Automatic Rock Depiction via Relief Shading

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Abstract. An automatic method for cartographic rock depiction on elevation grids is presented. The grid is generalized using line integral convolution, aggregating faces and enhancing edges. The generalized grid is hillshaded by applying a novel approach based on Poisson editing. The shaded relief is used in texturing the terrain with rock hachures.

Keywords: Terrain Generalization, Relief Shading, Rock Drawing

1 Introduction

Automated cartographic rock depiction is desirable due to the lack of experts in manually produced designs and for the saving of production costs. We present a method for a fully automatic derivation of renderings inspired by Swiss style rock hachuring [Jenny et al., 2014]. By *fully automatic* we mean, that along with the elevation data the user is only expected to provide global parameters like major lighting direction or output map scale, i.e. different users providing the same input will get identical results.

The basic input consists of gridded elevation data and a mask indicating rock areas. The output is an image consisting of monochrome hachures. Additionally, a shaded relief together with an elevation model that is both smoothed and skeleton line-enhanced is created.

In order to solve the problem of generating strokes having the properties of rock hachures, we start out by creating a shaded relief of a generalized terrain model. We argue that shaded relief serves well as a basis for rock hachures since both are instances of a terrain visualization scheme induced by the same lighting model [Gilgen, 1998], but with shaded relief having a more elementary structure, i.e. one grayvalue per pixel in contrast to meandering lines of variable width and distance. Once the shaded relief is created, the rock mask together with skeleton lines are used to fill the rock areas with rock hachures, in accordance to the grayvalues of the shading.

2 Terrain abstraction

Line integral convolution (LIC) was used by [Cabral and Leedom, 1993] as a method for visualizing vector fields and blurring images along streamlines. We use it to generalize elevation grids so that faces are smoothed and skeletal edges are emphasized. For a particular grid G, its gradient $V = (Gx, Gy)$ serves as a suitable vector field. Other vector fields are also useful, e.g. hydrologic flow fields ([Tarboton et al., 1991], [Freeman, 1991], [Fairfield and Leymarie, 1991], [Tarboton, 1997]), resulting in alternative generalizations. Given an elevation grid, a vector field, and an integration length L, each cell z' in the output grid is a mean of the original elevation value z and values sampled by going L steps forward and backward, respectively, along the vector field: $z' = (z + \sum_{ij \in V_+} z_{ij} + \sum_{ij \in V_-} z_{ij})/(2L+1)$ [1]. The parameter L determines the amount of smoothing. See *Figure* 1 for an example of a LIC-smoothed grid.

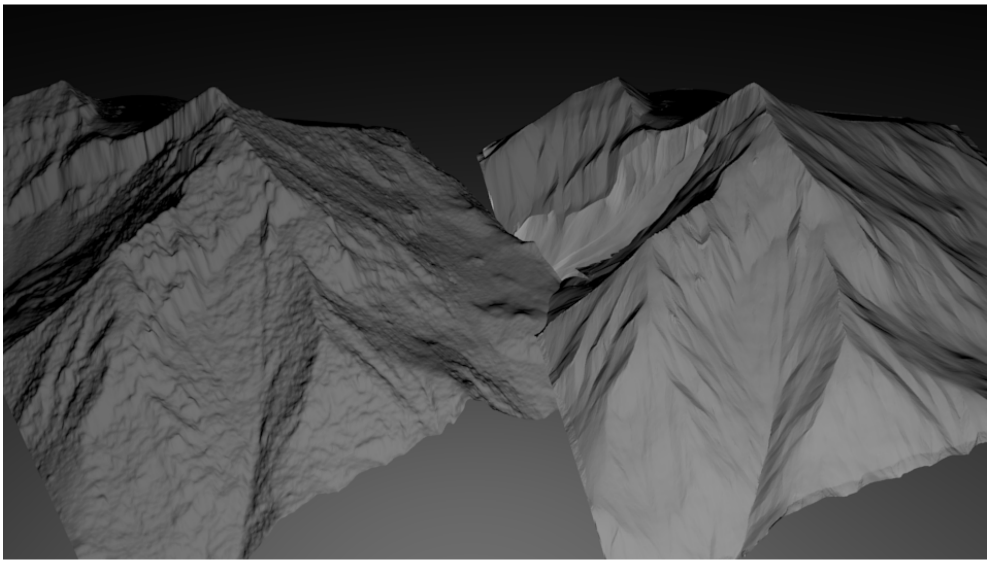

Figure 1: Rendering of an elevation grid (left) and grid smoothed by line integral convolution (right).

[1]This equation disregards values at the grid boundaries, where there are fewer than L samples available.

3 Relief shading

Looking at a *Lambertian* shaded [Horn, 1981] grid [2], one can identify numerous reasons why such a rendering is unsuitable for cartographic purposes [Imhof, 2007].

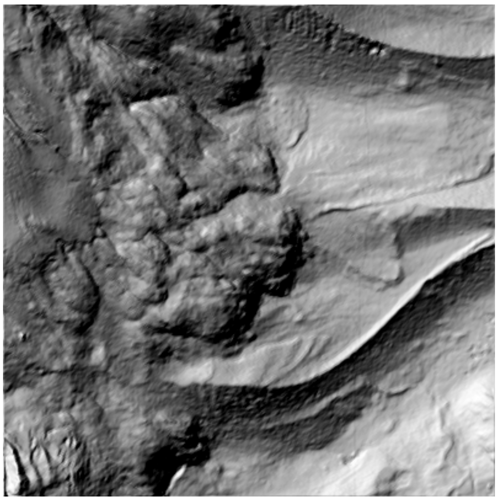

Figure 2: Lambertian shading, light from northwest at an altitude of 45 degrees.

There is both too much detail in an ungeneralized topography, and too little detail regarding dark patches where there are steep cliffs turned away from the lighting direction as well as insufficient contrast along ridges and ravines parallel to the main lighting direction.

The former shortcoming is independent of the shading method, of course, and is regarded in this work as being amended by LIC-smoothing the grid as described above.

Acknowledging the general value of Lambertian shading in depicting terrain topography, however, we would like to overcome the problem of lacking local detail due to the relation of aspect and slope to the main lighting direction. In manual shading, the problem is solved by locally brightening or darkening adjacent faces across topographically important ridges or ravines as if the light source had been rotated, to produce higher contrast, and thus more detail.

In our approach, we start out from a Lambertian hillshading of a LIC-smoothed elevation model, and locally enhance contrast using *Poisson* im-

[2] As produced by such tools as `gdaldem` (www.gdal.org).

age processing ([Pérez et al., 2003], [McCann and Pollard, 2008]). This technique works by manipulating gradients of images rather than the images themselves and solving a Poisson equation to produce the desired result. Specifically, we solve $\Delta y(i,j) = \Delta x(i,j)$ for y, where Δ denotes the Laplacian of a function. The function x is set to be $max(|\nabla h|, |\nabla H|)$, where ∇ denotes the gradient of a function, h is the Lambertian hillshading, and H is a shading with a lighting direction perpendicular to the main lighting direction, ensuring large gradients across edges where the original shading lacks contrast. H does not need to be a Lambertian shading, since we are only interested in the gradient of H; instead, we use $(G_i \cos(\alpha + \frac{\pi}{2}) + G_j \sin(\alpha + \frac{\pi}{2}))$, where (G_i, G_j) is the normalized gradient of the elevation grid, and α denotes the azimuthal angle of the main lighting direction. Adding the angle $\frac{\pi}{2}$ introduces a bias, of course, by favoring a light source to the left of the main direction. Combining the shading with another image whera $alpha$ is rotated by $-\frac{\pi}{2}$ leads to mutual nullification of gradients, resulting in reduced contrast.

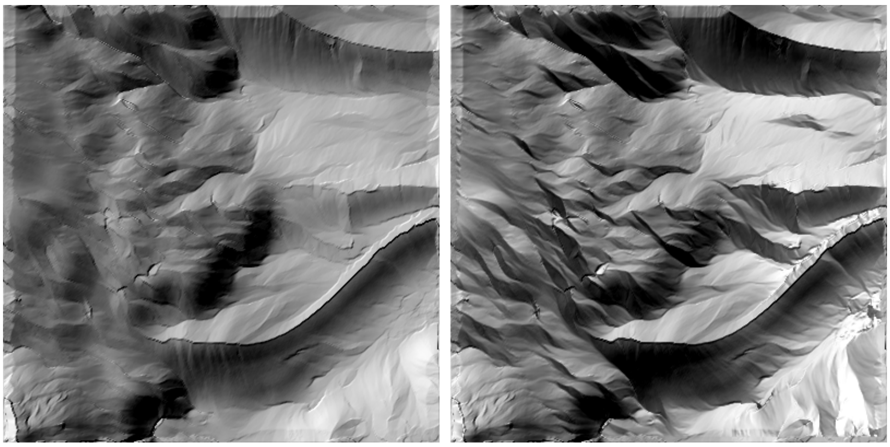

Figure 3: Lambertian-shaded smoothed grid (left), with Poisson-blending on the right.

Finally, the result is Poisson-blended with the mean curvature (scaled by -1) of the elevation grid. This texture adds detailed relief structure to faces especially in dark regions blotted out due to low light incidence, i.e. steep faces turned away from the main lighting direction. For an example, see *Figure* 4.

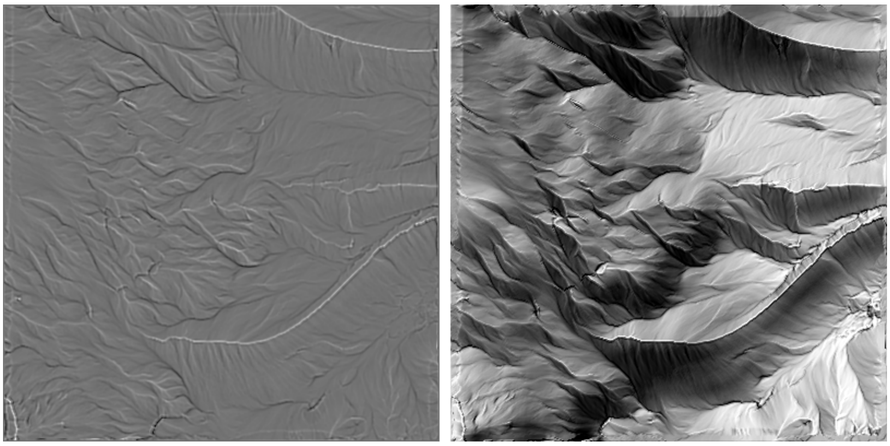

Figure 4: Left: Mean curvature. Right: Shading on right of *Figure* 3 Poisson-blended with mean curvature.

4 Rock hachuring

Swiss style rock depictions consist of monochrome hachures, see the Swiss National Map [geo, 2015] for examples. We draw hachures at regular intervals using the method of [Jobard and Lefer, 1997]. That is, along the gradient rotated by $\pm\frac{\pi}{2}$ we start drawing a line somewhere within a rock area and derive a seed point for an adjacent line by offsetting a vertex in the direction of the vertex normal. Hachure lines stop at edges extracted by a Canny detector [Canny, 1986] from the shaded relief. For each line, we displace its vertices by a sine wave with gaussian noise to produce the irregular, wiggly appearance of rock hachures. Line width is defined at each vertex according to the grayvalue in the relief shading at that position. We add the extracted edges as skeletal lines to the rendering. To enhance edge contrast, we erase the hachures touching skeletal lines on the 'light side' by translating skeletal lines for some pixels in the direction of the gradient of the relief shading. This results in *mach banding* [Hertzmann and Zorin, 2000] between skeletal lines and the background grayvalue, in effect raising the contrast percepted at these lines.

The final image is a combination of mach banded contour lines stamped out by a mask indicating which pixels classify as rock, as well as overlaid skeletal lines.

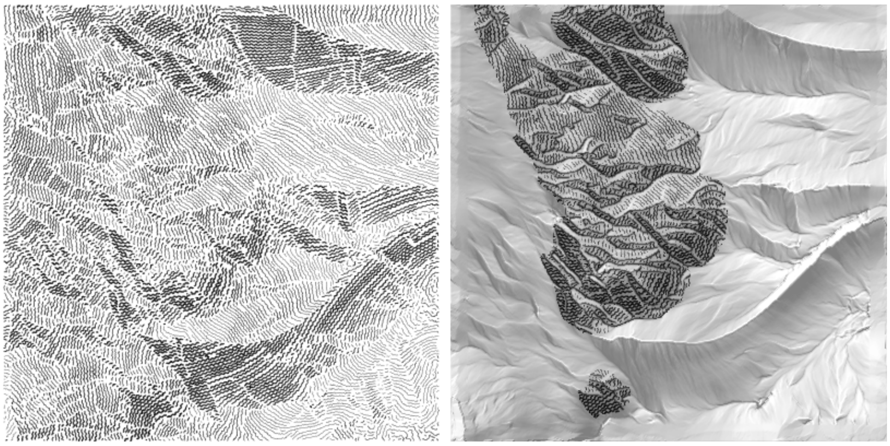

Figure 5: Left: Rock hachures. Right: Stamped out mach banded hachures with skeletal lines and relief.

5 Conclusion

We presented a method for automatic hachuring of rock faces. The intermediate products, the LIC-smoothed grid and the shaded relief, are useful in their own right. For example, the 3d model generated from the smoothed grid in *Figure* 1 contains much less triangles than the model of the original grid, useful when memory or bandwidth is a scarce resource, e.g. in streaming geometry web services or level-of-detail algorithms. The shaded relief could serve as a vantage point for deriving other lighting based cartographic signatures such as *scree*. Concerning the rock hachures, several important ingredients of Swiss mode hachures have not been considered, like vertical hachures for steep cliffs, or broad framing strokes of rock formations (*form hachures*). The shaded relief algorithm is still lacking a general purpose scheme for incorporating multiple light sources.

6 Appendix

This work is accompanied by a stand-alone Python package available at [mot, 2015], useful for trying out the methods described above.

References

[geo, 2015] (2015). Webpage map.geo.admin.ch. `https://map.geo.admin.ch`. Accessed: April, 2015.

[mot, 2015] (2015). Webpage motlimot.net. `http://motlimot.net`.

[Cabral and Leedom, 1993] Cabral, B. and Leedom, L. C. (1993). Imaging vector fields using line integral convolution. In *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*, pages 263–270. ACM.

[Canny, 1986] Canny, J. (1986). A computational approach to edge detection. *IEEE Trans. Pattern Anal. Mach. Intell.*, 8(6):679–698.

[Fairfield and Leymarie, 1991] Fairfield, J. and Leymarie, P. (1991). Drainage networks from grid digital elevation models. *Water Resources Research*, 27(5):709–717.

[Freeman, 1991] Freeman, T. (1991). Calculating catchment area with divergent flow based on a regular grid. *Computers & Geosciences*, 17(3):413–422.

[Gilgen, 1998] Gilgen, J. (1998). Felsdarstellung in den Landeskarten der Schweiz. In *Hochgebirgskartographie – Silvretta '98, High Mountain Cartography*, number 11, pages 11–21.

[Hertzmann and Zorin, 2000] Hertzmann, A. and Zorin, D. (2000). Illustrating smooth surfaces. In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques*, pages 517–526. ACM Press/Addison-Wesley Publishing Co.

[Horn, 1981] Horn, B. (1981). Hill shading and the reflectance map. *Proceedings of the IEEE*, 69(1):14–47.

[Imhof, 2007] Imhof, E. (2007). *Cartographic Relief Presentation*. ESRI Press.

[Jenny et al., 2014] Jenny, B., Gilgen, J., Geisthövel, R., Marston, B. E., and Hurni, L. (2014). Design principles for swiss-style rock drawing. *The Cartographic Journal*, 51(4):360–371.

[Jobard and Lefer, 1997] Jobard, B. and Lefer, W. (1997). Creating Evenly-Spaced Streamlines of Arbitrary Density. In *Visualization in Scientific Computing'97*. Springer Vienna.

[McCann and Pollard, 2008] McCann, J. and Pollard, N. S. (2008). Real-time gradient-domain painting. In *ACM Transactions on Graphics (TOG)*, volume 27, page 93. ACM.

[Pérez et al., 2003] Pérez, P., Gangnet, M., and Blake, A. (2003). Poisson image editing. In *ACM Transactions on Graphics (TOG)*, volume 22, pages 313–318. ACM.

[Tarboton, 1997] Tarboton, D. G. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research*, 33(2):309–319.

[Tarboton et al., 1991] Tarboton, D. G., Bras, R. L., and Rodriguez-Iturbe, I. (1991). On the extraction of channel networks from digital elevation data. *Hydrological Processes*, 5(1):81–100.