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An attempt of road network and settlement generalization in the General Geographic Database using DynaGEN environment

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Abstract: The attempts at formalization of cartographic knowledge and its implementation in computer-aided environment to achieve the most automated level of the process have been performed for over ten years. For the past couple of years, the research on generalization have been focused on some particular tasks such as: collecting cartographic knowledge aimed at identifying the principles regulating the generalization process; formalizing of generalization principles; developing generalization models; evaluating new cartographic algorithms and data structures supporting generalization processes (ex. Applying the Delauney triangulation in the process of shifting buildings).

The predominant sort of elaborations, however, concerns the generalization of either maps or spatial databases on large scales. The reason of such a state of art is directly connected with a wide sort of practical solutions of such kind of data. Basic spatial databases on country levels have been kept exactly on the scales of 1:10 000, 1:25 000 and 1:50 000 – and hence the need for automated generalization. However, until now, there are neither general standards nor unified principles of small-scale maps generalization. Both complexity and specific character of generalization process in overview-scales, which in practice bases mostly on an author's experience and intuition as well as on the need for taking a map context into account, make the whole task very difficult and complex.

The main purpose of the performed experiments was to establish possibilities and limitations of the automated generalization of small-scale spatial data. The problem was studied from the point of view of its formalization as well as further development of a knowledge base concerning small-scale spatial data generalization in commercial software DynaGEN by Intergraph.

The scope of the studies covered carrying out two generalization experiments. The first one concerned the generalization of thematic layers - road network and settlement for the area of the Lower Silesia Province. The second one was applied to the generalization of the same thematic layers in the Lodz Province.

Keywords: Generalization of spatial data, General Geographic Database, DynaGEN environment

1. Introduction

The cartographic generalization is one of the basic elements of maps production, together with data collecting, storing, maintenance, keeping it up-to-date and also redaction and print (or visualization of a database). Ware and Jones (2005) identify manual and automatic generalization processes with trying to search for balance between two basic tasks, which a map (or visualization) should fulfill. The first of them is the destination of a map being elaborated. The second one is keeping readability, adequately to a scale or to a level of detail. Based on that, it is the task of a cartographer to adjust a quantity of information contained by a map to the aim and its scale (Steiniger, 2007). According to the definition proposed by the International Cartographic Association generalization covers selection and simplifying of geographic information appropriately to the scale and destination of a work (Neun, 2007).

Many authors emphasize a holistic character of generalization process paying attention to the fact that generalization activities performed for one class of objects may have a big impact on different objects belonging to other classes, so their mutual relations should be monitored (Sarjakoski, 2007).

One of the very first works issued as a collection of articles describing methods of control and optimizing the generalization process by using systems based on principles was published in 1991 (Buttenfield and McMaster, 1991). The majority of systems proposed then have not been applied in practice because of difficulties in formalizing and implementing the generalization principles in the form of computer algorithms. An exception is the "Change" system (Powitz, 1992). The abovementioned problems have partially been solved by obtaining a knowledge base (generalization principles) by using computer learning techniques (e.g. neural networks) (Weibel et al., 1995).

While performing generalization of large scales, it is advisable (taking into account spatial conflicts arising between generalized objects) to divide the area into small fragments. In case of topographic maps such natural division lines can be roads. An example of such a solution was described in the work of Robinson and Lee (1994) as well as in the agent-modeling concept where map's fragments divided by roads are controlled at the level of so called "meso-agents", "macro-agents" (the whole area of a map) and particular objects at the level of "micro-agents". The level consisting of meso-agents controls the run of generalization process by means of a proper selection of operators as well as solving conflicts between particular objects (Ruas, 1999).

The problem of generalization operators control was also tried to be solved by applying optimization methods. Such methods aim at reduction of conflicts between generalized objects generated as a result of action of the generalization operators. In one of the very early works concerning the use of optimization methods in generalization processes, the functioning of two methods: "simulated annealing" and "discreet gradient descent" used to control the maintenance of minimal distances during generalization of surface objects was compared. In this particular case, more correct results were obtained by using the first method (Ware and Jones, 1998). Furthermore, this method has been applied for generalization of multi-arrangement spatial data as well as to control the mutual localization of objects during generalization (Ware et al., 2003).

The "finite element method" (FEM) was developed for machine engineering to make it possible to simulate the results of pressure exerted on physical structures having determined properties. That method was implemented into cartography by Høјholt (2000). Applying the FEM aimed at keeping (maintaining) minimal distances between roads and buildings during the generalization process. Højholt assigned different levels of resistance to particular map objects and then, introduced pressure elements which were a function of mutual distance of objects. Similar researches were performed by Bader et al. (2005), who used the abovementioned method to shift buildings without changing their shapes and distances between them. A different optimization method aiming at maintaining mutual distances between objects during generalization is the "snakes method" introduced to cartography by Burghardt and Meier (1997).

Harrie (2000) proposed to use the Least Squares Method for iterative process of adjusting an current generalization result to the correct one, described in the instructions for map redaction.

A predominant part of researches concerns however the generalization of either maps or spatial databases in large scales (Bildirici, 2004; Revell, 2005; Hardy et al., 2008). It is mainly due to a wide practical range of applications of such kind of data. The basic spatial databases on a country level have been kept exactly on the scales of 1: 10 000, 1: 25 000 and 1: 50 000, hence the need for their automatic generalization. Unfortunately, until now, there are neither coherent standards nor unified generalization principles of small-scale maps. The complexity of map generalization as well as a special character of the process on overview-scales which in practice bases to a significative extent on a redactor's experience and intuition as well as the need for taking a map's content into account makes the task very unusual and complex.

The main purpose of the performed experiments was to establish possibilities and limitations of the automated generalization of small-scale spatial data. The problem was studied from the point of view of its formalization as well as further development of a knowledge base concerning small-scale spatial data generalization in commercial software DynaGEN by Intergraph.

The scope of the studies covered carrying out two generalization experiments. The first one concerned the generalization of thematic layers – road network and settlement for the area of the Lower Silesia Province. The second one was applied to the generalization of the same thematic layers in the Lodz Province. That research has been a continuation of previous works concerning generalization possibilities of spatial databases (Chybicka et al., 2004).

2. General Geographic Database

The requirement for up-to-date spatial information in Poland was an impact on building the National Geographic Information System (NGIS). It consists of various spatial databases such as: Topographic Data Base (TDB) at the level of detail corresponding to a map in the scale of 1:10 000, vector map of the second level (VMapL2; 1:50 000) and General Geographic Database (GGD; 1:250 000). The concept of NGIS assumes a free data flow between the above mentioned databases (TDB, VMapL2, GGD), which, taking into account differences of their models and also different levels of detail, is very complicated both from scientific and practical point of view.

Being an essential component of the NGIS, GGD represents a set of spatial data, which are the reference for the other data and objects. Therefore, the General Geographic Database makes it possible to identify other reference data and objects related to land cover. It consists of the following thematic layers:

- administration border,
- settlement,
- hydrography,
- relief,
- transportation network,
- land cover,
- protected and restricted areas,
- geographical names.

The current work aims at determining the principles of generalization of the thematic layer concerning settlement and roads as well as at performing an analysis of possibilities and limitations of the used examination tools. The settlement layer of GGD contains two data categories:

- settlements presented as signatures,
- settlements presented as outlines.

Attributes characterizing settlements concern their administration status (cities, quarters, villages, colonies), headquarters of authorities (state, regional, district, comunal) as well as a number of citizens but only for settlements presented by outlines. For the category of "settlement", there is an information about the settlement's type (complex, loose, enclave).

Within the thematic layer of roads, there is an information regarding road management (by using this attribute state-, regional-, district-, private and factory roads were differentiated), road category (motorway, express way, main accelerated traffic road, main road, second-level and local road), road condition (existing road, road under construction or designed one), surface type (hard, stabilized, soil-surfaced road), route direction (on a surface, on viaducts or bridges, on a water dam, in a tunnel), number of roadways (double or single roadway road) number and length of road.

3. Generalization Model

The process aimed at retaining the picture readability accordingly to a projection space, resolution of a projector, perception level and application requirement of a receiver is generalization (Meng, 1998). For small scales such process is subjective and intuitive. The decisions within the area of basic generalization steps are in most cases based on knowledge and cartographic practice coming from the experience of a cartographer. Until now, neither rules nor any standards of small-scale maps generalization have successfully been elaborated.

The operations forming the generalization process may be classified in different ways. The authors agree with the concept of dividing the process into the data model generalization and the cartographic generalization.

Data model generalization is identified with the process of data preparation (covering e.g. spatial and attribute analyses) to a proper stage of cartographic generalization, which results in visualization (Sarjakoski, 2007). A similar idea has been represented by Bell et al. (2004). In the authors' opinion, the role of data models generalization is to reduce the number of data (by class or object class selection) according to the assumed level of detail. The authors include to the generalization steps connected with a data model the following items:

- selection of classes or subsets of object classes,
- selection of single objects based on their typical attributes,
- change of geometry type of an object (change of its way of presentation on a map), e.g. double line into a single one; from an outline to a point (signature),
- selection of objects representative within a considered group,
- simplifying of objects geometry.

The authors also emphasise that the above-mentioned generalization activities can strongly influence each other. It is hence obligatory to group them in a right sequence.

The aim of the second stage of generalization process is to obtain an optimal map readability (visualization) related to presentation and map production scale. Cartographic generalization consists of:

- applying right symbols for particular objects,
- modifying objects geometry, e.g. moving or aggregation.

The described experiments concern first of all the first stage of generalization process that is the generalization of a data model.

4. Research Tools

The author made use of the commercial software by Intergraph called "GeoMedia", which makes it possible to perform complex and advanced spatial analysis, and DynaGEN – special system for supporting map generalization process.

In the DynaGEN Environment there are possible two operation modes: automatic process and interactive one (executed under user's supervisory). The system provides a dynamic work – in other words a user can change values of any parameters by using "sliders" and visually valuate generalization results.

The idea of a generalization operator was defined as an elementary map conversion (transformation), which can be expressed as a mathematic formula or equivocal procedure description (algorithm). Such a conversion can be called a generalization action. The process of a computer-aided generalization may have the form of a sequence of such conversions with proper parameter values. This sequence and its parameters should be selected in a way that assures the occurrence of proper relations between generalized objects. During the generalization process accordingly to a type of generalized object the user has an access to a wide range of operators, algorithms and generalization parameters (Chybicka and Iwaniak, 2005).

5. Building the knowledge base

The implementation of generalization rules in the DynaGEN environment is closely connected with the elaboration of the knowledge base (in the MS Access format) containing:

– list (which describes following generalization actions) consisting of:

- the name of a generalized object,
- operator,
- algorithm,
- values of default parameters,
- name and values of the attributes assigned to objects created as a result of the generalization,
- condition of proper implementation method.

– description of forbidden topological changes (definition of forbidden spatial relations between generalized objects).

A knowledge base in the DynaGEN system consists of two sets of rules. The first one covers the principles performed in an automatic mode and focuses on data preparation. The second set is composed of rules describing basic generalization processes executed interactively and supervised by the cartographer.

6. Generalization of transportation network and settlement for particular scale levels

A content selection of visualization process in particular levels of detail defining sequential generalization activities has been elaborated experimentally considering:

- analysis of existing general-geographic maps on the scales of 1:500 000 and 1:1 000 000,
- literature studies concerning this subject,
- interviews with cartographers and experts in generalization,
- practical experiences coming from previous experiments performed in the DynaGEN environment.

The generalization of a transportation network and settlement covered performing of sequential generalization tasks. Herebelow the author described basic generalization actions, which are a part of the generalization of both transportation network and settlement for particular scale levels. The activities connected with the use of advanced attribute and spatial analyses have been performed in the GeoMedia environment for the sake of a wide range of available tools. However, all actions related to the simplifying and aggregating of objects have been carried out using the DynaGEN software, which includes a rich set of generalization operators.

The generalization process of the transportation network was preceded by the preliminary data preparation. It consisted in combining smaller road segments (obtained as a result of digitizing) into bigger continuous objects used in an interactive generalization. This task was performed in the DynaGEN software, whose operator made it possible to join object elements into the network structures (feature blending, merging). The criterion of joining objects is fulfilled by the same attribute value related to the number of an international road and department managing this road (Province, District, Community). The process was carried out automatically. The following steps concerning the generalization of roads were performed in an interactive mode.

When generalizing settlement areas, the authors did not have to execute preliminary data processing. Hence, the following generalization steps were performed exclusively in the interactive mode.

7. Generalization actions undertaken to visualize data at the resolution level representative for the 1:500 000 scale

The visualization process at the resolution level characteristic for the 1:500 000 map scale was performed by executing the following generalization actions (Table 1):

Table 1. Generalization actions for the 1:500 000 map scale

Generalization step	Description of a generalization action	Criterion	Implementation	
			GeoMedia	DynaGEN
1	Preliminary selection of settlements represented by signatures	Presenting cities and government seats of a province, district or community	Attribute queries	–
2	Selection of roads	Selection of national, province and district roads; rejection of dead-end communal and private or factory roads; by attribute values	Attribute and spatial queries, free end points tool	–
3	Additional selection of settlements represented by signatures	Complying with the topological criterion of a connection between roads and settlements	Attribute and spatial queries	–
4	Preliminary aggregation of settlements represented by outlines	Aggregation of settlements' parts adjoining to each other	–	Operator Area aggregation, Algorithm adjoining
5	Additional selection of settlements represented by outlines	Aggregation of settlements' parts situated from each other within a distance inferior to 0.5 mm on the map	–	Operator: Area aggregation, Algorithm non-orthogonal tolerance parameter's value = 0.5
6	Selection of settlements represented by outlines	Presenting areal symbols whose area is larger than 9 mm^2 on a map as well as cities and seats of province and district governments	Area calculation by applying the functional attribute; object selection – attribute query	–

8. Generalization actions undertaken to visualize data at the resolution level representative for the 1:1 000 000 scale

The visualization process at the resolution level characteristic for the 1:1 000 000 map scale was performed by executing the following generalization actions (Table 2):

9. Visualization of the GGD at assumed resolution levels

The final visualization of the generalized data was performed in the GeoMedia system. The figures below (Figures 1 – 4) present the generalization results and effects of selecting map contents according to the particular resolution levels.

Table 2. Generalization actions for the 1:1 000 000 map scale

Generalization step	Description of a generalization action	Criterion	Implementation		Notices
			GeoMedia	DynaGEN	
1	Selection of settlements represented by signatures	Representing cities and government seats of a province, a district. Rejection of community seats	Attribute queries	–	Change of the object presentation method from outlines to signatures for cities, seats of provinces and districts
2	Selection of roads	Selection of national and province roads; rejection of district roads; by attribute values	Attribute queries	–	–
3	Preliminary aggregation of settlements represented by outlines	Aggregation of settlements' parts adjoining to each other	–	Operator Area aggregation, algorithm adjoining	–
4	Additional selection of settlements represented by outlines	Aggregation of settlements' parts situated within the distance inferior to 0.5 mm on the map	–	Operator: area aggregation, algorithm non-orthogonal tolerance parameter's value = 0.5	–
5	Selection of settlements represented by outlines	Representing aeral symbols, whose area is larger than 9 mm^2 on a map	Area calculation by applying the functional attribute; object selection – attribute query	–	–

10. Limitations and problems

- As a result of verification of the elaborated knowledge base concerning small-scale spatial data generalization for the second test area (District of Lodz, Central Poland), there was a number of hitherto methodical assumptions for a sequence and a sort of performed generalization steps that were validated and furthermore modified. Based on that, more accurate effects from the cartographic point of view were obtained.

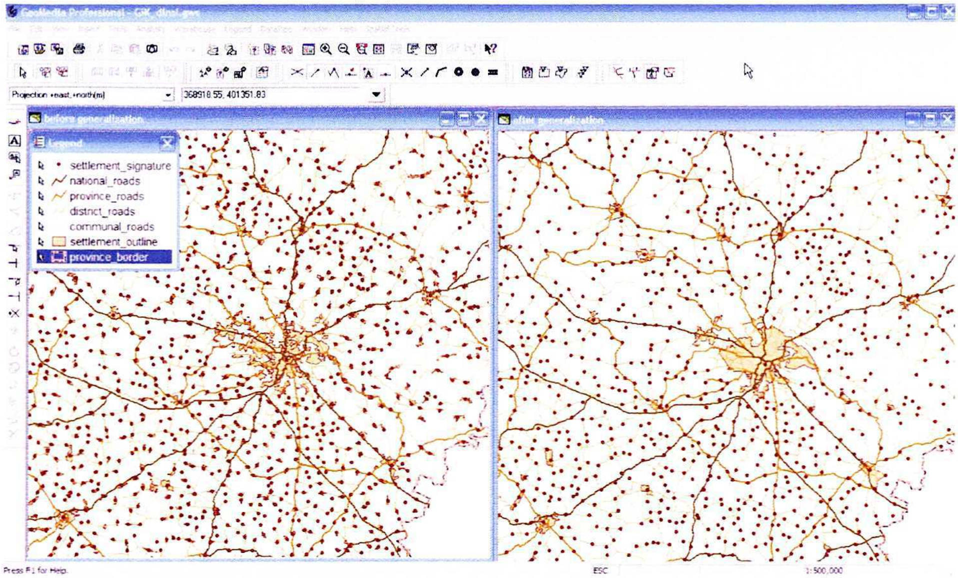

Fig. 1. Visualization of the generalized data in GeoMedia (District of Lower Silesia; scale 1:500 000)

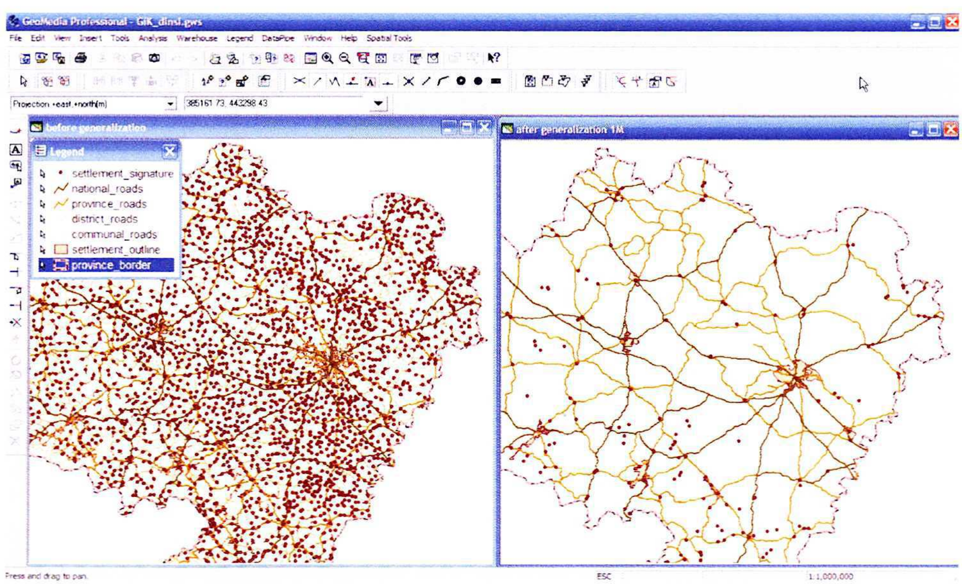

Fig. 2. Visualization of the generalized data in GeoMedia (District of Lower Silesia; scale 1:1 000 000)

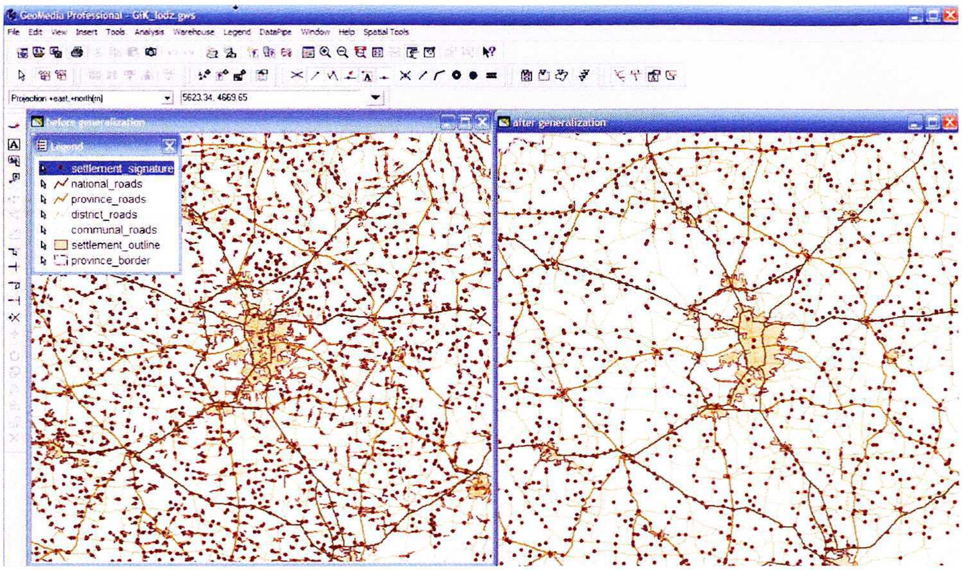

Fig. 3. Visualization of the generalized data in GeoMedia (District of Lodz; scale 1:500 000)

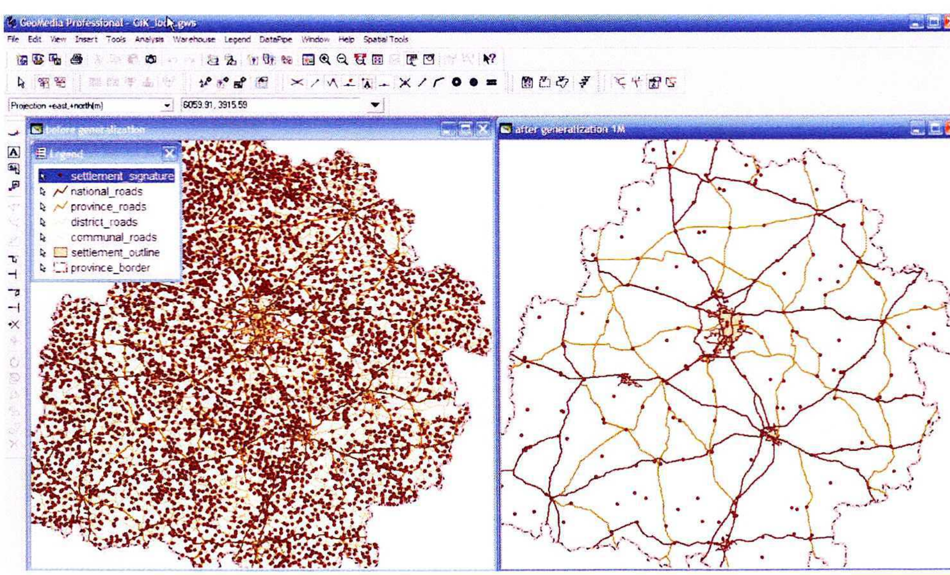

Fig. 4. Visualization of the generalized data in GeoMedia (District of Lodz; scale 1:1 000 000)

- Obtaining new tools of spatial analysis from the "Spatial Tools" group made it possible to process and develop hitherto experimental results concerning mainly the identification of dead-end road fragments.
- A range of generalization activities (concerning mainly the generalization of a road network) will be used in the second research area. However, there are some limitations related to a settlement, which in case of their specific require an individual approach, e.g. in the selection of aggregation parameters.
- The problems of topology correctness between generalized layers result from vectorizing errors of the source database.
- There is a lack of detailed information on functions performed by the particular towns in the source database (GGD), which is very important from the point of view of the settlement generalization.
- After aggregation of some settlements presented by outlines, too significant shape simplifications arose (this step should be performed in the second stage –cartographic generalization in interactive mode) (Fig. 5).
- An improper identification of dead-end roads lying on a district border can be noticed.
- As a result of rejection of other roads there are new – secondary dead-end roads (Fig. 6).

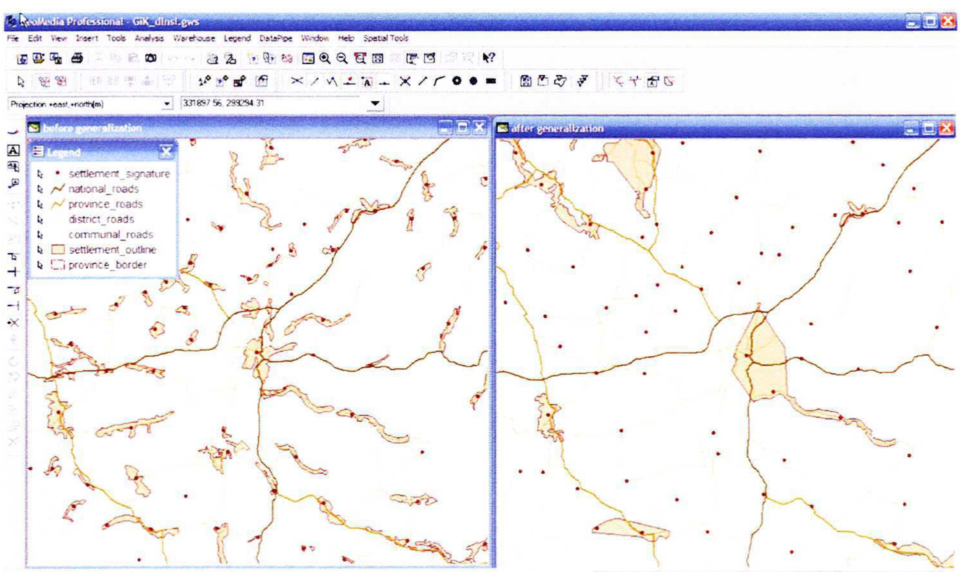

Fig. 5. The example of improper simplification of the settlement shape at its aggregation

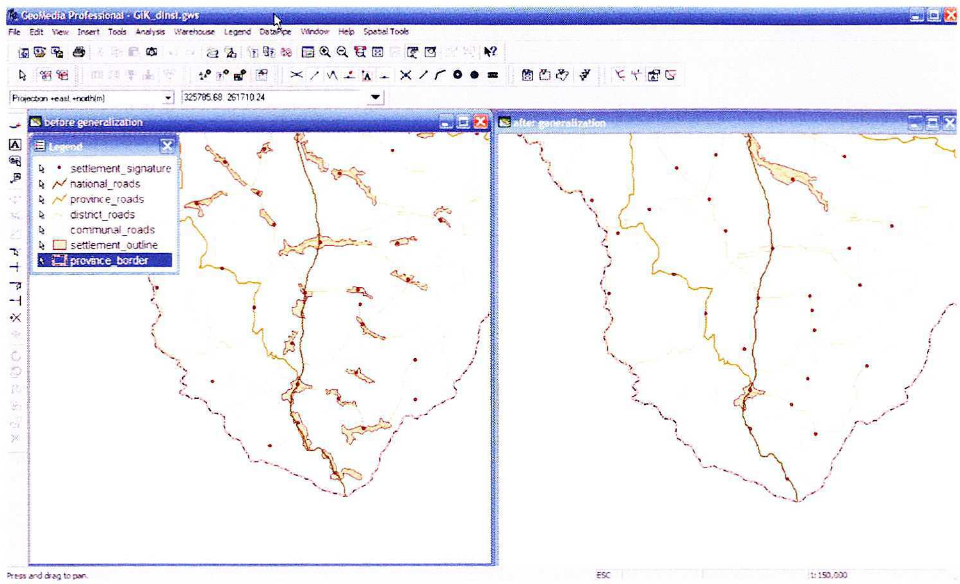

Fig. 6. The example of appearing of secondarily dead-end roads

11. Conclusions

The results of performed experiments make it possible to formulate the following conclusions:

- The small-scale generalization mainly depends on the experience and knowledge of a system cartographer. Due to a very subjective character of the process there are no precise instructions of small-scale map redaction. Such a situation makes it significantly difficult to elaborate a knowledge base concerning the process and its formalization as well as its implementation in the DynaGEN system.
- Generalization operators available in the DynaGEN system cover not only geometry of objects but also the topological relations between them. For example, during the process of line simplification, the proximity of other objects is considerable. Before (or during) the generalization process, it is possible to declare erroneous spatial relations (Disallowable Topological Changes). Such an approach allows to a user the continuous analysis and maintenance of spatial relations between objects during the generalization process. It is especially important in the process of road and settlement generalization. Due to their strict common relation (e.g. each town on a map has to be joined by a road as well as important settlements should be presented on maps), to obtain right generalization results it is mandatory to keep the right topological relations.
- While performing an implementation sequence in the DynaGEN system, several difficulties connected with identification of dead-end roads were encountered. Such a problem also appeared in researches on generalization of large scales (Chybicka et al., 2004). In this situation, it was decided to use additional tools of spatial analysis (selected from a group available in GeoMedia application of Intergraph).

Unfortunately, although the results obtained in this category are more accurate, they are still insufficient. As an example, one can mention the roads leading to district borders wrongly identified by the system as "dead-end" or secondarily "dead-end" created as a result of rejecting other roads. It seems that the solution of this problem would be the implementation of self-developed tools for spatial data analysis. However, due to a closed character of the DynaGEN system, such an approach is not possible.

- An automatic generalization in small scales needs an individual approach due to various graphical cases as well as taking into consideration both context and objects surrounding. This is the element, which up to now cannot be handled within the systems supporting generalization process. In DynaGEN it is possible to generalize whole areas in the same way. However, there are no alternative operations, which bring out the need for executing generalization processes in an interactive mode on relative small areas or in a fully automatic mode implying manual proof-reading by the cartographer.

Summarizing – based on the performed experiments of generalization it was found out that the DynaGEN system is a universal and very advanced tool supporting the generalization process of spatial data. Although the DynaGEN system was developed to fulfill the needs of large-scales data generalization, the implementing operators and algorithms provide a coherent methodology for the generalization performed in small-scales as well. What is more, covered researches are crucial for the further determination of possibilities and limitations and also for comparing the existing systems supporting automated generalization of spatial data. According to that, the knowledge base of small-scale generalization obtained experimentally will also be implemented to other GIS systems.

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Próba generalizacji sieci dróg i osadnictwa Bazy Danych Ogólnogeograficznych z wykorzystaniem środowiska DynaGEN

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Streszczenie

Próby formalizacji wiedzy kartograficznej oraz jej implementacji w środowisku komputerowym, w celu uzyskania jak największego stopnia automatyzacji procesu, podejmowane są już od ponad dziesięciu lat.

W ciągu ostatnich lat badania dotyczące generalizacji skupiały się wokół kilku zagadnień takich jak: pozyskiwanie wiedzy kartograficznej w celu identyfikacji reguł rządzących procesem generalizacji; uściślenie (formalizacja) zasad generalizacji; rozwój modeli generalizacji; opracowywanie nowych algorytmów generalizacji oraz próby przenoszenie na grunt generalizacji kartograficznej algorytmów i struktur danych wspomagających prowadzenie procesu generalizacji, np. zastosowanie triangulacji Delauney'a w procesie przesuwania budynków.

Przeważająca część opracowań dotyczy jednak generalizacji map lub danych przestrzennych w skalach dużych. Przyczyny należy upatrywać w szerokim zastosowaniu praktycznym tego typu danych. Podstawowe bazy danych przestrzennych na szczeblach krajowych utrzymywane są właśnie w skalach 1:10 000, 1:25 000 i 1:50 000, stąd potrzeba ich automatycznej generalizacji. Nie opracowano jednak dotychczas ani spójnych standardów ani ujednoliconych zasad generalizacji map małoskalowych. Złożoność i specyfika procesu generalizacji map w skalach przeglądowych, który w praktyce bazuje w dużej mierze na doświadczeniu i intuicji redaktora, oraz konieczność uwzględnienia kontekstu mapy, powoduje, że jest to zadanie niezwykle skomplikowane.

Podstawowym założeniem prezentowanych badań jest określenie możliwości i ograniczeń automatycznej generalizacji danych przestrzennych małoskalowych. Problem przedstawiono z punktu widzenia możliwości formalizacji zasad generalizacji oraz pozyskania kartograficznej bazy wiedzy, związanej z generalizacją danych małoskalowych. W badaniach wykorzystano komercyjne środowisko programowe służące do wspomagania procesu generalizacji DynaGEN, firmy Intergraph.

Opracowanie dotyczy przejścia od poziomu szczegółowości 1:250 000 do poziomów szczegółowości 1:500 000 oraz 1:1 000 000 dla dwóch warstw tematycznych: dróg oraz osadnictwa na obszarach badawczych BDO obejmujących województwo dolnośląskie oraz łódzkie.