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Can analytical shading be art?

Reflections on the canvas of experiments with ArcGIS and Surfer

Abstract. Despite numerous theoretical and experimental studies of analytical relief shading, devised about half a century ago, its quality has not yet reached the excellence of traditional (manual) shading. The paper discusses its basic principles and the main factors affecting the quality of shading. It also stresses the crucial importance of the digital terrain model used as the basis for shading as well as the proper generalization of the relief. Experiments with shading modules of ArcGIS and Surfer, aiming to explore the functionality of algorithms they employ, have demonstrated significant similarity of the results. In conclusion, the authors attempt to answer the question posted in the title of the article. In their view, analytical shading is not art because shading algorithms are incapable of producing the visually beautiful effects that an experienced cartographer with artistic talents can create.

Keywords: digital terrain model, analytical shading, art in cartography, GIS programs

1. Introduction

In the article "The art and science in cartography – dualism or unity?", J. Mościbroda (2001) wrote: "In discussions of theoretical foundations of cartography, the topic of inter-relations between science and art in cartography made frequent appearances" (p. 99). In the midst of varying opinions on the subject, the most fitting appears to be the view adhered to among others by E. Imhof (1977) and asserting that although cartography is a science, it also has a place in the realm of arts. The argument supporting this outlook includes some maps themselves – of course, the fine maps. Their artistic value manifests itself in the harmony between graphics and map content, while the perception of beauty becomes particularly moving when the mastery of maps with shaded relief evokes the artistry of the Italian Baroque paintings (J. Siwek 1998, 2000).

The development of the shading technique was a long lasting process in the quest for an effective presentation of land relief. The first attempts were made by Leonardo da Vinci the map of Tuscany in 1502 and 1503. Later we see them on the Jost Murer's map of the Canton of Zürich (*Karte des Zürichgaues*) in scale of about 1:56,000 (1566) and the Philip Apian's map of Bavaria (*Bayerische Landtafeln*) in scale of about 1:144,000 (1568). Roughly one hundred years later, shading shows up again on the Hans C. Gyger's map of the Canton of Zürich (*Grosse Landtafel des Zürcher Gebiets*) in about 1:32,000 (1667), where terrain was shown for the first time in horizontal perspective and shading was combined naturalistic coloring (E. Imhof 2007), while in the eighteenth century, shading was featured on the maps drawn by hand.

As S. Pietkiewicz (1930, p. 13) remarks "... the shading technique really took off only after the invention of lithographic crayons as their use cut down twentyfold the time needed to make a drawing with a technique similar to linear hatching". As a result, the third quarter of the nineteenth century saw shading to become a major competitor of hatching with oblique illumination. It is surprising how quickly the rules for shading underwent formalization. Already in 1878, H. Wiechel developed a formula permitting to determine the lighting level for any topographic surface, based on the slope and azimuth as determined by the shape of contour lines. In his considerations, he adopted a fixed angle of illumination with rays beaming from the northwest at the angle of 45 degrees relative to the horizontal plane. But even with the aid of nomogram that H. Wiechel developed to make the task easier, his rules were very difficult to apply at the times of manual shading. They were resurrected only after P. Yoëli (1965, 1967) started his work on analytical shading based on the digital terrain models.

W. Pawlak (1979, p. 25) defines shading "as a horizontally continuous representation of vertical relief projected orthogonally on the horizontal plane and graphically represented by means of the varying light intensity that depends on the assumed parameters of illumination of the actual terrain". Traditional shading is an activity requiring from a cartographer the power of spatial vision and the ability to express it graphically. As the task is also time-consuming (though not as much as hatching technique), the procedure became automated as soon as it became possible. Already in 1981, B.K.P. Horn expressed his opinion that computer shading had reached the mature stage of development. But despite more than 30 years that have passed since Horn's assertion, automatic shading has not reached the quality level of shading by hand.

The procedure of traditional shading is usually simple (but procedural simplicity should not be confused with the ease of performance, as shading requires exceptional abilities), and particularly so on topographic maps. The base material for shading consists of the contour layer. On maps that cover large areas in smaller

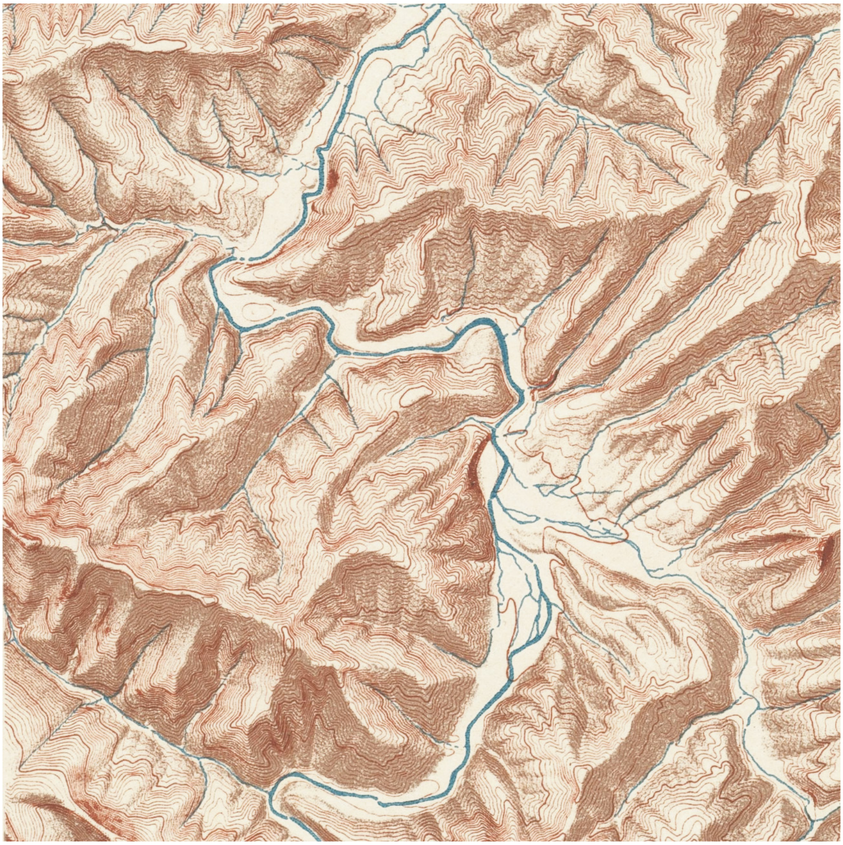


Fig. 1. Shading on the Polish topographic map 1:100,000, part of sheet P-55, S-39 Mikuliczyn (*Catalogue of maps*, the Military Geographical Institute 1938, Warsaw)

scales, the knowledge of the processes of landscape formation – as well as the types and characteristics of the resulting landforms – is additionally required. The ultimate condition for achieving the high-quality shading have been always the natural aptitude of the cartographer and expertise gained through the years of practice. As numerous examples indicate, of which a very successful instance is presented in figure 1, these qualities have been always guiding cartographers towards the best solutions in specific topographic contexts.

2. Digital Terrain Model (DTM)

Automation of shading required the traditional procedures to become formalized to make their digital implementation possible. The backdrop for the process became a digital terrain model (DTM) created from the aerial and satellite images, laser scans and topographic maps. The shaded image of the surface is created through the model processing that involves calculating the value of light reflected from the surface. As an abundant Polish and foreign literature[1] exists on the topic, the discussion of DEMS in this article is limited to the bare minimum needed to understand the impact of the model on the shading quality.

It has been assumed in this study that a digital terrain model is a set of points with precisely defined positional coordinates and elevation, all representing the entire physical land surface (Z. Kurczyński 2015), and speaking more precisely: “A Digital Terrain Model is a numerical, discrete (point) representation of the topographic elevation, along with the interpolation algorithm enabling the restoration of the surface shape for a specified extent” (Z. Kurczyński, R. Preuss 2003, p. 301). In the latter definition the authors direct attention not only to the numerical records preserving the topological relations among elevation points but also to the algorithm needed for its rendering. This inclusion is extremely important because the “reading” of the land surface represented by the three-dimensional model enables the performance of cartometric analyzes of relief and affects the outcome of shading. Therefore, it is fitting to consider the properties of such a model as they affect the distribution of light during the transformation into the shaded image.

The quality of the digital terrain model, and subsequently the fidelity of the surface recreated from the model, depend on the model structure and the method of approximation (D. Kładoczny, W. Żyszkowska 1995). This is due to several factors: the method used to collect the data and density of the source data, as well as the size of the pixel in raster image and interpolation method (P. Hu, X. Liu, H. Hu 2009). The method of spatial interpolation should be tailored to the character of the data and terrain features, and incorrect choices may affect the quality of the model (M. Wieczorek, M. Szymanowski 2010). The most commonly used in computer systems are two types of models – abbreviated as TIN and GRID – while the hybrid model is employed less frequently.

The triangulation model (TIN – Triangular Irregular Network) is formed as an irregular network of triangles where triangle vertices coincide with the elevation points. These points should be arranged in the manner taking into account the essential features of the relief including skeletal lines, local height extremes, locations of slope changes, and lines of discontinuity (escarpments, cliffs). The advantage of data organization in the TIN model is the preservation of the exact location of data points. The model construction should meet the Delaunay requirement, i.e. interpolation points should not be located within a circumcircle constructed based on the triangle’s vertices. The model surface becomes smoother (closer to the actual surface) with the increasing number of triangles forming the triangulation.

The raster model (GRID) is based on the regularly spaced height points. They are the result of interpolation between the measurement points in TIN model, which lowers the accuracy of the ground surface approximation. We are dealing here with the surface data recorded as a matrix of points spaced at regular intervals, most commonly in the square grid. The advantage of this arrangement is the ease of data recording and computing the basic morphometric characteristics of the terrain. The main disadvantage is the unnecessarily excessive amount of information – particularly for flat plains that do not require as high density

[1] Compiled by J. Ostrowski (2010) and included in the materials from the Nineteenth Cartographic School, the summary of Polish literature on digital elevation models features 188 items published between the late sixties and 2010.

of height points as areas with higher energy of relief and greater variety of landforms – which consumes more memory than the TIN model (M. Kochman, R. Olszewski 2005; D. Gotlib, R. Olszewski, M. Kochman 2005). Among other applications, the raster data organization is employed in the open models generated by the SRTM (Shuttle Radar Topography Mission) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer).

The hybrid model is a combination of two previous types. It consists of a network of regularly spaced height points and those omitted in the GRID model points and lines that are important for the fidelity of relief representation. An example of a hybrid model is used in the ASCII TBD[2] database administered by the National Center for the Geodetic and Cartographic Documentation in Warsaw.

In practice, the most commonly used is the GRID-type model based – as it is worth to remember – on values interpolated rather than on the actual measurements. The amount of detail captured in the model depends on the spatial resolution that varies with the size of data collection unit. Excessively large fields of reference cause small landforms to become invisible, edges to blur, slope angles to change, with all these problems deriving from the use of interpolation to determine the elevation at points building the model.

When making transition from the TIN to GRID models, each point is assigned an approximate height value in the course of interpolation. Even the values falling within the acceptable margin of error do not guarantee the preservation of the actual elevation relationships. In models constructed for specific purposes, preserving the orderly sequence of elevations observed in the field is also essential. For example, such ordering is imperative for the accurate determination of the direction of water flow in hydrological models (X. Liu et al. 2015).

As in the case of every model, a digital terrain model is a generalization of reality and to represent it well, the model must capture all essential characteristics of the terrain. As discussed earlier in the context of TIN models, selecting the most characteristic elevation points should be used to accomplish this goal. In the up to date literature, studies assessing methods used to develop the DTM models were focusing primarily on the accuracy of determining elevation and paid less attention to such factors linked to the capture of the essential structure of the terrains as the appropriate choice of data points, their isomorphism (proper height relationships in particular) as well as generalization. Dissemination of high accuracy data derived from laser scans produced by LiDAR (Light Detection and Ranging) will help to shift the research focus to these "neglected" issues (X. Liu et al. 2015).

It's hard to resist the impression that discussing the appropriate form of digital terrain model is to some degree a step back into the past. After all, the proper choice of measurement points is the basic and long time resolved issue in land surveys performed with a plane table (in use since the first half of the seventeenth century). Generalization of the relief represented with contours also does not pose a big problem for experienced cartographers. But discussion of these topics has been revived when it came to implement the old rules with new tools. The need for such adaptation arouse not just within the scope of terrain visualization but also in selection and generalization of all other elements of the map content. The process of compiling the map content that until not a long time ago was dependent on the knowledge, experience, and sometimes intuition of the cartographer, nowadays requires an algorithmization, i.e. formalization and "translation into language of computers" of rules developed in traditional cartography. But this conversion does not always yield the satisfactory results.

3. Generalization of the Digital Terrain Model (DTM)

The numerical model of terrain can be generalized from source data up to different levels of detailedness using various algorithms developed to automate the process. Generalization of the DTM entails reducing the number of elements in the set of height points and fundamentally differs from classic generalization that calls for simplifying the image created with contour lines (R. Olszewski 2005). But in similarity to traditional generalization, it is a complex

[2] TBD (Topographic Data Base) is the official system of spatial data maintained in Poland. For DTM applications, the TBD elevation data is encoded in the ASCII (American Standard Code for Information Interchange) format.

process that does not succumb easily to full automation. In this instance we see the persistence of two of the three “reefs” that E. Sydow articulated nearly 150 years ago: graphic representation of the land relief and generalization. In this case, the two “reefs” come together reflecting the difficulty of the task at hand.

Generalization of DTM can be performed using three basic methods: global filtering, local filtering and heuristic approach (R. Weibel 1992). The global filtering method – used only in raster models of the GRID type – maintains the fixed number of points present in the input model but changes their original value (height) by replacing it with the weighted average of elevations of points present within the moving window of the arbitrarily adopted size (filter mask). Three types of numerical filters can be applied in the filtering process: low-pass filters are used for the model smoothing; high-pass filters for sharpening the edges; and composite filters combine the functionality of the other two filters. Local filtering (for small sets of data) entails selection of points from the source model and can be used in both the TIN and GRID models. Filtering of the source model removes input points with little relevance and leaves behind the characteristic points that are important for recognizing landforms. These points must be assigned weights that reflect their significance. The heuristic approach is applicable to both the TIN and GRID models and relies on the operator interactively cooperating with the computer program. The gist of heuristic approach is the generalization of structural lines in the source model by means of removal, merging, simplifying and other operations used in classic generalization (R. Olszewski 2005; R. Olszewski, A. Żyła 2004).

Filtering of the source model serves the purpose of generalization but it is useful also for removing imperfections. This becomes necessary in cases of models containing multiple points with incorrect elevations derived from remotely sensed images.

The essential problem in DTM generalization through filtering is the danger of losing crucial points that define the terrain topography. The enlargement of raster fields during generalization leads to gradual averaging of height values and smoothing of the surface, which brings about the undesirable changes in morphometric features of the surface. The most prone to this effect are areas with high energy of relief – and mountainous landscapes in particular (R. Olszewski 2006). Simple averaging of height values of individual cells distorts the shapes of landforms and should be replaced with a calculation of weighted averages for points subjected to prior ranking, in the course of which points are assigned weights commensurate with their importance for the relief.

Laser scanning is a source of highly accurate data since the 1990s. The unprecedented density of measurement points makes the detailedness of the resulting images to exceed the needs of many user groups (5 points per m^2 for flights at the altitude of 1,000 m and 25 points per m^2 for flights at the altitude of 400 m – J. Kolejka, M. Tejkal 2010) and difficult to interpret (T. Pingel, K. Clarke 2014). Similar issues arise when laser scan data are used to generate a digital terrain model as a foundation for shading. This necessitates a significant reduction of data points prior to the model generation (X. Liu et al. 2015). Otherwise, excessive detail would become an obstacle to obtaining a quality shading.

4. Principles for shading based on the digital terrain models

From the user’s perspective, analytical shading based on the DTM has become much easier than traditional shading, but complexity increased from the procedural perspective. The process that was formerly performed directly from the contours is now split into several stages (fig. 2) and in contrast to the ease of evaluating the

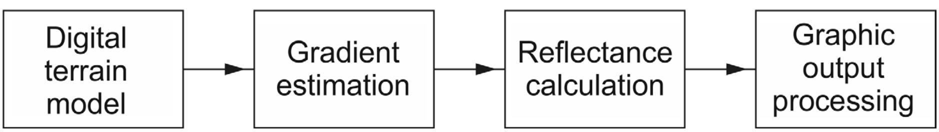


Fig. 2. Diagram of the stages of automatic (numerical) shading according to B.K.P. Horn (1981)

quality of the contour drawing, assessing the usefulness of DTMs is quite difficult

The detailedness (resolution) of the digital terrain model used for automatic shading should match the scale of the map for which the shaded relief is produced. This relationship was easier to observe in the past but now apparently needs a reminder because shading often does not match the map scale. Such incongruity indicates the use of the under-generalized model – perhaps even the raw source model – and becomes easy to spot as a substantial discrepancy between the contours and the shading.

Analytical shading involves calculations of the component gray levels on the basis of a "measurement" of light reflected from the DTM surface. Figure 3 illustrates this process.

The shading algorithm incorporates fixed parameters (adopted arbitrarily) such as the hypothetical position of the light source given as the azimuth and elevation above a horizontal plane as well as variable values changing

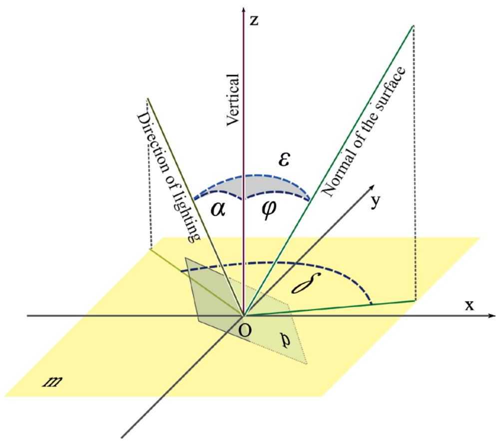


Fig. 3. Geometric relationships in light reflection:
m – the horizontal plane
p – a plane tangent to the land surface at point O corresponding to the pixel, for which the gray intensity (shade) is calculated
α – zenith angle between the direction of observation and direction of lighting
φ – surface inclination (slope) corresponding to the angle between the observer and normal to the surface
ε – the spherical angle between normal to the surface and the direction of illumination
δ – the plane angle between normal to the surface and the direction of illumination

with the orientation of landforms. The surface of those landforms in the DTM consists of grid cells with the intensity of grey shade computed for each.

For example, the formula used in the ArcGIS (*How Hillshade Works*) algorithm for calculating shades on the 8-bit grayscale (256 levels) goes as follows:

Hillshade = 255.0 * ((cos (Zenith_rad) *
* cos (Slope_rad)) + (sin (Zenith_rad) *
* sin (Slope_rad) * cos (Azimuth_rad –
– Aspect_rad))) (1)

The formula is based on the assumption that the mapped surface perfectly diffuses light (so-called Lambertian reflectance) and the light distribution follows the theory of H. Wiechel. This means that the intensity of gray shade at any given point is proportional to the cosine of the angle between the light beam and a normal to the elementary unit area (cell) containing the point. In figure 3, it is the angle ε in a spherical triangle, that can be calculated from the simplified equation (1):

$$\cos \varepsilon = \cos \alpha \cos \varphi + \sin \alpha \sin \varphi \cos \delta \quad (2)$$

Thus:

$$\text{Shade intensity} = 255.0 \cos \varepsilon \quad (3)$$

For automatic calculation of the shades in each cell of raster model, the elevations needs to be related to the height of adjacent units – at

Z_{-+}	Z_{0+}	Z_{++}
Z_{-0}	Z_{00}	Z_{+0}
Z_{--}	Z_{0-}	Z_{+-}

Fig. 4. Symbolic notation in the matrix of cells included in the intensity calculation of the shade value for the central cell (B.K.P. Horn 1981)

least four, and most often eight neighbors (fig. 4). On this basis, the slope and exposure are calculated. This operation is performed for all cells in the model, with each treated as a center unit, hence the name the of the moving window. It is also noteworthy recalling that this very method, sometimes called the method of a "crawling disc" has been used in "classic cartography " for nearly 50 years (V.A. Červjakov, V.I. Červjakova 1970).

The algorithm employed in ArcGIS formalizes just one of many ways of shading. Yet all of them require calculating the amount of light reflected from the modeled surface and first yields a so-called reflectance maps that is later converted into the shaded drawing. Among the numerous papers on the subject, the most often referenced is the article by B.K.P. Horn (1981) that discusses eighteen ways to calculate reflectance.

5. Analytical shading with ArcGIS and Surfer

For testing grounds in target scale of 1:50,000, we chose a small area located in the macroregion of Carpathian Foothills (South-Eastern Poland) and covered by the 1:10,000 map, sheet M-34-79-D-b-4 Jasło – os. Ulaszowice. The area has a mountainous relief with topography "susceptible to shading" (fig. 5).

In terms of the source data for shading, consideration was given to the TBD data available from the National Center for the Geodetic and Cartographic Documentation in Warsaw (http://www.codgik.gov.pl/) and some open-access satellite models.

An assessment of the official TBD data in the ASCII format for the topographic sheet of our choice has led us to conclude their unsuitability for the shading purposes. The decisive reason for their inadequacy was a low accuracy of elevation readings in forested areas because the precise photogrammetric methods were used only in the clearances and cuts through the woods (what is acknowledged in the accompanying technical specifications). For the remaining stretches of forest, the height values

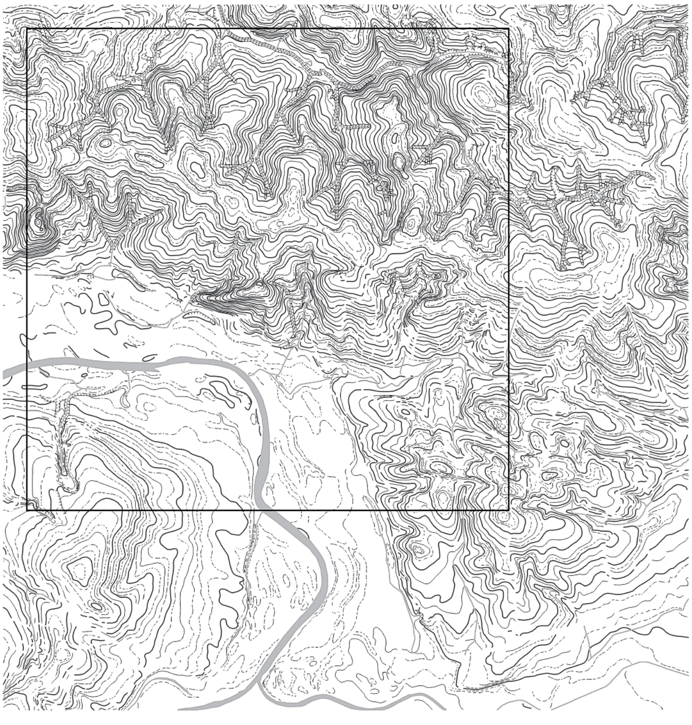


Fig. 5. Relief on the topographic map 1:10,000 reduced to scale 1:50,000 with the extent of test area shown in figures 6–11. Basic contour interval is 10 meters, auxiliary contours every 5 meters, complementary contours every 2.5 meters; drop on the test area 121 meters

for each vertex in the superimposed grid of regularly spaced points (GRID) have been linearly interpolated from the actual points of measurement and those were often very far apart. This solidified deformations in the resulting surface and made it impossible to supplement the model with data from other sources without first removing the aberrant points.

Similarly unsuitable turned out to be the commonly accessible models of SRTM and ASTER GDEM (Global Digital Elevation Model) derived from satellite imagery with resolution making them more suitable for overview rather than topographic maps. Additionally, those data do not include adjustments for the height of vegetation and buildings (K. Jancewicz, J. Krupski 2012; P. Śleszyński 2009; J. Nita et al. 2007).

Given the shortcomings of data collected with the remote sensing methods, a topographic map was deemed to be the best source of spatial information needed to generate the numerical terrain model for shading tests (J. Nita et al. 2007, Z. Kurczyński 2015). Subsequently, ArcGIS was used to digitize the contours as well as topographic features needed to adequately represent the terrain: streams, ridges, scarps and so on (fig. 5). The best illustration of the extent of this massive task is the total number of 52,017 vertices forming the TIN model and including[3]:

– 2,499 sections of contour lines (the total length of 453,767 meters in the actual terrain)
– 88 streams (68,130 meters)
– 173 ridge lines (25,215 meters)
– 119 scarps (50,411 meters)
– 96 elevation markers
– 695 additional points for location in need of revision.

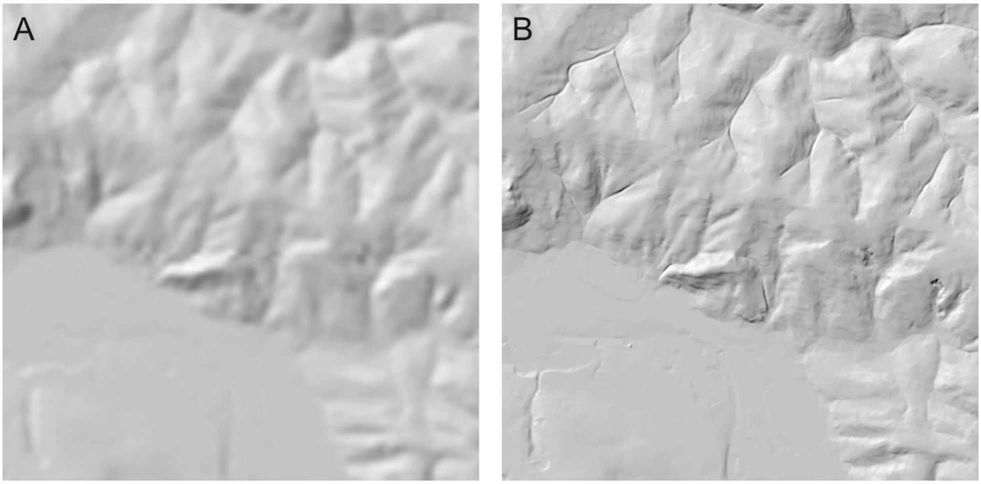
The effects of analytical shading were tested with ArcGIS 10 (*How Hillshade Works*) and Surfer 10 (www.goldensoftware.com). The data digitized previously from the map was used to create a TIN model and later converted into the GRID format. The transformation was performed using the 3D Analyst extension, which increased a fairly modest range of shading options that comes originally with ArcGIS 10. However, the single shading algorithm in the 3D Analyst extension permits users to choose only the lighting parameters and the vertical exaggeration factor. Other functions that expand shading capabilities in ArcGIS 10 are scattered in different segments of that comprehensive program and this hinders their use. Surfer 10 is much better in this respect because it is geared specifically toward the task and offers less complicated access to shading functions. This gives users a more effective control over the process of shading, for example, by adjusting the parameters of the algorithm for calculating the gradient components in the DTM or choosing one of the four available shading algorithms.

Aiming to compare the capacity of both programs and evaluate the quality of yielded results, this study tested over 50 shading alternatives produces with different parameters. The most crucial step in the process was to determine the model resolution as a prerequisite for good shading. Visualization and comparison of five models with resolutions ranging from 30 to 2 meters has led to adopting the 7-meter variant as a compromise between blur and excessive detail (fig. 6). That pixel resolution corresponds to a 0.14×0.14 mm square at a scale of 1:50,000 placing it in the middle between 0.1 mm (a value close to the theoretical limit of human perception) and 0.2 mm (a value close to the practical possibilities of recognition).

The study has also examined the impact of lighting direction and height on the shading quality with the goal of selecting the optimal parameters for this particular study. As this has led to the choice of the 315° azimuth from eight directions encompassing the 180°–360° range, standard lighting from the northwest proved to be the best for this area. Choosing the incidence angle of 45° also complied with traditional solutions (and default in computer programs) for mountainous areas (the optimum angle of incidence is smaller for lower relief). Both of these parameters were adopted as a "common denominator" in subsequent tests.

After making those preliminary decisions, hill-shaded maps were produced using the ArcGIS algorithm assuming Lambertian reflectance (perfectly diffuse reflection from the ideally matte surface) and the four Surfer algorithms based on the Lambertian reflectance (again), Peucker's approximation (simplified Lambertian reflectance), the law of Lommel-Seeliger (reflection from the porous surface) and the simplified Horn's algorithm. The resulting shade maps clearly demonstrate that assuming va-

[3] The data apply to the entire worksheet topographic map of 1:10,000 M-34-79-D-b-4 Jasło – os. Ulaszowice.



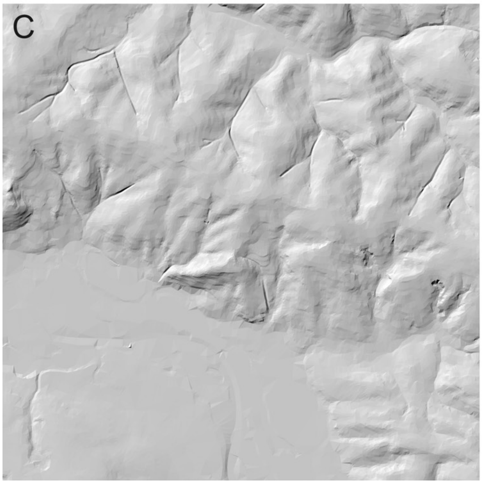
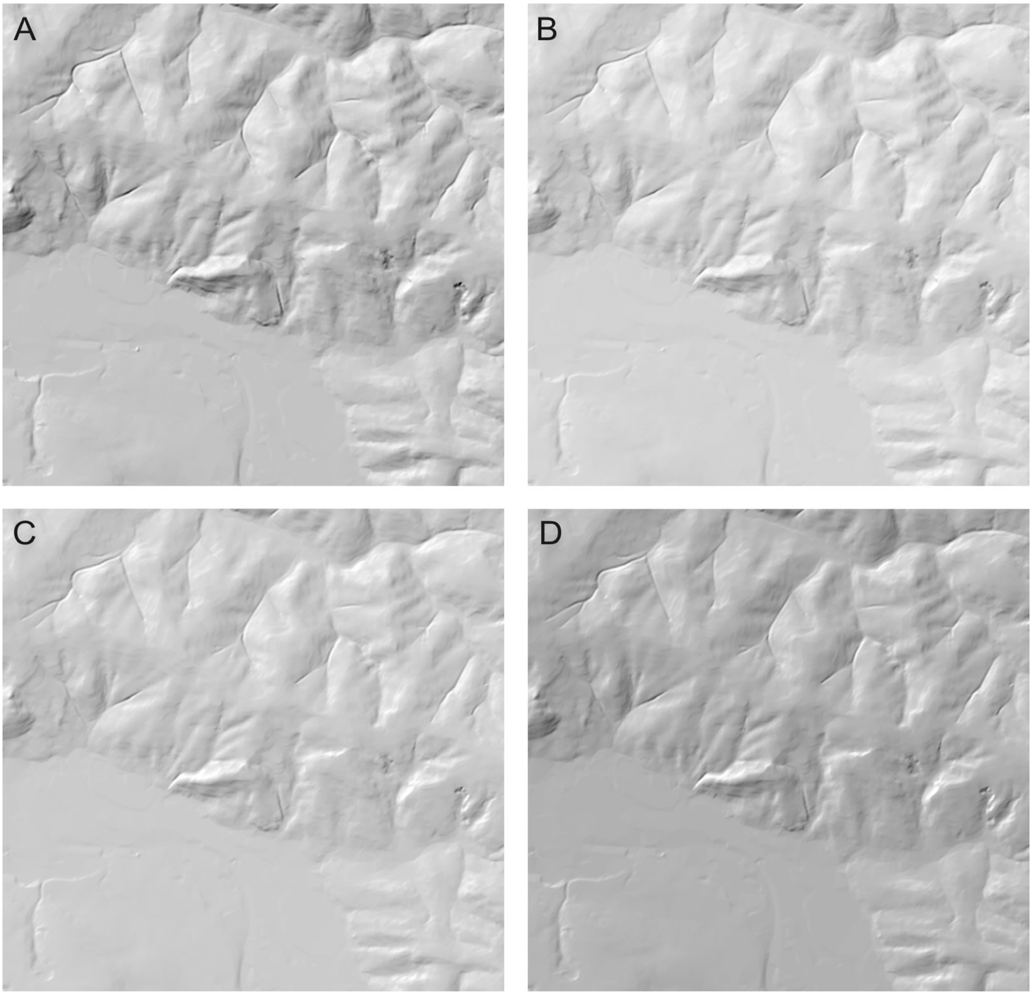


Fig. 6. Comparison of digital elevation models with different resolutions: A – 30 meters, B – 7 meters, C – 2 meters

rious ways of light reflection from the mapped surface impacts primarily the map brightness and contrast, i.e. the properties affecting map perception, but has no effect on the geometry of the underlying topographic surface. The shade map based on the Lommel-Seeliger's law turned out to be the brightest (fig. 7E) and consequently not very contrasting and expressive. The diffuse reflection from the Lambert's surface in the ArcGIS rendition yielded a more contrasting and darker image than that in the Surfer (fig. 7B). But despite this difference, these two are the most alike images in the group. As suspected earlier, the shade map based on the Peucker's approximation (fig. 7C) yielded an effect similar to the Lambertian reflectance algorithms – but darker than its Surfer's version, while lighter and more contrasting than the ArcGIS rendition. The simple Horn's algorithm turned out to be the darkest in the group with just a few small bright areas (fig. 7D).

In the next part of the testing, the shade map produced with the Lambertian reflectance algorithm in the Surfer was used to inspect the effects of vertical exaggeration (z-scale factor). As seen in figure 8, the image sharpness (contrast) increases with the rise in vertical dimension. The topography on the shade map with the z value equal to 0.5 is barely legible (fig. 8A), while z values greater than 1 make it much more pronounced (fig. 8C, D). Excessive exaggeration in vertical dimension can distort the topography by changing its character. An analogy exists here to the 3D diagrams and topographic profiles, where disproportional enlargement of vertical scale brings about similar problems.

The last experiment was concerned with examining the impact of model filtering, i.e. the impact of generalization on the shading quality. This effect was investigated by using the low--pass and high-filters as well as by varying the size of the filer mask and the number of filtering iterations. The observed effect of filtering confirmed their properties as described earlier. Low-pass filters and moving averages led to



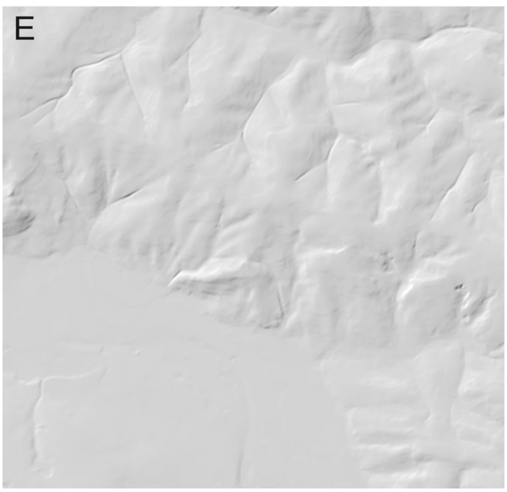


Fig. 7. Shading by algorithms in ArcGIS and Surfer: A – ArcGIS: Lambertian reflectance; B – Surfer: Lambertian reflectance, C – Surfer: Peucker's approximation D – Surfer: simple Horn, E – Surfer: the Lommel-Seeliger law.

the image blurring. Since the test surface did not contain any significant noise – what would require its removal – the filtering effect was not immediately apparent and blur was becoming visible only after five filer passages (fig. 9A, B). On the other hand, even just one pass of the weekest high pass filter highlighted the skeletal lines and escarpments, yielding the undesirable effect of excessive detail (fig. 10).

Increasing the number of moving windows intensified the effect of the filter comparably to the increased numbers of passes with a smaller window. And thus, a filter with 25 fields (5×5) (fig. 11A) produced an image similar to the five passes of the window of just 9 fields (3×3) (fig. 11B), while the filter with 49 fields (7×7) (fig. 11C) yielded an image similar to ten passes of the smallest window (fig. 11D).

6. Conclusions

The use of different algorithms has demonstrated no significant differences between the various approaches to shading. This finding should not be surprising if we consider that they differ only in terms of the modeled surface (ideally scattering light or porous) and they all are based on the Wiechel's principle of light reflection. Significant differences could occur only in cases of shading based on different terrain models because the DTM plays the main role in shading since the beginning of the process (fig. 4). It is the model structure, contingent upon the previously discussed factors, that determines the quality of the rendition of the mapped surface.

Understanding the mechanisms of shading

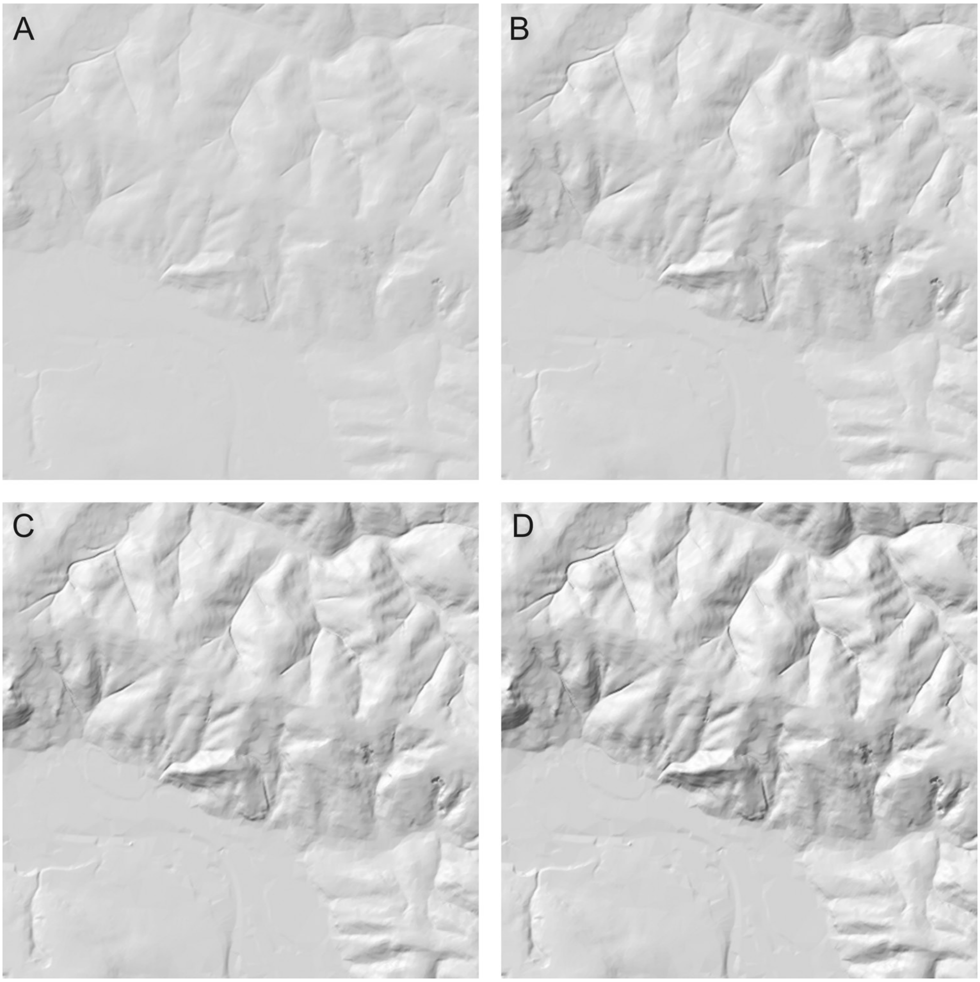


Fig. 8. Effects of vertical exaggeration clearance model for shading (Surfer, Lambertian reflectance): A – coefficient 0.5; B – coefficient 1.0; v; C – coefficient 1.5; D – coefficient 2.0

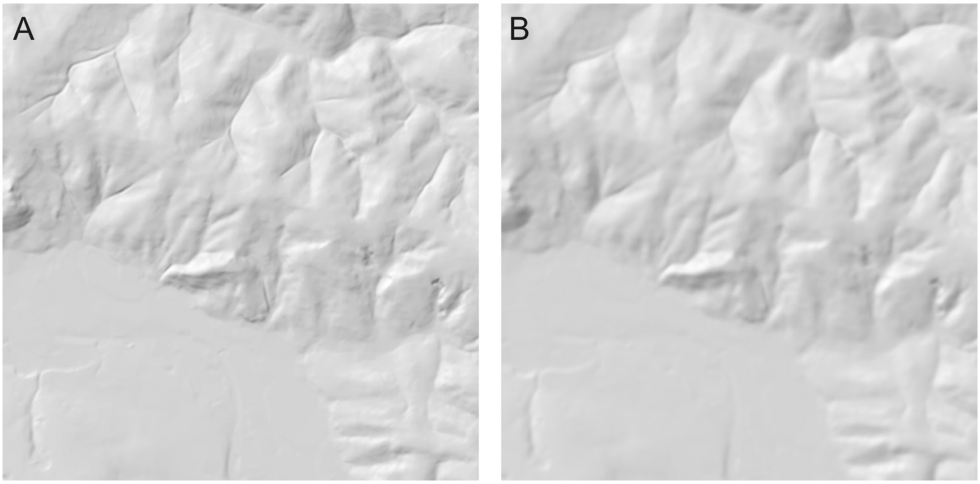


Fig. 9. Effects of the model filtering with a low-pass filter (Surfer, Lambertian reflectance, Gaussian filter): A – 1 pass, B – 5 passes

– albeit helpful – is not sufficient to evaluate its quality. The image of topographic surface representation is subjected to visual perception and regardless of the generation technique, it is judged primarily by means of visual assessment. Digital computing methods have many indisputable advantages as they formalize and greatly accelerate the process. But paradoxically, the repeatability is also a disadvantage in analytical shading.

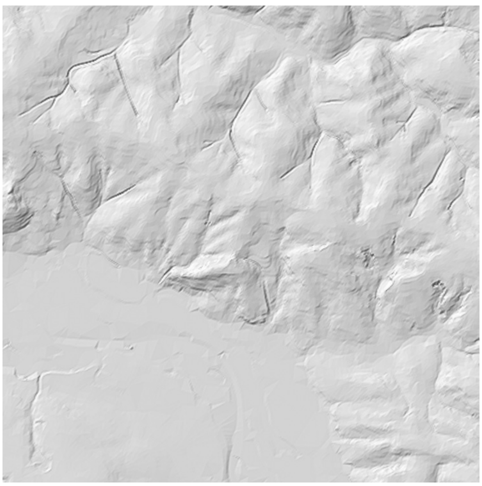


Fig. 10. Effects of the model filtering with a high-pass filter (Surfer, Lambertian reflectance, Gaussian filter): 1 pass

Algorithmic objectivity applied to individual pixels – as this is the level of detail at which the value of gray shade is "decided" – does not necessarily produce an expressive image because good quality shading effect requires a broader perspective and attention to the topographic context. A conscious decision about the distribution of shadows requires looking at the entirety of the terrain instead of its separate components. The final product of the process should be a hierarchical, orderly image of the relief that is easy to interpret even at the expense of geometric accuracy (L. Hurni et al. 2001). Such analysis of topography is not pursued in analytical approaches despite being a standard in manual shading.

A good remedy to this problem would be to take advantage of the experience amassed at the times of manual shading, i.e. going back to the roots as called for by authors such as B. Jenny (2001) and L. Hurni et al. (2001) apparently dissatisfied with the contemporary level of shading. It seems that despite the passage of time, the issue still persist. Generally accessible shading programs typically have a relatively small diversity of algorithms. They typically produce similar maps (P.J. Kennelly 2009) because they all assign the gray value to areal units based on the cosine of the angle between the normal to the mapped surface and light angle. Perhaps this function should be modified – just like the Lehmann's "cosine" function

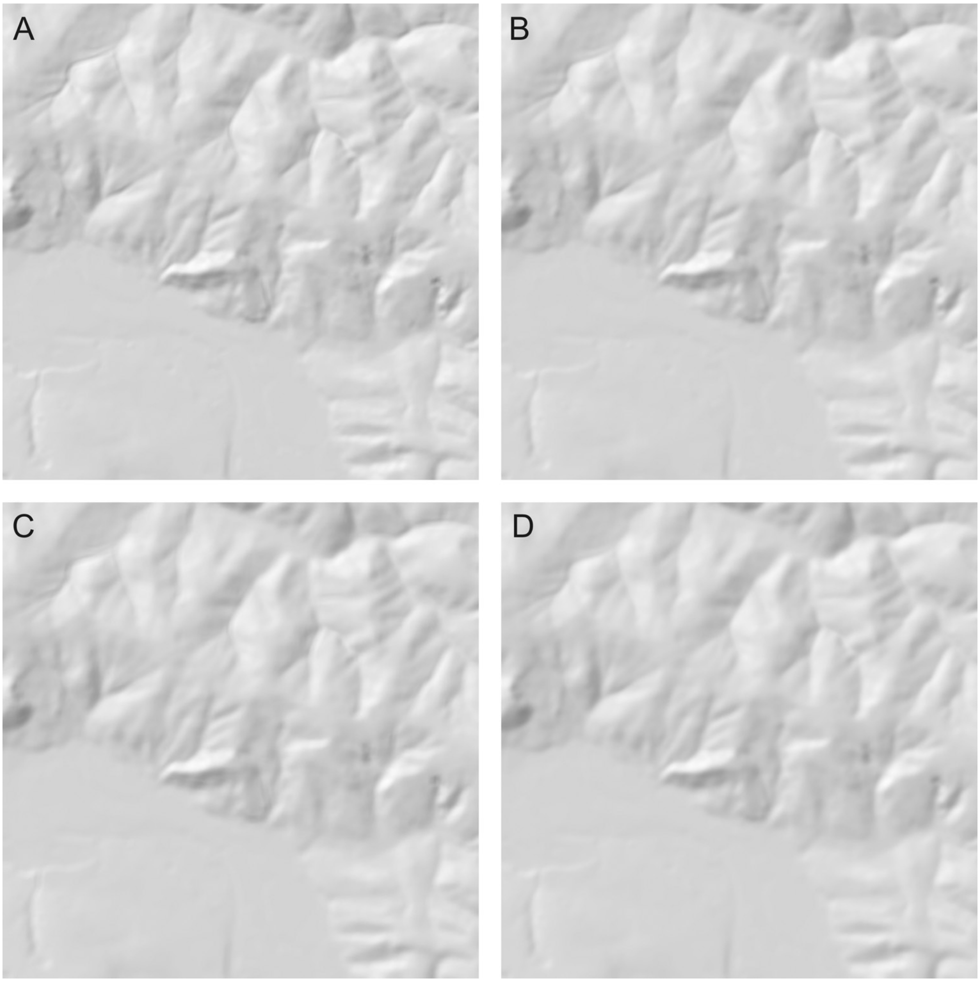


Fig. 11. Effect of the moving window and the number of filter passes on the model shading (Surfer, Lambertian reflectance): A – window size 25 cells, 1 pass; B – window size 9 cells, 5 passes; C – window size 49 cells, 1 pass; D – window size 9 cells, 10 passes

was adjusted when it turned out to poorly differentiate the proportion of white and black on hachure maps. Some reports of shading studies also articulate the need to improve shading quality, for example by local matching of the light direction and intensity or the use of an "air view" perspective (P.J. Kennelly 2009; B. Jenny 2001; L. Hurni et al. 2001; W. Pawlak 1979).

A substantial importance for the quality assessment wields the comparison of shaded maps with the source image provided by a contour map (fig. 5). It is easy to see that the shading brings to the view many relief details, yet it weakens the main skeletal line extending in the direction of light (NW). When the attempt was made to direct the light from the north, the skeletal line became more visible but at the expense of smaller landforms extending perpendicularly to the main ridge. On the other hand, the ridge nearly disappeared under the illumination from the west, while the visual presence of smaller relief details was enhanced or weakened depending on their orientation. Adjusting graphic differentiation to ensure proper perception of the importance of landforms would not be a problem in manual shading.

But the situation encountered in this study reveals perhaps the main shortcoming of the analytical shading, namely the lack of means to organize the image into a proper hierarchy of landforms.

A functional image of shaded relief requires an effective "interplay" of light and shadow that includes a skilful use of gray value and contrast. Shading generated from a digital terrain model "is inherently continuous" (J. Jancewicz, J. Krupski 2012), so it rarely features the full whiteness of the well-lit slopes, and therefore, contrast sufficient to emphasizes the skeletal lines (fig. 6–11). In this respect, figure 8D presents the best image obtained in this study by doubling vertical exaggeration.

Despite changing a variety of parameters of both the model and its illumination, tests performed within this study using ArcGIS and Surfer programs have not produced an effective shade map for the test area. An improvement of the obtained shading quality is still possible, but requires some "non-algorithmic" retouching, for example with help of Photoshop, as perfectly presented by other authors dissatisfied with the shading produced by ArcInfo (J. Jancewicz, J. Krupski 2012).

In the end it is fitting to answer the question posted in the title of this paper. Can analytical shading be art – in similarity to traditional shading? At the current stage of technology advance, it certainly is not and doubts persist whether it could ever be. But let's not lose hope as long as attempts are being made to improve it. Each piece of true art always carries the imprint of its author's individuality, uniqueness, and this applies also to many older maps. Contemporary maps are technically very correct, often perfect, but do not come even close to art. The same is true about analytical shading on relief maps. Algorithmic formalization took away its beauty. And this is just too bad...

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