INTERNATIONAL PUBLICATIONS ON CARTOGRAPHY

CARTOGRAPHICA

Special Issue: ICA Commission on Mountain Cartography
Edited by Lorenz Hurni, Karel Kriz, Tom Patterson, and Roger Wheate

Endorsed by the
INTERNATIONAL CARTOGRAPHIC ASSOCIATION / ASSOCIATION CARTOGRAPHIQUE INTERNATIONALE
and endorsed as the journal of the
CANADIAN CARTOGRAPHIC ASSOCIATION / ASSOCIATION CANADIENNE DE CARTOGRAPHIE
and supported by grants provided by the
SOCIAL SCIENCES AND HUMANITIES RESEARCH COUNCIL

EDITOR 1965–1994 AND FOUNDER, BERNARD V GUTSELL

Editor: Brian Klinkenberg
UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, BRITISH COLUMBIA

ISSN 0317-7173
Printed in Canada

An Interactive Approach to Analytical Relief Shading

BERNHARD JENNY

Institute of Cartography / Swiss Federal Institute of Technology (ETH) / ETH Hönggerberg / CH-8093 Zurich / Switzerland

Abstract

The software currently available for analytical relief shading does not generally permit local adaptations of the light direction, the simulation of aerial perspective, and other necessary techniques developed for manual relief shading. To remedy this deficiency, a program for computer-assisted relief shading has been developed that allows users to locally adapt shading characteristics, permitting seamless interactive control over the entire process. The grey values of the image are determined by a combination of aspect-based shading for steep regions, diffuse reflection for lowlands, and a bright grey tone for flat areas. Furthermore, an algorithm for the simulation of aerial perspective is presented. Tests with the program have shown that, with minimal investment of time, the quality of analytically produced shaded relief can be improved significantly. Using the proposed techniques and software presented herein, experienced cartographers can transfer their manual relief-shading knowledge and experience to the digital realm.

Introduction

Relief shading is used in cartography to depict topography. Historically, it was produced by traditional manual methods based mainly on the interpretation of contour lines and hydrographic networks, and, more recently, by computer calculations based on digital elevation models. Different attempts with analytical relief shading have been undertaken, and the associated algorithms have been improved. If digital elevation models are available, analytical shaded relief can be produced much more quickly and thus less expensively than with manual relief shading. Unfortunately, the currently available computer programs largely ignore the specialized rules and guidelines that have been developed for manual relief shading. Among mountain cartographers, the legibility and aesthetic quality of a well-executed hand-shaded relief is generally considered to be superior to that of a computer-generated relief, and therefore it is preferred for demanding applications. To overcome the limitations associated with digital relief, a prototype program for computer-aided relief shading was developed. The goal was to simulate the techniques used for manual relief shading with an interactive digital approach. The program enables the cartographer to locally adapt relief shading to enhance topographic features that defy clear depiction, and it uses a new method to simulate aerial perspective. To determine the grey values of the shaded relief, diffuse reflection is combined with aspect-based shading and a tone for flat areas. A series of tests in collaboration with the Swiss Federal Office of Topography demonstrated that, with a small amount of invested time, the overall quality of analytical relief shading can be improved significantly, approaching the standard of well-executed manual shading.

This paper provides a detailed description of interactive analytical relief shading. A more conceptual presentation can be found in Hurni and others (2001). To illustrate the discussed methods, a series of figures show the sequential improvement of relief shading generated from a digital elevation model of Mount Rigi (including three surrounding lakes) near Lucerne, Switzerland.

Manual Relief Shading

The manual depiction of terrain according to a specific illumination model (northwest lighting) is a time-consuming task. Topography is not generally represented in a mathematically correct form. Instead, the shaded relief is slightly altered to make it more intuitive for readers. This goal is achieved by applying the following techniques (Imhof 1982): adjustments of the light source; placement of bright grey tones in flat areas; adjustments of brightness; aerial perspective; and the use of colour.

In traditional relief shading, a fictional light direction is chosen, usually from the northwest, to globally illuminate the relief. In addition, highly skilled cartographers will turn the main light direction slightly in order to emphasize and clarify selected topographic features, such as ridges, valleys, and watersheds.

Bernhard Jenny, Institute of Cartography, Swiss Federal Institute of Technology (ETH), ETH Hönggerberg CH-8093 Zurich, Switzerland. Tel.: ++411 633 30 36. E-mail: jenny@karto.baug.ethz.ch

Figure 1. Manual relief shading.

Flat areas on the landscape are often densely populated by humans. Hence, topographic maps also tend to show a high density of information in these areas. To avoid overburdening the overall graphical appearance of the map, a tint is applied to flat areas on the shaded relief, which is brighter than the mathematically correct value. This bright grey tone is needed to build a relationship between opposing illuminated and shadowed hillsides that are separated by flat lowland.

Aerial perspective is a phenomenon observable in nature, due to haze and other particles in the atmosphere. These particles place a grey-blue veil over the landscape, increasing in density with the distance from the observer. On maps, cartographers use aerial perspective as a graphical device to differentiate between high mountain summits and lower, more distant lowlands. When applied, contrast gradually sharpens towards the highest peaks and softens towards the lowlands.

Shadows observed in nature vary from grey to bluish tones, according to weather conditions and the distance of topography from the observer. Imhof (1982) therefore suggests that grey-blue or blue-violet-grey colours be used for coloured shaded relief.

Cast shadows, reflected light, and glittering highlights are omitted in order to simplify the reading of the map. Although these phenomena can be observed in nature, they may lead to wrong interpretations of the final cartographic product.

Experienced cartographers can achieve appealing descriptive images by employing the rules outlined above. Figure 1 shows an example of a hand-shaded relief from the 1:50,000-scale Swiss National Map series.

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 cartography. Shaded relief consists of grey values, stored as raster images. An algorithm taking into account the DEM and a virtual light source determines these grey values. Yoëli (1959, 1965, 1966, 1967a) was the first to produce analytical relief shading using a DEM and diffuse reflection (Figure 2). With this method, the grey value is proportional to the cosine of the angle between the surface normal and the light vector (Foley and others 1990).

Various authors have produced cartographic relief shadings with illumination models developed for computer graphics, such as Phong illumination (Bui-Tuong, 1975), Blinn reflection (Blinn 1977) or ray-tracing (see Foley and others 1990). Shape from shading, a photo-

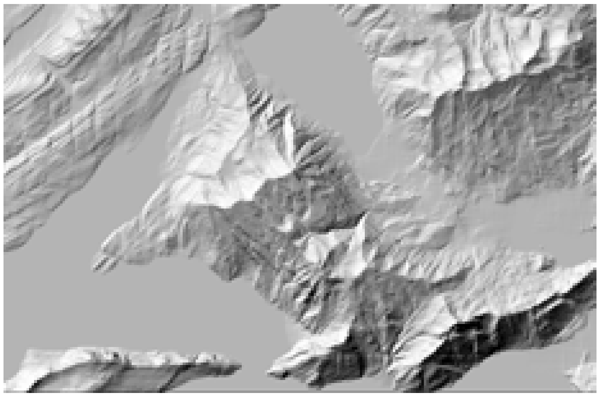

Figure 2. Diffuse reflection.

grammetrical method, has been used by Batson and others (1975) and Horn (1982). Both use the simplest form of the Lommel-Seeliger Law. Horn (1982) also proposes a normalized form of Minnaert's reflectance function (Minnaert 1961) for relief shading.

Böhm (1998, 1999) developed a technique based on raster operators that are applied on a DEM. He derived a series of grey-tone images and combined them using logical and mathematical operators. Gradation curves and filters are applied on the different grey-tone images. The appearance of the shaded relief can be controlled by the appropriate combination of different intermediate results. Experience and imagination, however, are required to achieve satisfying results.

Some shading algorithms have been adapted and extended to meet the specific needs of cartography. Yoëli (1967b) conducted the first experiments with local adjustments of the light direction. Brassel (1974) proposed a model based on topographic structure lines to automatically adapt the main light direction. Using his technique, first one has to draw structure lines and assign them a weight according to the importance of the topographical feature that the line represents. Then, for each point on the DEM, a light direction is calculated as a function of its distance from neighbouring structure lines, their direction, and their associated weight. This method is an interesting approach and could be further accelerated by an automatic geomorphological feature extraction of the terrain. However, it has the following intrinsic disadvantage: when editing the structure lines, it is very difficult to anticipate the influence of a single structure line on its neighbouring area. An additional structure line may have the desired positive effect on certain parts of the relief, but it may worsen others. During the 1960s and 1970s when they conducted their pioneering research, Yoëli and Brassel had to struggle with the primitive computer technology of the day. Hence, practical application of their methods was very difficult.

Zhou and Dorrer (1995) presented a method to automatically adjust the light direction. In their method, a wavelet transform of the DEM is first calculated and then subsequently used to adjust the main light direction. Prechtel (2000) developed an alternative technique, identifying clusters of similarly oriented cells. From the clusters, a triangulation is derived that is used for the deflection of the light direction.

Brassel (1974) developed a method to simulate the effect of aerial perspective. When applied, contrast is strengthened or reduced as a function of elevation.

Interactive Analytical Relief Shading

In general, the solutions presented above do not contain the option to interactively control relief-shading calculations in a manner helpful to map makers. Many GIS (geographic information systems), CAD (computer-aided design), and computer graphics software applications offer the ability to generate shaded relief. Unfortunately, these programs do not respect the rules and guidelines developed for manual relief shading. Today's personal computers offer enough performance for interactive editing at a global level (that is, for an entire map sheet or for a series of maps), while simultaneously allowing customized shading for a single topographic element. For software to achieve acceptable responsiveness on these systems, programmers must implement time-effective algorithms and eschew lengthy calculations. For example, when deriving grey values, simple local reflection models (for example, diffuse reflection) should be used instead of global ones, such as ray-tracing or radiosity (Foley and others 1990). Local reflection models consider only the interaction between an object and a light source, whereas global reflection models take into account how light interacts between objects, including reflection, transmittance, or refraction.

Experiments with the prototype software have shown that abandoning global reflection models is not a shortcoming. In fact, local adjustment of illumination yields much more effective shading than strict adherence to global illumination models.

To successfully apply the conventions and rules developed for manual relief shading, computer programs should simulate working procedures of experienced cartographers. The minimal set of functionalities required by such a user-friendly software application includes: adjustment of the light direction; the option to adjust brightness and contrast; the application of a constant tone to flat areas; and simulation of aerial perspective. These functions must be applicable at a global level and to smaller sub-areas on the map sheet. Contour lines, drainages, and other geo-referenced structure lines, which serve as guidelines for both manual and computer-assisted relief shading, must be available in a computer program as a temporary overlay.

ASPECT-BASED SHADING

Especially in mountainous areas, comparisons of analytically and manually shaded relief show that the analytical

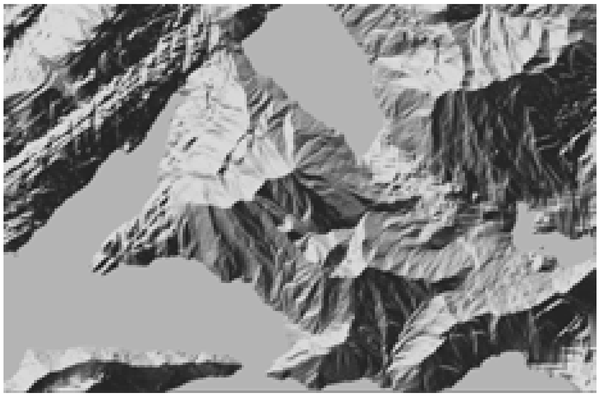

Figure 3. Aspect-based shading.

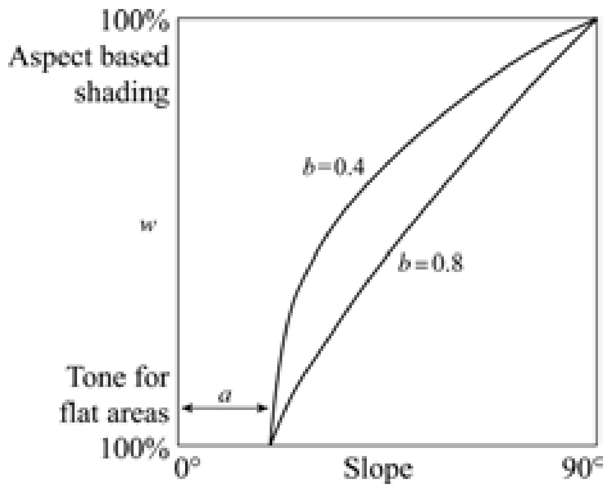

Figure 4. Weight for aspect-based shading and tone for flat areas.

relief often contains undesirable detail. By comparison, manual relief better accentuates vertical transitions (compare Figures 1 and 2). This preferred manual style can be simulated in analytical computations by ignoring slope information and basing the shading on aspect only. Aspect-based shading is calculated according to a modified cosine shading equation (Moellering and Kimerling 1990):

$$g_{asp} = \frac{cos(\alpha) + 1}{2} \qquad (1)$$

where

g_{asp} Grey value derived from aspect [0..1]
α Angle between aspect and the azimuth of the light direction

Aspect-based shading, combined with the simulation of aerial perspective (described below), results in improved depictions of mountainous and hilly areas. Figure 3 shows aspect-based shading calculated with the formulas presented above.

In flat areas, the grey tones in relief shading display disconcerting random values. Using a supplemental bright grey tone to cover these regions improves the appearance. The grey tone and the aspect-based shading are combined by a weighted mean:

$$g = w \cdot g_{flat} + (1 - w) \cdot g_{asp} \qquad (2)$$

where

g Grey tone [0..1]
g_{flat} Grey tone for flat areas [0..1]

The weight w is calculated using the following formula (Arnet 1999):

$$w = \begin{cases} e^{ln\left(\frac{s-a}{90-a}\right)\{ b} & \text{if } s > a \\ 0 & \text{if } s \leq a \end{cases} \qquad (3)$$

where

w Weight for aspect-based shading
s Slope of the point [degrees]
a Maximum slope without shading [degrees]
b Curvature [0..1]

Areas with a slope below a are fully covered by the assigned bright tone for flat areas. Parameter b determines the influence of this tone. Figure 4 illustrates the effect of the two parameters together. As an alternative to the above function, the program offers an interactive dialog to adjust the weight $(1-w)$ as a function of slope at a more detailed level (Figure 5). Additionally, the influence of the flat tone can be limited to areas below a certain elevation (lower part of the dialog in Figure 5). Figure 6 illustrates the results achieved with the weights selected in the dialog of Figure 5.

Aspect-based shading is well suited for portraying mountainous areas. However, diffuse reflection methods more accurately depict flatter and uneven lowlands (compare the upper left corner of Figures 2 and 6). The two methods of shading can be mixed as a function of slope of the terrain. First, a matrix containing slope information from the DEM is calculated, and then smoothed by a mean or median filter. Diffuse reflection and aspect-based shading are then combined as a function of slope according to the following diagram (Figure 7). The user of the program can adjust the shape of the curve choosing α and d.

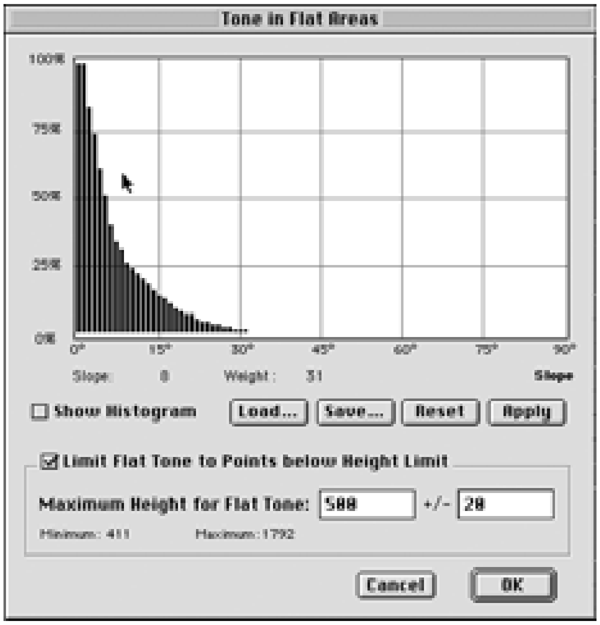

Figure 5. Dialog to select the weight of flat area tones.

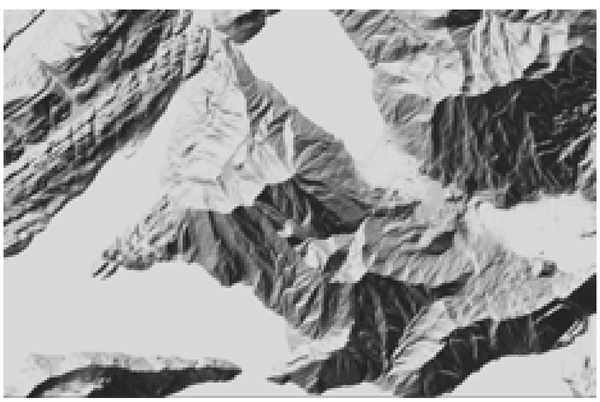

Figure 6. Relief shading with a tone for flat areas.

AERIAL PERSPECTIVE

Analytical relief shading computed with the algorithms described above can be improved further by simulating the effect of aerial perspective. To achieve this effect, three different components are each transformed to a weight and then applied to the previously calculated grey values. The three components are the relative elevation w_h (equation 4), the orientation of the slope towards the light direction w_a (equation 5), and the relative position on a hillside w_p (equation 6).

The first weight w_h is the relative elevation within the elevation model (equation 4). The lowest point of the elevation model receives a weight w_h equal to 0, and the highest point has w_h equal to 1.

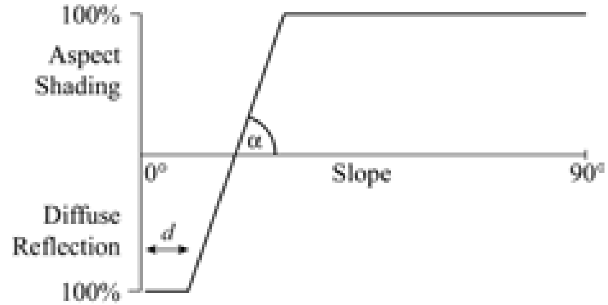

Figure 7. Combination of diffuse reflection and aspect-based shading.

$$w_h = \frac{h_p - h_{min}}{h_{max} - h_{min}} \tag{4}$$

where

w_h Weight of relative elevation [0..1]
h_p Elevation of the point
h_{min}, h_{max} Minimum and maximum elevation of the DEM

The second weight w_a is based on the aspect (orientation) of the slope facing the light direction (equation 5). The sign of this weight determines if the initial grey value will be darkened or brightened. w_a equals –1 if the point is opposed to the light direction, and +1 if aspect and light direction coincide.

$$w_\alpha = \cos(a) \tag{5}$$

where

w_a Weight of aspect [−1..1]
α Angle between aspect and azimuth of the light direction

The third weight w_p is based on the relative position on a hillside, which is identified using slope lines. (Here *slope line* is defined as the line of maximum steepness.) The slope line is followed in ascending and descending direction, as long as the absolute value of the slope is larger than a definable minimum steepness. If the total length of the slope line is shorter than a minimum length, the weight for the relevant point is set to zero. Otherwise, the relative position of the point on the slope line is calculated (equation 6). This yields a weight between 0 (that is, the point does not lie on a hillside) and 1 (that is, the point lies on the top of a hillside). These values are calculated for a regular grid. The grid is filtered in a subsequent step using a low-pass matrix filter to remove disturbing structures.

$$w_p = \begin{cases} \dfrac{l_{below}}{l_{above} + l_{below}} & \text{if } l_{above} + l_{below} \geq l_{min} \\ 0 & \text{if } l_{above} + l_{below} < l_{min} \end{cases} \quad (6)$$

where

w_p Weight of relative position within the hillside [0..1]
l_{above} Length of the slope line above the point
l_{below} Length of the slope line below the point
l_{min} Minimum length of the slope line

Before the three weights can be applied to the previously calculated grey value, the contrast of the grey value must first be reduced (equation 7).

$$grey9 = grey\{(1 - m\{n) + \frac{m\{n}{2} \quad (7)$$

where

grey' Grey value with reduced contrast
grey Initial grey value
m Contrast reduction [0..1]
n Aerial perspective [0..1]

m and *n* are user-definable parameters.

Including *n* in the contrast reduction ensures that contrast will not be reduced when aerial perspective is not applied (that is, *n* equals zero). After the contrast reduction, aerial perspective is added to the grey value using the following correction:

$$grey'' = grey' + w_h \cdot w_a \cdot w_p \cdot n \quad (8)$$

where

grey'' Grey value with aerial perspective

When comparing Figure 6 to Figure 8, one can see the effect achieved with the described algorithm.

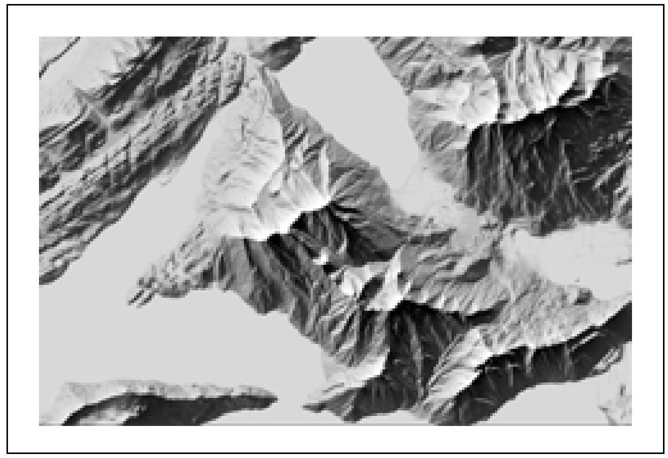

Figure 8. Addition of aerial perspective.

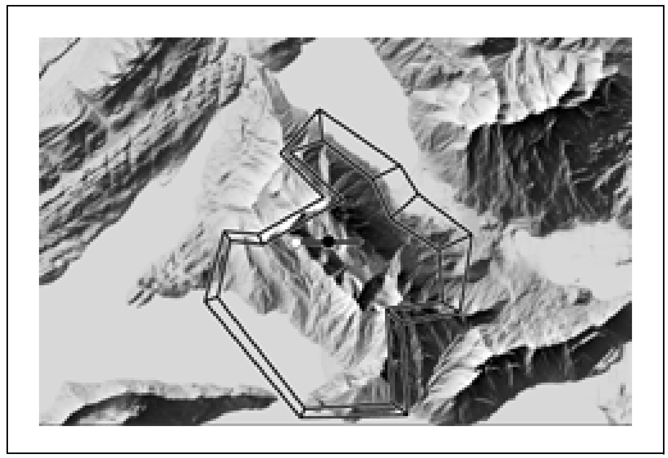

Figure 9. Local adaptation of the light direction.

LOCAL ADAPTATIONS

For applying local adaptations to shaded relief, the prototype software uses the concept of fences – an interface metaphor borrowed from CAD applications. To use fences, the user draws a fenced enclosure to isolate a portion of a DEM, in which parameters may be adjusted to locally alter the appearance of the shaded relief. The following parameters can be adjusted: light direction; vertical exaggeration; brightness; tone for flat areas; and interpolation between diffuse reflection and aspect-based shading.

Figure 9 illustrates local adjustment of the light direction within a fence. In this example, the main northwest light source is locally replaced by a light source from west. After the user has finished constructing a fence, the program automatically constructs a second fence inside the first and interpolates the value of parameters between them – creating a diffuse buffer zone. The inner and outer fence polygons remain editable: nodes can be added, deleted, and moved.

Fences may be created for each type of shading parameter, and fences are organized on layers according to their function. For example, all fences used to locally adjust vertical exaggeration are placed on the vertical exaggeration layer, fences used to adjust light direction are placed on the light direction layer, and so forth. The user can switch between the different layers and thereby hide and show the adaptations. The fences on each layer are ordered in a tree structure. This allows fences to lie side by side or inside each other. However, the program prohibits the construction of overlapping fences within a layer.

In Figure 10, the aspect-based shading has been replaced by a diffuse reflection in the upper left corner. In the same area, topography is further accentuated by vertical exaggeration applied to the DEM. Other minor local adjustments have been applied to Figure 10 throughout the image.

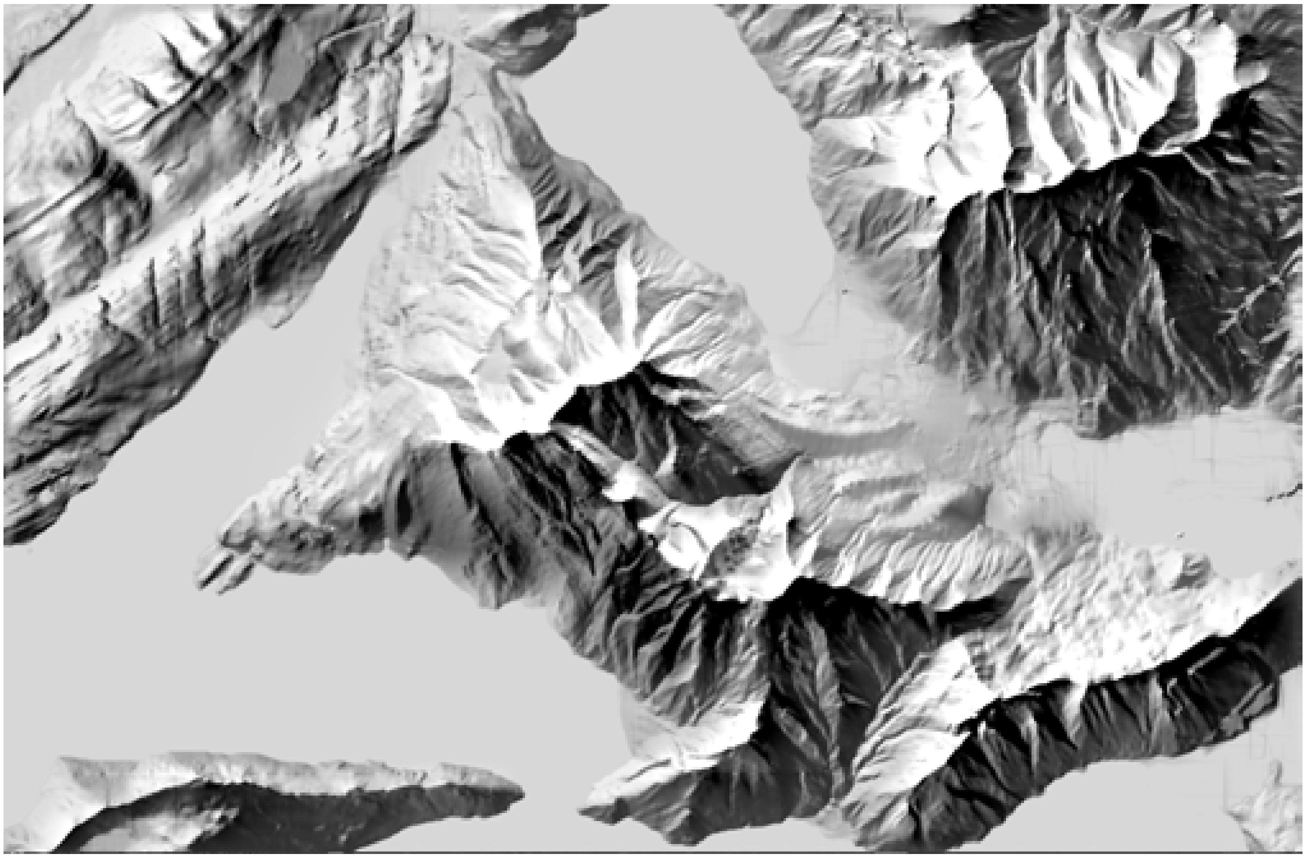

Figure 10. Shaded relief with a series of local adaptations.

Using the fence technique, cartographers have at their disposal a flexible workflow for analytical relief shading that leverages their knowledge of manual relief shading. As soon as the DEM is loaded into the computer's memory and displayed on screen, most of the terrain's details become visible immediately. This is in contrast to traditional relief shading, where the cartographer first draws the major landforms on a blank sheet of paper and slowly builds up smaller details. To facilitate the transition from manual to analytical production, and to structure and tighten the workflow, production steps were determined through a series of tests. First, the terrain has to be subdivided into mountainous and flat regions, applying the aspect-based algorithm to the mountains and diffuse reflection to the flats. In the next step, the user selects the magnitude of aerial perspective for the entire map sheet, followed by changes to the brightness and the light direction of large landforms. When these steps are completed, the tone for flat areas is applied to the lowlands. Finally, smaller details should be emphasized locally by adjustments within fences of the light direction and brightness.

RESULTS

When comparing Figures 2 and 6, one can see that the aspect-based shading results in clearer images of stronger contrast. Horizontal structures following contour lines are repressed by emphasizing vertical gradients. With the proposed algorithm for simulating aerial perspective, mountain summits and large landforms are accentuated. Aspect-based shading and aerial perspective proved to be well suited for mountainous regions, whereas diffuse reflection was preferred for lowland and flat areas. The two techniques can be combined at a global level as a function of slope. As can be seen from Figures 3 and 6, the addition of a bright tone covering flat areas clears the image – an essential consideration when combining the shaded relief with other cartographic information.

Tests with the prototype software have shown that local adjustments with fences are intuitive to use. With adjustments of light directions and brightness, important landforms, small details, and characteristic structures of the terrain can be easily emphasized. Cartographers were able to successfully transfer their experience and knowledge of manual shading to a digital workflow.

Conclusion

Analytical shading is less time-consuming than traditional manual relief shading. Using the local and global techniques presented in this paper, only minimal time need be invested to improve the quality of an analytically shaded relief.

Further improvements and developments in the field of computer-aided relief shading for cartography are necessary. Of particular importance are interactive tools to manipulate digital elevation models to locally accentuate unique geomorphological forms and to remove undesirable artifacts.

Weibel (1989) developed an interesting approach for the generalization of digital elevation models. However, currently available computer programs still lack user-friendly interfaces and effective algorithms to accomplish this task. Digital elevation models produced by airborne and space-borne synthetic aperture radar (SAR) present new challenges for analytical shading. For instance, valuable land cover (forests) and anthropogenic features (buildings and roads, for instance) have the potential to become graphically distracting elements in a shaded relief. Methods have been developed to remove these elements, if so desired.

Locally adjusted relief shading could be automated, at least partially, by an automatic extraction of geomorphological features.

The quality and level of detail found in digital shaded relief depends largely on the DEM used for the calculations. Providing that the DEM is of sufficient resolution and quality, analytical shading can portray terrain in a more objective way than manual relief shading. However, effectively designed shaded relief, as with other elements on a map, involves much more than blind devotion to geometrical precision. The techniques presented in this paper will, I hope, allow cartographers to blend the best traits of traditional manual and modern analytical relief shading.

Figures

All analytical relief shadings of the area of Rigi-Lucerne are derived from DHM25 © swisstopo (BA035538). Manual relief shading (Figure 1) © swisstopo (BA035538).

Further Information

For more information about relief shading and the developed prototype software, please visit http://www.reliefshading.com

Acknowledgements

The author would like to thank the following individuals involved in the project: Heinz Stoll, Orell Füssli Kartographie, Zürich; Paul Ehrlich, Rudolf Morf, Felix Arnet, Swiss Federal Office of Topography, Wabern; Stefan Räber, Lorenz Hurni, Institute of Cartography, ETH Zurich.

References

Arnet, F. 1999. Oral communication.

Batson, R.M., E. Edwards, and E.M. Eliason. 1975. "Computer-Generated Shaded-Relief Images." *Journal of Research, U.S. Geological Survey* 3/4: 401–8.

Blinn, J.F. 1977. "Models of Light Reflection for Computer Synthesized Pictures." *SIGGRAPH* 77: 192–8.

Böhm, R. 1998. "Kartographische Reliefdarstellung mittels digitaler Bildfilterverfahren." PhD diss., Dresden University of Technology, Institute of Cartography.

———. 1999. "Filter-Kombinationsschummerung mittels adaptiver Operatoren." *Kartographische Nachrichten* 6: 229–35.

Brassel, K. 1974. "A Model for Automatic Hill-Shading." *The American Cartographer* 1/1: 15–27.

Bui-Tuong, P. 1975. "Illumination for Computer Generated Pictures." *CACM* 18/6: 311–7.

Foley, J.D., A. van Dam, K. Feiner, and J.F. Hughes. 1990. *Computer Graphics: Principles and Practice.* Addison-Wesley.

Horn, B.K.P. 1982. "Hill Shading and the Reflectance Map." *Geo-Processing* 2: 65–144.

Hurni, L., B. Jenny, T. Dahinden, and others. 2001. "Interactive Analytical Shading and Cliff Drawing: Advances in Digital Relief Presentation for Topographic Mountain Maps." *Proceedings of the 20th International Cartographic Conference, ICC 2001 Bejing.*

Imhof, E. 1982. *Cartographic Relief Presentation.* New York and Berlin: Walter de Gruyter.

Minnaert, M. 1961. "Photometry of the Moon." *Planets and Satellites* 3: 231–48.

Moellering, H., and A.J. Kimerling. 1990. "A New Digital Slope-Aspect Display Process." *Cartography and Geographic Information Systems* 17/2: 151–9.

Prechtel, N. 2000. "Operational Analytical Hill Shading within an Advanced Image Processing System." In *High Mountain Cartography 2000*, ed. M.F. Buchroithner. Institute for Cartography of the Dresden University of Technology, Kartographische Bausteine, vol. 18. Dresden: Dresden University of Technology.

Weibel, R. 1989. *Konzepte und Experimente zur Automatisierung der Reliefgeneralisierung.* Geoprocessing Series, Department of Geography, University of Zurich, vol. 15. Zurich: University of Zurich.

Yoëli, P. 1959. "Relief Shading." *Surveying and Mapping* 19/2: 229–32.

———. 1965. "Analytical Hill Shading." *Surveying and Mapping* 25/4: 573–9.

———. 1966. "Analytical Hill Shading and Density." *Surveying and Mapping* 26/2: 253–9.

———. 1967a. "The Mechanisation of Analytical Hill Shading." *The Cartographic Journal* 4/2: 82–8.

———. 1967b. "Die Richtung des Lichtes bei analytischer Schattierung." *Kartographische Nachrichten* 2: 37–44.

Zhou, X., and E. Dorrer. 1995. "An Adaptive Algorithm of Shaded-Relief Images from DEMs Based on Wavelet Transforms." *Digital Photogrammetry and Remote Sensing '95*, SPIE Proceedings Series, vol. 2646: 212–24.

Résumé L'estompage est un moyen de visualisation du relief en cartographie qui peut être produit de manière traditionnelle (dessin manuel) ou par des calculs informatiques. Les logiciels d'estompage existants actuellement ne permettent pas d'adaptations locales de direction de la lumière. La simulation de perspective aérienne ou des modifications manuelles y sont également impossibles. Pour combler ces lacunes, un programme d'estompage assisté par ordinateur à été développé. Il permet à l'utilisateur d'adapter localement les estompages grâce à un contrôle interactif de l'intégralité du processus. Les valeurs de gris du relief y sont définies à partir d'une combinaison de deux méthodes : l'estompage des pentes raides est calculé à partir de l'orientation du relief, et l'estompage des surfaces plus planes est calculé à partir de la réflexion diffuse de la lumière. Par ailleurs, un nouvel algorithme pour la simulation d'effets de perspective aérienne à été utilisé afin d'améliorer ces estompages. Contrairement à d'autres programmes du même type, il s'est avéré que les cartographes ayant une solide expérience manuelle des techniques d'estompage, peuvent ici facilement transférer leurs connaissances au monde digital.

Zusammenfassung Analytisch berechnete Geländeschattierungen können mittels verschiedener Softwarepakete erstellt werden. Meist können jedoch für die manuelle Schattierung entwickelte Techniken nicht angewendet werden. So ist es zum Beispiel meist unmöglich, die Lichtrichtung an die Geländeform anzupassen oder Effekte der Luftperspektive zu simulieren. In diesem Artikel wird ein Programm zur computergestützten Reliefschattierung vorgestellt, welches dazu eine mögliche Lösung aufzeigt. Der Benutzer kann die Parameter zur Berechnung der Geländeschattierung lokal anpassen. Damit wird es möglich, die Schattierung interaktiv für die einzelnen Geländeteile zu kontrollieren. Die Grauwerte des resultierenden Bildes werden durch eine Kombination von zwei Berechnungsmethoden bestimmt: Schattierung aus der Geländeorientierung für steile Gebiete und diffuse Reflexion für flache Gebiete. Ein neuer Algorithmus zur Simulation von luftperspektivischen Effekten wird zur weiteren Verbesserung der Schattierung verwendet. Im Vergleich zu andern Programmen hat sich gezeigt, dass erfahrene Kartografen ihr bisheriges Wissen weiterhin nutzen können und gegenüber sonstigen analytisch hergestellten Geländeschattierungen erhebliche Qualitätsverbesserungen erzielt werden.

Resumen Actualmente, el software disponible para el sombreado digital del relieve no permite adaptaciones locales de parámetros como la dirección de la luz, la simulación de perspectivas aéreas, ni otras técnicas utilizadas en el sombreado manual. Para paliar esta deficiencia, se ha desarrollado un programa de sombreado del relieve asistido por computador que acepta el uso de adaptaciones locales de las características del sombreado, permitiendo un control interactivo continuo sobre la totalidad del proceso. Los valores de gris de la imagen se determinan por una combinación entre las sombras en regiones abruptas, con una reflexión difusa hacia las zonas bajas, y los tonos de gris brillante en zonas llanas. Además, se presenta un nuevo algoritmo para la simulación de perspectivas aéreas. Las pruebas con el programa han demostrado que, con una inversión mínima de tiempo, la calidad de los sombreados digitales del relieve puede mejorar significativamente. Usando las técnicas propuestas y el software presentado, los cartógrafos experimentados pueden utilizar en un entorno digital sus conocimientos y experiencia en la generación de sombreados del relieve.