DEVELOPMENT AND QUALITY ASSESSMENT OF ANALYTICAL ROCK DRAWINGS

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Abstract

Rock drawing can be an important part of the map content in large scale topographical maps. Especially for new mapping projects the cartographic design of a new rock plate cannot be achieved anymore due to high costs. The different styles of rock representations are quite manifold. In the presented work, a classification and an assessment of about 60 existing rock representations and their major design components is carried out. According to the frequency of the application of those components, a priority list is set up. By applying existing and newly developed filter operations, it is then tried to calculate the different (high priority) components. For the following assessment of the digital rock representations and their components, numerical criteria are set up. In a survey, manual and analytical rock representations were evaluated by both cartographic experts and laymen on the base of a questionnaire. The results were statistically interpreted.

1. Historic development of rock depiction

The first depiction of rock areas on maps has been introduced in the 18th century. Many maps of this era were drawn using the cavalier perspective (ground plan and perspective of height elements), they were also depicting rocks schematically in that way. In maps based on an orthogonal projection, rock was hachured similarly to the terrain, but with shorter hachure strokes and more morphological details. During the 19th century, the hachure technique has been refined. Furthermore, due to the introduction of lithographic techniques, terrain hachuring was slowly replaced by shading techniques, whereas hachures were still used for rock depiction. The introduction of printed multicolour maps made it even easier to distinguish rock from the surrounding terrain.

Since the early 20th century, photogrammetrically compiled contour lines can be used as a geometrically precise base for rock drawings. Due to the availability of data with higher height and ground precision, several tests were carried out in order to develop an improved representation of rock areas. In the Swiss National Map Series which was introduced in 1938, fill and ridge line hachures make up the main structural elements. The equidistance of contour lines is reduced to 100 m. A variant is the pure ridge line representation without fill hachures. Other tests of the German and Austrian “Alpenverein” used contour lines with an equidistance of 20 m, resulting in an adapted rock hachuring or even in a replacement by locally modulated shading.

Furthermore, so-called “naturally-looking” maps, developed from techniques of artistic map paintings, were developed in the 20th century. Their aim was the depiction of the real world or the “nature” like it is perceived from an airplane or on an aerial image, making the map legend more or less obsolete. Other variants are orthophoto maps or orthophoto-based line maps or even maps overlaid with a rock-resembling texture.

2. Components of rock representations

In a survey carried out for this study, 65 different existing variants of rock depictions could be distinguished. An analysis of these representations showed, that the following structural elements or combinations play an important role for building up a rock depiction:

a) Area elements:
   Orthophotos, homogeneous areas, textures, relief drawings, shadings
b) Line elements:
   Hachures, ridge lines, contour lines

Those elements were found between 1 and 27 times in the 65 different depictions. Based on this, a list of priorities was set up. The elements can be divided in 4 classes of priorities (Table 1)

Priority 1	Continuous contour lines, rock ridges, light modulated hachures
Priority 2	Diverse filling hachures, shading, interrupted contour lines
Priority 3	Fall line and talus hachuring, monotonous and textured homogeneous areas
Priority 4	Hair line hachuring, Talus shading, mixed shading, orthophotos

Table 1: List of priorities: Underlined are the representations which have finally been implemented and tested, double underlined are the most promising and important representations after the testing.

3. Existing algorithms for calculating rock representations or single components

3.1 Algorithms dedicated to rock depiction

Hurni (1995) developed an algorithm to generate a ridge line rock representation. The vertices of the upper and the lower edge of the rock area are used as input for digitisation. They formed the framework for the edge lines and the vertical ridge lines. Hurni (1995) modelled the line weight and the run of the lines by applying an illumination model. Based on Hurni's model, Dahinden (2000) developed an algorithm to generate fill hachures in a predefined area. Patterson (2002) replaced the rock surface with a resembling surface structure by applying various Photoshop functions. For 3D visualisations, a rock representation can be generated by methods of texture mapping and fractal mathematics (Fournier et al. 1982).

3.2 Algorithms originally developed for generating other map elements

There are numerous algorithms for generating map elements which were originally not developed for rock representation. However, they could be used for that purpose because they produce morphological elements which may also be part of rock drawings.

Yoëli (1985) proposes a method to generate terrain hachures after the historic description of J.G. Lehmann and he bases on the five rules Imhof defined in 1965. Kennelly and Kimerling (2000) calculate a kind of terrain hachures with arrows using ArcGIS functions and base also on Lehmann's method. Assuming a tilted illumination, they calculate orientation, length and colour/luminance of the hachures. The size of the arrow tips is proportional to the slope.

Regnauld et al. (2002) developed an algorithm in order to represent slopes in archaeological plans using hachures. As input data they use the upper and lower edge of the slope. The hachure lines are placed in a way that they do not intersect.

For the calculation of relief drawings/shadings, quite a number of software appliations has been developed in the last 40 years. Most algorithms base on the methods of Yoëli (1965) and Brassel (1973) which are further developments of Lambert shaders. Van Dorn (2002) compared several available implementations and preferred the one developed by Jenny (2000) which allows the change of light directions in selected areas.

Contour lines can be calculated with different methods. They mainly base on finding points on the same height (e.g. by interpolating grid points) and the connecting those points.

In order to detect convex ridge and concave valley lines, the largest gradient (flow direction) is being calculated. By following the fall lines, ridge and valley lines can be detected. They can serve as a "skeleton" for the rock drawing.

For perspective 3D-maps there are also hachuring algorithms (e.g. Buchin et al. 2004, Geisthoevel 2003). They base on the "Pen-and-Ink" illustration technique, a pen illustration technique developed in the 19^{th} century. Winkenbach und Salesin (1994) and Sallisbury et al. (1994) automated this technique, also for non topographic applications. As input parameters and templates serve an example hachure line, a grey scale representation of the digital elevation model and a vector field for the orientation of the hachures. All places where hachures have already been and still must be generated are stored in a buffer image. The difference between the buffer and the original grey scale image allows to define the point with the highest priority to calculate the next hachure.

3.3 Computer Graphics Algorithms

In order to generate rock components, also methods of computer graphics can be used, particularly non-photorealistic rendering. There is however an adaptation and validation of those algorithms necessary.

Strothotte und Schlechtweg (2001) present an extension of the Floyd-Steinberg error diffusion, where a grey value is not replaced by a dot, but by a line. This leads to a hachure representation.

Veryovka und Buchanan (1999) propose a modulated screening, which is an extension of the dithering technique where the grey value is replaced by an image cell. The images used could e.g. be hachure lines.

A possible approach to build up the ridge lines could be the use of edge detection algorithms. There are literally countless algorithms of this kind available. For this work, the most common types have been applied and tested:

Convolution filters: Sobel, Roberts, Kirsch, Prewitt, Laplace;
Advanced filters: Laplace of Gaussian, Difference of Gaussian, Non-linear Laplace, Canny, Iverson and Zucker, Bergholm.

4. Data and methodology

4.1 Data and programming environment

The following geometrical models have been at disposal for the testing of the different algorithms:

a) A Raster-DEM of Mt. Matterhorn with a resolution of 3 m, derived from contour lines,
b) an extract of the DTM-AV of swisstopo with a resolution of 2 m, acquired by laser-scanning,
c) the DHM25 swisstopo with a resolution of 25 m,
d) geometrical figures and primitives.

Model a) allows the depiction of a relatively large rock area. Model b) is an example of a laser-scanning model, representing the latest generation of digital terrain models, whereas c) is a “classical” DTM derived from existing topo maps.. The geometrical models d) allow the testing of algorithms in an ideal environment with predictable results.

All algorithms have been implemented in C using the graphics development package “netpbm”, the “gcc” compiler and a Linux and a Macintosh environment for testing.

4.2 Assessment methods

In order to be able to assess the generated rock depictions, several methods have been applied. The calculated components have been judged by the authors based on the geometrical figures. From that, rock representation examples have been derived and they were assessed in a survey among a focus group consisting of cartographic experts and laymen. Furthermore, for every component and depiction variant, a series of numerical characteristics have been determined: Resemblance to an analytical shading, quality of edge lines, average local contrast, invariance regarding the rotation of model, effect of disturbing influences, amount of used ink (=overall brightness), classification of hachure sizes, classification regarding the existence of a (uniform) rock tint, classification regarding the amount of contour lines.

5. Results

5.1 Calculation of rock components

Investigated methods

In order to generate the rock depictions, we experimented with the algorithms mentioned above and some basic algorithms from image processing. Numerous new methods resulted from the combination of those algorithms.

Using screening techniques we tried to generate a kind of hachuring. The technique has been further developed in a way that the single textures were not only chosen according to an input grey value but based on the area normal at the specific point. The textures used consisted of tiles depicting hachures pointing in the direction of the gradient. The result is a rather chunky, knitwear-like image, which also revealed the difficulty of the choice of an appropriate texture.

Another possibility to generate a hachure is again based on the allocation of a colour of a texture on every single input (DTM) pixel. The defining textures are again turned in the direction of the gradient. However, in order to get a result where the texture and the terrain are well perceivable, the resolution of the DTM had to be reduced. For middle to low resolution terrain models, the method is suitable. (Fig. 1)

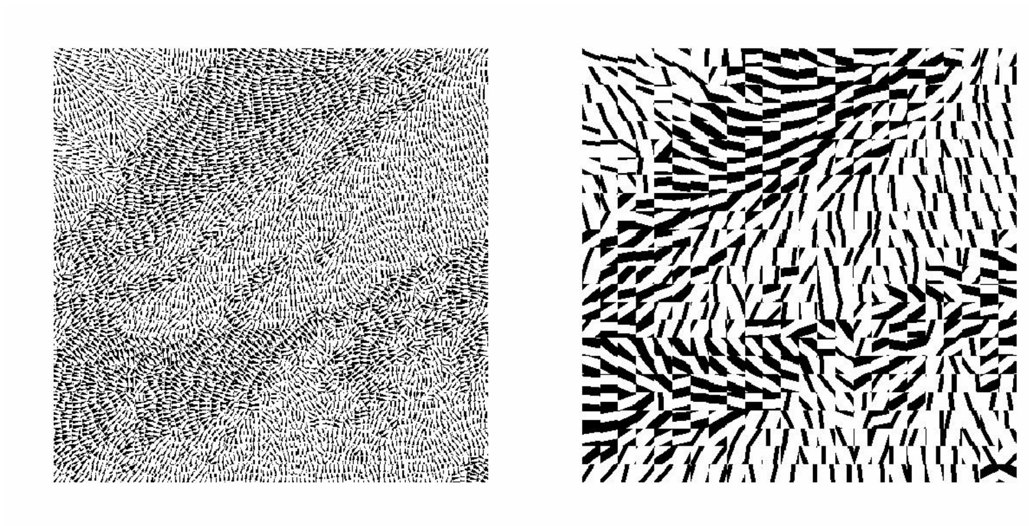

Figure 1: Normal based, pixel-wise texture assignment for the DTM-AV. Left: Triangles, width 5 pixels, scaling factor 10. Right: Rectangles, width 10 pixels, scaling factor 20.

A further method is following the pen-and-ink-technique. A not necessarily rectangular texture is placed on a point in dependence of the gradient direction. In a buffer image, the points which are hidden by the texture are stored. Furthermore an area around the texture centre is defined as hidden. Another texture is only placed if it is not in that area in order to avoid an overlap of the textures. The defining texture can be chosen according to the area normal (slope) and the direction of light. (Fig. 2)

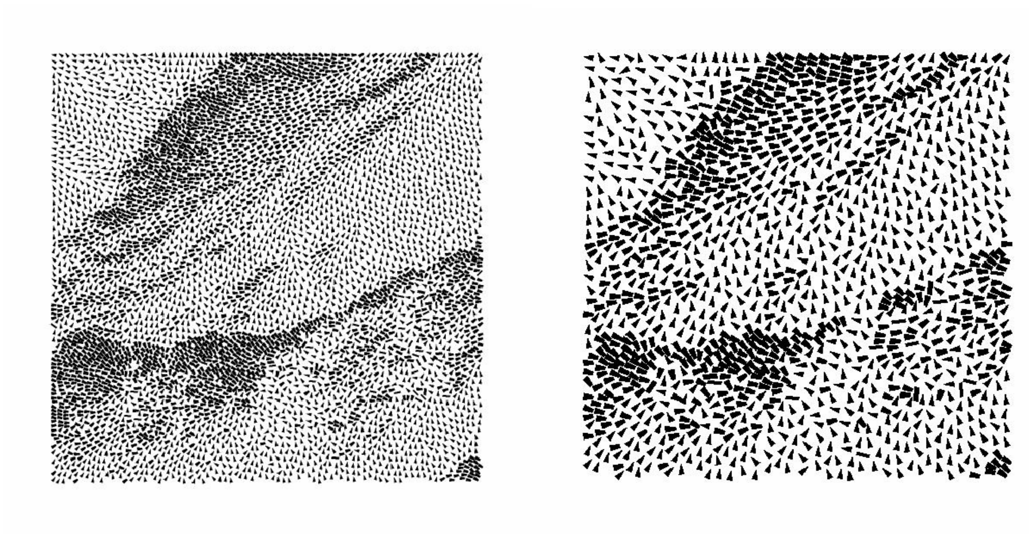

Figure 2: Buffered, normal based textures, applied on the DTM-AV. Left: 2 pixel distance, scaled, size 4x8 pixel. Right: 1 pixel distance, size 8x16 pixel.

The Floyd-Steinberg error diffusion method has been modified in a way that the direction of the lines is drawn according to the area normal. This results in a fur-like representation of the surface. However the short single lines can also form unwanted long lines due to overlap effects. (Fig. 3)

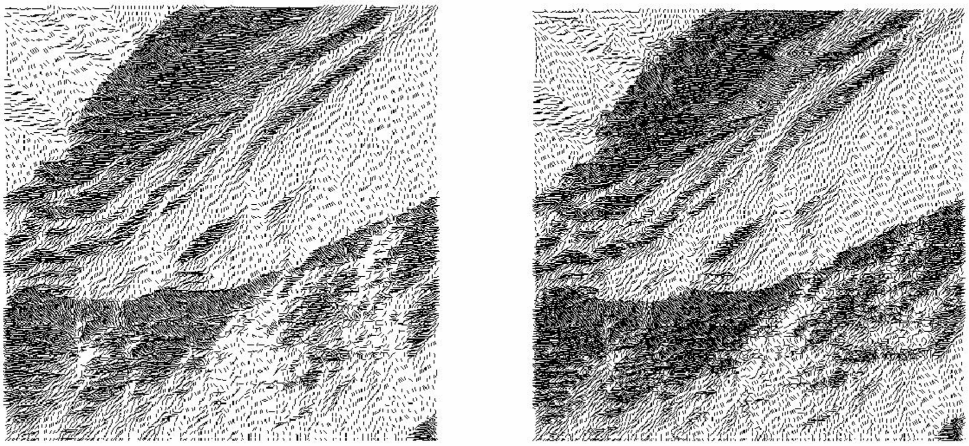

Figure 3: Floyd-Steinberg error diffusion taking the area normal into account. Apllication of direction dependent hachure length. Left: Average length 7 pixel. Right: 7 pixel plus “turbulence”.

Some tests were also done using shading methods. The traditional Lambert shading of the terrain proved to be sufficient for a cartographic representation.

On the other hand, none of the tested edged detection methods was entirely convincing. Either pieces of edges are missing, or edges are detected where no edges should be. Furthermore, the properties of the terrain model and possible interpolation artefacts seem to play an important role, so that the edge detection method has to be chosen according to the “deficits” of the terrain model!

A Terrain, modelled by a DTM, can be hachured in the direction of the falling lines. If this is done for every point of the raster, a very fine, almost uniform hachuring is generated. However, ridge and valley lines can be seen. In order to detect them a smoothing filter for the hachured areas and in a second step, an edge detection filter is applied.

For calculating the contour lines, a method related to the one proposed by Saito und Takahashi (1990) is applied. In the grid model, the height values in between two contour lines are rounded down to the lower value. Then the edges are detected, leading directly to a clear contour image.

Comparison with the requirements on the priority list

With the mentioned methods, numerous components of rock representations can be generated automatically. A visual comparison of the calculated with the manually drawn components clearly shows that the latter cannot be re-created in a sufficient way. Especially for the creation of ridge lines, no significant progress could be made. However, rather good results were obtained with filling hachures. The list of priorities could only be marginally reduced (Table 1, double underlined features).

5.2 Assessment of the rock representations

Focus group and evaluation

Out of the collection of components, 12 different rock representations have been generated, which (hopefully) should fulfil cartographic expectations (Fig. 4). Together with a series of traditionally produced maps, these 12 examples have been shown to a group of cartography students. The students discussed the examples in 3 groups during 10 minutes. Following that, the examples were discussed in the plenum. Based on this discussion, it was tried to find out the main factors which influence the perception and the overall quality of arock representation.

- Is the overall structure of the rock terrain visible? (up, down, steep areas)
- Is the detailed structure visible? (breaks, edges, trenches, degree of slope)
- Is the density of information sufficient, are the structures clearly visible?
- Is the image smooth enough, without disturbing noise?
- Are parts of the image too bright, dark, flat (not sufficient contrast)?
- Is the difference to other signatures (especially scree) perceivable?

Based on these findings, a digital query sheet for the assessment of 12 digital and 15 analogous rock representations was created. In the survey, the examples were shown and for each the same four questions were asked:

- Rough/overall orientation: Is the shape of the whole terrain perceivable; e.g. steep/flat areas, uphill/downhill?
- Fine orientation: Are rocky bands, edges, ridges, trenches, chimneys, blocks and summits visible?
- Similarity: Is the type of the terrain (rock) perceivable?
- Would you use this kind of rock representations in topographic maps?

For each question, a maximum of 5 points could be assigned. The questionnaire was published on the Internet during 6 weeks and a total of 81 persons filled it out. Among those 32 persons, according to their own declaration, had no experience in cartography nor do they use maps with rock representations.

It could be seen clearly that the traditional examples were regularly judged higher than the calculated ones. Answers from persons with cartographic and alpinistic experience were significantly different from the remaining group. Unfortunately some strong correlations between the answers could be observed.

Factors of assessment

For each rock representation, the different assessment factors (see 4.2) have been recorded numerically. The similarity to analytical shadings could only be detected for the analytically calculated examples. The other factors could also be determined for the traditionally produced examples. These factors alone do not prove the suitability of a rock representation. Only concerning the ink value there is a hypothesis by Tufte (1983) which says, that from two representations with the same information content the one with less ink should be preferred. Furthermore, a comparison of the edge images with the edge quality measure showed the impracticality.

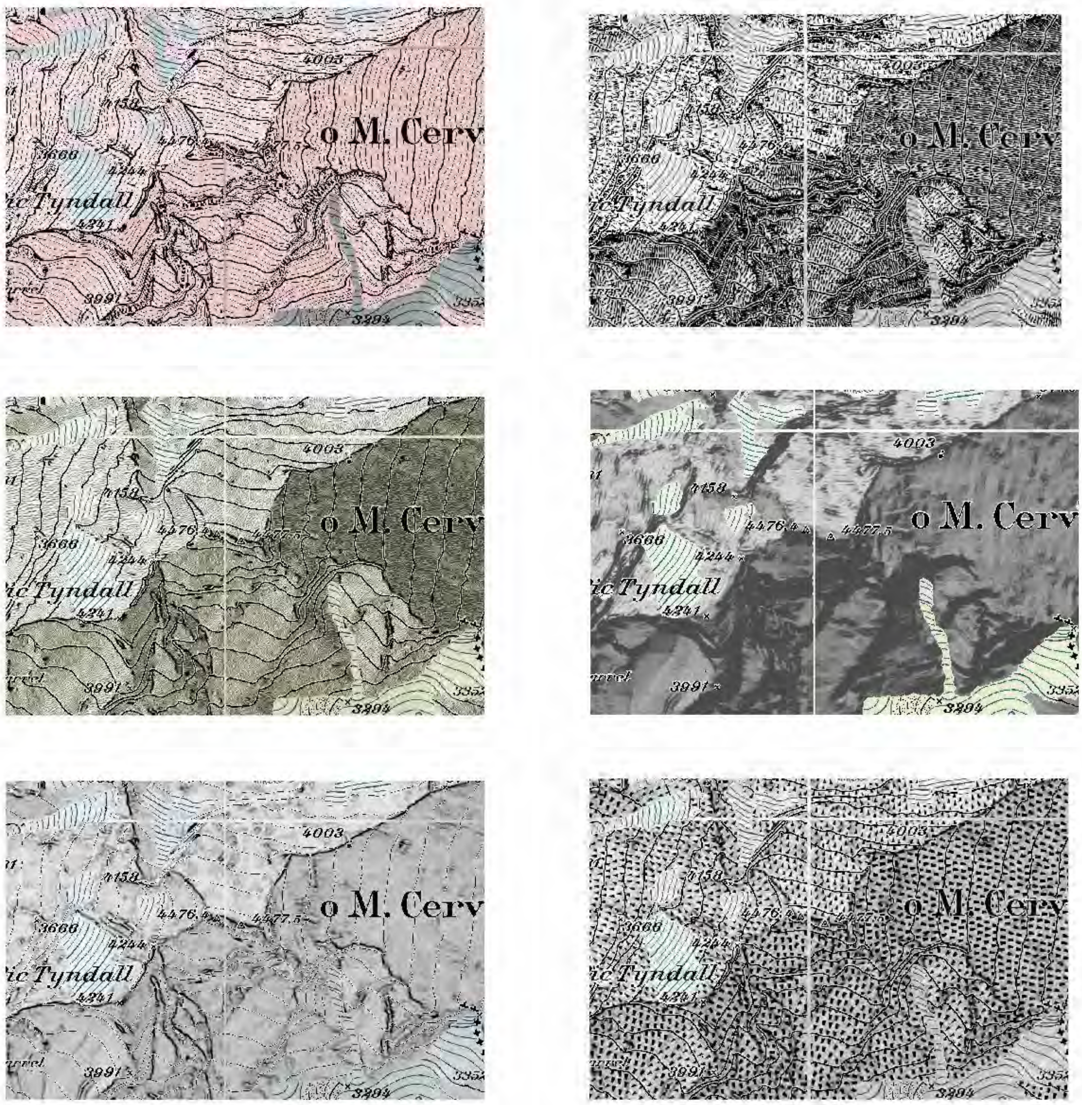

Figure 4: 6 examples of automatically generated rock drawings.

Comparison of assessment factors with the results of the evaluation

Several correlation tests between the assessment factors and the survey results have been carried out, leading to the following findings:

- No correlation between the similarity of a rock representation with an analytical shading and the quality of the rock representation could be found.
- The higher the average local contrast, the better the rock drawing is judged.
- The higher the amount of ink, the better the rock drawing is judged. Assuming the same information content for all rock depictions, this is contradicting Tufte's hypothesis.
- The less contour lines in the image, the better the rock drawing is judged.
- A rock representation with hachures is not generally preferred to ridge lines or rock tints.
- A rock representation with shading should be preferred to a drawing without tint.

With the different assessment factors, also multilinear models can be built up. If one extracts those models with the largest information value using Akaike's information criterium (Akaike 1973), one can see that out of the surveyed factors the "average local contrast" and the "fine granularity of the hachure" play an important role. A smaller influence can be observed with the "density of the contour lines".

6. Conclusions

An exact imitation of traditionally drawn rock depictions is only possible in exceptional cases. However, some flexible methods for the generation of elements of rock drawings could be developed. We could find some measures and rules which allow a prediction whether a rock depiction is more or less suited. However those measures do not comprise all factors which are finally playing an important role for the quality of a rock depiction.

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