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Resolving of Internal Graphic Conflicts of Broken Lines, which Shape Is Subject to Simplification**

1. Introduction

One of elements of cartographic generalization automation is simplification of objects shapes. There are many algorithms, that serves this aim [2], but despite their different complexity, most of them is characterized by an unwanted feature. While simplification of objects (especially linear objects) shapes progresses, the distance between them along with the width of their outline is being changed. And so there can occur new, previously not existing points or areas of their interaction, what can cause a conflict. In cartography and GIS the **conflicts** are *unsuitable selected sets, locations or shapes of cartographic symbols, which give the user wrong information about the spatial relations between different objects or different parts of the same object of the real world, or which are unfavourable to human perception of graphics* [2, 4]. Lack of ways of conflicts locating and resolving is one of the major problems of automatic generalization algorithms development and application [7].

2. Application of the Perkal Theory of Objective Generalization and the Chrobak Simplification Method

Perkal [6] in his objective generalization attempt used a circle as an element defining visibility of a point on a map at a new scale. Therefore the circle with a known radius R can be used as a **recognizability buffer** of the point on the map at the new scale. All points of such circle would be unrecognizable at the target

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scale. The ability of determining the radius *R* of the recognizability buffer for each of output scales implies the possibility of objective testing if two points would be recognizable on the map at a new scale. Namely, *two points will be mutually recognizable if their recognizability buffers will not intersect* (Fig. 1a – unrecognizable points, 1b – mutually recognizable points), or, equivalently, *two points will be mutually recognizable if none of them will find itself inside the recognizability buffer of double size of the other point* (Fig. 1c – unrecognizable points, 1d – mutually recognizable points).

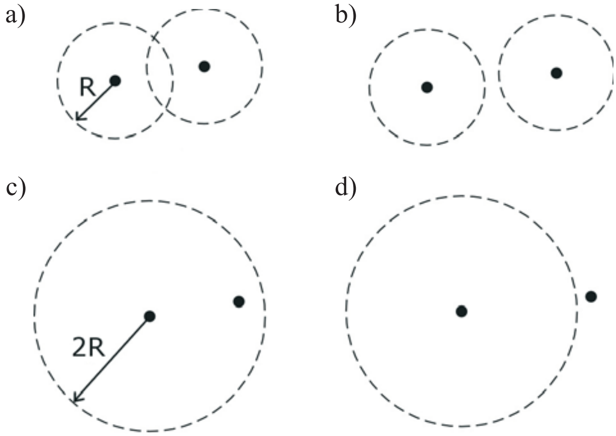

Fig. 1. Points mutual recognizability

T. Chrobak [1] stated, that recognizability of points of the map at the scale to which the shape simplification is being processed, depends on the shortest length of sides of the elementary triangle and on the denominator of the output scale. The value e_f, that corresponds the mutual map objects recognizability at the output scale can be calculated with the formula

$$e_f = s \cdot M \tag{1}$$

where:

s – the threshold measure of recognizability of map drawing (independent on its scale),

M_i – denominator of the elaborated map scale.

Putting those observations together one can determine the recognizability buffer size for original line, using the recognizability measure e_f [1], what enables finding areas that need to be simplified. Simultaneously, using this buffer can cause finding areas, where either direct topological inconsistency (such as independent curves intersection) or indirect (relative) conflicts can occur [2]. Thus *point recognizability buffer will be the Perkal circle with the diameter equal to* e_f *value*, because all the points of such circle, according to the Chrobak recognizability measure, will not be mutually recognizable on the generalized map. The R sized recognizability buffer of a broken line is made of equally sized recognizability buffers of all of its points.

Intersection of the $e_f/2$ sized recognizability buffers means lack of the elements mutual recognizability. Therefore one can assume, according to Chrobak definition of recognizability [1], that the point position change limited to its buffer (Perkal circle) will not influence accuracy of visualized data (with e_f value precision), because points closer to each other than e_f value will not be recognizable. Therefore conflicts resolving can be conducted by an excentre eks_i of a vertex of the tested broken line, where the size of the shift can be defined by the relation

$$eks_i \leq e_f \tag{2}$$

One should notice, that such shift takes place only on the map at the output scale and is dictated by drawing recognizability requirement satisfaction. It does not change the accuracy of the input data, that is reference database source data.

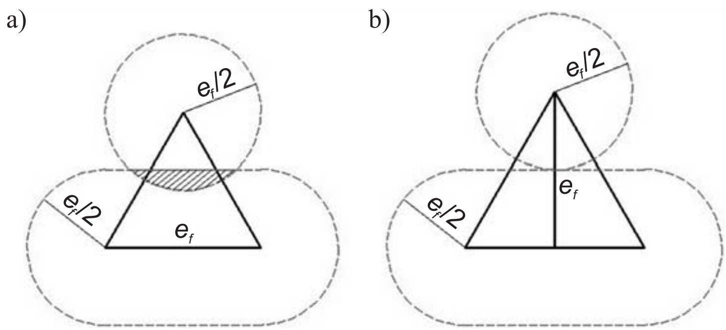

Fig. 2. Modification of the elementary triangle dimension

While studying dependencies between the Perkal circle and the Chrobak elementary triangle there was found out that simultaneous application of both recognizability conditions causes a conflict: the $e_f/2$ sized buffer, built for any of the elementary triangle sides (the triangle is made of sides of minimal recognizable in output scale length), intersects the analogous buffer built for the opposite triangle apex (Fig. 2a).

To avoid the mentioned above ambiguity, for the purpose of studying border graphic conflicts, in the elementary triangle, it is proposed to examine two conditions:

1) necessary (arising from the Chrobak theory [1]) – lengths of all the triangle sides should be greater or equal to the e_f value,
2) sufficient – the elementary triangle height should be greater or equal to the e_f value (Fig. 2b).

3. Identification of Conflicts Supported by Their Groups

Having conflicts recognition buffer defined one can start their identification. Recognition of broken line internal conflicts should be based on breadth-first search of a graph that represents internal topology of broken line vertices (f.e. Delaunay triangulation), while for the currently processed point both potential *point – point* and *point – segment* conflicts should be examined (where the segments are defined by the broken line vertices sequence, compare [2]).

In the generalization process graphic conflicts occurrence is a transitory and unique phenomenon. A *priori* neither number nor mutual connections of conflicts are known. Where the mutual connections of conflicts means the fact, that often a single element is in the conflict with more than one other element. Thus the **group of conflicts** is a *set of spatially mutually connected simple conflicts between objects or their internal elements* (Fig. 3).

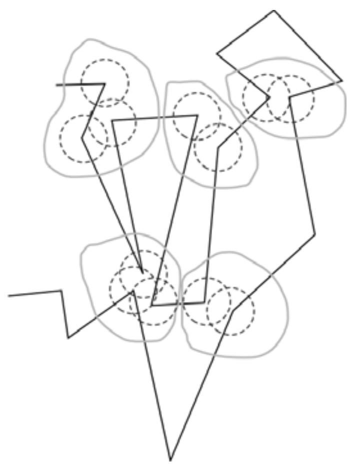

Fig. 3. Groups of conflicts

Research has shown, that during preliminarily identification of conflicts of any type their possible connections should be considered. So they should be registered in groups rather than as single occurrences. Analogical is the case of their elimination – conflicts resolving should be carried out in their groups. The aim of such approach is a specific optimization of the process, where the objective is to solve conflicts with preserving maximal similarity to the results of preliminary simplification. This means running the process in a way that minimizes necessities of objects (or their parts) removal.

The above-mentioned approach to conflicts resolving is strictly connected to objects (or line vertices) hierarchy.

Before proceeding to conflicts elimination one should examine nature of conflicts groups, what means to consider what elements are in the conflicts group and what role do they play in it. Conflicts group, besides directly conflicted elements, should also include additional ones, which restrict and guarantee a solution to be free from new conflicts. Not taking the latter condition into account could lead to infinite loop resolving old and generating new conflicts. The restricting elements should be those points and segments, that lie at a distance not causing $e_f/2$ sized recognizability buffers to intersect, but simultaneously causing double sized buffers to intersect. The buffers of conflicted elements of considered group of conflicts should be tested here. This requirement is connected with the fact, that shifting a conflicted element for a maximal allowed distance, that is $e_f/2$, causes shifting its recognizability buffer. Such shift, which aim would be to solve the existing conflict, could cause a new one. But decreasing allowed shift distance by the double sized recognizability buffer of restricting element enables finding a maximal shift distance, that would not generate new conflicts.

4. Solving Groups of Conflicts

The process of conflicts resolving can differ, depending on the number and types of conflicts in the group. Similarly as in the case of objects and broken line vertices, conflicts groups hierarchy should be established and then the groups should be resolved sequentially, in an order depending on their hierarchy. For it may happen, that f. e. one of the conflicted vertices is the restricting one of another conflicted vertex. Local change in internal line topology can disorder this relation: vertices can find out themselves in a conflict or on the contrary, they can be shifted to a distance that no longer causes restricting dependency.

For solving this problem additional conditions are assumed. These are restrictions activity testing conditions: the restriction will be active (that means taken into account in the conflicts resolving process) only if:

- the restricting element will be higher in the hierarchy than the restricted one,
- they will not be found in the same conflicts group.

The restrictions formed by not conflicted elements are assumed to be always active. The groups of conflicts hierarchy results from the conflicted elements hierarchy, what means that the higher is the group that includes conflicted object of the highest objects hierarchy level.

As it was mentioned before, the way of solving conflicts group depends on its internal structure, that is the number and types of conflicts, the number of restrictions and complication of relations between them.

Thus groups of conflicts can be classified as:
- simple groups of conflicts – groups including conflicts of identical type, with no restrictions,
- complex groups of conflicts – groups including conflicts of different types and/or including restrictions.

It is assumed, that:
- lines selfintersections can be solved by the preliminary line division into star-shaped fragments [8],
- all the other types of conflicts elimination is based on the set of "IF – THEN" rules.

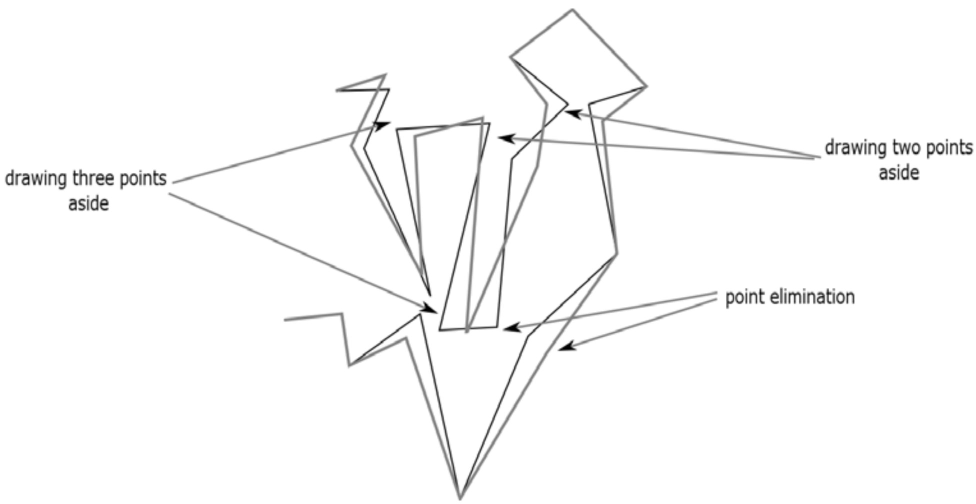

Fig. 4. Conflicts resolving

So, if it is possible, the conflict should be solved through shifting one or more elements. Otherwise some elements should be removed from the drawing, pursuing minimization of their number. The change of position of the conflicted element depends on the topology and the size of the recognizability buffer at the generated visualization scale (Fig. 4).

The process of conflicts resolving should be characterized by the following statements:
- no topological inconsistencies can occur after conflicts elimination;
- the vertex shifting is limited by its recognizability buffer;
- the distances between all the broken line elements (vertices and segments) should be greater than or equal to the e_f value; it is a sufficient condition to conflict not to be found.

5. The Example of Open Broken Lines Simplification Connected to Internal Conflicts Resolving

For the need of verification of the internal conflicts resolving algorithm in the process of broken lines simplification, selected testing data were processed using a developed program. For this purpose a map was vectorized. The selected map represents the coastline of Greece at the scale of 1: 4 000 000. This choice was connected with the high complication level of such broken line, what enabled testing many conditions and rules included in the algorithm. The results are shown on the figure 5. One can observe improvement in simplified drawing recognizability when the conflicts resolving method was used (lower table row) in comparison to the drawing simplified with the classical Chrobak method (upper row).

Scale	1 : 10 000 000	1 : 20 000 000
Without conflicts resolving		
With conflicts resolving		

Fig. 5. The example of simplification with and without internal graphic conflicts resolving

6. Summary

The described algorithm of graphic conflicts identification and resolving is deterministic and based on the set of "IF – THEN" rules, which are suitable for particular types of conflicts groups. Such a solution ensures full repeatability of the outcome for any maps scale of generalization destination.

The proposed method is objective, because its basic parameter – the recognizability buffer size – is defined unambiguously and depends only on the accepted output map scale and width of the map object outline. This approach is an extension of map drawing recognizability [1].

Like the other procedures connected to digital cartographic generalization this method requires designing suitable data model, which would be topological and would support classification and hierarchization of map contents objects and elements that builds those objects (that is vertices forming broken lines, which are the objects outlines).

It has to be noted that the method purpose is to generate a temporary map drawing at the output scale. The method does not interfere in source data, which are written in the reference database. The basic aim of the method is improvement of recognizability of drew up map.

The method significantly automates the process of graphic conflicts resolving. Although it is partially based on specific simplification method (that is the Chrobak method), its assumptions and planned sequence of necessary procedures and rules are universal enough to adapt it for other algorithms used in cartographic generalization automation. Additionally, it can be used in other areas, f.e. techniques of data acquisition remote sensing images [5].

References

[1] Chrobak T.: *Badanie przydatności trójkąta elementarnego w komputerowej generalizacji kartograficznej*. UWND AGH, Kraków 1999.

[2] Chrobak T., Kozioł K., Szostak M., Żukowska M.: *Podstawy cyfrowej generalizacji kartograficznej*. UWND AGH, Kraków 2007.

[3] Cormen T., Leiserson C.E., Rivest R., Stein C.: *Wprowadzenie do algorytmów*. Wydawnictwo Naukowo-Techniczne, Warszawa 2001.

[4] Fei L.: A *Method of Automated Cartographic Displacement: on the Relationship Between Streets and Buildings*. Leibniz Universität, Hannover 2002 (Ph.D. thesis).

[5] Kozioł K., Żukowska M.: *Zastosowanie metody Chrobaka upraszczania linii w rastrowych technikach pozyskiwania danych*. Roczniki Geomatyki, t. V, z. 2, 2007, pp. 85–93.

[6] Perkal J.: *Próba obiektywnej generalizacji*. Geodezja i Kartografia, t. VII, z. 2, 1958, pp. 130–142.

[7] Ruas A., Lagrange J.P.: *Data and Knowledge Modelling for Generalization*. [in:] Müller J.C., Lagrange J.P and Weibel R. (Eds), GIS and Generalization, Taylor & Francis, London 1995.

[8] Wu S.–T., Marquez M.R.G.: *A non-selfintersection Douglas – Peucker Algorithm.* Computer Graphics and Image Processing, XVI Brazilian Symposium, SIBGRAPI 2003, pp. 60–66