A comparison of methods for automatic generalization of contour lines generated from digital elevation models

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Abstract. A significant issue is to reduce the human work at the automation of cartographic generalization. The authors compared two methods of line simplification, the Douglas-Peucker line simplification to the linear regression with the aim of replacing the polylines with curves. These methods guarantee that the post-processing on contour lines becomes minimal, and they also allow the simple display in vector graphic programs and on the web.

Introduction

The sources of terrain representation greatly changed in the last few years. The free downloadable digital elevation models are widely used in the cartographic practice. These models are suitable for generating contour lines with GIS programs. Additionally, the hypsometric maps can be created directly from the DEMs, therefore the number of maps with contour lines and hypsometry decreased, and the hypsometry combined with the hill-shading became dominant on the geographical maps in small scales.

The cartographic generalization of contour lines manually always was one of the time-consuming processes of map making. The algorithms of GIS software solved the problem partially, but the output of polylines is broken, which is not adequate to the aesthetic requirements of the maps. Our motivation was to compare two methods of line generalization, the conventional, and the well-known Douglas-Peucker algorithm, and a statistical method, the linear regression, and its usage for line generalization. Then the authors replace the simplified polylines with Bézier curves to reach the earlier described requirements. The first algorithm interpolates the control points of the Bézier curve to fit it. The second one uses the linear regression to create the tangent of the Bézier curves, and then calculates the graph. The authors compare the usability of these two methods according to different map scales, the number of points, and the shape of polylines, the program's run-time, and the post-processing time to create the hypsometric map.

The automatic generalization methods do not replace the human thinking, therefore they never may be perfect, but they can help to reduce the working time.

Sources of terrain data

The SRTM 90 version 4 can be downloaded for free from the Internet. The spatial resolution of this model is 3 arc seconds for the whole world (CGIAR CONSORTIUM, 2004). Because of the spatial accuracy, this model allows to create correct maps at 1 : 150 000 scale maximum. The GIS software ensures the generation of contour lines from DEMs (the authors

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used the Global Mapper version 13). This program offers the user to simplify the generated lines, but it reduces only the sampling rate, therefore the polylines become partially discontinuous, furthermore the lines can intersect each other.

The generated contour lines can be exported to several text file formats, which are suitable for further processing (GLOBAL MAPPER, 2013).

Using the conventional algorithm

Due to the quick technological development, line simplification methods were already used in the 1970's. One of them is the Douglas-Peucker algorithm, built in some GIS software like ArcGIS and PostGIS (DOUGLAS & PEUCKER, 1973; NAKOS, 1999).

The result of the algorithm is a simplified polyline; the simplification's rate depends on the determined tolerance. In the last section of this paper, the authors shows on figures the relationship between the tolerance and map scales (Figure 1).

The authors think that it is wrong and not aesthetic to use broken lines neither in printed paper maps, nor in digital maps. However, this application of lines spreads through the GIS software due to reducing the size of files. The authors experimented fitting different curves to polylines (e.g. Cardinal Splines), but the best solution was the application of cubic Bézier curves, because they are built in several vector graphic formats (SZIRMAY-KALOS–ANTAL–CSONKA, 2003).

The mathematics behind the curve fitting:

The nodes of polylines are known, and then the program interpolates the control points of the Bézier curve by line segments. The calculation of the coordinates of control points needs four points (P_{i-1}, P_i, P_{i+1} és P_{i+2}), where P_i is the current node . The curve is drawn from P_i to P_{i+1}. The tangent of each curve at the same node has to be symmetrical. To construct the Bézier curve it is necessary to set the smoothing value of Bézier curves between 0 and 1. The 0 means the broken line, and the optimal curvature is between 0.7 and 0.8 according to the author's observations (ANTI GRAIN GEOMETRY, 2006).

The program simplified the contour lines and wrote them into a text file. Finally, the two possible output formats were found: the AI (Adobe Illustrator File Format) and SVG (Scalable Vector Graphic). In the first case, the authors voted for SVG. The most important pro argument was that the SVG can be embedded to a webpage, and hopefully it will became a file interchange format (W3C, 2010). In view of format structure, the program generates the SVG file. It joins each curve to the SVG path type. Sometimes the polylines are closed objects; hence, the SVG path „Z" command closes the curve to polygon to make the post-processing easier.

The Figure 2 shows the process of creating generalized contour lines.

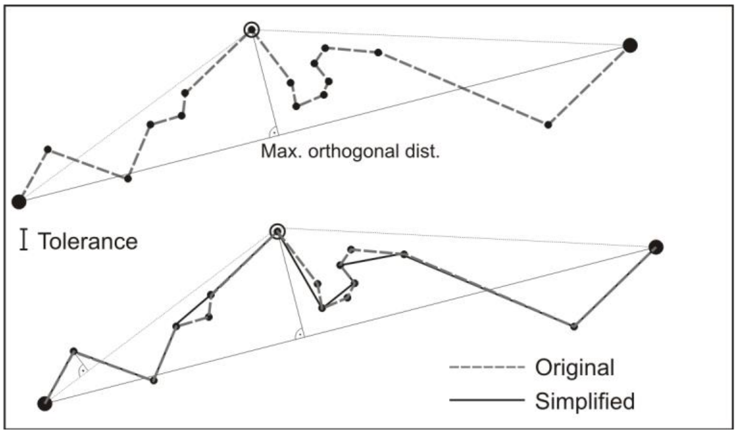

Figure 1: Ramer-Douglas-Peucker algorithm

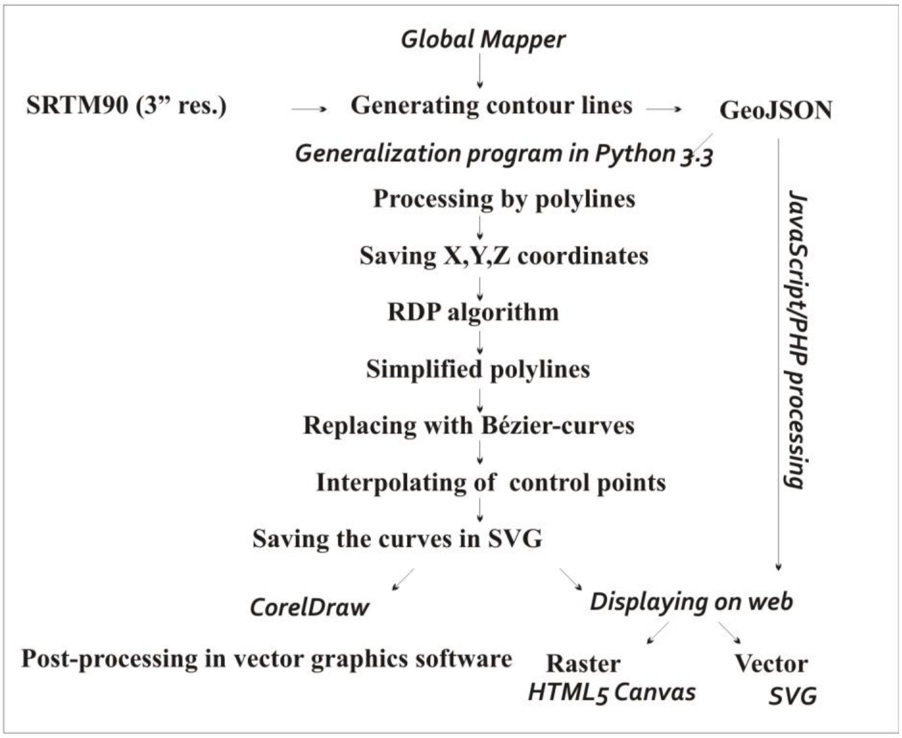

Figure 2:Creating contour lines with DP algorithm

The new method

In the first case, the authors used a conventional algorithm. In this case, the authors tried out a new method for automatic generalization. In statistics, regression analysis is a statistical technique for estimating the relationship among variables. At this time, the two variables are the X and Y coordinates.

The algorithms in geoinformatics helped to create this method. The first step is to get the number of nodes of a polyline. If it is lower than the given minimum and the area of these contour lines is too small at the given scale, the object will be omitted. After this step, the algorithm examines only every second or third point of the polyline (N^{th} point method). After this selection, the statistical technique, the linear regression method was run. The algorithm replaced each parts of polyline with straight line. The program calculates the point’s distance from the suggested line, and if this distance from the regression line is bigger than the tolerance, the program begins to calculate the next one (Figure 4). (MORDECAI E.–KARL A. F. 1970).

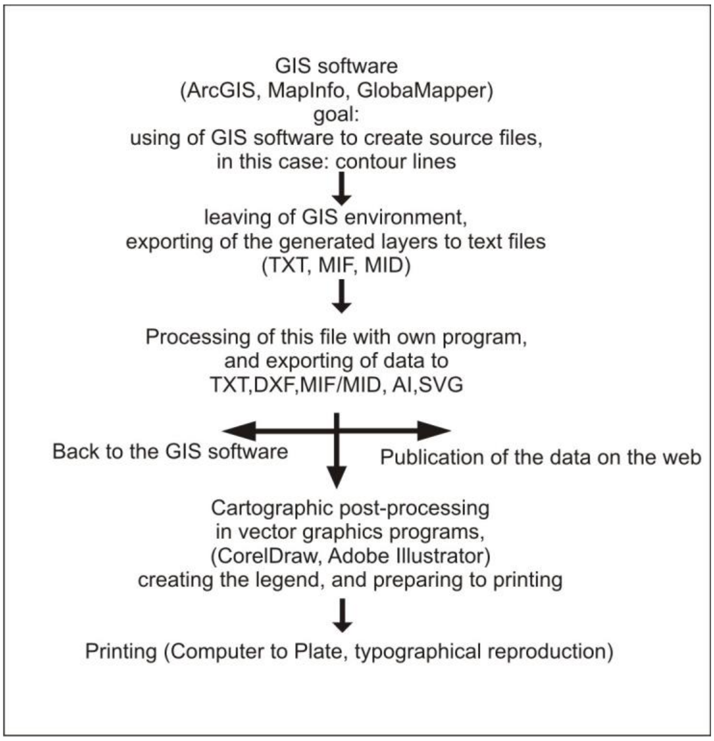

*Figure 3: The process of the methods (*AGÁRDI N. 2012)

Fitting the Bézier-curve

The best solution was to cut the regression line at the half, therefore the midpoint of this line became the node of the Bézier curve. Thereby these regression lines were the tangents, the cubic Bézier curve stayed continuous (MORTENSON M. E 1999).

Comparison of methods

Defining the useful range and scales

The sources of contour lines were the SRTM 90 v4. The spatial resolution of SRTM 90 is 3 arc seconds, therefore this model is originally suitable for making maps at 1 : 100 000 or 150 000 scales maximum. The goal of running the algorithm is to reduce the number of points and simplify the shape of polylines. The authors tested various values of reduction number at the DP algorithm and the regression method (Figure 5 and 6). These algorithms are nearly useless on SRTM 90 over 1 : 3 000 000, because the shape of contour lines became disordered, the nodes were further away from each other, and the tangent of the Bézier curves became longer, therefore the lines may have intersected each other. Additionally, the DP algorithm retained the tight valleys, but the number of nodes was lower in smaller (1: 1 500 000<) scales, therefore the tight valleys were closed. The difference between the scales 1 : 100 000 and 2 000 000 is twenty-fold, and the traditional map making does not use 1 : 100 000 maps as sources to create 1 : 2 000 000 maps in one step (Figure 7 and 8) (MÁRTON, 2012). The authors offer to choose other sources, like SRTM 30 or ETOPO1.

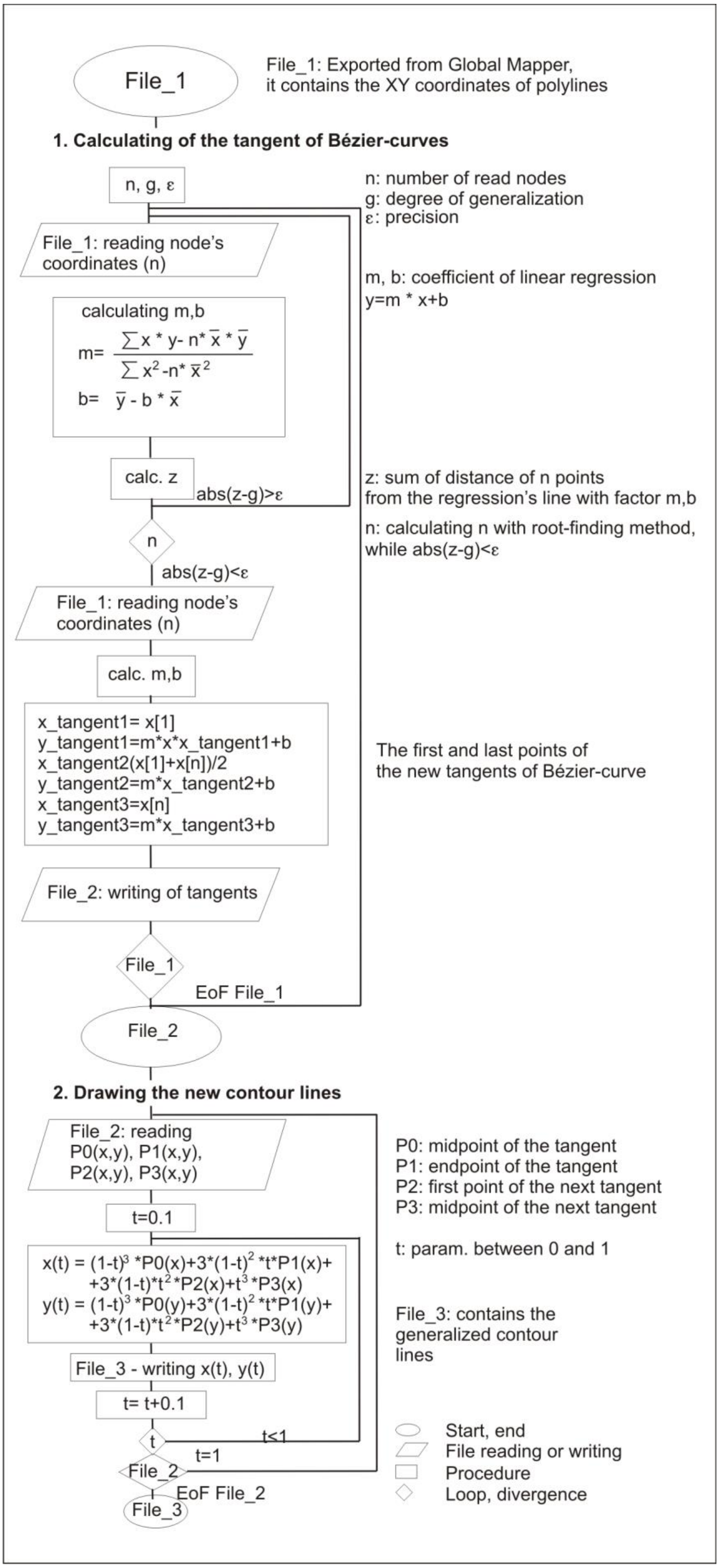

Figure 4: Calculation of the new contour lines with linear regression

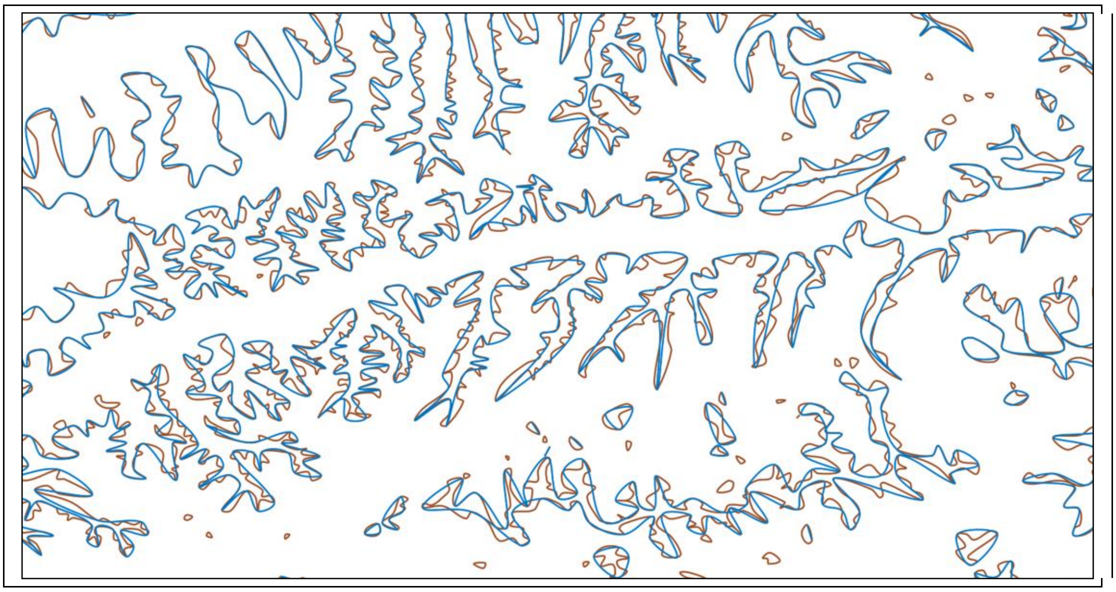

Figure 5: Different generalization of contour lines with Douglas-Peucker algorithm

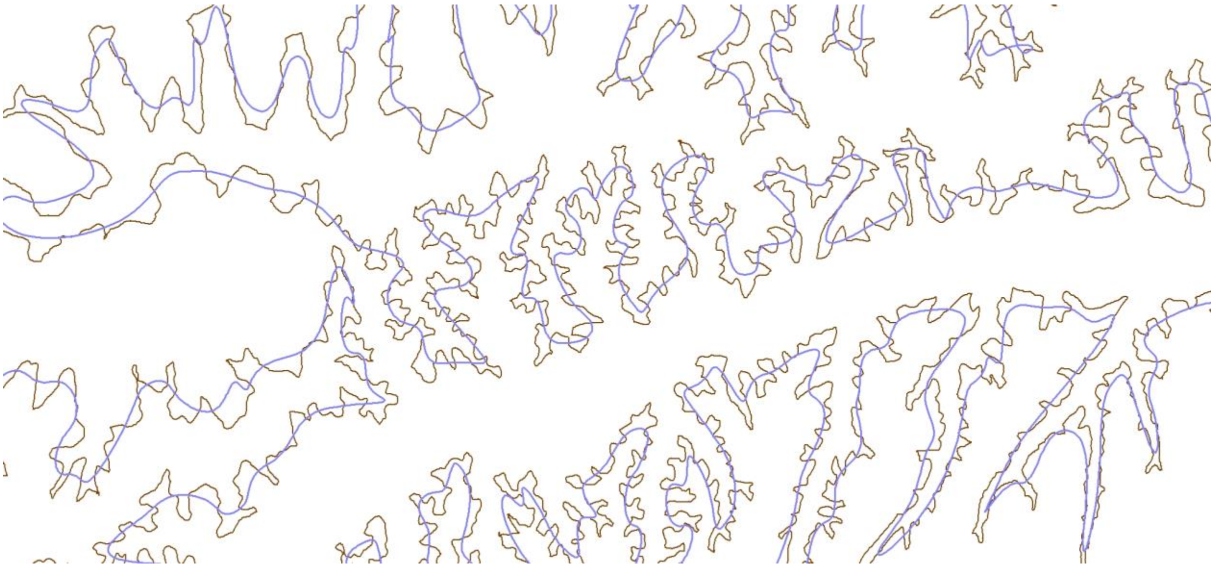

Figure 6: The original and the simplified contour lines with linear regression

Furthermore, another interesting question is how we can find out which scale belongs to which degree of generalization. The authors examined several topographic maps in various scales, and on this basis they stated the values and the map scales (THE WORLD ATLAS, 1999; WORLD MAP).

The program's run time

The program's run time I the case of Douglas-Peucker algorithm is quite fast, it takes four minutes at 1 : 750 000 scales for a 100 000 km^2 area. If the generalization degree is higher, the run time is under two minutes. Using the linear regression, the program is slower, because of the lot of calculations.

Creating hypsometric maps

The contour lines are suitable for creating hypsometry (Figure 8). The authors plan that this process is going to be fully automated with these programs in the near future. Now the making of the hypsometric map takes about one or two hours manually, which will be much shorter with automation.

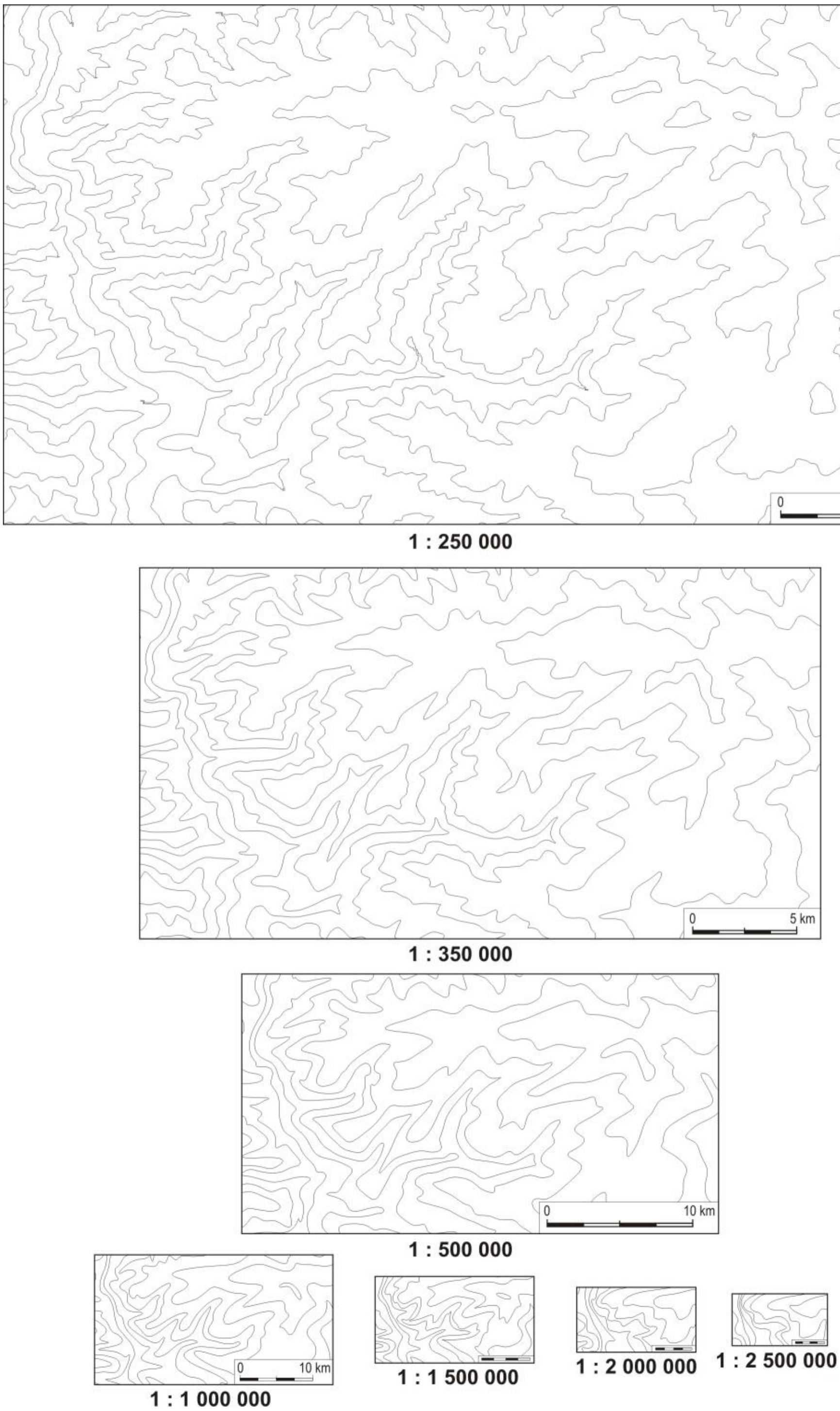

Figure 7: Simplification with linear regression's method

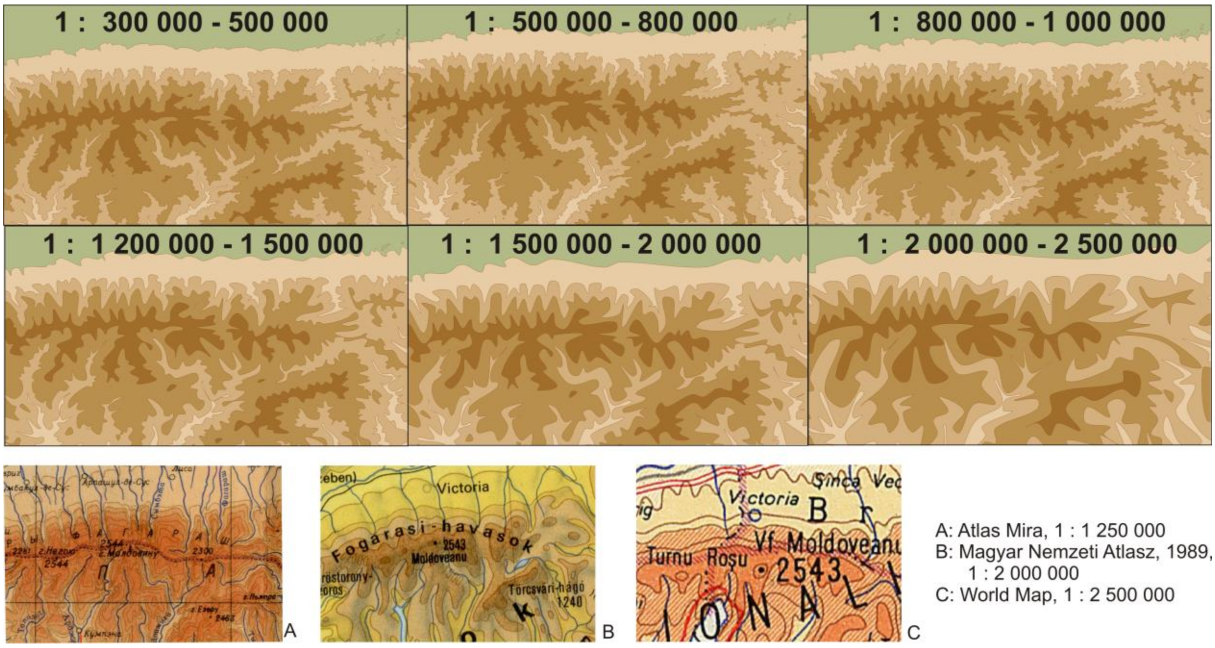

Figure 8: Hypsometric maps about the Făgăraș Mountais (Romania). The contour lines were simplified by the Douglas-Peucker algorithm.

Application on web

Terrain maps can be released also on the web, among others, an important advantage of SVG is that this file format can be embedded directly into a webpage. The developed programs are appropriate for writing SVG files.

Another solution is a real-time running of scripts in the browser (JavaScript) or on the server, like PHP. The disadvantage of these solutions is that if the script's running-time is too long, the browser becomes slow, and asks the user about the script's running in a message box, and this is undesirable. The authors exported the contour lines from Global Mapper to GeoJSON format, which one contains beside the X, Y, Z coordinates other information about features, like the object is a polyline or a polygon. Additionally, the most programming language, also the script languages, supports the decoding of JSON's which is important the reading and visualizing the data on the Internet. If the GeoJSON files are not too complicated (maximum 2000 lines in the file) and depicted area is quite small, the latter mentioned problem is avoided. The scripts can display raster graphics (as an image) with the HTML5 Canvas element and also vector format data in SVG.

Real-time visualization of data on the web is possible, but it is important to know their limits.

Conclusions

The authors compared the conventional DP algorithm to linear regression and stated that both of them are good and quick method for line simplification. The optimal range of these methods is between 1 : 250 000 and 3 000 000 on SRTM 90. These algorithms are suitable not only for the contour line generalization, but also for the generalization of every isolines from various sources. The method allows to take bigger steps between different map scales, than in the traditional old techniques.

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The present study was sponsored by the Hungarian Scientific Research Fund (OTKA No. K 100911).