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Geographic and Cartographic Contexts in Generalization

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ABSTRACT

Apart from the cultural differences, the common expectation from national mapping agencies (NMAs) is to have a fully equipped GIS system that can help them manage and accomplish multiple scale map production with as much automation and flexibility as possible. The popular aim of the NMAs is to build a large-scale digital landscape model (DLM), from which medium- or small-scale DLMs are to be derived. The digital cartographic models (DCMs) are then to be compiled from the correspondent DLMs. Generalization is at the heart of such a production strategy.

The challenge in developing generalization solutions roots from the complexity of generalization tasks itself – no features should be generalized in isolation. This paper discusses the geographic and cartographic aspects of contextual generalization, that is, generalizing features that are related and interfere with each other. Wherever possible, our development experience and solutions will be illustrated. In both database and cartographic generalization, feature spatial relationships and geographical patterns are the main consideration of the geographic context, while in cartographic generalization symbolization and clarity govern the cartographic context.

INTRODUCTION

Generalization in traditional mapping simply relies on a cartographer's analysis and decisions. "Due to scale restrictions, the cartographer makes a selection, classifies, standardizes; he undertakes intellectual and graphical simplifications and combinations; he emphasizes, enlarges, subdues or suppresses visual phenomena according to their significance to the map. … he reorganizes the many elements which interfere with one another, lie in opposition and overlap, thus coordinating the content to clarify the geographical patterns of the region (Imhof,1982)." The more scale reduction, the higher possibility of having conflicts among the mapped features.

We used to say, every map is a generalized representation of the real world. Well, in digital mapping or database-driven cartography, such as the database-driven multiple representations project at ESRI (Hardy, 2004), we must first say that every geographic database (or DLM) is a generalized model of the real world. Although a DLM can be built as scale-independent, it usually corresponds to certain scale range and serves as a starting point for compiling DCMs at that scale range, as presented in Figure 1 – Swisstopo's MRDB data flow (Kreiter, 2003). For example, the DLM200 might contain data that is only relevant to the creation of DCMs at 1:200,000 – 1:500,000. Therefore, a DLM data can be selectively

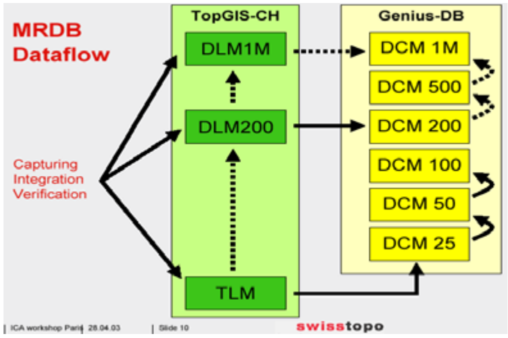


Figure 1: Swisstopo MRDB dataflow, DLMs and correspondent scale ranges

collected with only the necessary level of detail and accuracy. Since the scale restriction applies to both database and cartographic generalization, resolving conflicts in geographic context and in cartographic context must be addressed in developing generalization solutions. The following sections examine the geographic aspects and cartographic aspects of contextual generalization and how they have challenged the creation of automated solutions.

GENERALIZATION CONSIDERING GEOGRAPHIC CONTEXT

Although database generalization emphasizes data content, completeness, and accuracy, while cartographic generalization deals with symbol conflicts and legibility in map space (Weibel and Jones, 1998), the one principle that both have in common is to preserve the geographic characteristics. Generalization is about representing the spatial relationship of features and their geographical patterns as faithfully as possible at a given scale, and therefore requires to analyze, to recognize, and to manipulate features in such geographic context.

At the very basic level, each geographic feature is stored as a record (point, line, or polygon) in a database, usually with a set of geographic attributes. Early generalization algorithms, such as those for simplification (Douglas and Peucker, 1973) and smoothing (Brophy, 1972; Chaiken, 1974), treat coordinates uniformly, that is, to apply a mathematical “filtering” function with certain parameter(s) and obtain a reduced and altered shape of the feature. These algorithms process one feature at a time. The result may look “consistent”, but the spatial relationship may be destroyed and the geographic pattern may be distorted.

1. Spatial relationship

In generalization, it is critical to know or to find how certain features are spatially related to surrounding features and to represent such contexts properly. Some of the spatial relationships can be modeled and maintained in the geographic database; others need to be analyzed and computed. A few examples will be given below to illustrate these cases.

1-a. Ensuring correct topology in generalization

Geographic features can be related to each other in special ways: some are adjacent or intersect; while others should not touch or overlap one another. In GIS technology, such as in ArcGIS (the GIS software created by ESRI), these relationships are maintained through an association known as topology. ArcGIS implements topology through a set of validation rules, which define how features may share a geographic space, for example, polygons (administrative boundaries) must not overlap; lines (contours) must not cross. A generalization process should respect these rules and preserve shared geometry, connectivity, and other topological relationships.

As the topology engine (containing topological operators) became available in ArcGIS, the development of generalization tools within the geoprocessing framework (Lee, 2003) has begun to enhance the way of preserving spatial relationship. Using the Simplify Line tool as an example, the tool works with topological context in the following ways:

<u>Preserving input topology in the output:</u>

If the input contains intersecting lines, whether there is a vertex on the line at the intersecting point or not, you will have a choice of keeping the intersection positions unchanged. For example, a river may end and connect to a lake shoreline at an existing vertex of the shoreline. Without knowing this connection, the shoreline can be simplified such that the vertex is eliminated and the connection broken. Using the topology engine, the intersection can be found and marked so that the vertex on the shoreline won’t be altered by simplification.

When the input contains network features (routes, for example), coincident lines may exist, meaning multiple routes may share the same segment of a road. To ensure the shared geometry is simplified the same way and the network is not broken, the topology engine is used to recognize the coincident line segments such that they can be simplified consistently and then the routes are reconstructed.

Detecting and resolving topological errors introduced during simplification:

Due to the nature of the line simplification algorithms (Pointremove and Bendsimplify) used in the Simplify Line tool, the topological errors that might be created during simplification are: line-crossing, coincident lines, and collapsed zero-length lines. The user has the option to have these errors detected and resolved. There could be different resolutions, but since these errors usually occur in relatively congested areas or where the feature is relatively "small" and therefore indicate that the simplification tolerance is relatively too large, the following strategy has been implemented:

The input lines are first simplified using the specified tolerance. The topological error detection routine will then locate the three types of topological errors, if any, and mark the involved line segments. A reduced tolerance (half of the original) will be applied to re-simplify these segments. This detection and re-simplification with a reduced tolerance (half of the last used) will repeat until no more errors are found. Figure 2 shows a comparison between an input line and its simplified form. The bend where the arrow points at is much smaller than those in the left circled area, but can not be removed as those were in the right circle without causing line-crossing; so it was under-simplified and kept in the result.

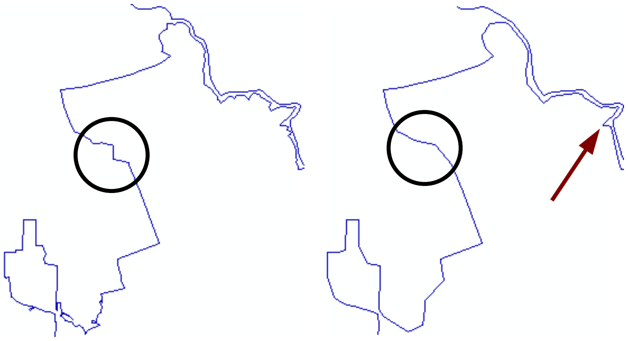
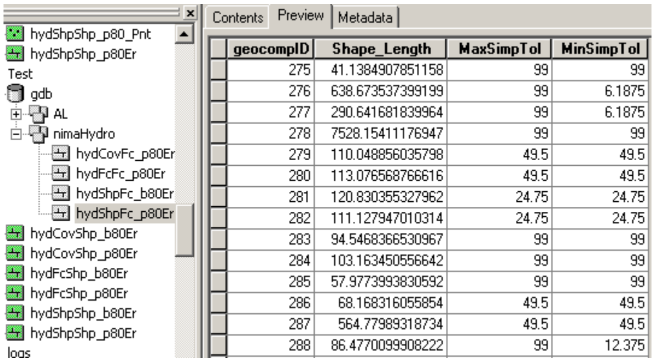


Figure 2: **Before (left) and after (right) simplification: where the arrow points at is obviously less-simplified compared to the shape change in the circled area; it's the result of resolving line-crossing errors. (Thanks to the US Census Bureau for providing the test data.)**

To make the user aware of the situation and be able to review the under-generalized lines easily, two new attributes, MaxSimpTol and MinSimpTol (the maximum and minimum simplification tolerances used to simplify a line), are written for each line in the output. The user knows immediately what range of tolerance is used for a particular line. Figure 3 shows the MaxSimpTol and MinSimpTol values in a partial attribute table of a simplified line feature class. In this case, the specified tolerance was 99 map units. Where 49.5, 24,75, 12.375, and 6.1875 are listed indicates that four iterations were needed in the process and that the lines were simplified adaptively to ensure correct topology.



geocompID	Shape_Length	MaxSimpTol	MinSimpTol
275	41.1384907851158	99	99
276	638.673537399199	99	6.1875
277	290.641681839964	99	6.1875
278	7528.15411176947	99	99
279	110.048856035798	49.5	49.5
280	113.076568766616	49.5	49.5
281	120.830355327962	24.75	24.75
282	111.127947010314	24.75	24.75
283	94.5468366530967	99	99
284	103.163450556642	99	99
285	57.9773993830592	99	99
286	68.168316055854	49.5	49.5
287	564.77989318734	49.5	49.5
288	86.4770099908222	99	12.375

Figure 3: **Partial attribute table showing the MaxSimpTol and MinSimpTol values.**

The simplified output may also suggest the following: one, the suitability of the specified tolerance. If the specified tolerance (99 in the above case) appears in most of the MaxSimpTol and MinSimpTol records, it must be suitable for the majority of the data; otherwise, a smaller tolerance might need to be considered. Also, it may suggest the need for adapting a different generalization operation in certain areas. If significantly reduced tolerances appear in the MaxSimpTol and MinSimpTol fields for certain lines and these lines look under-simplified, then simplification may not be the proper solution for them. For example if the two closely located lines in Figure 2 represents a narrow river, they should probably be collapsed into a single line representation. Being able to detect and recognize different characteristics of features or areas will lead to the next level of contextual generalization, that is, making decisions for multiple types of features and actions.

1-b. Fulfilling spatial constraints in generalization

Generally speaking, spatial constraints in generalization are the spatial conditions or restrictions that need to be checked or compelled to avoid or perform some action. It is not the purpose of this paper to research on the complete list of spatial constraints, but to mention a few:

> Relative positions of features – generalization should preserve the relative positions of features, for instance, a gas station on one side of a road should not end up on the other side;
>
> Interference – generalization should avoid undesired interference, for example, buildings within one street block should not be aggregated with those in another when the streets are represented;
>
> Proximity – Generalization may treat features differently according to their distances to other features, for example, a house that is small enough to be excluded, but located near (in certain distance) a country road with no other buildings around (within a certain radius), must be shown at the minimum allowable size instead of being deleted.

To meet these spatial constraints, spatial analysis would be needed along with generalization operations. The following two examples show how spatial analysis is involved in deriving the desired results.

<u>Aggregation considering proximity and interfering features:</u>

Aggregation is a very common generalization operation that combines features of a certain type(s) in close proximity to form larger areas, for example combining patches of trees within 20 meters to each other into forest areas. Aggregation with a given distance has been discussed and attempted by a number of researchers (Jones et al, 1995; Peng, 1997), but little has been addressed and implemented on dealing with interfering features.

When streets need to be represented, building aggregation must avoid crossing the streets, that is, the streets are acting as barriers to the aggregation. In responding to the HK LIC generalization benchmark, we derived a procedure to aggregate buildings without crossing the streets even when they are within the aggregation distance as shown in Figure 3. The main spatial analysis involved in this procedure included: finding the building clusters and the candidate resulting polygons, identifying where streets intersect the candidate polygons, separating the building clusters by the interfering streets, and reconstructing aggregated polygons from the separated clusters. More details were given in the previous paper (Lee, ASPRS 1998).

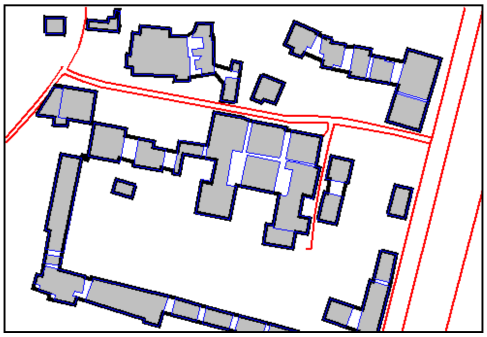


Figure 3: Building aggregation constrained by roads (thanks to HK LIC for the data)

<u>Actions depending on feature spatial configurations:</u>

From the many existing maps produced by the NMAs, it is not hard to find cases where, at a local level, features of the same type are generalized differently seemingly depending on specific spatial configurations. Although we have not been able to obtain or derive all the explicit descriptions about these spatial configurations, the one that we were challenged to solve was given by the Kort & Matrikelstyrelsen (National Survey and Cadastre, Denmark – KMS) as one of the benchmark requests. The specification (under "Generalization of farms or estates", KMS, 1999) states: "Buildings in groups of 1-5 buildings with less than 20 meters between them and more than 75 meters to the nearest other buildings are grouped and simplified; others are simplified only". Our solution is shown in Figure 4. The farm buildings (actually in the "rural districts") were generalized differently according to how they form a group and how they spatially related to other buildings.

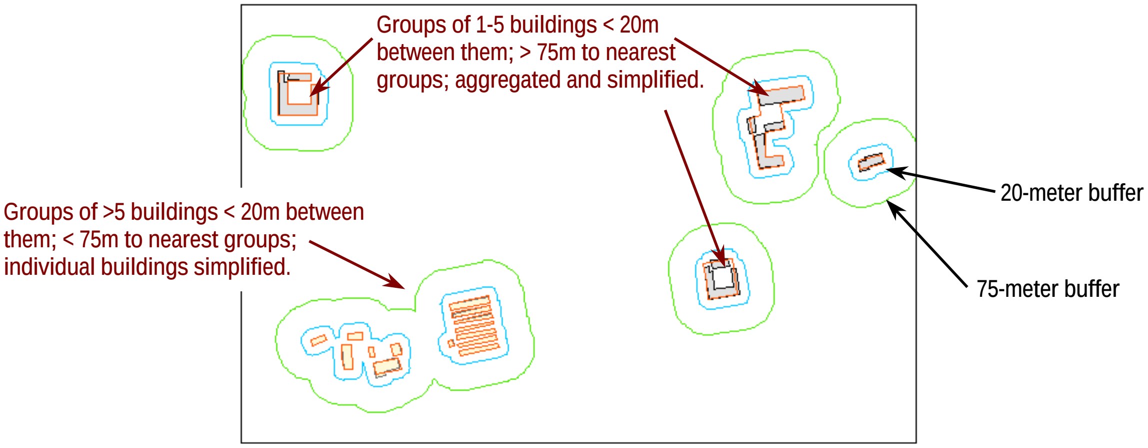


Figure 4: Generalization of farm buildings based on feature spatial configuration - (thanks to KMS for the data)

Generalization considering the spatial relationship of features can be far more complicated than illustrated above. However, being able to maintain topology, resolve interfering problems, and analyze feature configurations at the fundamental level is the first step towards more comprehensive solutions for generalization. ArcGIS and the geoprocessing framework provides a suitable environment in which more generalization tools will be built and enhanced with the access to the topology engine, the triangulated structure, and many other spatial analysis functions; and multiple feature classes and feature types can participate in a process simultaneously.

2. Geographical patterns

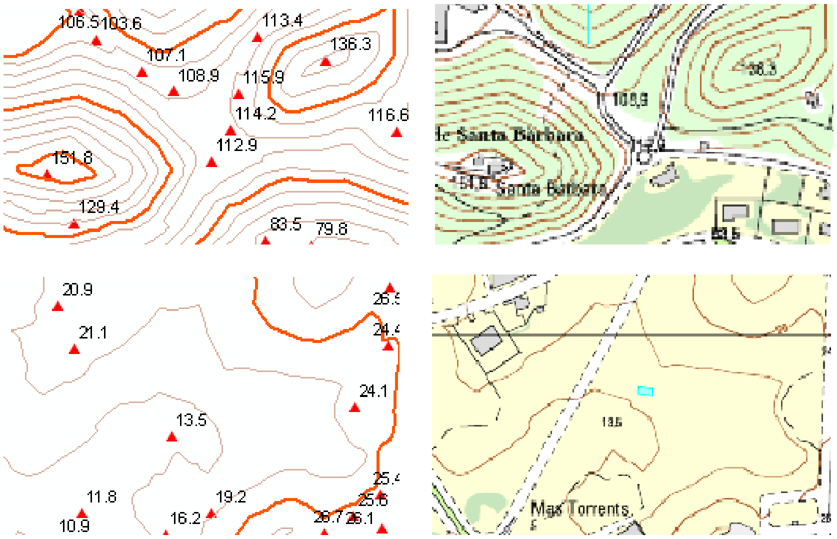
Another major part of geographic characteristics of a mapped area is the wide range of geographic patterns. A geographic pattern can be a unique natural formation (a mountain range) or a cultural phenomenon (an urban or a rural area). A geographic pattern can cover a very large region (a hydrographic watershed or network) or a relatively small area (a residential block or a group of similar buildings). Such geographic patterns are most often not explicitly defined and stored as features in a database and are difficult to model and generalize digitally.

2-a. Specifications regarding geographic patterns

During our continuous investigation and research, sometimes reverse engineering studies, on generalization requirements and issues, a good variety of generalization specifications making references to geographic patterns have been found among NMAs mapping guidelines. The following examples illustrate just a few of such specifications.

Spot height selection in terrain context (Pla, 1999):

> Example specification 1 – "In mountain passes, always preserve one or more spot height with the first consideration of the lowest ones and the second consideration of the most centered ones". Figure 5-a shows the digital data (Topographic Database at 1:5.000) with a very high density of spot heights and the map of 1:10,000.
>
> Example specification 2 – "In open area, raised areas, leveled areas, and rustic parcels, consider keeping the most centered ones. Figure 5-b shows the same digital data and the generalized map.



a: **Mountain pass spot heights in database (left); selected spot heights on the map (right)**

b: **Open area spot heights in database (left) ; selected spot height on the map (right)**

Figure 5: Spot height selection in terrain context - (thanks to the Institut Cartogràfic de Catalunya for the data)

Feature importance and representation in natural or cultural context (NIMA, 1990):

> Example specification 3 – In arid and undeveloped areas, depict as many drains as possible.
>
> Example specification 4 – In areas where numerous tanks exist, a representative pattern is used which will retain the general layout of the entire tank area.

The geographic patterns mentioned and underlined in the above specifications may not have a clear boundary on the ground and therefore not collected and stored as geographic features, but they are the keywords in the specifications and set the scope of each particular requirement.

2-b. The challenge in automation

It is already not easy for a human cartographer to visually recognize the geographic patterns on a base map and portray them at a reduced scale. Developing a digital solution such that the geographic patterns could be “perceived” automatically is definitely not a straightforward job. There are many possible elements or measures that can be used to describe a geographic pattern, but first and most importantly is its spatial extent.

The extent of a geographic pattern can be seen as a generalization solution space within which uniquely structured features reside and are usually closely related. Certain generalization actions and rules may only apply to features within the extent and the alteration of feature locations or shapes as in typification or displacement should only consider features in context within the extent and should not propagate to beyond the extent.

In order to find the digital extent of a geographic pattern, such as the “open area” or the “arid area” stated in the above specifications it definitely needs to involve terrain analysis, perhaps combined with the help of geographic attributes of features and interactive decision-making. There haven’t been clearly defined guidelines and techniques that could lead to solid implementation; this is one of the areas where more questions may remain than answers.

GENERALIZATION CONSIDERING CARTOGRAPHIC CONTEXT

When deriving a DCM from a DLM for the production of cartographic outputs, full symbolization as to be printed must be taken into account, as well as the clarity requirements.

1. Symbolization and clarity

As the map scale reduces, the representation of the mapped features becomes more and more symbolic. A symbol on a map must maintain a minimum dimension so it can be printed legibly. Below certain map scale, a symbolized feature may no longer be measured to scale and will occupy more space than it does on the ground; this causes the space between features to reduce or diminish and the symbolized features appear collapsed to each other or overlap. It is necessary to clarify the lost spacing so that features are properly separated and recognizable. Cartographic generalization deals with symbolized features in map space and resolves symbol conflicts. For example, a point typification process needs to take into account the point symbol dimension and to satisfy a minimum spacing between the point symbols; a line simplification process needs to consider the width of the line symbol.

2. Prototyping in symbol context

The database-driven cartography project at ESRI aims at establishing a framework to support multiple-scale representations. These scale dependent representations can be obtained through cartographic generalization and editing in a WYSIWYG environment. In a similar way as the database generalization tools detect and resolve the spatial conflicts, cartographic generalization tools can apply the spatial rules to the symbol space while generalizing features. Of course, a set of symbolization rules, feature priorities, and rendering orders need to be taken into account as well. Figure 6 shows some initial result of resolving linear feature conflicts as they are fully symbolized.

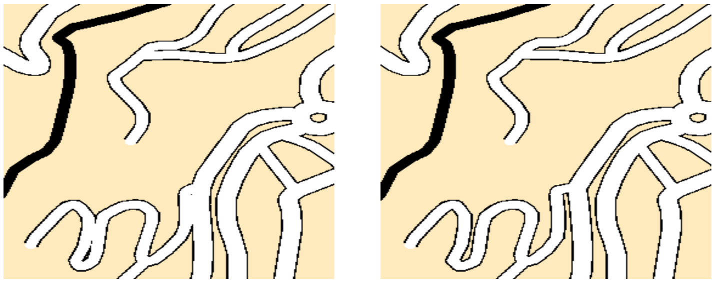


Figure 6: Resolving linear symbol conflicts input (left) and output (right)

WORKING TOWARDS ADAPTIVE PROCESSES

Our recent reverse engineering study has led to some interesting findings about how cartographers might have thought in generalizing a particular map. A set of rules has been derived and the trial implementation is in progress. The St. Davids data obtained from the Ordnance Survey of Great Britain (OSGB) contains:

- vector polygons of the OSMM (OS Master Map) database at 1:1250
- raster image of the existing map covering the same area at 1:10000
- vector road centerlines for the scale of 1:10000

Part of the map was chosen to focus on generalization of buildings and roads.

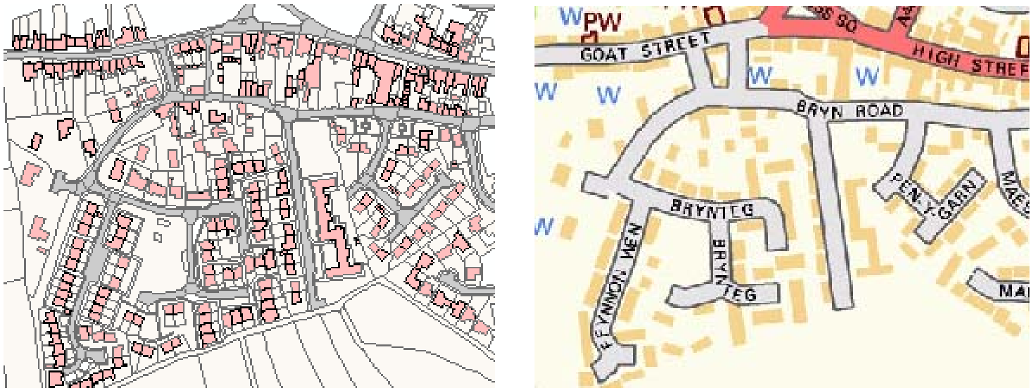


Figure 7: Vector polygons at 1:1250 (left) and the scanned map at 1:10000 (right) . Thanks to OSGB for providing the data.

The existing geoprocessing tools in ArcGIS were used to:

- Select and Dissolve "Buildings"
- Simplify the dissolved buildings (tol. = 5m; min. area = 30 sqm)
- Buffer the existing road centerline (8m) to obtain the geometry of equivalent symbol width
  (Note: this step could be replaced by Selecting and Dissolving "Road or Track" from the vector polygon data, then collapsing the road polgyon to obtain road centerline for buffering, but the collapsing algorithm currently available will need enhancing further to produce good results on this kind of data.)
- Intersect the simplified buildings with road buffers to find where buildings overlap roads

Comparing the intermediate result with the existing map as shown in Figure 8, most of the simplified buildings are quite close to the desired shapes. However, it was easily noticed that in the map some buildings are aggregated (see the green circle areas), some buildings are shortened (see the green box areas), and not all the buildings covered by the roads are displaced uniformly. So what could have been the analysis and decisions the cartographer made when he or she created the map?

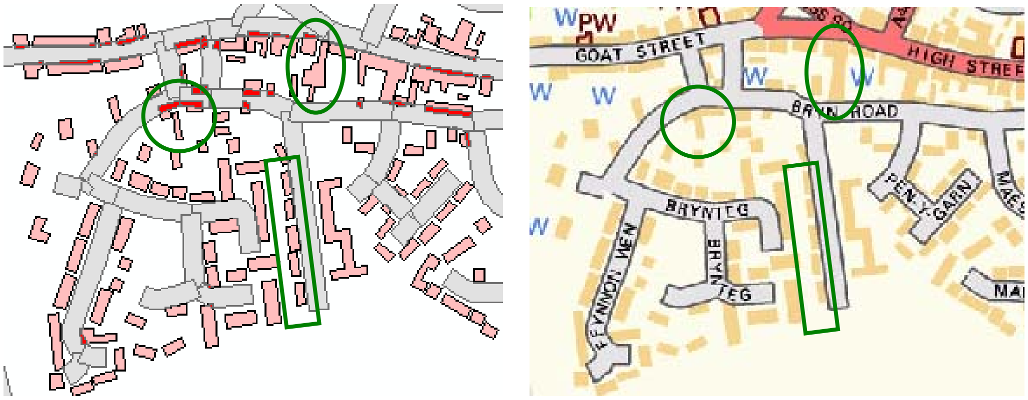


Figure 8: Comparing the intermediate result from geoprocessing (left) with the target map (right) .

From our initial observations, the following rules might be close to what the cartographer thought:

- A building needs to be moved away from the road only if more than certain % (20%?) of its size overlaps the road. (In otherwords buildings with minor overlap with the roads seem to stay where they are, not moved.)
- After building displacement from road, check if the moved buildings become overlapping other buildings; if yes, they will be aggregated; and the aggregated shape can be further simplified.
- Where a number of buildings tightly form a row along a road, the space between the buildings may be too small and displacement is not possible. If a space between two buildings is smaller than certain distance (1-2 meters?), both buildings or one of the two may be shortened at the tight end (therefore, enlarging/exaggerating the space).

Our research will continue to extend to other areas of the map, other features, and other scale ranges. The "discovered" rules along with the needed generalization tools, such as collapse, aggregation, displacement, shortening or shrinking, and so on, are being implemented to test and prove the ideas. We are working on how such adaptive, context-based processes would be integrated in ArcGIS.

CONCLUSIONS

Generalization research and development in the past decade has deepened our understanding about the spatial issues and cartographic issues. The increasing demands on contextual generalization have lead to some encouraging progress in finding the approaches and implementing solutions among researchers and developers. Since many complications in generalization happen in more populated areas, analyzing urban patterns, such as urban road network (Mackaness, 1995) and spatial structure in urban blocks (Boffet and Serra, 2001), has been an important research focus. Taking one step further, the AGENT project research has suggested techniques where the geographic objects, such as buildings, urban blocks, city street network, and so on, again with the ability to recognize conflicts automatically and to apply appropriate generalization algorithms to resolve the conflicts in context (Ruas, 2002). This kind of adaptive intelligent contextual processing is now being introduced into the ArcGIS generalization framework, but without the overheads complexity of needing software agents.

As more and more NMAs are taking GIS-based approach as their map production strategy, the potential and the efficiency of using their master databases to serve multiple-purpose and multiple-scale applications can be greatly extended relying on generalization capabilities integrated into the GIS systems. It is our goal and ambition to focus on the NMAs requirements and provide a competitive solution for GIS-based generalization.

In the ArcGIS 9.0 release, geoprocessing, combining its earlier command operation with a modern user interface and process modeling and scripting, has become an integral part of the data management module, Arc Catalog, and the map design and compilation module, ArcMap. The development of generalization tools within the geoprocessing framework is the first major step towards further comprehension of generalization capabilities, including automatic and interactive generalization in both the geographic and cartographic contexts, error tracking, database enrichment, and the support for updating.

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