

Interactive Analytical Shading and Cliff Drawing: Advances in Digital Relief Presentation for Topographic Mountain Maps

Lorenz Hurni, Bernhard Jenny, Tobias Dahinden, Ernst Hutzler

Institute of Cartography

Swiss Federal Institute of Technology (ETH)

ETH Hoenggerberg

8093 Zurich

Switzerland

[hurni, jenny, hutzler]@karto.baug.ethz.ch

dahinden@guv.ethz.ch

Abstract

In this paper two new and improved methods for digital relief depiction are presented: Interactive analytical shading and digital cliff drawing using fill hachures. Both methods have a long tradition in manual production of mountain maps which has been considered for the implementation of the new software tools. One of the main tasks was the decision to separate between interactive and automatic treatment within the software.

1. Introduction

Currently available software for analytical relief shading does usually not permit local adaptations of the light direction, the simulation of aerial perspective or other techniques developed for manual relief shading. Therefore, a program for computer-assisted relief shading has been developed that provides the possibility to locally adapt the calculations of the shading, permitting a seamless interactive control throughout the whole processing. Using the proposed techniques, experienced cartographers can continue to apply their knowledge and experience acquired with manual relief shading. The same applies for the automated generation of cliff drawing. Besides an approach presented by the authors two years ago, we do not know of any other comparable solution. This paper presents a new software allowing to simulate the cliff hachure technique applied in the Swiss National Map Series using so-called fill hachures. Both methods, the analytical shading and the digital cliff drawing, rely on extensive interactive (manual control) by the map producer (cartographer). To our opinion, this is the key to successful application of the programs.

2. An interactive approach to analytical relief shading

2.1 Manual relief shading

Manual relief shading is a time consuming task of depicting a terrain model modulated according to a specific illumination model. Highly skilled cartographers are needed to clarify and simplify the often cluttering topography. The aim is not to depict the terrain in a geometrically correct form, but to create an image that is easy to interpret. According to Imhof (1982), this can be achieved with the following techniques: Adjustments of the light source, bright grey tones in flat areas, adjustments of lightness, aerial perspective, and the use of colour.

Locally, the light direction is slightly turned out of the main light direction in order to emphasise and clarify topographical features. Landforms that lie in the main light direction are thereby accentuated. Among the methods listed by Imhof, this is probably the most important one. Moreover, flat areas are filled with a bright grey tone to build a relationship between hillsides separated by flat lowland. The applied tint is brighter than the physically correct value, in order to avoid any darkening of these usually densely occupied zones. Furthermore, a brightening of local shadows on the light side of hills, and a darkening on the shaded side, is used to emphasise large landforms, to structure the

landscape and to emphasise characteristic forms. Aerial perspective is used by cartographers to depict differences between high mountain summits and lower, more distant lowlands. Hence, contrast is sharpened towards the topographical peaks and softened towards the lowlands.

2.2 Analytical relief shading

Analytical relief shading is the computer-based process of deriving a shaded relief from a digital elevation model (DEM). Different methods for analytical shading have been developed in the field of computer graphics and for the particular needs of cartographers. Generally, grey values depend on slope and aspect (or exposition), both calculated from the DEM. Yoëli (1959, 1965, 1966, 1967) was the first to produce an analytical relief shading applying diffuse reflection on a DEM. This illumination model determines the grey value of each pixel by calculating the cosine of the angle between the surface normal and the light vector (see Foley et al., 1990). Figure 1 shows an example of a shaded relief, calculated with diffuse reflection.

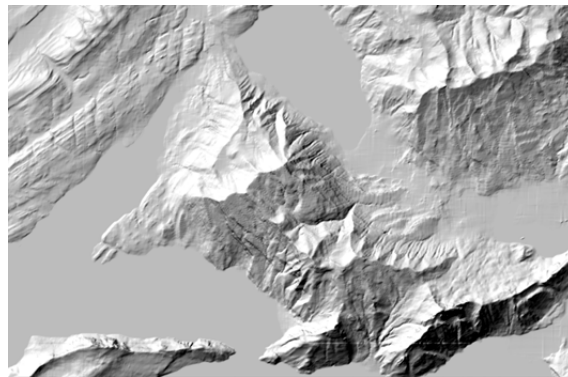


Figure 1: Diffuse reflection

Other illumination models may be used for cartographic applications, such as Phong illumination or ray-tracing (see Foley et al., 1990). A technique for elevation models in form of regular square grids and based on raster operators has been developed by Böhm (1998, 1999).

Some efforts have been made to adapt the different shading algorithms to the specific needs of cartography. Yoëli (1967) made first experiments with local adjustments of the light direction. Brassel (1974) continued this topic and proposed a rather complex model based on topographic structure lines to automatically adapt the main light direction. An interesting approach for local adaptations of the light direction was presented by Zhou and Dorrer (1995), who derive the corrections applied to the main light direction from a wavelet transform of the DEM.

Brassel (1974) developed a method to simulate aerial perspective based on the previously calculated gray value. Here, contrast is strengthened or reduced in function of elevation.

2.3 Aspect based shading

Especially in mountainous areas, comparisons of analytical and manually shaded reliefs show that the calculated versions often contain undesired details, whereas the manual shadings accentuate vertical transition. Smooth vertical transition is used in manual hill shading to emphasise aerial perspective and to structure the topography. If the slope information is ignored and shading is based on aspect only, this manual style can be simulated. Aspect based shading is calculated according to a modified cosine shading equation (Moellering and Kimerling 1990).

Since aspect is undefined in flat areas, a bright grey tone has to cover these regions. This grey tone can be mixed with the aspect based shading in function of slope, using a mathematical function or an interactive control panel.

Figure 2 shows an aspect based shading, where perfectly flat regions are identified by the program and provided with a standard grey tone. In nearly flat, but slightly undulating areas, aspect

based shading produces almost random values. In figure 3, this shortcoming is remedied by a bright grey tone covering the planes.



Figure 2: Aspect based shading



Figure 3: Aspect based shading with a tone for flat areas

Relief shadings calculated from aspect and combined with a tone for flat areas can be improved further. A comparison of figure 1 and 3 shows that uneven lowlands in the upper left corner of the image are more accurately depicted by Lambertian shading than by aspect based shading. Lambert shading is more appropriate for flat areas, whereas aspect based shading is better for mountainous areas. These two kinds of shadings can be mixed in function of slope of the terrain.

2.4 Aerial perspective

To simulate aerial perspective, three components are transformed into a weight for each pixel. The first weight is the relative elevation of the considered point. The second weight is based on the exposition towards the light direction and the third weight is based on the relative position of the considered point within a hillside that is identified using slope lines. These weights correct the previously calculated grey value.

The grey value is first reduced in contrast and then a definable constant value is multiplied by the three weights and added to the grey value. Figure 4 illustrates in comparison to figure 3 the effect achieved with the described algorithm.

2.5 Local adaptations

Many GIS, CAD (Computer-Aided Design) and computer graphics applications offer the possibility to calculate shaded reliefs. Unfortunately, these programs do not respect the rules and guidelines developed for manual relief shading. However, current personal computers offer enough performance for interactive editing at a global level (i.e. for the entire map sheet or for complete series of maps), and at a locally aimed level, allowing the customisation of the shading for a single topographic

element.

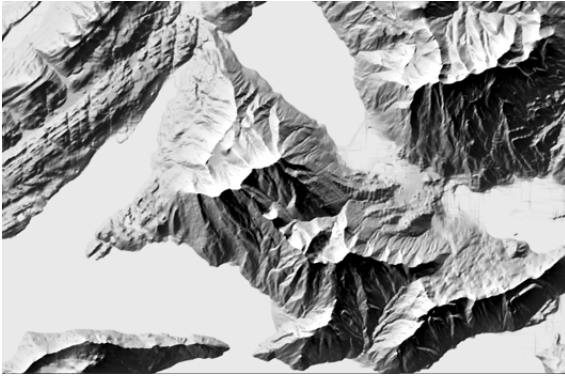


Figure 4: Addition of aerial perspective

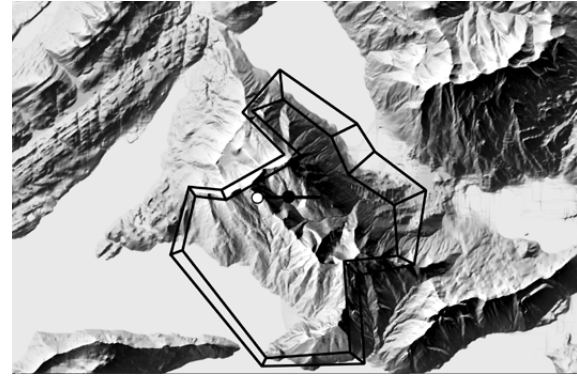


Figure 5: Local adjustment of light direction

For local adaptations, the user has the possibility to enclose sub-areas of the DEM and to provide them with adapted parameters for the calculation of the shaded relief. The following parameters can be adjusted: Light direction, vertical exaggeration, brightness, elevation depended contrast and interpolation between diffuse reflection and aspect based shading.

Figure 5 illustrates the effect of a local adaptation of the light direction. The main light source from north-west is locally replaced by a light source from west. After the user has finished the construction of a polygon, the program automatically constructs a second polygon inside the first one and interpolates the parameters between them.

With the technique of local adaptations, cartographers have to get used to a new workflow for analytical hill shading to further use the knowledge acquired with manual relief shading. As for manual relief shading, modelling starts with large landforms and continuously focuses on smaller details. First, the terrain has to be subdivided into mountainous and flat regions, applying the aspect based algorithm to the first ones and diffuse reflection to the latter ones. In the next step, the user selects the magnitude of aerial perspective for the whole map sheet, followed by changes of light direction and brightness for large landforms. When these steps are completed, flat lowland can be furnished with a light grey tone. Finally, smaller details should be emphasised by adjustments of the light direction and brightness.

2.6 Results

When comparing figures 1 and 3, one can see that the aspect based shading results in clearer images of stronger contrast. Horizontal structures are repressed by emphasising vertical gradients. With the proposed algorithm for aerial perspective, mountain summits can be accentuated and large landforms are emphasised. Aspect based shading and aerial perspective proved to be well suited for mountainous regions, whereas for lowland and flat areas, diffuse reflection should be used. The two techniques can be combined at a global level in function of slope. As can be seen from figures 2 and 3, the addition of a bright tone covering flat areas clears the image and is essential when combining the shaded relief with other cartographic information.

Tests with the prototype have shown, that local adaptations with fences are intuitive to use. With adjustments of light directions and brightness, important landforms can be easily emphasised. Important small details and characteristic structures of the terrain can be accentuated. Cartographers were able to transfer their experience and knowledge acquired in manual shading and to apply them to digital elevation models.

3. Digital cliff drawing

3.1 Why cliff drawing?

Large parts of mountainous areas throughout the world are covered with scree or solid rock. Those areas have an important influence on different aspects of the mountain environment and human presence, like natural hazards or mountaineering. Prevention and human activities in those domains require precise maps. In topographic mountain maps, unfortunately, cliff drawings are among those map elements which are most difficult to be produced. In the Alpine countries, techniques for a clearly designed but nevertheless precise terrain representation were developed already in the 19th century. Mostly, methods derived from slope shading hachures have been used. In Switzerland, already in the Dufour map (1838-1865) such hachures are overlaid by cliffs. When changing to contour line maps, cliff drawing and topography could be consequently disentangled. At the Federal Office of Topography at Wabern/Berne the technique of shaded cliff fill hachures has been developed further, especially after 1935 when the production of the new National Map Series began. Cliff areas are divided into morphologically compact units using structure lines. Structure or shape lines as well as the vertical or horizontal fill hachures are modulated according to an illumination model. Besides this method, a broad variety of alternative techniques exists.

3.2 The ridge line method

At the ICA congress in Ottawa in 1999, the authors presented such an alternative method which is based on a simplification of the shaded cliff fill hachures (Hurni et al. 1999). Only the upper and lower edge lines as well as the vertical ridge lines are being automatically drawn using random functions which help to simulate a natural appearance. This ridge line method has been successfully tested in four different mapping projects. Figure 6 shows an extract of a map of Mt. Rainier/USA using the ridge line representation (see also Beckel et al. 1998).

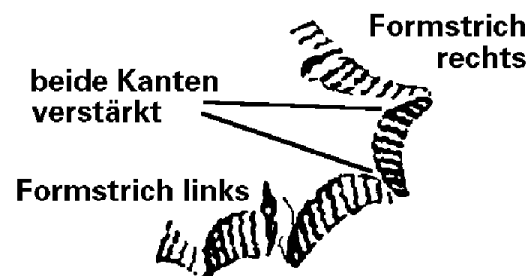
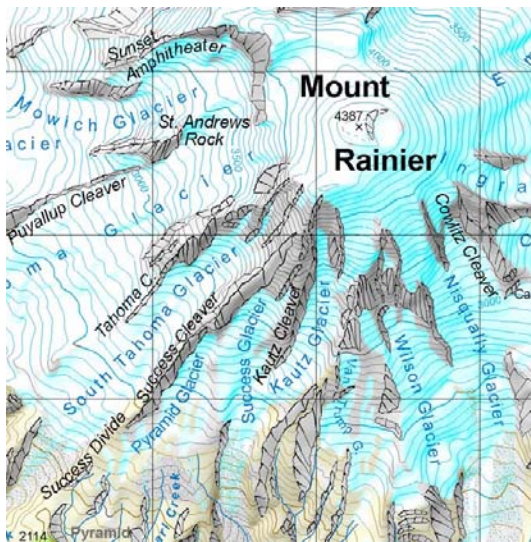


Figure 6: Extract of a map of Mt. Rainier/USA Figure 7: Modulation of shape lines (outlines) using the ridge line representation and filling hachures according to aspect

However, the ridge line method – which has also been used in Eduard Imhof's school atlases – has one major drawback: The depiction is rather difficult to draw because the modulation of the rock faces with their different aspects can only be accomplished by changing the line thickness of the edge lines. The faces of equal aspect usually stay almost empty. Only very talented cartographers are able to design readable and esthetical rock depictions using this method. The digital method still requires a

sound knowledge of relief interpretation in order to digitise the upper and lower edges correctly. Figure 7 shows an extract of the internal guidelines of the Federal Office of Topography covering the modulation of cliff hachures.

3.3 Implementation of fill hachures

Therefore, at the Institute of Cartography of ETH Zurich, the original cliff software has been developed further in order to automatically create cliff hachure fillings similar to those in the Swiss National Map Series (Dahinden, 2000). Instead of relying on edge and ridge lines, continuous cliff faces with equal slope and aspect are covered with regularly placed hachures, either horizontally or vertically. Like in the ridge line representation they must be modulated according to a similar illumination model.

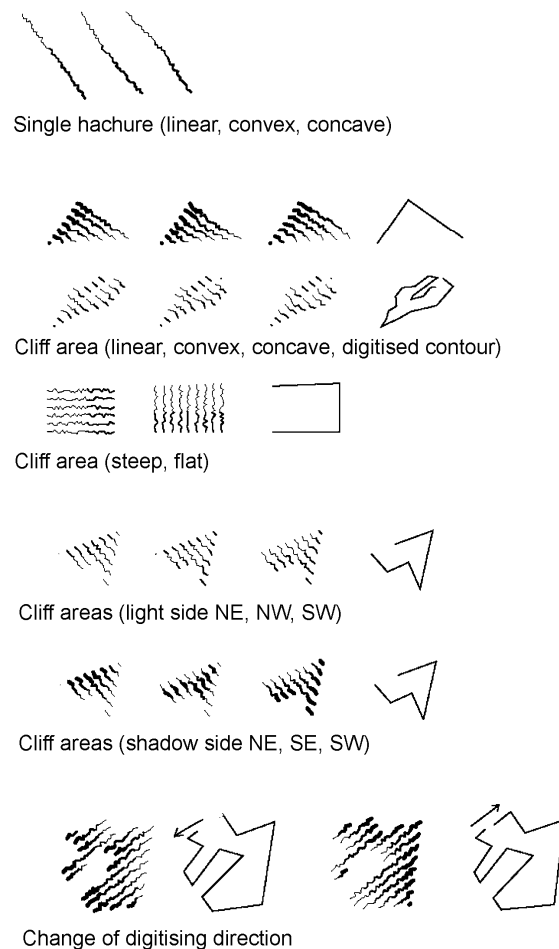


Figure 8: Change of parameters for cliff area fill

Areas of equal slope must be digitised by hand. It is possible to choose between single hachures or areas filled with hachures. The desired direction of hachures (horizontal or vertical) must also be indicated by the cartographer. The program then fills the area with hachures according to the spacing rules defined by the Federal Office of Topography (3-4 hachures/mm). Light modulation and random trembling of the lines are done automatically using the same functions as in the original software for ridge line generation (Hurni et al. 1998). The software again allows to distinguish between small, medium and large objects, between light and shadow sides and between concave and

convex cliff forms. Figure 8 shows the result when changing different parameters of the software.

The final implementation of the software was done in C++. As in the first software, the program has been integrated as a plugin for the graphics software Freehand (Windows version). A user-friendly interface allows an easy handling of the software. Figure 9, 10 and 11 show first results of digital fill hachures compared with an extract of the Swiss National Map series.

4. Conclusion

Analytical shading is less time consuming than traditional manual relief shading. Using the presented local and global techniques, only little time has to be invested to improve the quality of an analytical shaded relief. Further improvements and developments in the field of computer-aided shading for cartography are necessary. Particularly, interactive tools are needed to shape digital elevation models with the goal to locally accentuate geomorphological forms.

As for the digital cliff drawing, the presented results are encouraging as well. The knowledge and the experience of the cartographer is still necessary, but he/she is relieved from painful manual engraving tasks. Further improvements should include the modelling of geomorphological features and structure lines.



Figure 9: Extract of Swiss National Map Figure 10: Cliff drawing using fill hachures



Figure 11: Overlay of original map and new fill hachures

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Keywords

Mountain cartography, map design, relief presentation, analytical shading, aerial perspective, local adaptations, digital cliff drawing