Geomorphic Analysis of the low quality digital elevation model

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SUMMARY

Geomorphic interpretation of the landform genesis on the base of digital elevation model (DEM) that assists to expert-geomorphologist's interpretation purposes is discussed. Automatic detection or recognition of the landform features depends on availability of the more or less appropriate data sets and methods. By the classical approach in the geosciences the (geo)morphic features are interpreted by means of fieldwork inspection and by remote sensing techniques using aerial or satellite imagery. Non-robust techniques of the DEM analysis and visualization can cause that even relatively small errors of DEM nullify correctness of the morphological interpretations. An important role was to implement some simple but robust techniques for effective geomorphic analysis with stress on the low quality DEM data sets of Mars. Combination of different techniques can increase understandability and interpretability of the landform features. Two valuable spin-offs were described: topographic visualization and morphological quality analysis – both of them can be used for improved geomorphic analysis.

INTRODUCTION

The aim of this paper is discussing on morphologic interpretation of the landform genesis using relatively simple methods that assists to expert-geomorphologist's interpretation purposes. Automatic detection or recognition of the landform features depends on availability of the more or less appropriate data sets and methods. By the classical approach in the geosciences the (geo)morphologic features are interpreted by means of fieldwork inspection and by remote sensing techniques using aerial or satellite imagery.

A digital elevation model (DEM) has potentially high importance for the morphologic interpretation. However, there are advantages and disadvantages of the DEM in comparison to the satellite imagery, discussed in figure 1. One of the significant disadvantages of the DEMs is typically coarser resolution comparing to the resolution of images. Since the results of morphologic interpretations of DEMs and images are highly complementary, better results may be reached with powerful integration of both approaches. Nevertheless the endeavor in this study is put to demonstrate getting valuable information by visual recognition, robust automatic analysis and modeling of the selected significant morphological features, only from the DEMs.

Advantages of DEM

- analysis allow full control and more objective outputs (e.g. illumination on the images depends on a momentary Sun position and other properties as material, roughness, etc.)
- easily is accessed a higher level of automation than for images, especially for morphological interpretation

Disadvantages of DEM

- production already demands a lot of efforts
- it is highly undertaken to gross errors of data sources and processing
- resolution is commonly lower than the resolution of images
- it contain just information about relief, additional information (e.g. soil moisture) could be asses just indirectly

- relief structures, e.g. terrain skeleton are relatively easier accessed (processing, generalization) than from images
- powerful visualization of the relief using various techniques
- a high number of independent derivatives that can be the object of morphological significance

- it contain semantically less information than are inherently hidden in images
- sensibility of some interpretation methods is highly depended on its quality (e.g. visibility analysis from the top of hills or optimal pathway analysis)

Figure 1: DEM vs. satellite/aero images for morphological interpretation.

Two important spin-offs of the DEM analysis can support the more complex morphological interpretation of the particular geomorphic phenomena (Podobnikar, 2005):

- topographic visualization (enhancement of classical cartographical visualizations): visualization of the topographic maps may be improved; the developed variables may be implemented as individual visualizations of them, or for topographic corrections of the analytical shading
- morphological quality analysis: improvement of the DEM quality through detecting of possible incorrect patterns (gross and other errors)

Case study: planet Mars

Discovering and understanding the geological history of the Earth and additionally our neighboring planet Mars is one of the main topics in today's geology and planetary research activities. Morphological analysis currently mainly base on imagery by visual interpretation of geomorphologists. In the course of the Mars research the focus in on areomorphic analysis (i.e. relating to the morphology of Mars) by employing DEM data.

Selected areas on the Mars have been studied using DEMs produced from HRSC orthoimages (High Resolution Stereo Camera) on board of the European orbiter "Mars Express" mission of the ESA's research program "HRSC on Mars Express". The HRSC data were in this case used from the orbit 266 (Thaumasia mountain range, central coordinates: 43˚S, 95˚W). The DEMs were derived in the course of a DEM test (Heipke et al., 2007). The resolution is in our case 50 meters per pixel (the same as for orthoimages) covering the area of 45×80 km. In figure 2 is clearly seen that many more features are visually perceived on orthoimage than on DEM.

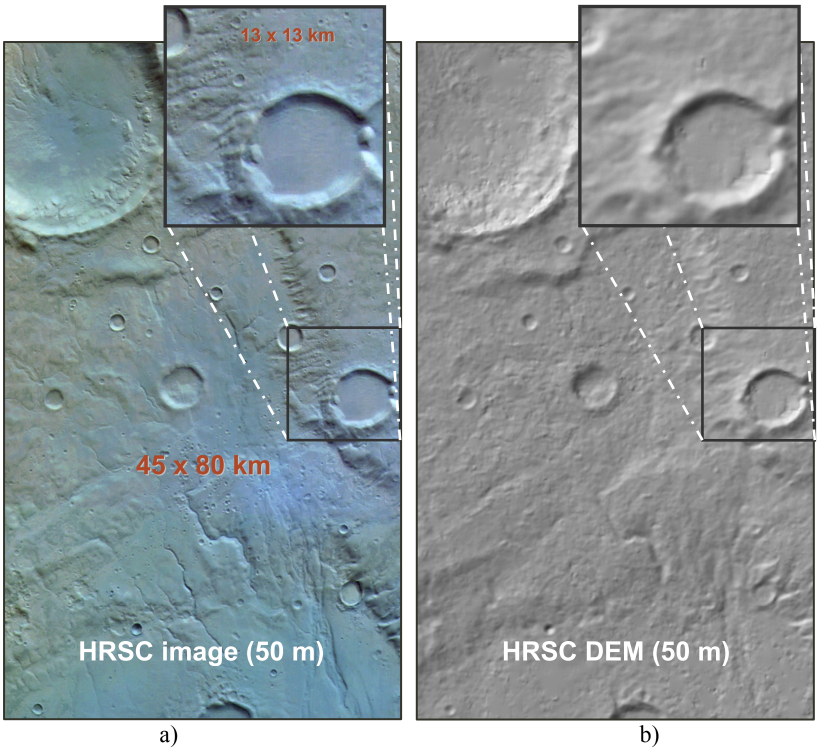


Figure 2: (a) HRSC orthoimage (iRGB channels), and (b) analytically shaded HRSC DEM (azimuth: 315°, elevation angle: 45°) both in resolution of 50.

Erroneous DEM

DEM is a model that approximates the relief or landform (in our case Mars' surface) relating to its nominal ground. The models might be different concerning their purpose of use, quality of data sources or interpolation algorithms, experiences of operator, etc. In general, the DEM should be carefully produced or chosen regarding purpose of required applications. A very important aim of the final product is to find a balance between the users' demands and the capability of the developed realization process.

The DEM can be generated in two scales, so call "small" and "large". For the large scale is adopted the most detailed DEM. For the small scale is used a generalized or smoothed DEM called as trend in the (spatial) statistic. The small scale DEM could be in a simple way generated by filtering. The size and the type of the filter depend on overall roughness of the terrain, and on the resolution and overall quality of the related DEM grid (Berry, 2007). In our case – low quality Mars DEM – the small scale DEM is basically used for topographic visualization. The large scale DEM is used for visual recognition of the morphological features and for phenomena detection (employing enough robust methods to avoid different errors), and additionally for visual recognition of particular errors (Podobnikar, 2005).

Especially geomorphic aspect of DEM's quality was neglected in the past. The first reason is that the quality of DEMs was expected to be low. The second is that the methods for evaluation of the quality were difficult to be realized concerning the processing capabilities. For the visual assessment of the DEM quality, hypsometrical (height-coding) and hillshading (analytical shading) methods were typically employed. Both of the methods are very robust concerning exposing to the potential gross errors – most of them are not perceivable through the visualizations (or classical cartography). Moreover, understanding of the landform morphology is quite poor by using just such visualizations of DEM.

Figure 3 presents the HRSC DEM and some potential errors that are encircled in the hillshaded visualization. The morphological quality of the HRSC DEM is obviously so low that many errors are even perceivable with classical methods of visualization. The main reasons for those morphological errors are problems in automated matching of the stereo images (HRSC) caused by lack of significance features on the Mars' landform. Robust methods are needed to be developed for visual and automatic recognition of the areomorphological features on the erroneous Mars' DEM.

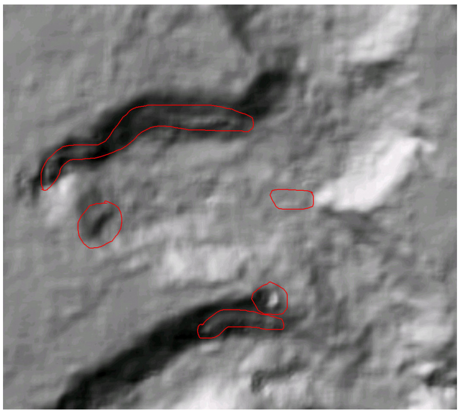


Figure 3: Potential morphologic errors on the Mars surface on the base of the DEM hillshading.

DETECTION PROCESS OF THE MORPHOLOGICAL FEATURES

A typical process of morphological features detection on the basis of low quality DEM starts with (1) generating or selecting best suited and reliable data sets (DEM) for the intended study. In an ideal case DEM needs to be a morphologically accurate surface with sufficient level of detail. Raster-based spatial analysis, as provided by geographical information systems (GIS), can be used to generate more or less independent variables or characteristic attributes, which contain specific information of spatial patterns of certain phenomena, e.g. dimensions, rims, shapes of craters (Haining, 2003). (2) In the next step the variables are visualized, semantically assessed, and interpreted with effective visualizations bases on thematic and topographic cartography. The result of this step supports selection and preparation of the significant variables or just generating a topographic map. Further step of features detection process is (3) combination of variables produced by spatial analysis for modeling the certain phenomena, e.g. model of craters. (4) The generated models can be part of an environmental decision support system (Kanevski and Maignan, 2004) for estimation of selected phenomena, e.g. erosion or shape of craters. (5) Interpretation of the variables and deriving the models continues with phenomena detection. This future high-level part as interdisciplinary approach needs collaboration of geomorphologists.

1	quality is controlled	DATA SET	DEM

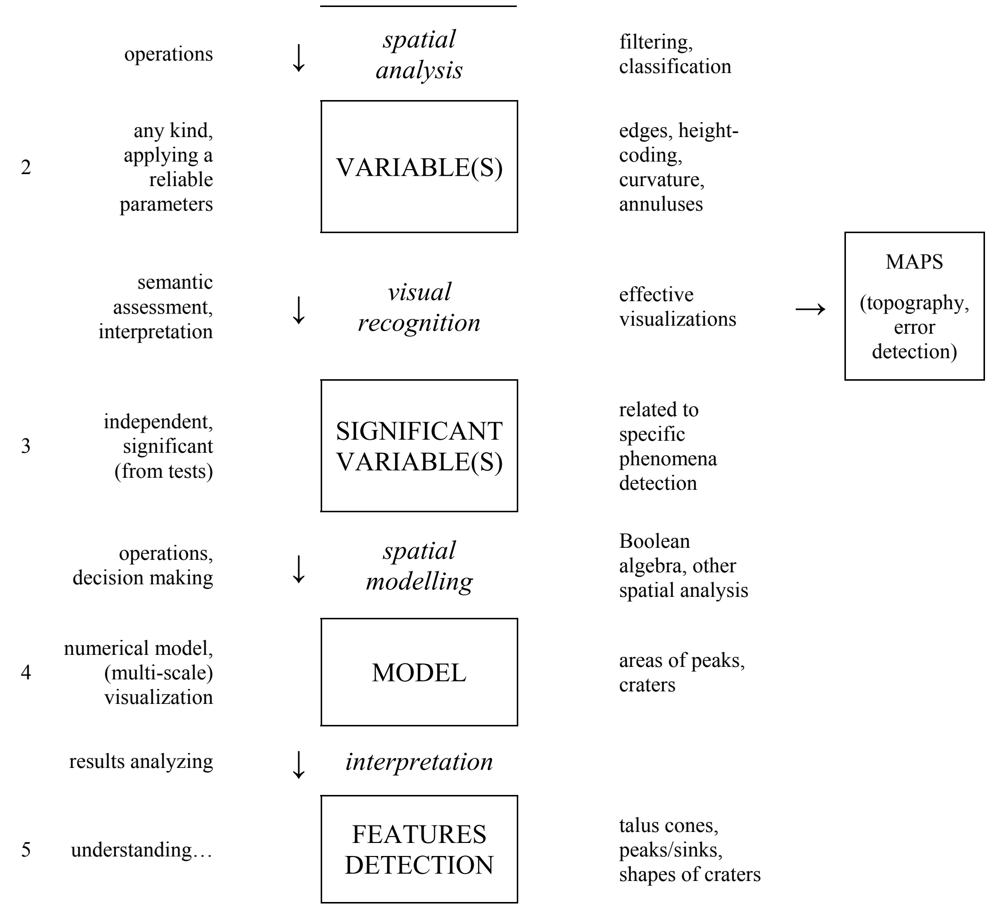


Figure 4: A typical workflow considering detection of morphological features and phenomena of the low quality DEM.

In the next sections the selected variables and feature detection, and additionally both spin-offs: topographic visualization and morphological quality analysis will be introduced.

Visual recognition of the morphological features and phenomena detection

Classical techniques for DEM visualization, e.g. hillshading, slope (shading), hypsometrical or contouring methods, and their combination do not reveal particular morphologic details (features) that are implicitly recorded to the relief models (de Smith, 2009).

Visual recognition of selected and studied characteristics of the landform bases on enhancement of the morphologically important features from the DEM. Generally, many of the features on the Mars planet are same as on the Earth, but there are still a significant differences (not part of this paper). The following basic features and more complex phenomena can be recognized in case of the Mars' areomorphological study: (i) structural lines and points (peaks, ridges, saddles, thalwegs, pits, etc.), (ii) river networks, (iii) circular- and annular-shaped features (impact craters, volcanoes and calderas), or (iv) annular and liner-shaped features (talus cones and talus slopes).

The enhanced techniques are important for carrying out certain task of effective visualizations by means of visual recognitions and phenomena detection. To handle a low quality DEM, robust methods (Huber, 1981) for visual recognition of the studied morphological features are suggested. Robustness might be proven by comparing the results of different methods or to use the same method in geographically different areas. The main incompetence of applying all remotely acquired data sets in Mars studies is that the most outputs/results can not be yet proven or inspected with the field work. Examples for the (robust) visualizations that can help for the visual recognition are: (i) bipolar differentiation (Wood, 1996; Podobnikar, 2007) as kind of continuous contour lines, and (ii) enhancing of the edges on DEM as kind of "wearing out the edges of jeans or furniture" based on different techniques, e.g. on multidirectional shaded relief (Mark, 1992) or on shadow simulation technique (Podobnikar, 2010).

The applied visualizations may be called "thematic maps" by means of cartography. Characteristics of the thematic cartography is: (i) morphologic features, structures and patterns are enhanced and therefore easily recognized, (ii) visualizations depend on the particular studied feature (which features are in our interest?), (iii) visualizations need more explanation to the other users (with legends and descriptively).

An example in figure 5 is visual detection detection of craters and their morphometrical description. Crater's relative height (shown in brighter color) can be automatically calculated with difference between the minima values of the annular-shaped windows and center points; another calculation considers the diameter of the crates that corresponds to the thickness of the rings around the craters; furthermore, shape of the craters can be analyzed.

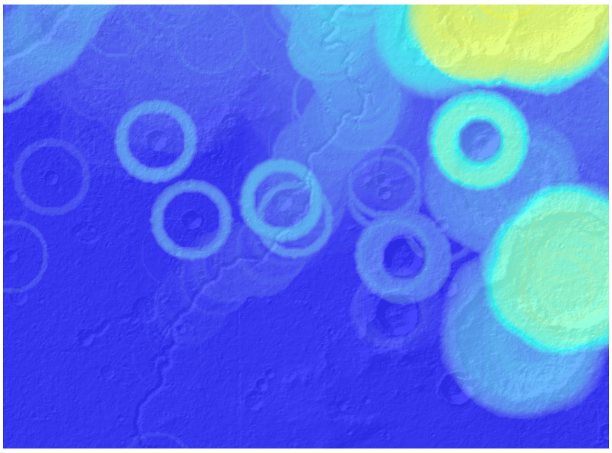


Figure 5: *Crater detection based on annular-shaped focal window technique.*

Another example in figure 6 presents a detection of the features based on robust morphological predictional analysis of talus surface (red) and upper outcrop (blue). The interpretation and approvement was performed by geomorphologists (Székely and Podobnikar, 2009).

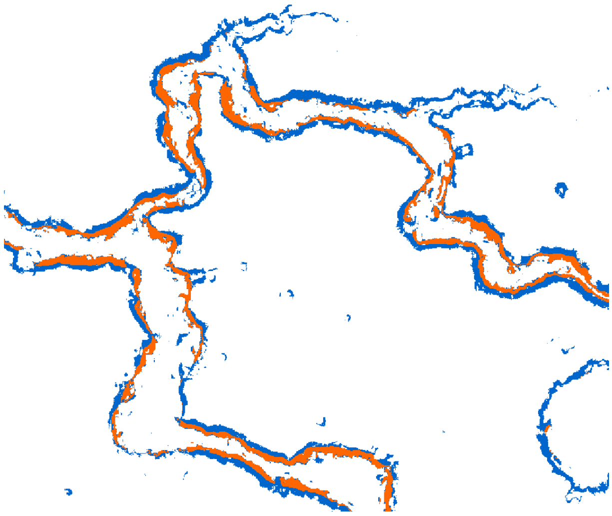
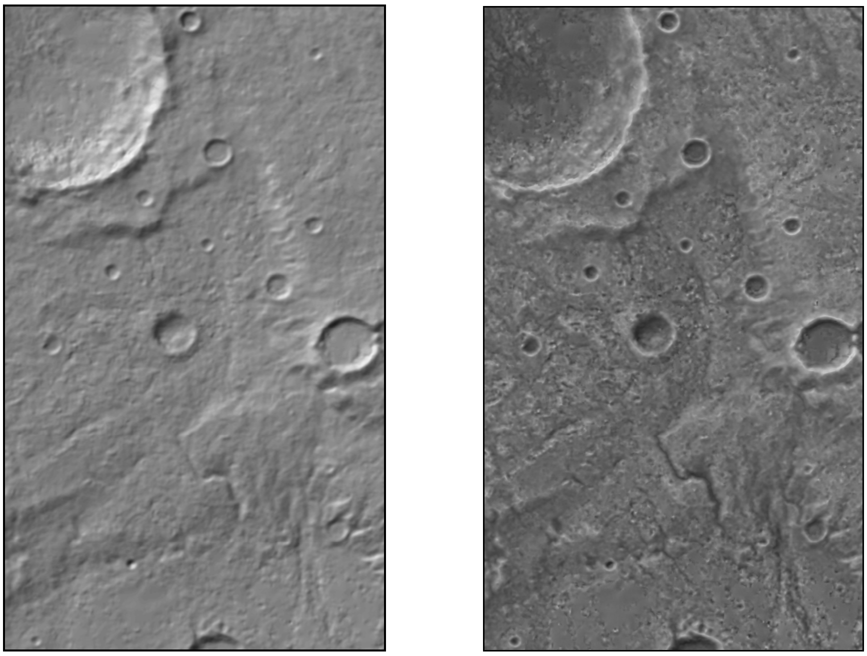


Figure 6: *Interpreted model of talus surface (red) and upper outcrop (blue).*

Spin-offs: topographic visualization and morphological quality analysis

Topographic cartographic visualization is more conservative than thematic one. It requires standard topographical rules for the relief presentation as part of an appropriate abstraction of reality (Imhof, 1965; Robinson et al., 1995). Appearance of such landform is generally more naturalistic than one by the thematic cartography techniques. This makes possibility for combination with other visualization techniques. The cartographer selects only the information that is essential to fulfill the purpose of the map and the information suitable for the selected scale (figure 7). Still, the map's interpretation depends on a cognitive and semantic perception of the World, depended on both, cartographers and users.

Motivating aspect of topographic visualization is multi-scale presentation combining small and large scale derivatives of DEM. Hypsometric and hillshading methods on generalized DEM can introduce the surface in small scale. This visualization gets insight into a large area of landscape and in the same time to a rough overview of it. Fine hillshading in combination with characteristic surface structures as enhanced edges can introduce morphological details of the landform. Both techniques are supplement to each other (figure 7b). Topographic visualization can be nicely used for additional improvement of the methods of visual features recognition as many balances and compromises for best non-erroneous visualizations are studied.

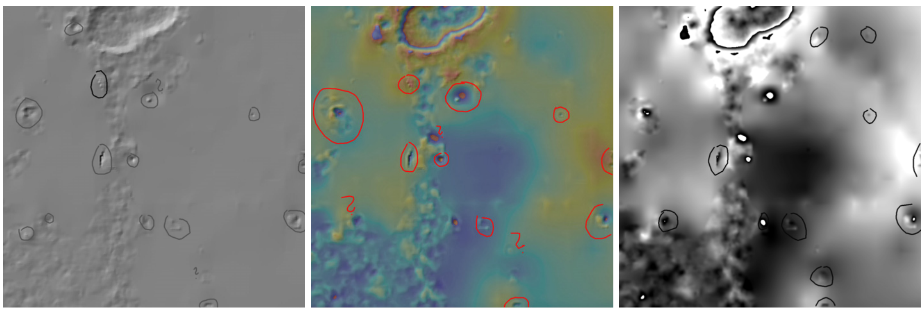


a) b)

Figure 7: *(a) Basic hillshading and (b) analytical shading with topographic corrections based on the relative relief grid of shadow simulation technique (Podobnikar, 2010).*

Data quality refers to the performance of the data set given the specification of the data model (Haining, 2003). Possible methodology for the errors recognition bases on detecting morphologically artificial features. On the Earth we have many experiences to distinguish the artifacts that are considered as gross errors or as natural features. Still, the gross errors may misinterpreted by anthropogenic changes on the Earth, but not on the Mars.

The visual methods can help to experts to examine the patterns and textures on the developed derivates of DEM (figure 8). Moreover, the proposed derivates could be used as inputs for the fully automated error of different type detection. Potential gross errors are visually inspected on the base of various visualizations. It is clearly seen that various visualizations allow different interpretations and that the success of such expert recognition strongly depends on visualization techniques. For the further analysis the detected (gross morphological) errors should be eliminated or identified in case of using robust methods of feature detection and interpretation.



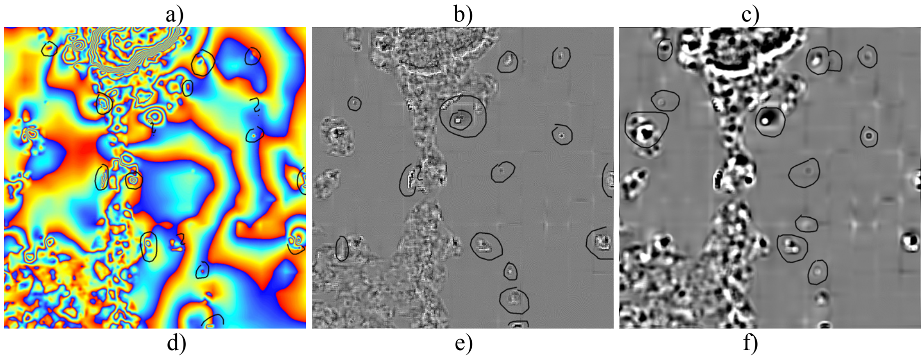


Figure 8: *Morphological quality analysis (visual error detection, encircled areas) based on the following DEM derivatives: (a) hillshading, (b) hillshading, bipolar differentiation, and slightly enhanced edges, (c) bipolar differentiation in grey cast and contour interval of 500 m, (d) bipolar differentiation in dischromatic colored cast and contour interval of 100 m, enhanced edges on (e) the original and on (f) smoothed DEM (as different scale).*

CONCLUSIONS

Some non-robust techniques of DEM analysis and visualization can cause that even relatively small errors of DEM nullify correctness of the morphological interpretations. Some known techniques for the DEM analysis were examined in the study, with emphasis to visual recognition of the selected morphological features and further phenomena detection. An important role of this study was to implement some simple but robust techniques for effective geomorphic analysis with stress on the low quality DEM data sets of Mars. Combination of different techniques can increase understandability and interpretability of the landform features. However, the demonstrated techniques allow only limited expert-driven conclusions in comparison to more objective classical statistical/numerical techniques. Two valuable spin-offs were described: topographic visualization and morphological quality analysis.

Further study needs more interdisciplinary research that incorporates the experts as geomorphologists, (planetary) geologists and tectonic researchers who have been specializing on Mars. Later on, an automated recognition process on the low quality data sets may be developed in order to support pure and less objective visual approaches. For more objective results, further analysis should comprise study area that allows performing the tests with independent reference data and additional numerical testing of correctness of the techniques presented in this paper (e.g. Andrienko and Andrienko, 2005).

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