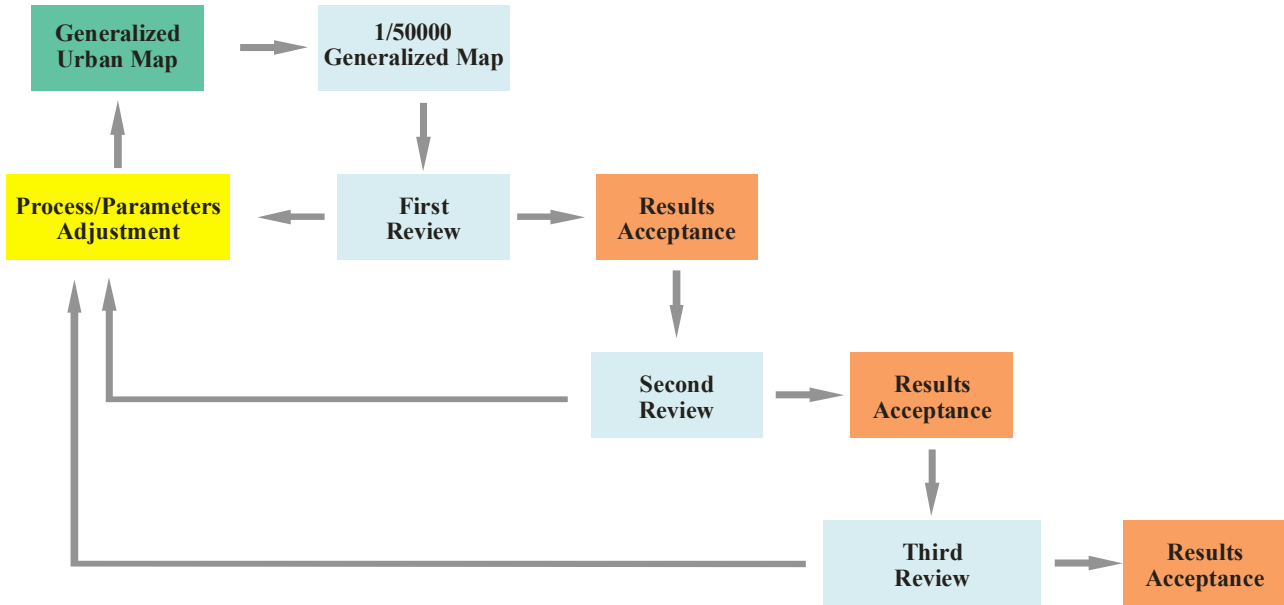
Three basic mathematical morphology operators have been included in the generalization engine: dilation, erosion and complementary image. Because of their relevance, opening and closing operators have also been included in the generalization engine. A set of morphological operators can also be automatically applied and the decision for defining the origins of morphological kernels (for displacement operators) is left to the generalization module.

## **5 The Generalization Process: Applying the Generalization Engine**

The generalization processes that can be applied with the previously described toolset are too many to mention here. However, the generalization engine needs a guide to achieve its goals, and for this reason we have developed a complete process, including expert revision of results, for the adjustment of operators and parameters.

Here it is of much relevance to keep in mind the cartographer's way of thinking when generalizing a city map. The laws of perception are one of the bases that control the generalization process. For that reason they are an important guide for the selection of objects (Thorisson, 1994; Rome, 2001; Anders, 2003).

The experience of the cartographer is very difficult to implement in an automatic generalization model. However, we have included part of this knowledge by means of a three-times reviewing process. Each revision produces a feedback that modifies operators/parameters of the generalization process for an appropriate tuning. For this reason, we believe that the result is a semiautomatic process which can reduce subjectivity when generalizing, but some expert edition is needed on the map to achieve a final cartographic solution. This process can be refined for each city and stored in the model as additional data or as process script. A general view of the feedback process is shown in Figure 2.



**Figure 2. Feedback of the generalization process developed in this paper.**

The first version of the generalization process was used to propose different sets of selections and amalgamations. Furthermore, shape simplification is included. All these operations have been considered as the principal ones in the generalization of urban city-block maps. This first generalization process was used to define those initial parameters which we believed to be the most suitable.

After a review of the results, we included an erasing algorithm to remove lower-density zones of the city and improve map reading. Later, we selected one of these sets of parameters/operators and improved it with a wider range of parameters. This process was reviewed by the staff of our cartographic sciences department.

After the second review, we modified the generalization process to the one shows in Figure 3. The main change was a new erasing operator of small city-blocks. When the definition of the third generalization process was completed, we sent the results to a number of external experts from various universities and mapping agencies. They gave us some interesting feedback:

- a) In general, solutions are acceptable for visualization purposes.
- b) Too many small objects speckle the image.
- c) The generalization process shows a low level of predictable behavior, from an external point of view.
- d) A more local process is needed.
- e) There is an extensive loss of spatial structure. This conflict and the smaller objects are the main problems.
- f) The rounding of city-block/building shapes shows in all examples.
- g) The process prefers city-blocks/buildings to other parts of the city. This increases the urban density of the whole city.
- h) The previous conflict shows in different parts of the city, so we have different densities in different parts. However, the global perception of the city is similar to the desired one.

We have solved all the previous conflicts in the following ways:

1. The conflict of paragraph b) has been solved by improving the set of objects to be erased.
2. The conflict of paragraph f) has been solved by changing the amalgamation operator for morphological closing.

3. The conflicts of paragraphs g) and h) have been solved by segmenting the city and using ratios of urban density both globally and zonally.

Given the limitations of the current technology, the problem of paragraph e) might only be solved if the results are reviewed by an actual cartographer. This reviewing process was previously included in the generalization engine. In this way, we propose a semi-automatic generalization process.

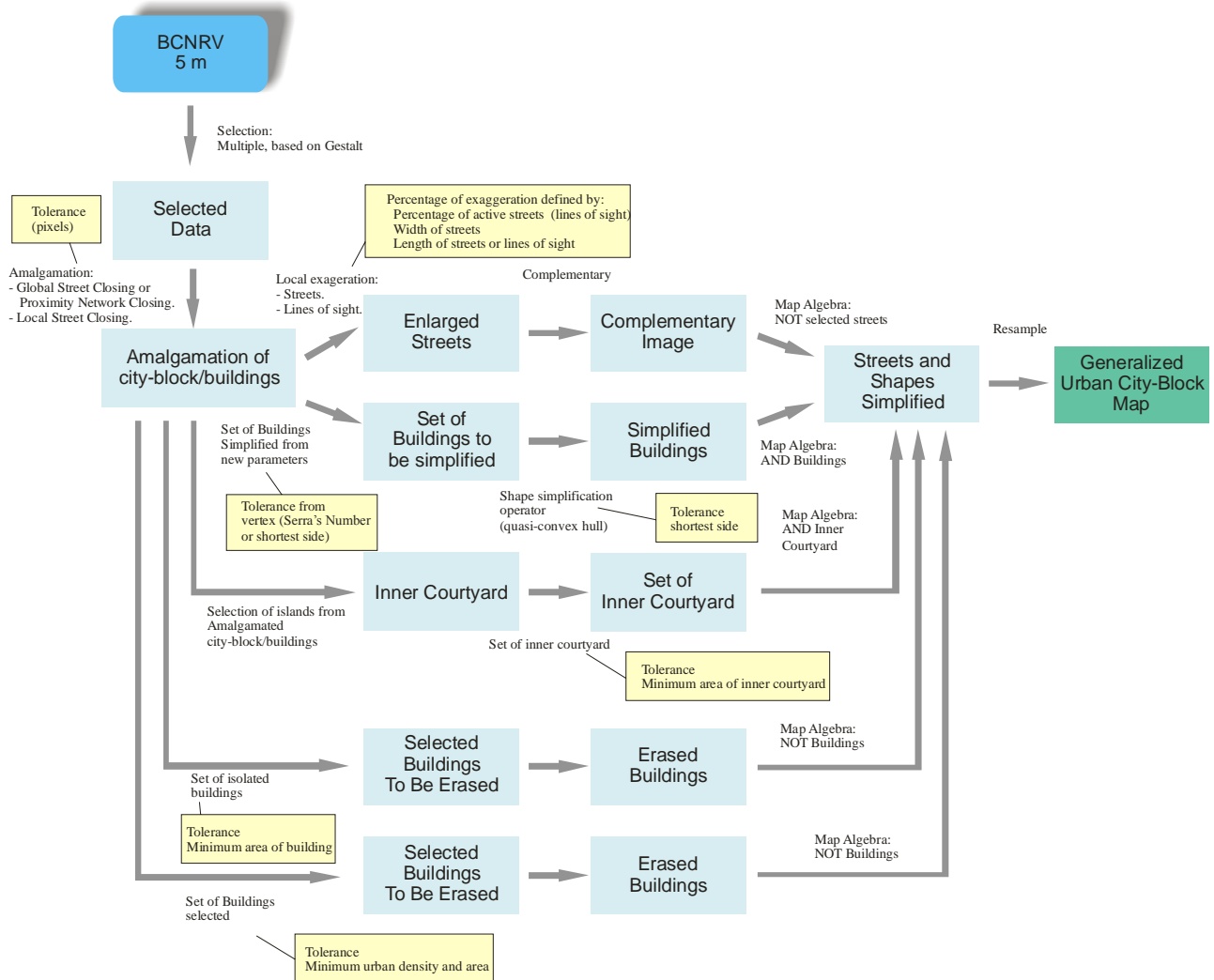


Figure 3. Final generalization process developed after three feedback reviews.

## 6 Conclusions.

In this paper we have presented two main aspects of our work. The first is the development of a generalization engine that integrates multiple operators and the management of the BCNRV objects in one program. The second is a generalization process that has been improved three times using a feedback mechanism.

The generalization engine has four sets of operators (Selection, generalization, map algebra and mathematical morphology operators). All these operators can be used either interactively or by batch-processing. Furthermore, the generalization engine enabled us to debug all batch programs and to manage different features of a city. All these operators have been applied to BCNRV, and thus we have improved the conceptual model adding the generalization to the storage structure.

The most complex implemented operators are amalgamation and shape simplification. Both of these have been extensively tested. These tests show that the first has a low level of predictability, and the second is more similar to the expected results. This is the reason why we test the amalgamation type and the tolerance parameter. The reviews indicate that morphological amalgamation is the best operator. However, the tolerance depends on street width and other parameters such as urban density.

The generalization process developed, as shown in Figure 3, has been implemented for both parallel and serial applications. We have determined that the critical phase is the selection. We have tested via different attribute, spatial and object selections (city-block/buildings, proximity network, streets and lines of sight) before proceeding to develop our first generalization process. The gestalt laws have been used to determine the similarities between objects, mainly city-blocks. Our results (see Ureña and Ariza, 2005a) have shown that these laws associate objects in the same way a cartographer would do during generalization process.

On the other hand, we have achieved a new envelope of objects we call the quasi-convex hull. We control the size of the selected set of objects in order to produce an amalgamation in a quasi-local process. This extension or reduction of the set is based on the graph that connects all objects (proximity network from BCNRV).

The generalization process, proposed in this paper, is an interpretation of the results of the pool of experts we carried out previously (Ureña and Ariza 2005a). This interpretation was applied to the operators/parameters in the BCNRV on three different occasions. So, part of the experts' and authors' knowledge has been included in this process, but even more knowledge is needed if we hope to attain the generalization level of the cartographer. For this reason, this knowledge must be embedded in the generalization engine. However, the current process is incomplete and thus needs the later modifications of the solutions by a cartographer (a semiautomatic process).

In this paper we have shown the process of semi-automatic generalization and the generalization engine on which it is based. This generalization engine also includes a toolset which allows reviewing and modification by a cartographer. Nevertheless, our research continues to seek to develop a generalization process which is completely automatic.

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