DE GRUYTER
OPEN

Polish Cartographical Review
Vol. 49, 2017, no. 1, pp. 5–15
DOI: 10.1515/pcr-2017-0001

PAWEŁ CEBRYKOW
Maria Curie-Skłodowska University, Lublin
Department of Cartography and Geomatics
pawel.cebrykow@poczta.umcs.lublin.pl

Cartographic generalization yesterday and today

Abstract. The author presents evolution of views on cartographic generalization since it was defined by Emil von Sydow (1866) until today. It is divided into three chapters which present the evolution of views on cartographic generalization, models of generalization and digital generalization, respectively.

Views on the topic of generalization evolved in the direction of broadening the term itself and towards a different perception of its nature. Originally generalization was understood as a process which can be performed on maps only. Now the prevailing understanding is that it begins earlier, at the conceptual stage of map making. Determination of the method of contents' presentation is an indication of such generalization.

The character of generalization is another important aspect of the discussion on its nature. The notion of a subjective nature of generalization, expressed, among others, by Max Eckert (1921), was originally predominant. Later there also appeared different opinions, allowing its objectivization (K.A. Saliszczew 1998). This direction helped to result in automation of the process of generalization of map contents. Currently a dualism in perceiving generalization can be observed, with a strong bias towards its objective aspect.

In a separate chapter the author discusses conceptual models of generalization proposed by: L. Ratajski (1967, 1973), J. Morrison (1974), B.G. Nickerson (1988), K.E. Brassel and R. Weibel (1988), as well as R.B. McMaster and K.S. Shea (1992). They are divided into the universal models of theoretical character and those constructed for the purpose of computer automation of the process.

Attempts at digital generalization which currently develop in the context of generalization of general, and especially topographic maps, are discussed separately. Most important algorithms concerning generalization of linear objects are presented chronologically, concluding with a description of comprehensive generalization systems.

The summary presents two main conclusions. Firstly – work on generalization will continue to consider the geographical context during the process. Secondly – generalization of thematic, and especially statistical maps is the prospective direction.

Keywords: cartographic generalization, automation of generalization, models of generalization

1. Introduction

Issues of cartographic generalization have often been discussed in literature, among others in „Polski Przegląd Kartograficzny" ("Polish Cartographical Review"). In the past century the understanding of generalization has evolved and widened to include the conceptual stage of a map. In the last several decades cartographers' interest in the process resulted mainly from the technological revolution, which left its mark on the contemporary understanding of a map and cartography. The will to objectivize the process of generalization and its digitalization was the main impulse for change. As a consequence the definition of generalization has been modified. It presented cartography with new problems, which in turn determined new research directions and resulted in the development of cartography as a science. This article attempts to describe the directions of development of research on generalization basing on the retrospective review of opinions on its subject.

2. Evolution of views on generalization

Generalization refers to both general and thematic maps. The term itself comes from the French "généralisation". The Latin "generalis" meant the same as general or main (K.A. Saliszczew 1998). Initially this activity had not been defined and was performed intuitively. The first to use the term "generalization" was the German officer and teacher Emil von Sydow. In 1866 he determined the three main, in his view, scientific problems of cartography called "cartographic reefs". Cartographic generalization was one of them (E. Sydow 1866).

This issue became a point of interest for a well-known German geographer Alfred Hettner, who established the basis for differentiation between quantitative and qualitative generalization. He understood generalization as a subjective process, depending on the person who performed it (M.Sirko 1988). This view was shared by O.L. Meyer, who stressed dependence of generalization on the scale and purpose of the map when he wrote: "what can be drawn adapts to the scale, what has been drawn must be defined by the map's purpose" (O.L. Meyer 1913, after M. Sirko 1988, p. 6). He also noticed that cartographer's experience and acquaintance with the phenomenon presented on the map has huge impact on the quality of generalization.

In 1921 Max Eckert published the first volume of his work *Die Kartenwissenschaft* which included the first comprehensive description of cartographic generalization, although he had also presented his views on this topic earlier. In 1907 in Nürnberg he delivered a lecture which was later published in "Bulletin of the American Geographical Society", where he identified generalization with scientific endeavor (M. Eckert 1908). He distinguished three types of generalization: qualitative, quantitative and technical. He perceived the core of the process to be the selection and generalization of map contents depending on its destination. Similarly to A. Hettner, O.L. Meyer stressed the subjective aspect of generalization and its dependence on the knowledge and experience of the cartographer. He did not consider it to be a flaw, but rather as an argument for treating generalization as an art. For the following decades M. Eckert's views left their mark on the understanding of the nature of generalization. M. Sirko (1988) claims that it had crucial influence on stopping the research on generalization which focused on the ways of making it objective.

E. Imhof (1924/25, 1936/37) spoke about generalization in a similar vein. He agreed with the view of its subjectivity, with the exception of generalization of settlement, which should follow rules allowing objectivity of the process. His remarks were based on experience and analysis of numerous maps which in his opinion had been generalized properly.

In the two decades between the World Wars the views of M. Eckert and E. Imhof were shared by many cartographers, also from Poland. They included S. Czarnecki (1925), S. Pietkiewicz (1935) and M. Müller (1937). According to M. Sirko (1988) the works of the above mentioned authors can be seen as the first attempts to determine the rules of generalization.

Another voice to introduce new views on generalization appeared at the beginning of the 1940s in a publication by John K. Wright (1942). The author related to the scientific reliability of maps which in a decisive way depends on generalization. According to him it consists of two components: simplification and amplification. Simplification consists in the generalization of original information which cannot be presented on a map, while amplification he understood as graphic underlining, magnification of information so that it is readable despite a small scale of the map. According to Robert B. MacMaster and K. Stuart Shea (1992) the conditions presented by J.K. Wright were one of the first attempts to determine and define components of which the process of generalization is built.

Views on generalizations were broadened by Erwin Raisz (1962). In his opinion generalization did not follow any particular rules, but was a combination of three processes: association, omission and simplification.

Works of Arthur Robinson had great influence on the understanding of generalization. In subsequent editions of his handbook *Elements of cartography* he summarized the state of research on generalization[1]. In the fourth edition

[1] The handbook had six editions which reflected the development of American academic cartography after the Second World War (A.J. Tyner 2005). In the last edition published in 1995 there were few changes in the description of generalization, but examples of generalization based on the map of Poland are a curiosity.

he devoted a separate chapter to it. A. Robinson et. al. (1978) differentiated activities constituting the process of generalization and called them the elements of cartographic generalization. They are: selection and simplification, classification, symbolization, and induction. They are applied during elaboration of maps, whose authors strive to meet various requirements. Therefore for various maps there exist various sets of processes conditioned by the factors of cartographic generalization: purpose, scale, graphic limitations and data quality. The proposed formal structure of the process of generalization became the basis to which cartographers – mainly from Western countries – referred to in the 1980s. A. Robinson's views to a certain degree reflect the spirit of generalization of M. Eckert, with his search for an element of art in it.

Cartographers from Eastern Europe gave significant input into research on generalization. L. Ratajski (1989) knew A.Robinson's stance and supported it. He agreed with the view that generalization is a creative act and, as he called it, "the art of map vocabulary" (L. Ratajski 1989, p. 198). He distinguishes two types of generalization: qualitative and quantitative. Qualitative generalization is divided into generalization of form and contents. Within generalization of form he distinguishes two approaches: approximation of distance and shape. Generalization of contents consists in the selection of signs on a map, which is done by applying nine selection criteria: size, functionality, centricity, currency, historic-traditional criterion, change tendency, frequency, local particularity or typicality and F. Töpfer's radical law (F. Töpfer, W. Pillewizer 1966). In the case of qualitative generalization it is a process leading to synthesis. It can be achieved through symbolization, grouping and changing the way of contents' presentation. Although L. Ratajski divided generalization into elements, he stressed that it is a comprehensive process and that its particular types can be performed in parallel. He also appreciated practical experience in editing maps, because teaching generalization can be done only through practice. L. Ratajski extended generalization also to map reading, noticing that in such case it is unintentional and results from the method of perception. Map editor can influence it by introducing graphic levels of reading of the contents (L. Ratajski 1989). At that time in Poland generalization of linear objects was also researched by W. Pawlak (1971, 1972), who evaluated it from the perspective of distortion of some map elements and simplification of hypsometric presentation of relief.

Views on subjective nature of generalization dominated from the times of M. Eckert till the end of the 1960s (M. Sirko 1988). This current was represented by the work of such authors as: E. Meynen (1958), D.H. Maling (1959), A.M. Floyd (1962), A.J. Pannekoek (1962), A. Götz (1963), O.H. Miller, R.J. Voskuil (1964). Domination of this direction did not however exclude a different approach, whose representatives searched for rules, often mathematical, which would allow objectivization of the process of generalization. K.A. Salishchev was critical towards the views of M. Eckert, stressing that generalization can be an objective process. This view was sketched already in the first handbook by K.A. Salishchev from 1939. In the summary of views on generalization he distinguished several types. He claimed that signs of it are in the selection of contents, approximation of object shapes, quantitative and qualitative characteristics as well as merging of objects. In striving for objectivization he gave a significant meaning to censuses which excluded or included objects on a map. An important role was also played by the norm of object density, which after being exceeded required a reduction of the number of objects (K.A. Saliszczew 1972). He referred to F. Töpfer's radical law (1966), although he noticed its flaw of determining only the number of reduced objects without indicating which ones should be reduced. Objectivization of generalization he saw in a combination of the condition of object density and their significance, which would make it possible to indicate not only the number, but also particular objects selected for reduction. Proposals of Erhart Srnka (1968) are examples of this approach. K.A. Salishchev stressed that objectivization and automation of the process of generalization is necessary for the development of cartography, with the knowledge of geographical specifics of generalized objects being a necessary condition for its correctness.

George F. Jenks had big influence on the understanding of generalization. He broke with the popular view that generalization is performed on map only by expanding it into the conceptual stage of map preparation. Thus he provided an example that it also applies to statistical maps (G.F. Jenks 1862). W. Pawlak (1988) saw it in a similar way, calling the conceptual stage "pre-graphic generalization".

3. Models of generalization

The view that it is possible to perform objective generalization became especially significant with the introduction and development of systems of geographical information. Attempts to automate brought on the necessity of new systematizing of known and newly defined elements constituting generalization as a whole. This new research approach was pioneered by Günter Hake (1973), who focused on the model character of a map. According to him, a cartographer first builds a space model, and a map, which is also a model, is being created only on the basis on this model. Basing on this idea, Joachim Neumann (1977) distinguished two types of generalization: object generalization – performed during land survey, or during a selection of objects from a database, and the second type – generalization proper which is performed exclusively on a map.

Parallel to identification and determining of the factors and elements of generalization there were attempts to elaborate generalization models. They aimed at objectivization of the process itself by description and systematizing of activities being a part of it. Models referred to as conceptual (I. Karsznia 2015) attempt to approach the process of generalization in a general way which would allow to distinguish its basic elements and relations between them (A. Iwaniak et al. 1998). The first models of generalization by L. Ratajski and J. Morrison were of universal character and referred to all map types, while models developed in the "epoch of automation" of map edition refer only to generalization of general geographical maps.

The first model was elaborated by L. Ratajski, who in 1967 announced a theory of generalization thresholds, which are the key point of the generalization process[2]. The author assumed that every input map contents can be generalized quantitatively, adapting to the capacity of the map, decreasing with the scale. When we continue the generalization process map capacity becomes so small that it is impossible to present the contents with the same cartographic method. However, map capacity can be renewed by applying a different cartographic method with a different method of presentation. This is synonymous with application of qualitative generalization. L. Ratajski called the point of method change a generalization threshold. This model of generalization was described in many publications (e.g. L. Ratajski 1967, 1971, 1973, 1989; L.T. Sarjakoski 2007).

A different concept of generalization was suggested by Joel Morrison (1974). Referring to A.H. Robinson, he formalized relations between the four basic elements of generalization – simplification, classification, symbolization and induction. He based the model on the set theory where a map is a set of elements building a representation of reality in cartographer's imagination. The preliminary idea was to explain generalization with mathematical rules (T. Slocum et al. 2009). Highlighting of induction, understood as application of a process of logical deduction is especially noteworthy. It can be explained with the use of isotherms drawn on the basis of point data which is used to estimate the temperature between them. As W. Ostrowski (2008) noticed, treating induction as a generalization method is dubious because generalization usually results in loss of information.

Presented models were created at the time when first attempts at automated generalization of linear elements were already being performed. Although they solved only elementary problems, they had been a necessary stage before comprehensive solutions could be developed. Before such attempts were made it had been necessary to build new generalization models accounting for the specifics of computer environment.

The first step was to divide the generalization process into two stages. The first stage

[2] As described by Jerzy Ostrowski (1978), L. Ratajski presented the theory of generalization thresholds in public fora, such as international conferences: in April 1967 at the III International Cartographic Conference in Amsterdam, in May 1967 at the III Polish-Czech Geographic Seminar in Warsaw and in 1968 at the I National Cartographic Conference in Lublin. Originally the author proposed the term "generalization knots", but after suggestion of F. Uhorczak he changed his view and after 1968 introduced the term "generalization thresholds".

was the generalization of the data model, referred to as a Digital Landscape Model (DLM). The second stage was cartographic generalization leading to a Digital Cartographic Model (DCM) (U. Meyer 1986). The idea of the two stages was shared by M. Powitz (1990) and D. Grünreich (1995). A similar view was also represented by M.-J. Kraak and F. Ormeling (1998, 2010), as well as W. Ostrowski (2008), who accepted the division of generalization into conceptual and graphic. The first stage is treated as preparation of database for the second stage – the proper cartographic generalization which results in a visualization in map form (L. Sarjakoski 2007, I. Karsznia 2009). Data preparation includes reduction executed by selection of classes or sub-sets of objects, as well as spatial and attribute analyses. M. Bell et al. (2004) juxtaposed generalization activities listed in literature: object selection, joining in networks, selection of representative objects, aggregation and simplification of geometry. The second stage leads to optimum readability of the map in connection to its scale and purpose. Using a single database in the form of a digital landscape model one can generate numerous digital cartographic models, but not maps in different scales. For the purpose of such maps intermediary landscape models have to be developed.

The model developed in 1986 by Bradford G. Nickerson and Herbert Freeman (A. Iwaniak et al. 1998) was in this context a pioneering one. They considered generalization as a sequence of tasks transforming the source map into the resulting map in a smaller scale. They defined tasks as modification of the elements of contents, scaling of symbols, changing object location and distribution of conventional signs, decreasing the scale and application of names. These tasks are executed using generalization operators (B.G. Nickerson 1988). Introduction of an intermediary map which serves to move and place enlarged signatures is an interesting solution in this model.

In the next model, authored by Kurt Brassel and Robert Weibel from Zürich University (1988), the structure of phenomena and the corresponding structure of information are the starting point. The process of generalization itself is divided into five stages. Firstly, the structure of data (or its sets) is recognized and its spatial relations determined. Next stage is recognition of the generalization process, in which it is decided what should be done with the original database, what types of conflicts should be determined and solved and what types of objects should be placed in the resulting database. Further on, processes which can be selected from the set of procedures are modeled. The set of procedures is key for the model and it contains three elements: operators, knowledge (generalization rules) and values of tolerance for particular object types. In the fourth step proper digital generalization is executed using generalizational processes selected and combined before. The last stage is visualization.

The authors of the model distinguish two goals of generalization: a statistical goal and a cartographical goal. Statistical goal stands for selection of information from the database. Cartographical goal can be understood as modeling of elements selected from the database. The elaborated model has features of completeness and perfectly meets the needs of integrated expert systems (A. Iwaniak et al. 1998).

According to R.B. McMaster and K.S. Shea (1992) the presented models are not complete because they focus on technical issues. Therefore they presented a model, in which they tried to approach the issue by answering three questions: why, when and how one should generalize. They understood generalization as a transformation of spatial and attribute data performed to provide proper contents and readability of the map. The procedure consists of three stages. The first answers the question – **why generalize?** There are six reasons: excessive complexity of the contents, preserving spatial accuracy, preserving accuracy of attributes, preserving esthetical value, preserving logical hierarchy and consistent application of generalization rules. Purpose of the map and pragmatic conditions related to costs also should be considered. The first stage provides theoretical basis for generalization. The second stage answers the question – **when to generalize?** The possible reasons for generalization can be smaller scale, border conflicts or poor visibility of the contents. After having decided that the contents of the map should be simplified one should enter the next stage and select proper generalizational operators, which include spatial and attribute operators. They help to answer the question – **how to generalize?**

Among spatial operators one can distinguish simplification, smoothing, aggregation, separation and other (R.B. McMaster, K.S. Shea 1992). The second group includes operations on attributes which can undergo classification and symbolization. The described model consists of three spheres: theoretical, generalization knowledge base, and tool sphere which includes generalization operators and their implementation in computer programs (A. Iwaniak 1993; A. Iwaniak et al. 1998).

Generalization models are the basis for further steps towards automatic generalization. They provide theoretical basis for creating particular systems (or parts of them) which realize tasks of earlier defined generalizational operators in digital environment.

4. Digital generalization

Despite progress on works on automation of generalization it still remains one of the "reefs" of cartography (R. Olszewski 2006). Mark Monmonier (1982) noted the complexity and multi-thread character of generalization which makes its automation a great intellectual challenge. The number of scientific papers devoted to the topic in the last twenty years shows how valid it is. Cartographic centers of Western Europe lead in this area. Here one can mention the universities in Zürich, München and Hannover as well as other research centers such as the French Institut Géographique National (IGN) or Dutch International Institute for Geo-Information Science and Earth Observation (ITC). Activity in this field can also be seen in the doctoral theses of Anne Ruas (1999), Annabell Boffet (2001) and Stefen Steiniger (2007). Research on automation of generalization is also visible in Poland in the published works of T. Chrobak (1999, 2001, 2003, 2007, 2010), W. Ostrowski (2001, 2003), W. Żyszkowska (2000, 2001), R. Olszewski (2006, 2010, 2012) and I. Karsznia (2009, 2011, 2015). This activity is to a large extent caused by pragmatic needs of efficient automatic generation of general maps on the basis of digital databases. Bases of topographic data have been established since the 1990s. Currently in many countries such bases are run by government agencies, e.g. in Poland by the Database of Topographic Objects (BDOT).

Development of automatic methods of cartographic generalization can be divided into a number of stages. In the first period, which began in the mid-20th century, development of simple generalizational algorithms was the main point of interest. They were based on statistical or mathematical formulas and were used to simplify the shapes of linear elements (I. Karsznia 2015). Such generalization is still one of the most common research topics (M. Hurba 2006). The pioneer of applying generalizational algorithms was Julian Perkal, who in 1958 made an attempt to objectivize generalization on the basis of an elementary circle which modified the line limiting the generalized area. The disadvantage of this method, as J. Perkal noticed, was that the results depend only on the shape of the generalized area, disregarding other important geographical factors (J. Perkal 1958, M. Żukowska 2008).

The rule of omitting every nth point from the set of points in a curve, introduced by Waldo Tobler (1966) was one of the first procedures. Attempts to modify random selection of omitted points did not improve the usefulness of this method, because they did not result in a correct representation of the curve shape.

Improvement of generalization was to be achieved by algorithms enabling the analysis of the curve in a complete way. The Douglas-Peucker procedure elaborated in 1973 was the pioneering proposal. It allowed slight change of the line shape within a corridor of set width. The method became popular, becoming one of the most commonly used generalizational algorithms.

The algorithms developed at the early stage founded the basis for research on the efficiency of automatic generalization (I. Karsznia 2015). However, works on new algorithms had not been abandoned. A solution concerning generalization of linear objects suggested by T. Chrobak (1999) is an example. The algorithm is based on an elementary triangle the sides of which are of the length corresponding to the smallest visually perceivable size in a given scale. Elements below this threshold are deleted. Similar type of reasoning can be found in the algorithm of P. Raposo (2010) which is based on tessellation using hexagons.

The so-called radical law developed by F. Töpfer and W. Pilewizer (1966) played an important role in algorithmic approach. This solution consists in a relation between map capacity and its scale. Regretfully it is not complete, since it deals only with the issue of quantitative generalization – it determines the number of objects to be omitted, without selecting which ones to exclude. Another problem, which was already noticed by K.A. Saliszczew (1972) and L. Ratajski (1973) is that it disregards variety in density of objects because of geographical reasons. F. Töpfer attempted to improve his method by differentiating object weight, but it did not significantly increase its usefulness K.A. Saliszczew (1972). Works of E. Srnka (1970) advanced in a similar direction. In 1968 he developed formulas using exponential functions accounting for the weight and distribution of objects. Despite some merit this solution had limited significance, which was proven in cartographical practice. In Poland attempts to automate generalization relating to the selection of settlements on maps were pioneered by Marek Baranowski and Wiktor Grygorenko (1974).

Algorithmic approach was the first step towards automation of generalization, with the initial focus on settlement, road network and rivers. Although algorithmization supported generalization, it did not consider geographical context. Therefore it remained the duty of the cartographer to evaluate the effects of generalization and connect them to the remaining contents of the map.

In the process of searching for a solution to this problem there appeared a concept of expert systems in which rules are created reflecting cartographic knowledge and experience. Here the formalization of rules is subordinated to their use in digital environment. The system was intended to comprehensively support the cartographer taking into account generalization of various objects. Relation of river network to terrain relief is an example. Due to difficulties related to an imperfect transposition of cartographic experience into generalization rules (A. Iwaniak et al. 1998), most of the developed systems have never been implemented or accepted in cartographical practice (I. Karsznia 2015).

In connection to difficulties with formalizing of cartographic knowledge necessary for automation of generalization, there appeared an intermediary proposal combining features of the algorithmic approach and expert systems. Its author was R. Weibel (1991), who called this approach the concept of amplified intelligence. In this approach the cartographer decides to start a procedure and controls its course, and finally evaluates it and accepts results. The systems where this procedure has been implemented are characterized by a possibility to make decisions on a high conceptual level, so the operator is more of a controller than editor (A. Iwaniak et al. 1998). A disadvantage of this solution is the lack of contextuality of generalization and results' reliance on the experience of the editor controlling the process. On the other hand, presence of an experienced cartographer makes it possible to notice spatial conflicts resulting from e.g. lack of conformity of generalization of two thematic layers.

Another direction of automation currently developed is represented by rule-based systems also known as constrained-based modeling systems. They are based on the assumption that a newly elaborated map should meet certain conditions which are determined by establishing object dimensions with set threshold values. This procedure resembles a formerly used so-called census method. In the case of rule-based systems several rules are applied for one object type. Sometimes there appear conflicts which should be solved by the system which suggests optimum solutions. This type of a generalizational system is used in commercial applications, e.g. Radius Clarity and Axpand (P. Revell 2008, I. Karsznia 2015).

Among commercial solutions another group with a different approach to generalization can be distinguished. They are semi-automatic systems in which there exists a large number of procedures executed without intervention from the person supervising the system, who only plays the role of a controller. Such procedures, called operators, can refer to object aggregation, simplification of their shape, etc. (I. Karsznia 2015). In the case of recognized errors the controller can introduce correction in an interactive mode. Such systems include the environment of DynaGEN, LAMPS2 and ArcGIS.

One of significant and still unsolved problems is the lack of a comprehensive approach and disregard of the context resulting from the influence of other factors, not considered in the data base, but evident in the characteristic spatial distribution of objects, which should be preserved in the process of generalization. Contextuality of generalization as an important issue was already noticed by J. Bertin (1983). Contemporary research aims to solve these deficiencies. An example of this direction of research is GAEL (Generalisation based on Agents and Elasticity) system, which preserves relations between objects and forces parallel generalization of related thematic layers (J. Gafuri J. et al. 2008).

The future poses new challenges connected to the formalization of cartographical knowledge, and related the introduction of a common generalizational platform which would allow exchange and testing of algorithms using online services. DEGEN (Data Enrichment for Adaptive Generalisation) program developed under the supervision of R. Weibel is an example of such approach. Its aim is to enrich the database with description of relations between objects in order to aid decision making during the process of generalization. Conducted research also resulted in dissertations by M. Neun (2007) and S. Steiniger (2007) which significantly helped to develop a prototype of the internet generalizational platform (I. Karsznia 2015).

5. Conclusions

Conflicting views on generalization of the last 100 years, which either treated the process as a certain art discipline, or as a formalized, objective procedure, should not be treated as contradictory. There is a lot to suggest that they are actually complimentary. In some instances, e.g. referring to topographic maps generated from databases, application of a formalized generalization method is an obvious necessity because of the cost factor. On the other hand there is a demand for thematic maps which present authors views on a given issue. In such case application of ready-made generalizational schemes is difficult to imagine. It would basically involve development of separate formal rules in each case, which would be pragmatically wrong. Also, each newly developed procedure would be original, which actually equals subjective generalization. Complementarity of the two approaches to generalization can be confirmed with an example of a thematic map, the base contents of which can be generalized in an objective way, while preserving the subjective attitude towards the contents which is the main theme of the map.

Solutions presented in the article are an important step in the direction of full automation of the process of generalization. Commercial solutions aiding generalization are already being used in practice. Despite many advantages, they are however not fully automatic, because they involve an element of human control. Neither are they universal, since they only serve to develop general maps, mainly topographical.

The direction of development of generalization seems to be connected to automation. The predominant conviction is that a single generalizational platform will appear built on the basis of online services. This leads to the development of efficient tools for map creation basing on databases. Currently the main focus is on general maps, but it can be assumed that thematic maps will be the next point of interest, and it is in this field that the research on generalization of statistical maps seems to be most prospective.

Literature

Baranowski M., Grygorenko W., 1974, *Próba obiektywnego doboru osiedli na mapie z zastosowaniem maszyny cyfrowej*. „Polski Przegląd Kartograficzny" T. 6, nr 4, pp. 149–155.

Bell M., Neuffer D., Woodsford P., 2004, *Agent-based generalisation – an update on progress*. „Kartograhische Nachrichten" Bd. 54, H. 4, pp. 170–177.

Bertin J., 1983, *Semiology of graphics: diagrams, network, maps.* Madison: The University of Winsconsin Press.

Boffet A., 2001, *Methode de creation d'informations multi-niveau pour la generalisation cartographique de l'urbain*. Doctor dissertation, Paris: Uniwersité Marne La Valle.

Brassel K.E., Weibel R., 1988, *A review and conceptual framework of automated map generalization*. "International Journal of Geographical Information Science" Vol. 2, no. 3, pp. 229–244.

Chrobak T., 1999, *Badanie przydatności trójkąta elementarnego w komputerowej generalizacji kartograficznej*. Kraków: Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH.

Chrobak T., 2001, *Techniczne i logiczne podstawy kartograficznego upraszczania i uogólniania*. In:

Główne problemy współczesnej kartografii. Uproszczenie – uogólnienie – synteza, ed. W. Pawlak. Wrocław: Uniwersytet Wrocławski, pp. 23–40.

Chrobak T., 2003, *Metoda uogólnienia danych w procesie generalizacji obiektów liniowych*. „Archiwum Fotogrametrii, Kartografii i Teledetekcji" Vol. 13A, pp. 33–38.

Chrobak T., 2007, *Podstawy cyfrowej generalizacji kartograficznej*. Kraków: Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH.

Chrobak T., 2010, *The role of least image dimensions in generalization of object in spatial databases*. "Geodesy and Cartography" Vol. 59, no. 2, pp. 99–120.

Czarnecki S., 1925, *Międzynarodowa Mapa Świata*. „Przegląd Geograficzny" T. 5, pp. 153–154.

Douglas D.H., Peucker T.K., 1973, *Algorithms for the reduction of the number of points required to represent a digitized line or its caricature*. "The Canadian Cartographer" Vol. 10, no. 2, pp. 112–122.

Eckert, Max. 1908. *On the Nature of Maps and Map Logic. Translated by W. Joerg*. "Bulletin of the American Geographical Society" Vol. 40, pp. 344–351.

Eckert, Max. 1921, *Die Kartenwissenschaft*. Bd. 1, Berlin: Walter de Gruyter & Co.

Floyd A.M., 1962, *Generalization problems in derived mapping*. "The Canadian Cartographer" Vol. 1, no. 1, pp. 4–7.

Götz A., 1963, *Hustota signatur a výběr sidel na geografických mapách*. „Sborník Československé Společnosti Zeměpisné" Roč. 68, č. 1, pp. 92–94.

Grünreich D., 1995, *Development of computer-assisted generalization on the basis of cartographic model theory*. In: *GIS and generalization. Methodology* and practice, eds. J.-P. Lagrange, R. Weibel, J.-C. Muller. London: Taylor& Francis, pp. 47–55.

Hake G., 1973, *Kartographie und Komunikation*. „Kartographische Nachrichten" Jg. 23, H. 4, pp. 137–148.

Hurba M., 2006, *Generalizacja sieci drogowej na mapach o różnej skali i przeznaczeniu*. Doctor dissertation, Uniwersytet Marii Curie-Skłodowskiej in Lublin.

Imhof E., 1924/25, *Siedlungsgrundrissformen und ihre Generalisierung im Kartenbilde*. „Mitteilungen der Geographisch-Ethnographischen Gesellschaft" Bd. 15, Zurich, pp. 5–60.

Imhof E., 1936/37, *Das Sidlungsbild in der Karte*. „Mitteilungen der Geographisch-Ethnographischen Gesellschaft" Bd. 37, pp. 17–86.

Iwaniak A., 1993, *Baza danych a baza wiedzy*. In: VIII Szkoła Kartograficzna, Wrocław, pp. 9–16.

Iwaniak A., Paluszyński W., Żyszkowska W., 1998, *Generalizacja map numerycznych – koncepcje i narzędzia*. „Polski Przegląd Kartograficzny" T. 30, nr 2, pp. 79–88, nr 3, pp. 163–172.

Jenks G.F., 1963, *Generalization in statistical mapping*. "Annals of the Association of American Geographers" Vol. 53, no. 1, pp. 15–26.

Karsznia I., 2009, *Aktualne problemy automatycznej generalizacji danych przestrzennych*. „Polski Przegląd Kartograficzny" T. 41, nr 1, pp. 5–16.

Karsznia I., 2011, *Badanie zakresu przydatności systemów DyanGEN oraz Clarity do procesu generalizacji osadnictwa i sieci dróg Bazy Danych Ogólnogeograficznych*. „Roczniki Geomatyki" T. 9, z. 1(45), s. 33–48.

Kasznia I., 2015, *Metodyka generalizacji wybranych elementów Bazy Danych Ogólnogeograficznych*. Warszawa: Wydział Geografii i Studiów Regionalnych UW.

Kraak M.-J., Ormeling F., 1998, *Kartografia: wizualizacja danych przestrzennych*. Warszawa: Wydawnictwo Naukowe PWN.

Kraak M.-J., Ormeling F., 2010, *Cartography, Visualization of Spatial Data*. Third Edition. New York: The Guilford Press.

Królikowski J., 2015, *Automatyczna generalizacja przenika do praktyki.* (http://geoforum.pl/?page=news&id=19583&link=automatyczna-generali zacja-przenika-do-praktyki&menu=46815,46847) (accessed 08.08.2016).

Maling D.H., 1959, *Training of cartographers*. "The Cartographic Journal" Vol. 125, pp. 141–142.

McMaster R.B., Shea K.S., 1992, *Generalization in digital cartography*. Washington DC: Association of American Geographers.

Meyer O.L., 1913, *Einführung in die Kartenkunde*. Habelschwerd.

Meyer U., 1986, *Software-developments for computer-assisted generalisation.* Proceedings of Auto-Cart, London, http://mapcontext.com/autocarto/proceedings/auto-carto-london-vol-2/pdf/software-developments-for-computer-assisted-generalization.pdf

Meynen E., 1958/59, *Einheit von Inhalt und Form der thematischen Karte*. „Geographisches Taschenbuch" 1958/59, pp. 534–540.

Miller O.M., Voskuil R.J., 1964, *Tematic-map generalization*. "The Geographical Review" Vol. 54, no. 1, pp. 13–19.

Monmonier M., 1982, *Computer-assisted cartography: Principles and prospects*. Englewood Cliffs, NJ: Prentice-Hall.

Morrison J.L., 1974, *A theoretic framework for cartographic generalization with emphasis on the process of symbolization*. "International Yearbook of Cartography" Vol. 14, pp. 115–127.

Müller M., 1937, *O generalizacji i kartografii słów kilka*. „Wiadomości Służby Geograficznej" T. 11, z. 1, pp. 40–44.

Neumann J., 1977, *Über Begriffe der kartographischen Generalisierung*. „International Yearbook of Cartography" Vol. 17, pp. 119–124.

Neun M., 2007, *Data enrichment for adaptive map generalization using web services*. Doctor dissertation, Eidgenossische Technische Hochschule in Zürich.

Nickerson B.G., 1988, *Automated cartographic generalization for linear features*. „Cartographica" Vol. 25, no. 3, pp. 16–66.

Olszewski R., 2006, *Systemy wnioskowania rozmytego (FIS) jako narzędzie nieliniowej generalizacji numerycznego modelu ternu*. „Polski Przegląd Kartograficzny" T. 38, nr 4, pp. 316–325.

Olszewski R., 2010, *Generalizacja rzeźby terenu z zastosowaniem modeli numerycznych*. In: *Główne problemy współczesnej kartografii. Numeryczne modele terenu w kartografii*, eds. W. Żyszkowska, W. Spallek. Wrocław: Uniwersytet Wrocławski, pp. 77–84.

Olszewski R., Bakuła K., Bujak Ł., Gnat M., Kietlińska E., Stankiewicz M., 2012, *Generalizacja NMT w opracowaniu metodologii reprezentacji rzeźby terenu na mapach topograficznych i ogólnogeograficznych*. In: *Ogólnopolskie Sympozjum Naukowe „Nowe wyzwania dla fotogrametrii, teledetekcji i kartografii w obliczu współczesnych systemów geoinformacji*", Kazimierz Dolny, pp. 19–32.

Ostrowski J., 1978, *Zasługi prof. Lecha Ratajskiego dla polskiej kartografii*. „Polski Przegląd Kartograficzny" T. 10, nr 1, pp. 5–14.

Ostrowski W., 2001, *Semiotyczne aspekty uogólnienia kartograficznego*. In: *Główne problemy współczesnej kartografii. Uproszczenie – uogólnienie – synteza*, ed. W. Pawlak. Wrocław: Uniwersytet Wrocławski, pp. 200–208.

Ostrowski W., 2003, *Rodzaje generalizacji map topograficznych na przykładzie mapy 1:50 000*. „Polski Przegląd Kartograficzny" T. 35, nr 4, pp. 251–258.

Ostrowski W., 2008, *Semiotyczne podstawy projektowania map topograficznych na przykładzie prezentacji zabudowy*. Warszawa: Wydawnictwa Uniwersytetu Warszawskiego, 209 pp.

Pannekoek A.J., 1962, *Generalisatie in de kartografie*. „Tidschrift Koninklijk Nederlandssch Aavdrykskund Genootschap" Jr. 79, 4, pp. 411–420.

Pawlak W., 1971, *Charakter zniekształceń wybranych elementów treści mapy powstałych w procesie generalizacji*. „Studia Geograficzne" 15, „Acta Universitatis Wratislaviensis" Nr 133, 112 pp.

Pawlak W., 1972, *Niektóre problemy generalizacji hipsometrii*. „Studia Geograficzne" 16, „Acta Universitatis Wratislaviensis" Nr 161, 55 pp.

Pawlak W., 1988, *Przedgraficzne stadium generalizacji kartograficznej*. „Polski Przegląd Kartograficzny" T. 20, nr 3, pp. 125–129.

Perkal J., 1958, *Próba obiektywnej generalizacji*. „Geodezja i Kartografia" T. 7, nr 2, pp. 130–141.

Pietkiewicz S., 1935, *La carte da la Pologne au millioniéme de L'institiut Géographique Militare*. In: *Comptes Rondus du Congrés, Travaux de la Section I*, Varsovie, pp. 286–289.

Powitz B.M., 1990, *Automationsgestützte Generalisierung*. „Kartographische Nachrichten" Bd. 40, H. 2, pp. 97–101.

Raisz E. 1962, *Principles of cartography*. Mcgraw-Hill: Michigan University, 315 pp.

Raposo P., 2010, *Piece by piece: a method of cartographic line generalization using regular hexagonal tessellation*. (http://www.isprs.org/proceedings/XXXVIII/part4/files/Raposo.pdf) (accessed 15.01.2017)

Ratajski L., 1967, *Phenomenes des points de generalization*. "International Yearbook of Cartography" Vol. 7, pp. 143–151.

Ratajski L., 1971, *Niektóre zagadnienia map tematycznych*. In: „Materiały Ogólnopolskich Konferencji Kartograficznych" T. 1, *Problemy kartografii tematycznej*. Lublin – Warszawa: PTG – PPWK, pp. 220–232.

Ratajski L., 1973, *Rozważania o generalizacji kartograficznej*. „Polski Przegląd Kartograficzny" T. 5, nr 1, pp. 49–55, nr 3, pp. 103–110.

Ratajski L., 1989, *Metodyka kartografii społeczno-gospodarczej*. Warszawa: Polskie Przedsiębiorstwo Wydawnictw Kartograficznych, 338 pp.

Revell P., 2008, *A review of the Clarity generalization platform and the customizations developed at Ordnance Survey research*. In: *ICA Workshop on Generalization and Multiple Representation*. Montpellier. http://aci.ign.fr/montpellier2008/papers/17_Revell.pdf

Robinson A., Sale R., Morrison J., 1988, *Podstawy kartografii*. Warszawa: PWN, (Translation of *Elements of Cartography*, 1978), 624 pp.

Robinson A., Morrison J., Muehrcke P.C, Kimerling A.J., Stephen C.G, 1995, *Elements of Cartography*, *6th* edition. New York: Willey & Sons Inc.

Ruas A., 1999, *Modele de generalisation de donnes geographiques a base de constraintes et d'autonomie*. Doctor dissertation, Universite Marne la Vallee, Paris ftp://ftp.ign.fr./ign/COGIT/THESES, https://cybergeo.revues.org/5227

Saliszczew K.A., 1972, *Historia i współczesny rozwój generalizacji kartograficznej*. „Polski Przegląd Kartograficzny" T. 4, nr 1, pp. 1–13.

Saliszczew K.A., 1998, *Kartografia ogólna*. Warszawa: Wydawnictwo Naukowe PWN, 308 pp.

Sarjakoski L.T., 2007, *Conceptual models of generalization and multiple representation*. In: *Generalization of geographic information: cartographic modelling and applications*, eds. W.A. Mackaness, A. Ruas, L.T. Sarjakoski. Oxford: Elsevier, pp. 37–66.

Sirko M., 1988, *Teoretyczne i metodyczne aspekty obiektywizacji doboru osiedli na mapach*. Lublin: UMCS.

Slocum T. A., McMaster R.B., Kessler F.C., Howard H.H., 2009, *Thematic Cartography and Geovisualization*, 3rd ed. Upper Saddle River: Pearson Prentice Hall.

Srnka E., 1968, *Kritéria vyūziti signatur pri kartografickém zobrazeni sidel*. „Geodeticky a Kartograficky Obzor" R. 14, nr 7, pp. 201–204.

Srnka E., 1970, *The analytical solution of regular generalization in cartography*. „International Yearbook of Cartography" Vol. 10, pp. 48–62.

Steiniger S., 2007, *Enabling pattern – aware automated map generalization*. Doctor dissertation, University in Zürich.

Sydow E., 1866, *Drei Kartenklippen*. „Geographisches Jachrbuch" Bd. 1, pp. 348–361.

Tobler W., 1966, *Numerical map generalization.* Michigan Inter-University Community of Mathematical Geographers Discussion Paper 8. Department of Geography, University of Michigan.

Töpfer F., Pillewizer W., 1966, *The principles of selection*. "The Cartographic Journal" Vol. 3, no. 1, pp. 10–16.

Tyner A.J., 2005, *Elements of Cartography*: *Tracing fifty years of academic cartography*, North American Cartographic Information Society, Cartographic Perspectives; No 51 (http://cartographicperspectives.org/index.php/journal/article/view/cp51-tyner), (accessed: 15.01.2017)

Weibel R., 1991, *Amplified intelligence and rule-base systems*. In: *Map generalization: making rules for knowledge representation*, eds. B. Buttefield, R. McMaster. London: Longman, pp. 172–186.

Wright J.K., 1942. *Map makers are human*. "Geographical Review" Vol. 32, no. 4, pp. 527–544.

Żukowska M. 2008, *Metoda wykrywania i usuwania konfliktów graficznych powstałych w procesie automatycznej generalizacji kartograficznej*. Doctor dissertation, AGH Kraków.

Żyszkowska W., 2000, *Modelowanie kartograficzne w procesie opracowania mapy*. In: *Główne problemy współczesnej kartografii. Złożoność – modelowanie – technologia*, ed. W. Pawlak. Wrocław: Uniwersytet Wrocławski, pp. 137–150.

Żyszkowska W., 2001, *Zmiany struktury treści mapy w procesie uogólnienia*. In: *Główne problemy współczesnej kartografii. Uproszczenie – uogólnienie – synteza*, ed. W. Pawlak. Wrocław: Uniwersytet Wrocławski, pp. 187–199.