# Analysis of Cartographic Generalization based on PYTHON Programming Language on Digital Topographic Maps

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Abstract: Cartographic generalization is a creative process of abstraction, which is used in the design and content preparation of topographic maps. It includes the study of the geographic environment, processing of geographic data, and an evaluation with regard to type, purpose, and scale of the map, or selecting and merging their graphical presentation, with a big or small degree of abstraction. In the era of digital cartography more attention is paid to developing tools for automatic generalization of cartographic content. In this paper, automatic cartographic generalization is analyzed based on PYTHON programming language for production of digital topographic map scale 1:50 000 (DTM50) from digital topographic map scale 1:25 000 (DTM25).

## 1 INTRODUCTION

Cartographic generalization is generally performed based on previously developed criteria. These criteria are formed upon maps development on the basis of tests before making the map and in the course of preparation, they do not change. It is a requirement that the map has uniformed values and standard quality throughout the territory being mapped. The need for a broader range of all of the map, not only in its size and content but also the form and manner of presentation, cartographer is bound to seek and find real special cartographic generalizing criteria for each map. Success in this is one of the key factors to create good and meaningful maps.

The research of automatic map generalization can be connected to different platforms for development. Automatic cartographic generalization is the process on which many studies are focused. The main task of mapping and the generalization process is to solve the problem of expressing the core, typical and characteristic features of the mapping territory and the occurrence of it in accordance with the purpose and scale of the map. From a large number of geographic data that exist on the mapping territory a logical amount of data should be drawn, which are of general interest and can be clearly shown on maps. Data selection is the result of a need for analysis with regard to the purpose of the map, the opportunities provided by a map scale and a geographic result of a study of the situation on the ground. (Burghardt et al., 2008; Kazemi et al, 2007; Lamy et al., 1999; Lee & Hardy, 2005; Regnauld, 2005).

Following the development of standards in the field of collection, organization, processing, and presentation of spatial data in the Military Geographical Institute (MGI) - Belgrade, spatial data of digital topographic maps at the scale 1:25 000 (DTM25) are organized in the Central Geospatial Database at the scale 1:25 000 (GSD25). It is used to generate other scale-based series maps produced in MGI, digital topographic maps in the scale of 1:50 000 (DTM50), 1:100 000 (DTM100) and 1:250 000 (DTM250) (Drobnjak et al, 2016; Tatomirović, 2017).

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## 2 GEOSPATIAL DATABASE AT SCALE 1:25 000 (GSD25)

The technological process of production spatial data for GSD25 is introduced into the technology of digital photogrammetric restitution, as well as global positioning technology (GPS) to support the GSD25 update on the ground. Applicability of GSD25 made this particularly important aspect of the whole production of different scale series topographic maps with cartographic generalization tools, cartographic reviewer and support in printing topographic map sheets.

The technological process of GSD25 is based on mapping methods, map content and digital photogrammetric restitution cartographic, processing it into a GIS environment, using reference alphanumeric data. The vectorization process is implemented in strict compliance with the logical data model respecting the possibility, or mode of the selected software environment. Anticipated technological solutions making GSD25 imply that the content and update methods also perform digital photogrammetric restitution. The whole technological process of developing the capabilities of GSD25 data distribution is shown in Figure 1.

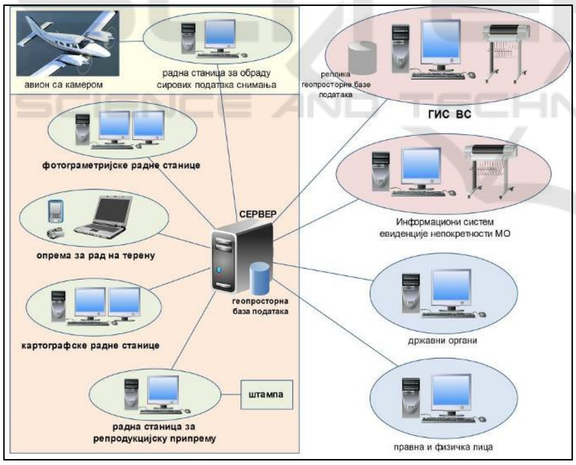


Figure 1: The technological process of GSD25.

To create GSD25 software, U.S. Company ESRI, ArcGIS platform was chosen, which contains a completely new approach to the formulation of geospatial databases. The software platform selection has caused the brand new technology in all phases of the work, but they retained the existing mapping solution. Given these requirements, the development process includes the following phases GSD25 work (Sekulović & Drobnjak, 2011):

- Making a logical data model;
- Creating a model for generalization;
- Making a physical data model;
- Creating symbology;
- Making a logical model of the process;
- Making a physical model of the process;
- Creation of procedures for generalizing and
- Training.

In the process of developing the logical data model DTM25, the geographical map elements are differentiated by the thematic groups. Individual cases each of system elements are defined by layer and codes as a unique indicator of belonging to the appropriate thematic group (Marković, 2009).

The physical data model is defined by the appearance of a database or “space” to store elements defined by tasks' logical model. Data types, method of data storage as well as all columns that are used for input attributes of object classes and individual objects are also defined in the design of the physical data model. Defining the visual appearance GSD25 physical data modelling in which will be used in the interface software determines the order of topics and, further defines the visual display of GSD25, a level that cannot be achieved through symbolism. This phase is the last step in the development of GSD25 in terms of practical preparation. Figure 2 shows the visualization of complete produced part of GSD25.

Figure 2: Visualization of complete produced part of GSD25.

The entire process of making GSD25 was conducted by relying on the ArcGIS environment, and the available hardware resources in the MGI-networked. This resulted in the division of responsibilities in working with spatial data, establishing a system of accountability in the process of sharing and flow of information in the network, and data archiving. During the whole process of making GSD25, special attention was paid to the backup data and monitoring the implementation of the entire task in map sheets and operators (Sekulović & Drobnjak, 2011).

# 3 AUTOMATIC CARTOGRAPHIC GENERALIZATION

The automation of cartographic generalization processes in the digital environment is increasingly evolving, with the aim of obtaining accurate and up-to-date spatial information through high-quality cartographic representations. Automatic generalization procedures are sets of algorithms that can be modified by parameters, depending on purpose, theme, and scale of the map. Automatic generalization should make possibility to obtain accurate choice as much possible as of the original data from the same database to different map details. The complexity of automatic generalization is determined by the selection of criteria that influence the choice of object type according to its importance for display. The generalization system involves a generalization of the original spatial database, taking into account the different attributes of spatial data, as well as adequate graphical solutions when presenting a generalizable dataset (Jovanović, 2017).

The goal of automation in cartographic generalization is to perform the steps by software in map-making process. In addition to speeding up work, automation avoids repetitive actions that do not require human decision-making or can be formulated. It eliminates the possibility of errors that may occur and optimizes map-making process. The problem is defining rules by which generalization would be done and organizing them into a single system. To translate all the knowledge and experience, rules and techniques from classical cartography, in order for a computer to simulate human decisions is a difficult task and a special challenge. The operations performed should be as close as possible to what a person would perform in each case.

One of the main problems in automation are steps in execution order, which are interdependent. All cartographic generalization procedures should be viewed as a unique process, not as a series of isolated independent procedures. The displacement of one content element often results in the displacement or elimination of another, and it may be that other elements must neither be eliminated nor displaced. To reduce complexity, the entire process is often subdivided into individual subprocesses (João & Elsa, 1998).

## 3.1 Mapping Generalization Subprocesses

The mapping generalization subprocesses perform some action on map elements. Each subprocess defines a transformation that can be applied to one or a group of spatial objects. Some are for one type of data only (point, line or polygon) and some for two or more. Despite the frequent use of subprocesses worldwide, there is no general agreement on either the number or the terminology used to describe these subprocesses. Although there are several classifications with different numbers of mapping generalization subprocesses, the ones that stand out to Lee are the following.

**Elimination** - This subprocess rejects different geographic objects because of their small size or less importance in relation to the map purpose (eg. elimination of small islands, elimination of short streets).

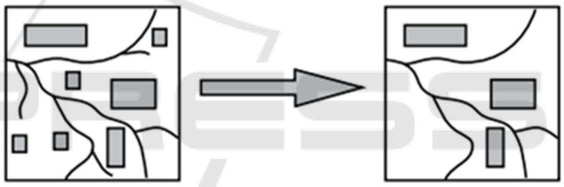

Figure 3: Subprocess Elimination (Lee, 1996).

**Simplification** - This subprocess is the selective exclusion, rejection, elimination, omission of single point or groups of points that make up an object. Parts of the building are discarded in order to simplify its appearance, but with the preservation of key parts, in order to maintain recognition.

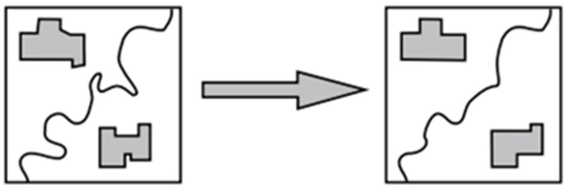

Figure 4: Subprocess Simplification (Lee, 1996).

**Aggregation** - By grouping groups of identical or similar and territorially close objects that do not touch each other, one object is displayed that represents them all. It is possible to present a group of points with polygons related to the surface on which they are located (eg. merging of small nearby lakes into one larger lake).

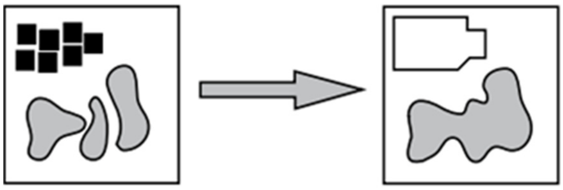

Figure 5: Subprocess Aggregation (Lee, 1996).

**Size reduction** - This subprocess reduces the size of a particular geographic object or stack of a group of parallel or near-parallel lines to a smaller number of lines.

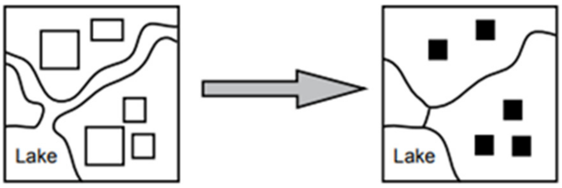


Figure 6: Subprocess Size reduction (Lee, 1996).

**Typification** - This subprocess reduces the density of spatial objects as well as the level of detail while maintaining a representative distribution pattern of these objects.

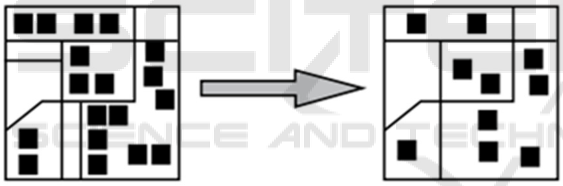

Figure 7: Subprocess Typification (Lee, 1996).

**Exaggeration** - This subprocess increases the spatial extension of the geometric representation of a given object, to focus on its significance and improve readability.

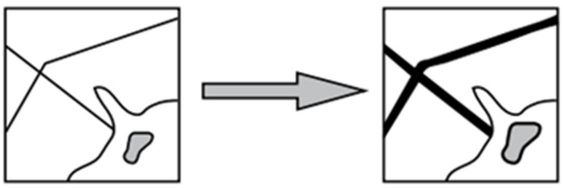

Figure 8: Subprocess Exaggeration (Lee, 1996).

**Classification and Symbolization** - This subprocess combines elements that share similar geographical attributes into a new object, which in turn has a higher degree of abstraction, in addition to the new symbol.

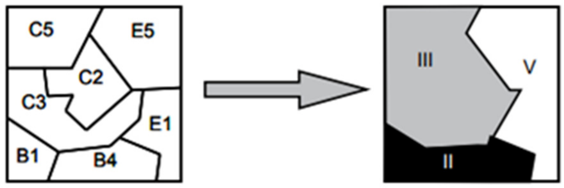


Figure 9: Subprocess Classification and Symbolization (Lee, 1996).

**Displacement** - This subprocess is used to resolve conflicts, that is, used to move an object on the map if it overlaps with another occurrence or is too close to it. When moving, the object retains its shape. This is the most complicated generalization operator since it requires complex measurements.

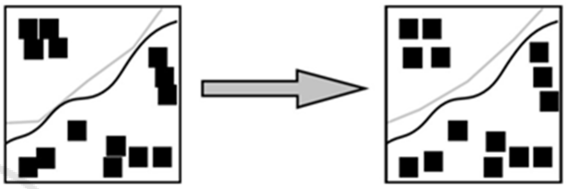

Figure 10: Subprocess Displacement (Lee, 1996).

**Refinement** - This subprocess changes and adjusts the geometry or appearance of an object to enhance the aesthetic (visual) aspect while ensuring its similarity to reality (eg. "smoothing" a line, modifying the orientation of some symbols).

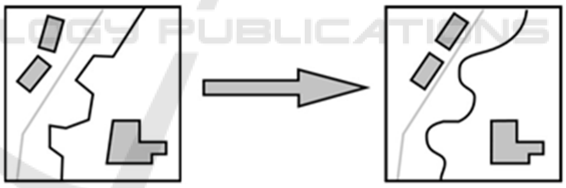

Figure 11: Subprocess Refinement (Lee, 1996).

## 3.2 Defining the Automatic Map Generalization Model

The model of cartographic generalization includes generalization of the entire content of digital topographic maps, which essentially can be graphic and conceptual. Processes related to the graphic generalization mainly deal with the geometric component of spatial data so that they can be automated. Opposed to them, the processes of conceptual generalization mainly affect component characteristics that occur, and those are harder to automate. The problem of automated generalization of geographical names is even greater due to fact that processes contain both types of generalization. (Stoter et al, 2009). This problem is solved by additional processing in preparation for printing.

Some subprocesses are present in both conceptual and graphic generalization, but there are differences in the causes of their application. Subprocesses performing graphic generalization are interdependent and cannot be viewed separately from other content on the map. Some activities require concurrent compliance with the resulting changes resulting from their implementation. For example, polygons representing a class and being displaced should merge with polygons of the same class as soon as they come into contact. Such simultaneous execution of activities can be upgraded by dividing the whole process into stages. This would lead to the activation of a predetermined subprocess after each phase, which would be executed if the given condition is fulfilled. For example, each time after moving polygons for a certain distance, if they are in contact with polygons of the same class, the displaced polygons merge with them. After that comes the second step in which the others move further and it is checked again that now these displaced polygons are in contact with polygons of the same class. Another factor that can influence the outcome of cartographic generalization is the order in which subprocesses will be used. Proper selection of the execution order can influence the final appearance of the map. Also, there are a number of different algorithms for each subprocess. Not all subprocesses are equally represented in the generalization process. Sublimation of two or more operators placed in a proper arrangement is a model of cartographic generalization (Stojanović, 2018).

It is possible to automate those forms of generalization that can be numerically interpreted and expressed in mathematical form, as well as those that necessarily generalize the classifications of mapped objects by creating models of cartographic generalization. It is easy to automatically reduce objects smaller than the established census or to select objects determined by normative indicators. In doing so, a set of choice indicators can be used on the computer at the same time, taking into account the correlation of an occurrence with other objects, if it can be expressed in mathematical form (eg. by setting a minimum distance between adjacent objects at the expense of reducing less significant ones) and may change the value indicators in different regions. The census approach can also be applied to geometric side of generalization in terms of automatic contours generalization or other lines, e.g. automatically reduce curves and fractures on lines smaller than a given size (Drobnjak, 2016). Figure 12 shows an example of automatic curvature reduction in detail and on an entire object using the Simplification subprocess.

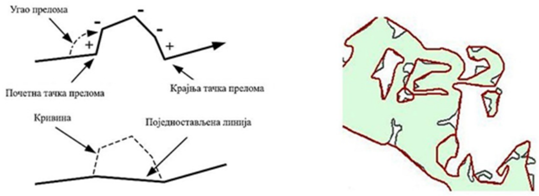


Figure 12: Automatic curve reduction using simplification subprocesses, detail view (left) and entire object (right) (Lee & Hardy, 2005).

## 3.3 Requirements and Limitations for Cartographic Generalization

Cartographic generalization is a complex process because of subjectivity and lack of well-defined rules in decision making processes necessary to compensate visual problems. During this demanding process, it is important to understand why, when, and how to generalize, in order to select and apply relevant subprocess to spatial objects (McMaster & Shea, 1992).

The relevance of the generalization subprocess depends on the particular design specifications to which the solution applies. These specifications are limitations that cartographers have to deal with. The restrictions apply to the accuracy, scale, and purpose of the map required, as well as to your visualization medium (Stoter et al., 2008). For example, when a tourist map is generated, priority is given to semantic content elements that represent objects of tourist interest in a picturesque way. This type of object does not require the use of complex subprocesses that offer high geometric accuracy. On the other hand, such subprocesses may be required when a map is generated for cadastral or military use. Moreover, constraints also apply to handle, readability of spatial objects (visibility threshold), forms, spatial relationships (positioning of objects relative to each other), and semantics. Considering the fact that it is difficult, even impossible, to overcome all limitations during cartographic generalization, it is important to identify those that are prioritized in relation to the purpose and scale of the map (Plazanet et al, 1998).

For successful cartographic generalization, the choice of the relevant subprocesses, as well as their interlocation, are important. The same subprocess will depend on where it is executed, generalize different content in different ways. Also, a particular subprocess may resolve a conflict that may re-occur after the execution of other subprocesses. Figure 13 shows the impact of selecting the relevant subprocess, set in the right place, on cartographic generalization. The upper part of the picture shows how inadequate selection of a subprocess can create new conflicts, and thus necessitates new subprocesses, while the lower part shows how the correct choice of subprocess simply ie. with fewer steps, a quality can resolve a particular conflict (Stojanović, 2018).

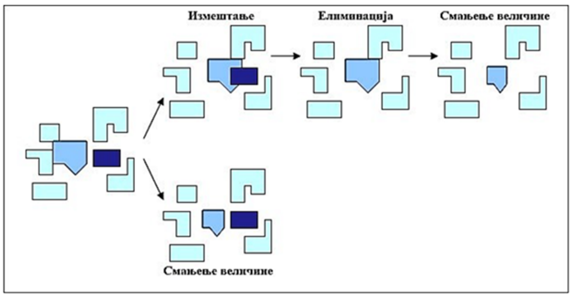


Figure 13: Impact of subprocess selection on generalization results (http://downloads.esri.com).

## 4 ANALYSIS OF AUTOMATIC CARTOGRAPHY GENERALIZATION USING PYTHON PROGRAMMING LANGUAGE

Automatic methods of cartographic generalization of spatial data that are the content of the GSD25 are additionally programmed using the Python programming language. Using ArcGIS software applications based on the development of automated tools using Model Builder, and their conversion to Python scripts are very useful tools. These tools are used for automatic conversion of content GSD25 to spatial data of digital topographic maps of smaller scales, primarily DTM50 (Figure 14).

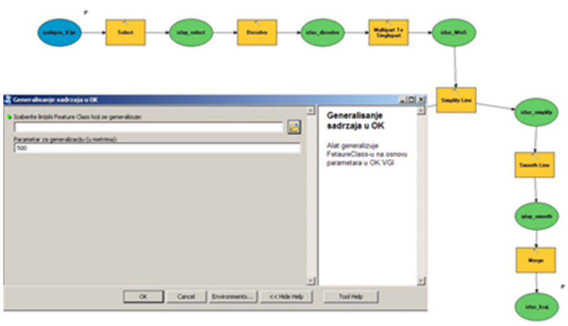


Figure 14: Example of tools for cartographic generalization of contour lines.

Different aspects of cartographic generalization can be automated by creating a generalization model, both numeric interpreted and expressed in mathematical form as well as those which generally classify mapped objects. Thus, for example simply is automatically reduced by objects whose size is less than the established threshold or select specific objects normative indicators. In doing so, the computer can simultaneously exploit a number of indicators of choice and to take into account the connection of phenomena with other phenomena, if it can be expressed in mathematical form (eg. providing the minimum distances between adjacent buildings at the expense of reduction of less important), and finally, it can change the value of the indicator in different regions. A census approach can also be applied to geometric side of generalization. For example, automatically reduce lines curve and fractures less than some specified size. In modern software, there are options that support reduction of curvature on the lines. For example, within the ArcGIS software, there is an option Smooth Lines performing this procedure.

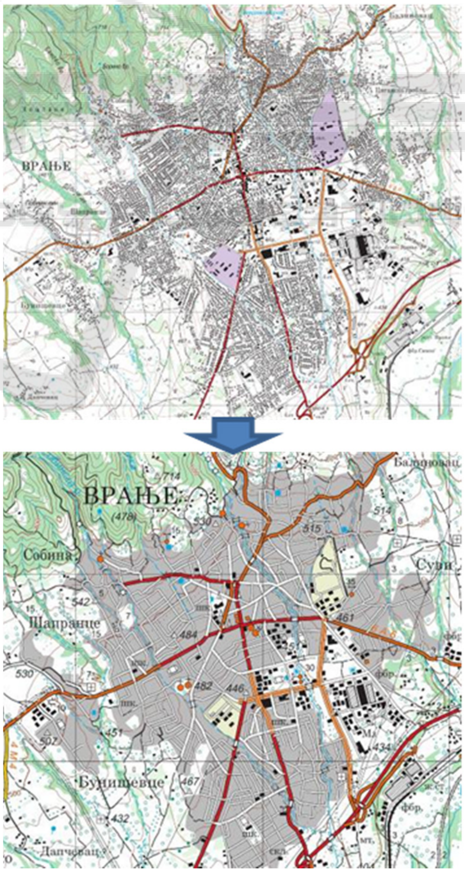


Figure 15: Example of urban area generalization in switching DTM25 (above) to DTM50 (below).

The main source for the cartographic generalization was DTM25 with predefined model data in a central database. The use of different, pre-defined tools and generating new and using Model Builder gave a very powerful tool for automated map generalization, which enabled the creation of a new, generalized DTM50.

The highest degree of generalization was defined by using thematic areas of populated places, where individual objects are grouped into two different sections, the city property, and settlement blocks. Objects of public interest are exempt from this kind of generalization so that they are a simple generalization of selection and reduction of geographic content (Figure 15).

Table 1 shows a portion of cartographic generalization model for thematic layer “Stagnant water 3” which is the content of the GSD25 and represents a conceptual generalization which define certain limitations and conditions for transfer from topographic map, scale 1:25 000 topographic maps at the scale of 1:50 000 1: 100 000 and 1: 250 000.

Table 1: A portion of cartographic generalization model for thematic layer “Stagnant water 3”.

| **Number** | | **246** | **247** |
|---|---|---|---|
| **Name of the symbol** | | A lake | |
| | | smaller | bigger |
| **DTM25** | **LAYER** | 46 | |
| | **SIFRA** | 461 | 462 |
| **Generalization condition DTM25>DTM50** | | An area greater than 5.000 $m^2$ | An area greater than 10.000 $m^2$ |
| **DTM50** | **LAYER** | 46 | |
| | **SIFRA** | 461 | 462 |
| **Generalization condition DTM50>DTM100** | | An area greater than 20.000 $m^2$ | |
| **DTM100** | **LAYER** | 46 | |
| | **SIFRA** | 461 | |
| **Generalization condition DTM100>DTM250** | | An area greater than 125.000 $m^2$ | |
| **DTM250** | **LAYER** | 46 | |
| | **SIFRA** | 461 | |

Other aspects that have a great influence on position accuracy assessment are cartographic generalization and symbolization processes. In this way, it should be left clear, as in some product specifications, the hierarchy applied in the generalization processes, since this affects possible displacements of the GSD25 elements.

# 5 CONCLUSIONS

Automatic cartographic generalization is the integration of many theories, methods, and techniques. Generalization quality and estimation is the main problem in contemporary cartography. In this article, during the technological process GSD25, we translate the content of the raster topographic map sheet 1:25 000 publication of the Military Geographical Institute in vector form with referential alphanumeric data and the direct photogrammetric mapping with modern substrates such as orthophotos. That can be achieved by using a mixture of generalization techniques (such as selection, merging, simplifying, symbology and displacement). The results of the analysis of tested areas on the topographic map show that the efficiency of automatic generalization can be improved, and the loss of information or distortion reduced.

Despite the current limitations, tested software can be applied in the production with automatic generalization. Finding complete solutions in commercial software requires a huge investment, given the small number of potential customers and a lot of effort in adapting commercial solutions in partial fulfilment of a specific request.

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