Analyzing and Deriving Geographic Contexts for Generalization

Dan Lee
ESRI, Redlands, California, USA, dlee@esri.com

Paul Hardy
ESRI, UK, phardy@esri.com

ABSTRACT

The stated aim of many national mapping agencies (NMAs) is to build a master large-scale digital landscape model (DLM), from which medium- or small-scale DLMs are to be derived. The digital cartographic models (DCMs) and subsequent cartographic products are then compiled from the corresponding DLMs. Generalization is at the heart of such a production strategy. Meeting the challenge of integrating comprehensive generalization capabilities into ArcGIS (ESRI’s core GIS software product family) to fully support the aims of NMAs requires more research focused on advanced and comprehensive solutions, while the development of fundamental generalization tools continues.

Generalization is about representing the geographic reality as faithfully as possible under map scale restrictions. Although automated tools have been developed to perform specific steps of generalization, such as aggregation of polygons or simplification of lines, it is obvious that post-inspections and corrections would be necessary when putting the individually processed features in context at a target map scale. The increasing demands for contextual generalization have lead to our investigation into typical geographic contexts involved in generalization and into analysis and geoprocessing for deriving information to facilitate contextual generalization.

Geographic features are spatially and semantically related, and interfere with each other in many ways - some are topologically connected, others in relative positions. Geographic patterns - natural subdivisions, cultural areas, clusters, or alignments, can be implicit or explicit. Both model and cartographic generalization share a common principle – they must recognize and preserve these characteristics. In the body of existing cartographic specifications, it is easy to find generalization requirements like these two: (1) - “A small building in a rural area should not be excluded if it serves as a landmark”, which would require the determination of the rural area, the neighboring situation of the building within certain extent, and the visibility and significance of the building to travelers; and (2) – “In areas where numerous point features of the same class exist, a representative pattern should be used which will retain the general layout of the features”, which requires measuring of density, recognition of the distribution pattern, and construction of a typified new layout. This paper discusses the various aspects and types of geographical contexts and illustrates the use of geoprocessing models to derive information for contextual generalization. As a parallel task, prototyping of an optimization mechanism for generalization is also in progress. This study and experience in defining and deriving contextual information will be an important input to the optimization process.

Keywords: contextual generalization, generalisation, geographic patterns, geoprocessing.

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1 INTRODUCTION

A common main task at NMAs is topographic mapping. Every digital landscape model (DLM) they create is a generalized model of the real world. Although a DLM may be considered by some people as scale-independent, it is usually constructed to serve as a starting point for compiling digital cartographic models (DCMs) at certain scale range. As presented in Figure 1 – Swisstopo's MRDB data flow (Kreiter, 2003), the DLM200 (DLM at 1:200,000) may contain data that is only relevant for building DCMs at 1:200,000 – 1:500,000. Therefore, DLM data can be selectively collected or derived with the necessary level of detail and accuracy for a desired scale range.

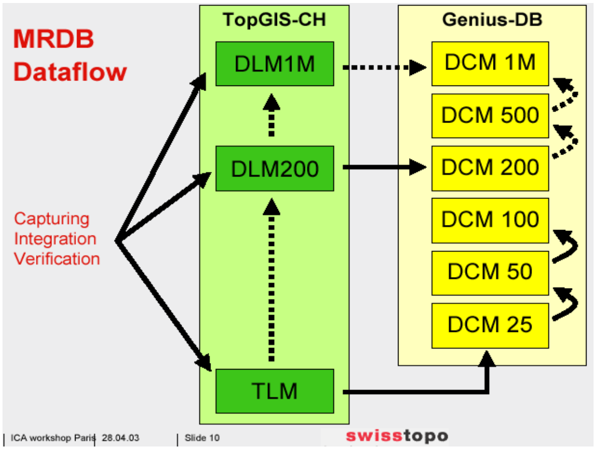

Figure 1:

Swisstopo MRDB dataflow showing DLMs and DCMs, and their correspondent scale ranges

Topographic mapping is a sophisticated process under scale restriction – "the value and importance of topographic features must be considered in their totality" [Böhme, 1984] – no features should be generalized and presented in isolation. Database generalization (compiling DLMs) and cartographic generalization (deriving DCMs) share a common principle – to preserve the characteristics and spatial relationships of geographic features as faithfully as possible for a given scale. Contextual generalization has become a main focus and strong demand in research and development. One of the most noticeable works was the AGENT project [Lamy et al, 1999], in which a great deal of constraints, priorities, and actions were defined and orchestrated to address contextual generalization. However, many aspects of contextual generalization still remain to be understood and automated effectively.

Geographic contexts exist at different levels – between immediate neighboring features, among features in a partitioned space, and beyond partitions in a mapped area. The success of automated generalization depends on how well the contextual information is recognized and preserved. An earlier discussion showed that certain spatial contexts had been considered in our existing generalization tools, and that others are to be addressed in the future [Lee, 2004]. This current paper examines some popular NMA specifications and practices requiring contextual analysis and presents analytical ideas and geoprocessing models built with existing tools in ArcGIS, that help characterize geographic features, derive their relationships, and support contextual generalization.

2 PRESERVING TOPOLOGICAL RELATIONSHIPS

Geographic features can be topologically related with shared connections or boundaries. Keeping correct topological relationships is a common requirement in mapping specifications and is fundamental in contextual generalization. Spatially joined features should remain connected at intersections or by shared geometries; spatially disjoined features should stay in their correct relative positions.

Although topological relationships are not explicitly stored in the geodatabase model in ArcGIS, many of them can be revealed on the fly through the topology engine for data analysis and derivation. Discussions and examples were given in two previous papers showing simplification of connected buildings [Lee and Hardy, 2005] and generalization of natural features with intersections [Lee and Hardy, 2006] using existing geoprocessing tools or models, as shown in Figure 2.

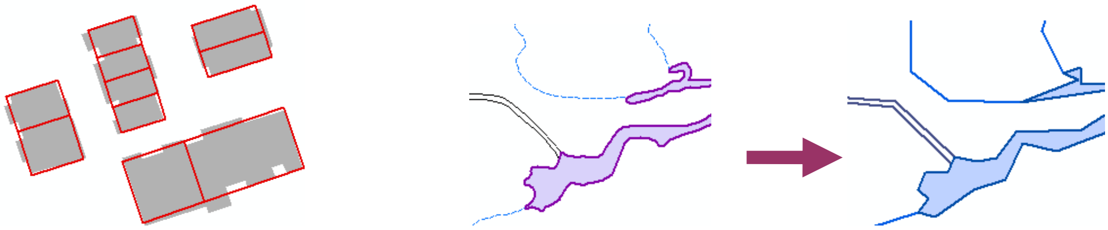

Figure 2:

Simplification of adjacent buildings (left) and generalization of rivers and lakes with connections (right)

In order to recognize and preserve the relative positions between features, an appropriate data structure would need to be built to hold the existing relationships and to help detect any violations or misplacements. A recent research task, as part of the Optimizer prototype project, has targeted this issue, in particular to simplify polygon boundaries while keeping point features on the correct sides of the boundaries [Monnot et al, 2007a]. Extensions of similar logic to other features in other types of generalization operations are to be explored.

3 RECOGNIZING GEOGRAPHIC PATTERNS EMBEDDED AMONG NEIGHBORING FEATURES

Geographic features can be tied in close proximity and distributed in certain patterns. These spatial characteristics need to be recognized and preserved. Patterns formed by features in a neighborhood are usually easy for human eyes to catch, but not explicitly stored in a database. It has been a challenge in contextual generalization to define or describe geographic patterns digitally and identify them computationally.

The difficulty about recognizing patterns embedded in a neighborhood lies in the complexity of the reality. Patterns would be easy to recognize if features are positioned in perfect configuration, such as equally spaced, aligned to a straight line or other regular shape, symmetrically laid out, and so on. But, in the real world, features may form some patterns close to being regular, but never perfect; they may look similar from one neighborhood to another, but vary in many ways. Analytical methods may be applied to help identify patterns with some success, but they are often sensitive to these variations or inconsistencies, as illustrated in the following example.

Example – finding areas with enclosing building patterns and high building density

It seems quite common that in urban area generalization from 1:10000 scale to 1:50000 scale, many individual buildings shown on the 1:10000 map are replaced by (or aggregated into) urban block areas. What are the factors considered during the decision-making and how are they weighted? According to an analysis of the Netherlands TOP10NL and TOP50vector products and 50K cartographic map specifications [van Smaalen, 2007]:

"Areas with buildings that conceal the enclosed area from the road are aggregated into built-up area. The buildings in this example cover 24% of the area in which they are located (2 parcels in centre)." The associated map areas are shown in Figure 3.

TOP10NL TOP50vector

Figure 3:
Buildings enclosing a street block with sufficient density in the block may be considered for aggregation into urban areas.

Deriving building density per street block

Building density in a street block can be a contributing factor in the decision of aggregating buildings into urban areas. Given that the TOP10NL database contains road casings (as polygons) and building polygons, a geoprocessing model (Figure 4) was built to do the analysis and calculation using existing tools without any custom programming. The steps are:

a) Dissolve road casing polygons so that the small junction polygons disappear.

b) Build street block polygons (str_polys) from road polygons. (Feature to Polygon tool)

c) Add an attribute field, bldg_density, to the str_polys table to store building density values. (Add Field tool)

d) Overlay buildings with the str_polys so that buildings obtain their associated street block polygon IDs, str_polys_ID. (Intersect tool)

e) Summarize the total area of buildings in each street block polygon. (Frequency tool with area summation by str_polys_ID)

f) Join the frequency table with the str_polys table by str_polys_ID to obtain a table view showing the total building area and the street block area for each street block. (Add Join tool using str_polys_ID as the common field)

g) Compute building density (total building area / street block area) for each street block polygon and store the values in bldg_density field, as labeled in Figure 5. (Calculate Field tool)

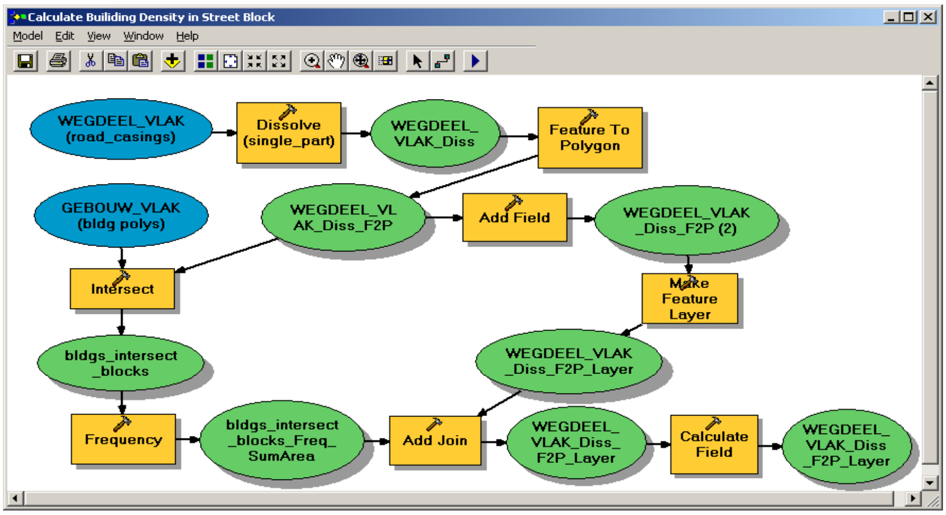

Figure 4: Geoprocessing model – Calculate Building Density in Street Blocks

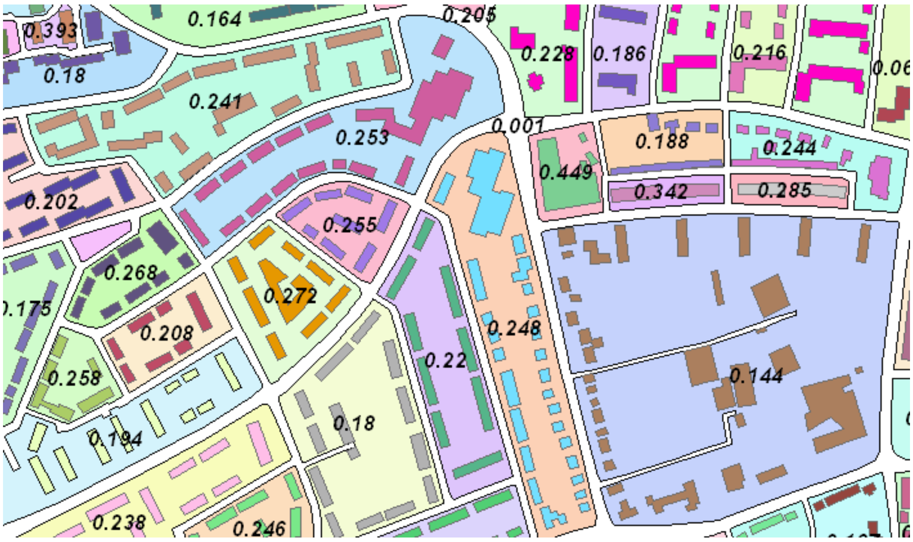

Figure 5: Building density values per street block polygon by geoprocessing.

(Data courtesy of Netherlands Kadaster)

<u>Identifying enclosing building patterns in street blocks</u>

The enclosing building pattern, as mentioned in Figure 3 and which can be visually recognized in Figure 5, seems to have the following characteristics:

- Buildings are within certain distance range from their associated street block borders.
- Many buildings have the longer side along the nearest street, although not necessarily parallel.
- Buildings have relatively smaller gaps between them – the smaller the total gap length, the stronger the enclosing pattern is.

A geoprocessing model (omitted from this paper due to the length limitation) was built to do the analysis and calculation using existing tools without any custom programming. The general steps are:

a) Create buffers inside each street block polygon using an experimental negative buffer distance. (Buffer tool)

   The reason for the buffer distance being experimental is that it may not be suitable for all street blocks, especially where block sizes and building sizes are very different. In order to find buffer distances tailored to specific street blocks, more detailed analysis can be done following the geoprocessing ideas described below:

   - Find the nearest distance from each building to the associated street block border. (Near tool, which adds a Near_Distance field and values to the building polygons).
   - Calculate the mean near_distance for buildings in each street block. (Frequency tool with mean on Near_Distance by str_polys_ID)
   - Add an attribute field, bldg_mean_dist, to the str_polys table to store building mean distance values. (Add Field tool)
   - Join the frequency table with the str_polys table to obtain a table view. (Add Join tool)
   - Calculate the bldg_mean_dist field in the str_polys table to equal to {negative values of (the mean distance values in the frequency table) + 0.2 (small building side)}. (Calculate Field tool with an experimental calculation; the negative values are for buffering inwards in the street blocks; the second term in the formula is intended to make the buffer distances slightly larger, therefore having a better chance to cross buildings)

- Select street block polygons by the absolute value of bldg_mean_dist value smaller than an experimental value so that only buildings relatively close to the street block borders are processed. (Select tool with a SQL expression)
- Create buffers inside each street block polygon using the negative values in bldg_mean_dist field as buffer distances. (Buffer tool)

b) Convert the buffer polygons to lines (black lines in Figure 6), carrying over the str_polys_ID. (Feature To Line tool)

c) Add an attribute field, segment_ratio, to the buffer line table. (Add Field tool)

d) Overlay the buffer lines with buildings to obtain the line segments going through buildings (yellow line segments in Figure 6). (Intersect tool)

e) Summarize the total length of the line segments in each street block polygon. (Frequency tool with length summation by str_polys_ID)

f) Join the frequency table with the buffer lines table to obtain a table view showing the total line segment length and the buffer line length for each street block. (Add Join tool using str_polys_ID as the common field)

g) Compute line segment ratio (total line segment length / buffer line length in each street block) for each street block polygon and store the values in segment_ratio field. (Calculate Field tool)

The segment_ratio values, as labeled in Figure 6, can be used as a contributing factor in determining whether or not an enclosing building pattern exists inside a street block, therefore, these buildings should be aggregated into an urban area.

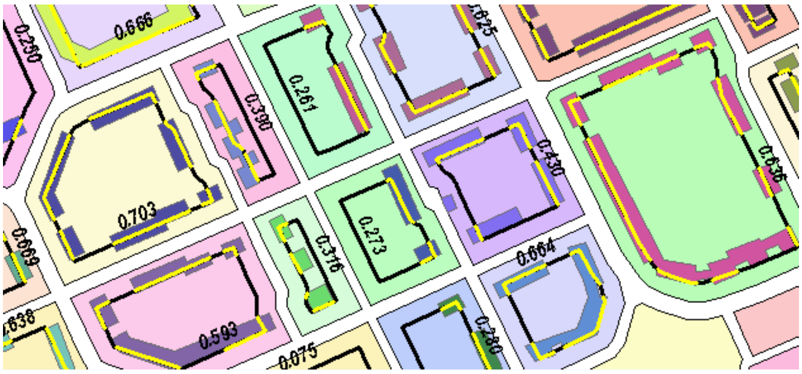

Figure 6: Identifying enclosing building patterns by geoprocessing. Black lines are buffers with negative distance inside street block polygons; yellow line segments are where lines pass thru buildings. The ratios of the line segments over their corresponding buffers are as labeled.

The above approach for identifying enclosing building patterns is often sensitive to the buffer distance, as one can easily imagine or see from Figure 6. In addition, the same segment ratio in different street blocks may not mean that they have similar building patterns – one may have buildings more evenly around with similar gaps; another may have the majority of buildings lined up around only part of the block. Further analysis can be done to distinguish seemingly "chained" buildings from others.

Recognizing "chained" building patterns

Buildings appear nicely "chained" when the gaps between them are more even and short in length. Where a big gap occurs, the chain looks discontinuous. It makes sense to measure the gaps (black portions of the buffer lines) – shorter gaps indicate stronger chain pattern of buildings.

A geoprocessing model (omitted from this paper due to length limitation) was built, without any custom programming, to extract closely chained buildings with the following steps:

a) Erase the buffer lines by buildings to obtain the gap lines and make them single part features. (ERASE tool followed by Multipart to Singlepart tool)

b) Select gap lines shorter than a desired length (25m in the example). (Make Feature Layer tool with a selection expression)

c) Select buildings that spatially touch the selected short gap lines to obtain closely chained buildings. (Select by Location tool with the BOUNDARY_TOUCHES rule)

The resulting closely chained buildings are shown in Figure 7 (left). If the majority of buildings are well chained in a street block, they are good candidates to be aggregated to urban areas. They may or may not fill an entire block depending on other contributing factors. The result is displayed on top of existing TOP50vector urban area polygons (yellow background polygons) in Figure 7 (right). Where the chains discontinue (indicated by the green lines), no urban areas are formed.

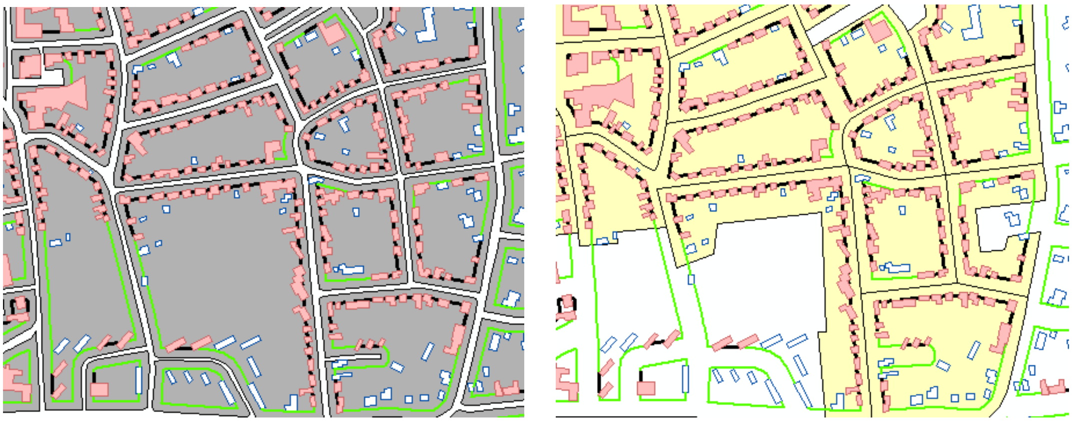

Figure 7: Recognizing closely chained building patterns by geoprocessing. Closely chained buildings have short gaps (black lines in the left image). The identified closely chained buildings seem to fall in the existing TOP50vector urban areas. (Data courtesy of Netherlands Kadaster)

To summarize this example exercise: sufficient building density (e.g. above 0.20), high segment ratio (e.g. greater than 0.50), along with short gaps between buildings inside street blocks are quantitative measures that support decision making about urban areas. Further study will model the combination of the above three or more factors to determine the final candidate street blocks in which buildings should be aggregated into urban areas. On the other hand, buildings or street blocks that don’t meet the above criteria indicate that different generalization strategy would apply based on additional measures and analysis.

4 EXAMINING OTHER GEOGRAPHIC CONTEXTS

4.1 Features in context with terrain

In topographic mapping it is very important to represent features in context with terrain. Many generalization specifications reference terrain formations, such as hill tops, mountain passes, valleys, open or level areas, and so on, as part of the constraints. These terrain formations usually don’t have clear boundaries on the ground and therefore are not collected and stored explicitly as geographic features; but they are the keywords in the specifications and set the scope of the requirements. Here are two example specifications and possible processing ideas:

a) For “Spot Height” on map of 1:5000, “Show on hilltop only.” [HKLIC, 1996]

   One obvious observation about hilltops is that they are surrounded by the most inner contours with local highest elevation. One possible approach for finding hill tops is to create a TIN from contour lines so that each TIN node has a Z value from the contour elevation attribute, assuming it exists. Then the local high points can be found statistically as hill tops.

b) Also on spot height selection: “In mountain passes, always preserve one or more spot heights with the first consideration of the lowest ones and the second consideration of the most centered ones” [Pla, 1999]. Figure 8 shows spot heights in high density from 1:5000 database and the desired selections displayed on the scanned map of 1:10000.

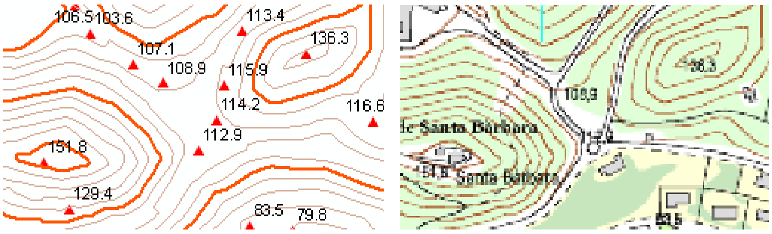

Figure 8: Spot height selection in terrain context - mountain pass spot heights in 1:5000 database (left); selected spot heights on scanned 1:10000 map (right) (Data courtesy of the Institut Cartogràfic de Catalunya)

Mountain passes are usually where mountain roads, paths, or streams are located and have the local lowest elevations. Therefore, recognizing mountain passes would require similar analysis, as described above, to find local low elevations, along with information on the existence of other common features mentioned here.

4.2 Road features interfering with other features

A few scenarios of generalizing road related features, such as bridges, elevated roads (overpasses), and tunnels, were observed at ICC, Barcelona [Lee, 2005]. The cartographer made interactive edits according to guidelines; here is an example:

> Where a man-made water channel connects to a river through a tunnel, the tunnel (entrance) wall must always be kept. If it is shorter than 25m, it will be exaggerated to 25m. If it becomes in conflict with a neighboring feature, such as a local path, the neighboring feature will be displaced, reshaped, or removed, as shown in the example case in Figure 9.

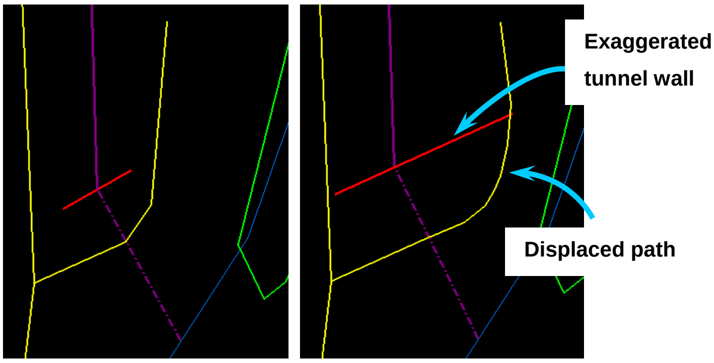

Figure 9: Generalization of road related features. (Screenshot courtesy of the Institut Cartogràfic de Catalunya)

The analysis process can start from each tunnel entrance wall – using them to select connecting man-made water channels and rivers by the INTERSECT topology rule. If both connecting features are found being associated to the same tunnel, then the condition is met. Next, the tunnel entrance wall should be extended, if it is shorter than the specified length, and checked against features in a search radius for conflicts, followed by displacement or reshaping, if necessary. New tools for line extension and displacement are therefore needed.

4.3 More on built-up area generalization

“The representation of built-up areas is of utmost importance at all scales. Besides buildings it also includes infrastructure facilities and the traffic network” [Swiss Society of Cartography, 2005]. Further research is underway to understand and to measure the complexity and the involved factors in urban area generalization. As mentioned at the end of section 3, when urban street blocks and buildings don’t form any particular patterns, other contextual measures and analysis are needed to suggest appropriate generalization actions. The alignment and consistency among subdivisions should not be ignored.

A built-up area generalization scenario using an interactive editing system was observed at ICC, Barcelona. The cartographer performed various generalization actions in context among buildings, road casings, block borders, and neighbor blocks, as explained in Figure 10. It was a complicated task because he had to look at the overall situation – the spaces, the alignments, the shapes, the connections, and so on, while making changes. The detailed interactive processes were described in the report [Lee, 2005]. We need to translate these descriptions into constraints and actions for the optimization prototype to explore [Monnot et al, 2007a].

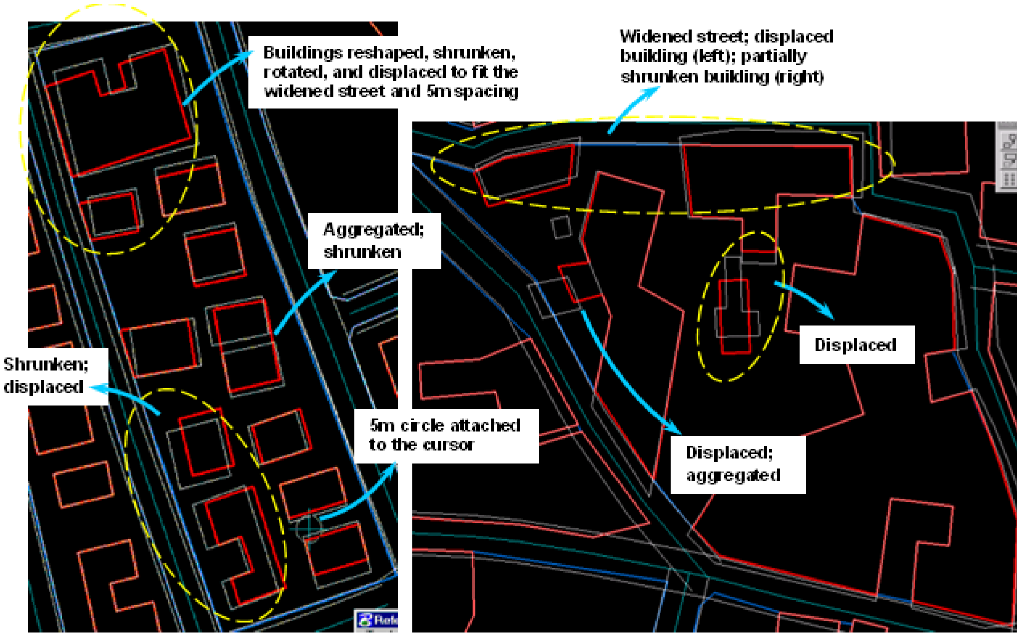

Figure 10: Built-up area generalization (Screenshot courtesy of the Institut Cartogràfic de Catalunya)

5 CONCLUSIONS

As more and more geoprocessing tools for spatial and semantic analysis become available in ArcGIS, and with the convenience of the ModelBuilder, much geographic context information can be derived through logical geoprocessing procedures. Topological connections can be analyzed and preserved on the fly; contextual measurements and feedback (new fields and values added during the processes) based on spatial and semantic context can be derived, used to characterize geographic features, and therefore, to support generalization decisions. As more explicit generalization specifications are being defined by NMAs, our effort will continue in building analytical tools and models to derive contextual information and to use this information to perform efficient and appropriate generalization.

Due to the complexity of the geographic world, generalization solutions must comprehend all contributing factors and abstract them to find the most relevant representation of reality. As we are exercising geoprocessing capabilities, we are also identifying measures and rules that are sensitive to variations in context and need more flexibility. We assert that these multiple factors, sensitivities, priorities, and flexibilities could be better balanced and addressed using an optimization approach, and therefore our prototype Optimizer is in progress to perform such tasks [Monnot et al 2007b].

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