Land-surface segmentation to delineate elementary forms from Digital Elevation Models

Lucian Drăguţ
Department of Geography
West University of Timişoara
Timişoara, Romania
lucian.dragut@cbg.uvt.ro

Jozef Minár
Department of Physical Geography and Geoecology
Comenius University in Bratislava
Bratislava, Slovakia
minar@nic.fns.uniba.sk

Ovidiu Csillik
Department of Geography
West University of Timişoara
Timişoara, Romania
cskovi@yahoo.com

Ian S. Evans
Department of Geography
Durham University
Durham City, England
i.s.evans@durham.ac.uk

Abstract—**In this paper, we introduce an algorithm to delineate elementary forms on Digital Elevation Models (DEMs). Elementary forms are defined by constant values of fundamental morphometric properties and limited by discontinuities of these properties. A multiresolution segmentation technique was customized to partition the layers of altitude derivatives into homogeneous divisions through a self-scalable procedure, which reveals the pattern encoded within the data. Layers were segmented successively, following the order of elevation derivatives, i.e. gradient, aspect, profile curvature, and plan curvature. Each segmentation was followed by extraction of elementary forms, thus leaving only heterogeneous surfaces for further segmentation steps. The sequential selection of elementary forms was based on dynamic thresholds of: 1) the inner variance of the respective land-surface variable (LSV); 2) the difference between the mean LSV value of the target segment and the mean LSV values of its adjacent segments; and 3) the shape indices of segments. The results were compared with an existing manually-drawn geomorphological map to evaluate the potential of the algorithm of producing morphologically meaningful land-surface divisions. The evaluation showed that most segments are either directly comparable with manual delineations, or have a clear morphological meaning. We conclude that algorithmic delineation of elementary forms from real DEMs is feasible; more work is needed, however, to design a fully operational process.**

INTRODUCTION

Geomorphological maps are fundamental to many applied studies of the Earth's surface [1], yet traditional symbol-oriented geomorphological mapping techniques are not able to meet the current scientific and technical requirements of land management [2]. Geospatial technologies and the ongoing progress in production of high-resolution Digital Elevation Models (DEMs) have revived the interest in geomorphological mapping [1], which is developing in a new form - Digital Geomorphological Mapping (DGM) [3]. Geomorphometry, the science of land-surface quantification [4, 5], is fundamental to quantitative geomorphology and geomorphological mapping [3, 6], potentially enabling manual delimitation to be replaced by automated recognition and delimitation of landforms [6].

In the last decade, land-surface segmentation has demonstrated a great potential to improve geomorphological mapping, it enables better representations of objects from DEMs [7]. Segmentation partitions land-surface into relatively homogeneous areas, bounded by discontinuities in the input variables; multiresolution segmentation (MRS), as implemented into eCognition®, is the most popular segmentation algorithm. Resulting segments are used further as building blocks in classification, based on attributes such as average values of derivatives, shape indexes, and topological relations of segments.

However, DGM to date is dominated by an exploratory or empirical approach, the work being done to conform to different objectives and landform definitions [3]. Robustness and generic applicability of landform mapping have not been evaluated adequately. The most critical aspect is mapping of a whole land surface, which is more difficult than extraction of specific landforms from it [6]. It is acknowledged that scientific progress in DGM has not kept pace with rapidly evolving geospatial technologies [3], therefore a theoretical and operational framework to relate land-surface form to processes would support objective geomorphological mapping [3]. Such a theoretical framework has recently been proposed by Minár and Evans [8]. Elementary forms have been mapped in the surroundings of Prášilské Lake (Bohemian Forest, the Czech Republic) to analyse patterns of glaciation [9]. While the approach proved successful, elementary forms were delimited manually by means of analysis of contour lines and a DEM. An operational framework to delineate elementary forms is still missing, yet this theoretical framework has a great potential for DGM [3].

The objective of this research was to investigate how and to which degree elementary forms can be delineated on a real DEM, to contribute to an operational framework automating this process. Here we present the preliminary results of the algorithm development, its application on a high-resolution DEM, and a first evaluation of the degree to which the algorithm approximates a manually-drawn map of elementary forms, which had previously been designed for the purpose of geomorphological mapping.

METHODS

I deal elementary forms are defined as 'landform elements with a constant value of altitude, or two or more readily interpretable morphometric variables, bounded by lines of discontinuity' [8]. The fundamental morphometric properties are altitude and its derivatives, i.e. gradient, aspect, profile and plan curvatures, which form a coherent system for the local description and analysis of the land surface [5]. Constant values of morphometric properties determine relations among elementary forms in a hierarchy that follows the order of altitude derivatives. Thus, a constant value of elevation corresponds to a zero value of gradient and undefined value of aspect. Constant values of gradient and aspect correspond to zero values of profile curvature and plan curvature respectively. Therefore the importance of constant value decreases from the variables of lower order (altitude) to higher order (curvatures). Spatial transitions between constant values of the five properties are ideally marked by discontinuities.

The above concepts were implemented within an object-oriented approach, which is well-suited to hierarchical analysis. The processing steps (Fig. 1) consist in computation of land-surface variables (LSVs) (Fig. 1, 2) and their pre-processing (Fig. 1, 3) as input layers for object-oriented analysis (Fig 1, 4), which was performed with eCognition®.

MRS, which is a region-growing segmentation algorithm [10], was employed to segment each of the five layers. Characteristics of segments produced by MRS, such as homogeneity, size and shape are controlled by user-defined thresholds called *scale parameters*. To optimize the scale parameters for segmentation (Fig. 1, 4), an automatic procedure devised by Drăguţ and Eisank [11] was applied. This procedure fits the segments to the scales of topographic features with the aid of local variance [12].

Land-surface variables were segmented in a stepwise fashion, starting with the layer of slope and followed by aspect, profile curvature and plan curvature, respectively (Fig. 1). This sequential approach follows the order and importance of the derivatives. While the altitude layer was not directly used in segmentation, it provided the information needed to extract objects constant in altitude, bounded by lines of discontinuity that resulted from segmentation of the gradient layer. Each segmentation was followed by extraction of elementary forms, thus leaving only heterogeneous surfaces for further segmentation steps.

The sequential selection of elementary forms based on dynamic thresholds of: 1) the inner variance of the respective LSV (i.e. variance within a segment); 2) the difference between the mean LSV value of the target segment and the mean LSV values of its adjacent segments; and 3) the shape indices of segments. Two shape indices were used in this study, namely *compactness* and *border index*. *Compactness* is computed as the ratio between the product of the length and width of an image object and the number of pixels within the object, showing how compact an object is [13]. *Border index* is calculated as the ratio between the border length of an object and the smallest rectangle enclosing the object, describing how jagged an object is [13]. These variables were calculated for each object, and the thresholds were given by the means of the scene, except that shape index thresholds were set following a trial-and-error approach. At each segmentation step, segments with variance below the mean, difference above the mean, compactness below 3.5, and border index below 3 qualified as elementary forms.

RESULTS AND DISCUSSION

The algorithm was tested on a DEM at 1 m resolution, interpolated from contour lines (Fig. 2). The DEM covers an elevation range between 145 and 241 m, and an extent of 329 X 323 m. It represents an area located northwest of Bratislava, Slovakia, around the hill of Slovinec and near the highest summit of the Devin Carpathians, Devinska Kobyla (514 m). The general landscape is dominated by two smooth summits situated in the central southwestern and southeastern parts and a large relatively flat area in the north-east.

The algorithm delineated the elementary forms as shown in Fig. 2. It is visible that polygons generally agree with changes in contour lines. In this study, a plausibility assessment was performed based on expert knowledge and comparison with two other manual geomorphological maps available for the study area. The first one was developed by Minár and Mičian [14] from a 1:10 000

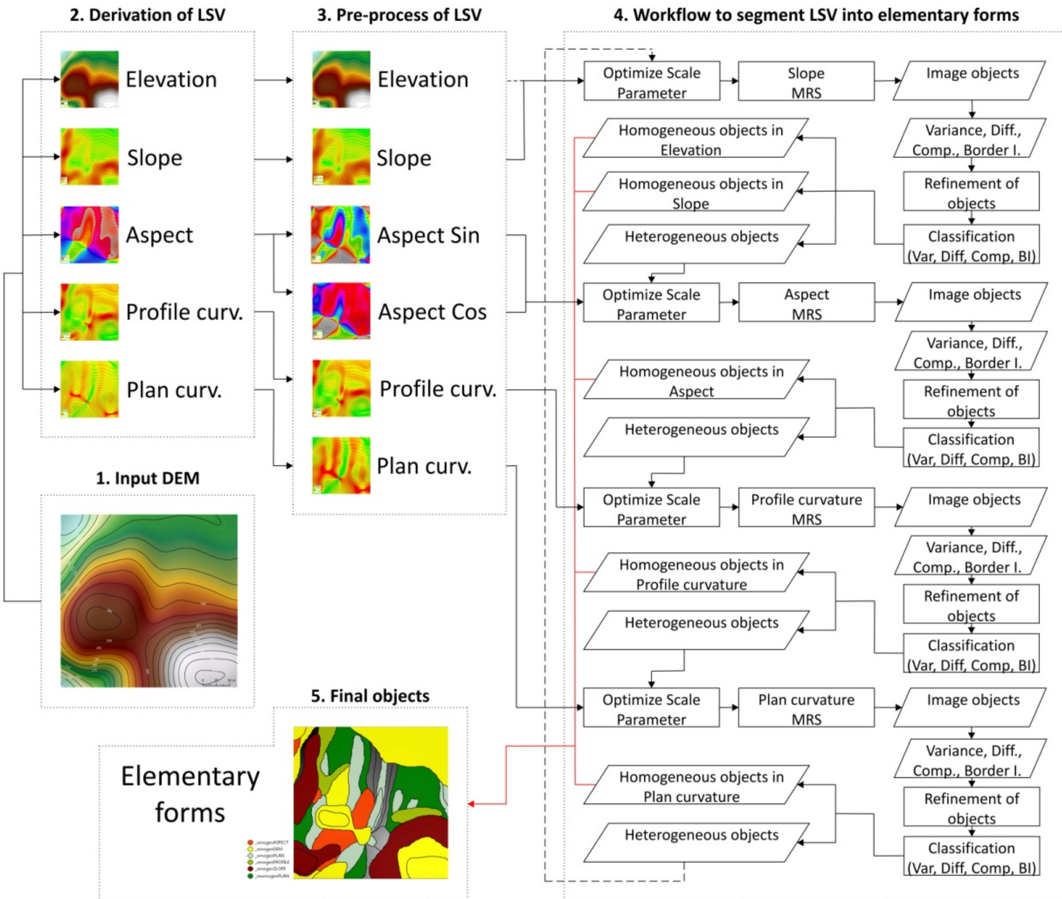

Figure 1. Flow chart showing the main steps in the algorithm development. See text for details.

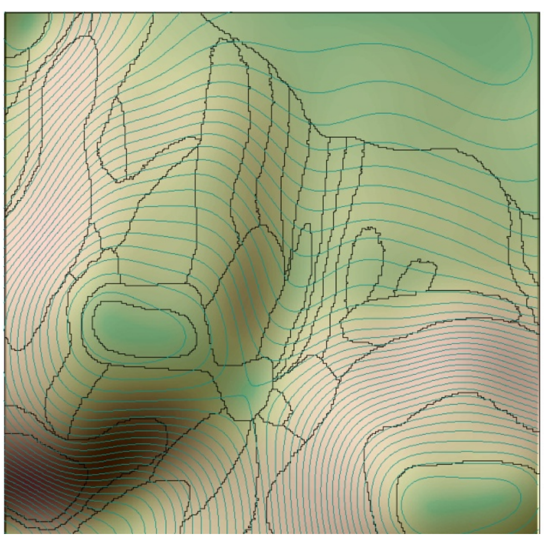

Figure 2. Results of delineation (black polygons), overlaid on a DEM. Contours at 1 m interval are displayed in green.

topographic map (Fig. 3), while the second one (not shown here) added two dells that in the first version were generalized because of the scale. Delimitation of elementary forms on these two maps was made through field research and visual expert analysis [8].

The assessment was conducted by one author of this study (Jozef Minár), by interpreting the geomorphological meaning of each segment against the two maps, based on his long-lasting experience in the geomorphology of the study area and its region. Results are presented on a scale from one (segments with clear geomorphological meaning) to five (elements considered genetically false) (Fig. 4). According to this evaluation, most of the polygons delineated by the algorithm (26 out of the total of 39) represent forms resembling manual delineations well (classes 1 and 2). Classes 3, 4, and 5 include 7, 2, and 4 polygons respectively. These results show that algorithmic delineation of elementary forms from real DEMs is feasible.

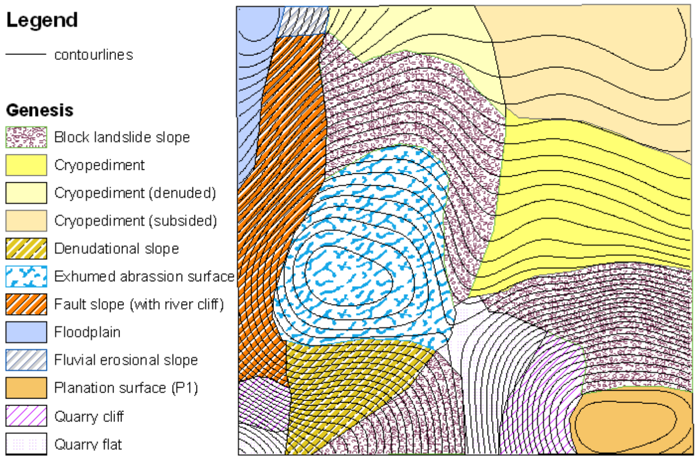

Figure 3. Geomorphological map of the Slovinec area, delineated manually on the basis of the elementary forms concept.

This work was carried out on a small and simple area. It remains to be seen whether comparable results are achievable on larger and more complex areas; tests on these issues are in progress. This study might be particularly important in the context of high-resolution DEMs (LiDAR), which make very fine-scale geomorphological mapping feasible.

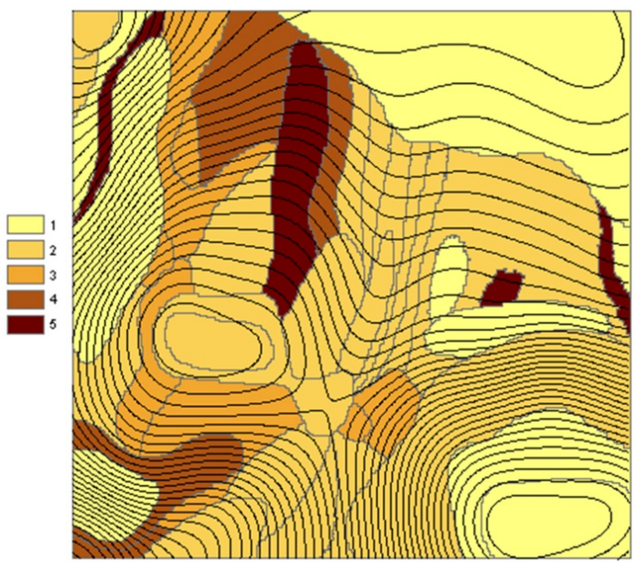

Figure 4. Results of plausibility assessment. Automatically delineated polygons represent: 1) Forms better or equal to manually delineated ones, where whole areas as well as boundaries have clear geomorphological meaning; 2) Forms equal to parts of their correspondent features, where small portions of areas or boundaries have less geomorphological meaning; 3) Approximations of manual forms, where large parts of areas or polygons are questionable; 4) Rough approximations of genetic forms, where majority of areas or boundaries are questionable; and 5) Genetically false elements.

ACKNOWLEDGMENT

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS - UEFISCDI, project number PN-II-ID-PCE-2011-3-0499. Jozef Minár was funded by the Slovak Research and Development Agency under the contract APVV-0625-11.Comments from three anonymous reviewers were appreciated.

REFERENCES

[1] Smith, M.J., P. Paron, and J.S. Griffiths, Eds., 2011. "Geomorphological Mapping: Methods and Applications". Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, Elsevier Science, 612 p.

[2] Dramis, F., D. Guida, and A. Cestari, 2011. "Nature and aims of geomorphological mapping", In Geomorphological Mapping: Methods and Applications, Edited by: Smith, M.J., Paron, P. and Griffiths, J.S., Elsevier Science, Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo.

[3] Bishop, M.P., L.A. James, J.F. Shroder Jr, and S.J. Walsh, 2012. "Geospatial technologies and digital geomorphological mapping: Concepts, issues and research." Geomorphology, 137: 5-26.

[4] Pike, R.J., 1995. "Geomorphometry-progress, practice, and prospect." Zeitschrift für Geomorphologie, Supplementband 101: 221-238.

[5] Evans, I.S., 1972. "General geomorphometry, derivatives of altitude, and descriptive statistics", In Spatial Analysis in Geomorphology, Edited by: Chorley, R.J., Methuen, London.

[6] Evans, I.S., 2012. "Geomorphometry and landform mapping: What is a landform?" Geomorphology, 137: 94-106.

[7] Drăguţ, L., and C. Eisank, 2011. "Object representations at multiple scales from digital elevation models." Geomorphology, 129: 183-189.

[8] Minár, J., and I.S. Evans, 2008. "Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping." Geomorphology, 95: 236-259.

[9] Mentlik, P., and M. Novotna, 2010. "Elementary forms and 'scientific reliability' as an innovative approach to geomorphological mapping." Journal of Maps, 2010: 564-583.

[10] Baatz, M., and A. Schäpe, 2000. "Multiresolution Segmentation-an optimization approach for high quality multi-scale image segmentation", In Angewandte Geographische Informationsverarbeitung, Edited by: Strobl, J., Blaschke, T. and Griesebner, G., Wichmann-Verlag, Heidelberg.

[11] Drăguţ, L., and C. Eisank, 2012. "Automated object-based classification of topography from SRTM data." Geomorphology, 141–142: 21-33.

[12] Woodcock, C.E., and A.H. Strahler, 1987. "The factor of scale in remote-sensing." Remote Sensing of Environment, 21: 311-332.

[13] Trimble, 2012 *eCognition Reference Book*. Munchen, Germany: Trimble Germany GmbH.

[14] Minár, J., and Ľ. Mičian, 2002. "Complex geomorphological characteristics of the Devínska Kobyla Mt." Landscape Atlas of the Slovak, Republic. 1st ed. Bratislava: Ministry of Environment of the Slovak Republic; Banská Bystrica: Slovak Environmental Agency, 92-93.