

Generalization of topographic maps of urban areas

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Abstract

This paper presents some results of a project aimed at combining the expertise of a human cartographer with software tools to automate the generalization of topographic maps of urban areas from 1:10,000 to 1:50,000 scale. A hybrid system has been created for such generalization, utilizing the MGE Map Generalizer in batch mode to perform the actual map transformations, and a rule based system for controlling the process. A fine level of control was achieved by performing the generalization in small steps working on individual map elements. The maps processed this way are not 100% correct; there are always a number of map elements incorrectly generalized. This is due to some specific features found in local areas, which require special treatment. Such special cases are classified either as exceptions or conflicts and approaches to deal with them are discussed.

Introduction

Despite many efforts undertaken of proposing a theoretical model for the map generalization process, as well as specialized methods and models such as line generalization, the problem remains an open research area. The explosive development of GIS systems and the growing volume of digital maps create a need for methods of efficient processing such maps. Generalization is one of the important such techniques, and therefore intensive research is being conducted on automation of map generalization using various approaches [João, 1998].

This paper focuses on one possible approach to the problem, taken from artificial intelligence, the knowledge-based expert systems. They work by using encoded knowledge of human experts about solving problems from their domain of expertise. Thus they are able to make the same choices based on the same premises as do the human experts and can recognize map characteristics important for generalization. The few prototype systems developed for generalization are limited to specific map elements and/or to a selected set of operations and a specific scale transition. Still, even with

such restrictions, these systems do not perform a fully automatic and complete generalization; there always remain manual adjustments to be made.

The AAI System

In the course of investigating the generalization processes the authors have constructed a rule-based expert system, called AAI, to perform the basic generalization steps, taking care of both the general principles and special cases, thus avoiding manual interventions. Originally developed for generalizing basic maps from 1:1000 to 1:10,000 scale [Iwaniak, Paluszynski 1998], it was later modified to generalize topographic maps from 1:10,000 to 1:50,000.

The system was implemented in CLIPS, a programming environment designed for implementing rule-based systems [CLIPS, 1993]. Running on an Intergraph 2000 series workstation, AAI co-operated with the MGE Map Generalizer. It worked by analyzing the source map in the object-oriented map database, and repeatedly selecting elements that did not correspond to the target map scale, see **figure 1**.

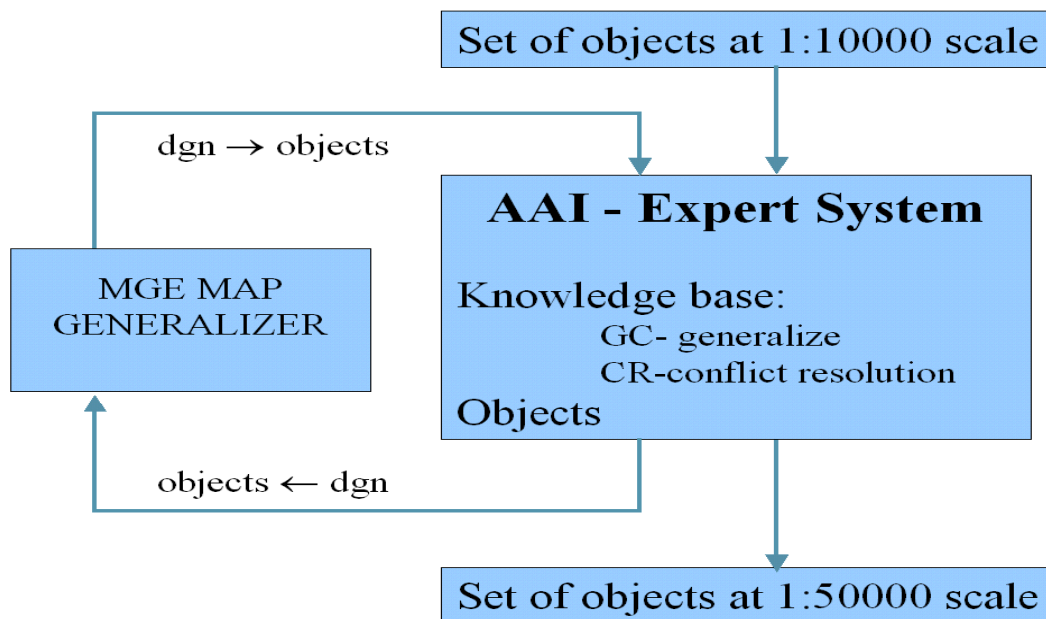


Fig.1: Basic scheme of the AAI system generalizing maps together with Map Generalizer

The system converted them to the “dgn” vector format required by the MGE Map Generalizer, and selected one the Generalizer's operators and all its parameters. Then AAI invoked the Generalizer to generalize thus created partial map. When done, the knowledge-based system converted the results back to the object format and analyzed by comparing them to the originally selected set of objects. If anything had changed,

the system replaced the original map objects with the newly created ones, possibly of different type, and repeated the cycle.

This prototype system was able to perform comprehensive generalizations on real size maps producing results similar to those obtained with the manual procedure. Its ability to deal with special cases was limited by the size of its knowledge base, as those had to be coded individually.

Some of the specific cases are more specialized versions of a general approach, or a different approach needed in these situations. These cases, which were termed *exceptions*, could be dealt with at the rule level, by specializing the system’s knowledge and developing its abilities to recognize them. There are still other specific cases, however, sometimes referred to as *conflicts* [Ware, Jones, 1998], which, when dealt with in a standard way, lead to incorrect generalizations. They correspond to situations, when there is a crowding of objects in one area of a map, which, when generalized according to the best cartographic knowledge, give bad results, and require the cartographer, to compromise some of the generalizations principles in favor of other correctness requirements, such as preserving adjacency. In other words, conflicts cannot be treated satisfactorily using any “proper” knowledge; they require some rules to be bent.

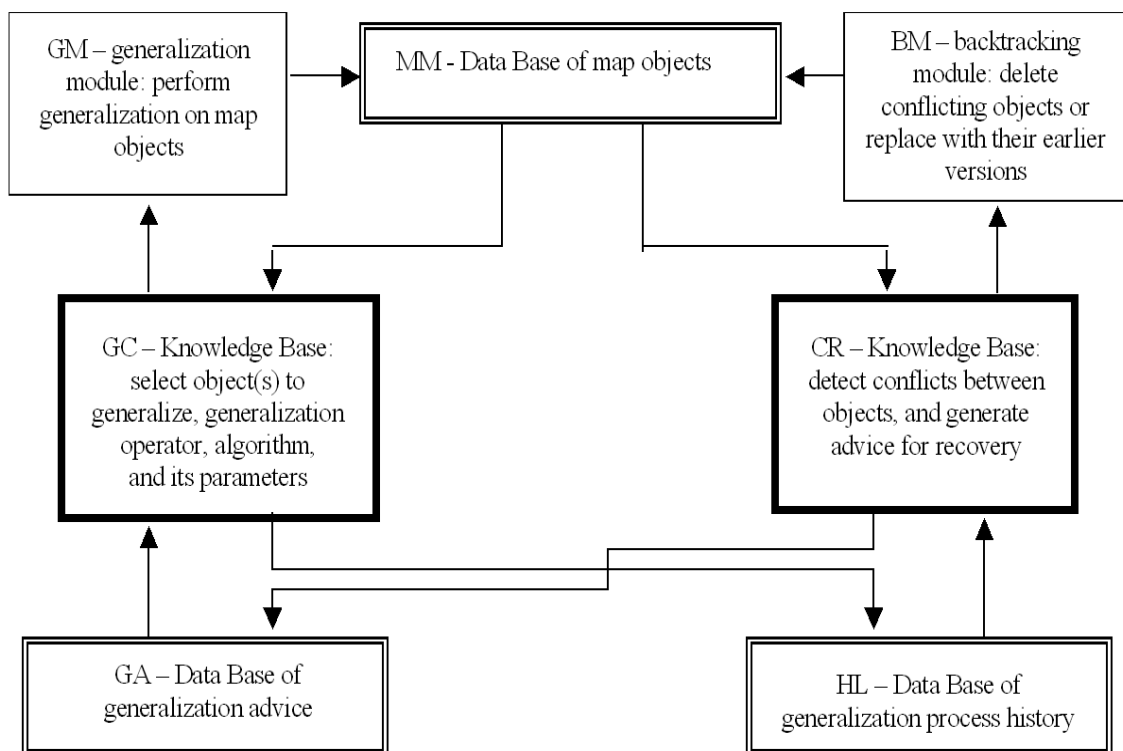


Fig.2: AAI system structure – logic for handling conflicts

The AAI system dealt with these conflicts on the basis of logic and reasoning, attempting to catch them when they occur, undoing the incorrect generalization steps, and repeating them with some options forbidden, **figure 2**. This approach is very general and can solve complex conflicts in theory. However, programming a system this way is costly and, on large data sets, the performance is a concern.

We are therefore experimenting with the system to complete its knowledge base and, at the same time, improve its abilities to deal with conflicts.

Experimental set-up

The source data for the experiments were numerical maps of residential areas of the city of Wrocław, processed using the MGE environment. Two sets of numerical data have been prepared by converting to vector raster maps of each area: at 1:10,000 and 1:50,000 scales. This way, for each 1:10,000 map there was its version generalized by hand to 1:50,000. The idea was to manually generalize maps of selected residential areas of the city of Wrocław using MGE Map Generalizer in order to build up the knowledge. In the course of this work typical generalization operators for these maps were determined. Generalized were the roads, buildings, and parcels.

The next step was generalizing the same areas using MGE Map Generalizer in batch mode and subsequent detecting and analyzing any errors. The correctness criterion used was similarity to the existing 1:50,000 map.

Generalizing an area using MGE Map Generalizer in batch mode implies applying the same operators with the same selection of parameter values for many elements in that area. This invariably leads to incorrect results in some specific cases, such as incorrect shapes for simplified objects or topological errors which make it impossible to proceed with further generalization steps.

Even for such a simplified problem, with only a few selected map elements in maps of specific type of urban areas, developing an expert system is difficult. The problem is working out detailed conditions determining "what", "when", "how", and, additionally, which topological constraints should be preserved.

From our experiments it is possible to decide what should be generalized. The question of when is harder since applying a specific generalization operator is triggered by object features and sometimes by its position relative to other objects. Unfortunately, the existing systems, such as MGE Map Generalizer do not have adequate mechanisms and tools to analyze such relations and often only offer measures of distance or area.

Similar problems arise when dealing with "how". Manual generalization experience allows one to determine ranges of parameter values and topological constraints. In order to utilize such constraints in the generalization process it is not sufficient to verify

them afterwards. It is necessary to build a topological "engine" into the knowledge-based system. The solution of the AAI system is inadequate here.

Following are the steps used in generalizing maps with MGE MG in interactive mode:

- Dual to single line conversion.
- Elimination (manual removal) of “dangling” roads.
- Road network simplification with the Douglas-Peucker algorithm.
- Adjoining areas aggregation – converting individual buildings to built-over areas.
- Disjoint areas aggregation – converting individual buildings to built-over areas.
- Shape simplification of built-over areas.
- Removal of single family and utility buildings in the vicinity of built-over areas.
- Simplification of selected building (those with appendices of 50-80 m² area).
- Manual editing – straightening of bent road ends.
- Multi-family building amalgamation.
- Manual editing – changing building shapes (merging) manually due to the inability to obtain satisfactory results from automatic operators.
- Building shape simplification using the Douglas-Peucker algorithm.
- Squaring of building shapes.
- Utility building amalgamation.
- Area squaring.
- Elimination of utility buildings of less than 400 m² area.
- Converting utility buildings to symbols.
- Point object typification – selection of characteristic utility buildings.
- Built-over area squaring in order to obtain better results with boundary extension.
- Built-over area boundary extension to roads.
- Displacement of buildings to roads.
- Manual editing – displacement of buildings to roads.

Results and conclusions

The sequence and scope of operations is very similar to batch mode, except for a few manual steps and adjustments. However, the outcome is different. Opting for batch mode operation leads to the following compromise:

1. whether to use a "careful" approach with minimal parameter values and often inadequate results and the necessity of manual editing,
2. or use the "extreme" approach applying the operators to a full extent and manually correct errors and constraint violations that result,
3. or perhaps use an intermediate approach, deciding each time which extreme to stick to.

Using the AAI expert system makes it possible to use the intermediate effect. The generalization rules fired make it possible to process single objects, which allows parameters to be set individually. The original goal was to determine a set of operator selection and value determination rules, which would be adequate for the map contents described, to obtain a complete and satisfactory result. However, some manual corrections turned out to be necessary. Even though large data sets could be generalized automatically under the supervision of a rule-based system, some intermediate steps had to be performed by hand, as indicated above. **Figure 3** shows an example map generalized with the AAI system.

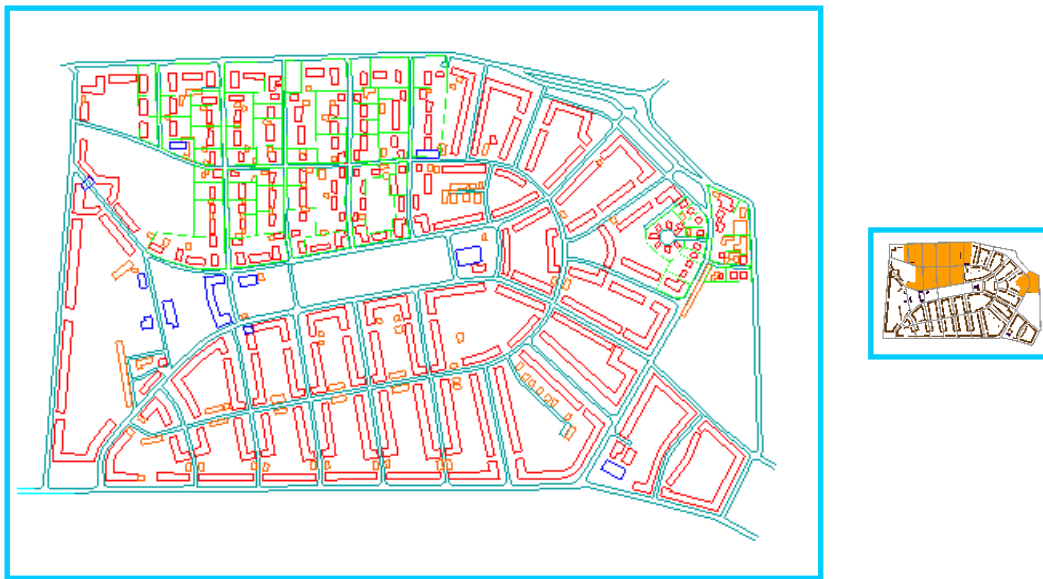


Fig.3: Vector map of Sępolno at 1:10,000 (l). Results after generalization to 1:50,000 (r)

In some situations generalization with AAI may be preferred to manual generalization in interactive mode. For example, trying to perform typification of utility buildings cannot use the standard typification operator available in MGE Map Generalizer since it is only available for point and line objects, which large buildings at 1:50,000 scale are represented as area objects. The AAI system deals with this by converting such buildings to point objects, performing typification, and then, by recognizing which objects have been eliminated, accomplish the actual typification of building outlines.

In AAI it is possible to use some topological dependencies, such as ensuring building agglomeration is not done across a road, even if it is a local road eliminated in the preceding step, but enforcing such constraints have to be individually programmed through the reasoning mechanism of the system. Therefore, the ability to analyze objects' specific location and topological relations to other objects are severely limited. For large data sets containing thousands of objects, the processing efficiency requirements enforced by conflict checking are hard to meet with the software system architecture like AAI.

Unfortunately, this MGE environment upon which the AAI has been built does not have a mechanism for controlling topology, which do have the newer tools, such as Dynamo, a new product from Intergraph. Also, there are problems with the implementation of some operators, and convoluted, but undocumented, way of specifying parameter values for batch mode operation.

On the other hand, among the advantages of basing the AAI system in the MGE environment was, in addition to being able to use its mechanisms, the ability of trying out the same operators interactively in manual mode to better learn their effects.

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