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REFEREED PAPER

Scree Representation on Topographic Maps

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Scree patterns are an important element of mountain maps in Swiss style. The size and density of scree dots vary with the exposition towards a source of illumination, which makes the dots extremely labour intensive to map without specialized algorithms. This paper identifies design principles for the symbolisation of scree fields on mountain slopes and presents a digital method for the quick placement of dot symbols requiring only minimal interventions by a cartographer. When digitally produced scree is combined with a shaded relief and a rock drawing, the terrain appears as a continuous three-dimensional surface to the reader. The described method is implemented in Scree Painter, a specialized free open-source software application. Scree patterns produced with Scree Painter match the quality standards of manually generated scree representations.

Keywords: Scree-mapping, Swiss-style relief representation, mountain cartography, Scree Painter

INTRODUCTION: MAPPING SCREE, GLACIAL DEBRIS, QUARRIES, PITS, RIVERBANKS AND GULLIES

Topographic maps of mountainous areas frequently use stippled small dots to represent scree, a mass of small loose stones that cover mountain slopes. The same stippling effect can also be applied to show debris on a glacier, stones in a quarry, clay and gravel in a pit, alluvial material on a riverbank or other detrital deposits (Figure 1). Small dots can also be arranged along a line to symbolize mountain gullies or small valleys that only drain water after a period of heavy rain (Figure 2).

The minute dots in Figures 1 and 2 are irregularly arranged and slightly vary in size. These symbolisations have proved to be effective and it is assumed that they are self-explanatory because most map-readers associate the dot symbols with stones in nature.

The cartographic representation of mountain scree is an often overlooked, but relevant element of Swiss style mapping. Swiss style mapping generates a strong three-dimensional relief impression by combining contour lines with shaded relief, rock drawing and scree patterns that together simulate the effect of an illuminated terrain surface. The size and the density of the dots in the scree pattern vary with the exposition towards a source of illumination.

Historically, scree patterns were relatively fast to generate when maps were engraved on copper plate, as the etcher could quickly generate a stippling effect with the needle. Today, dedicated digital tools generate simple dot patterns to represent stone quarries or gravel pits within seconds. However, the mapping of mountain scree that varies with the exposition towards a source of illumination is still extremely labour intensive and slow to produce, as each dot has to be placed individually. A specialized method for the quick placement of scree dots on mountain slopes requiring a minimum amount of intervention by a cartographer is therefore highly desirable.

RELATED WORK

Scree mapping has only received sporadic attention in the literature so far. Imhof dedicates less than half a page to the mapping of 'scree slopes and debris mounds' in his standard work on relief representation (Imhof, 1982: 291). There, he warns from overloading a map by too dense a scree representation and succinctly suggests arranging stones in lines that indicate the direction of slope, as in the top left example of Figure 1. He remarks that 'the finer scree, represented by very small dots, lies on the steep, upper slopes, while the larger pieces, depicted by larger dots and by small block-shaped symbols, come to rest in disorder at the foot of the slope where the terrain begins to level out'.

Attempts at automation of scree representation have been carried out in the past. Hurni *et al.* (1999) presented a digital method to fill polygons with stone symbols. They start from a grid of regularly spaced stones. The position of the stones is then randomized within a certain tolerance. The shape and the size of the stone symbols are also varied and the algorithm places stones with a minimum distance to the polygon edges (Figure 3). This simplistic approach is sufficient for the symbolisation of quarries and pits, but is not adequate for scree on mountain slopes as the size and the density of dots do not vary with the exposition towards a source of illumination.

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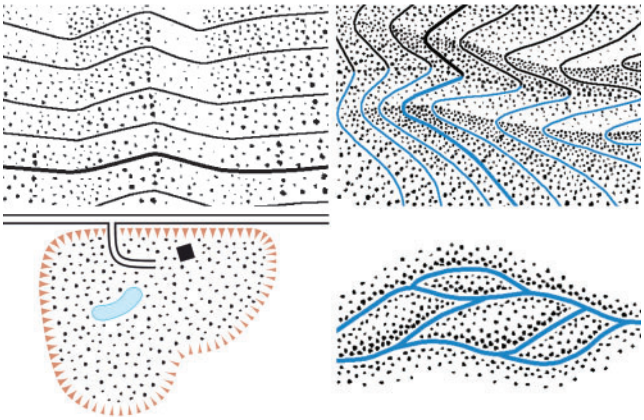

Figure 1. Stippling for representing mountain scree, glacial debris, a stone quarry and fluvial deposits (swisstopo, 2008)

The same paper by Hurni *et al.* (1999) also presents a digital method to symbolize gully lines. The method takes vector lines as input and places strings of stones along them (line 1, Figure 4). The position and shape of the stones are randomly varied within user-specified tolerances along the direction of the line and vertically to the line (lines 2 and 3, Figure 4). The size of the stones is increased toward the lower end of the line (line 4, Figure 4) and the shape of the symbols is randomized (line 5, Figure 4). This is a simple method and the graphical results are of sufficient quality for the mapping of mountain gullies.

Jenny and Hutzler (2008) added flow structures to the pattern filling approach of Hurni *et al.* by inserting intermediate lines that are treated as obstacle when generating a dot pattern. This approach successfully indicates the direction of slope, as suggested by Imhof (1982) when obstacle lines are placed close to each other. But the method fails when lines are more distant. Its basic assumption seems counterintuitive, as lines are not placed where scree should be arranged in lines, but where the scree density is thinned. As these obstacle lines are not automatically detected, the approach also requires much interactive editing.

To fill scree areas with dots of varying density, cartographers at the Swiss Federal Office of Topography (swisstopo) have experimented with a diffuse dithering filter applied to a shaded relief image (Figure 5; Feldmann and Kreiter, 2006; details in Jenny and Hutzler, 2008). The density of dots varies with the brightness of the shaded relief, but results are not satisfying: many dots are too close to other map elements, scree lines symbolizing the direction

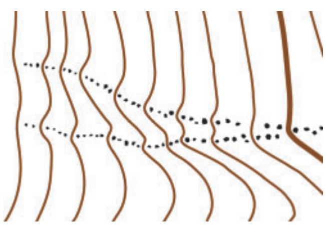

Figure 2. Gully lines symbolized by strings of dots (swisstopo, 2008)

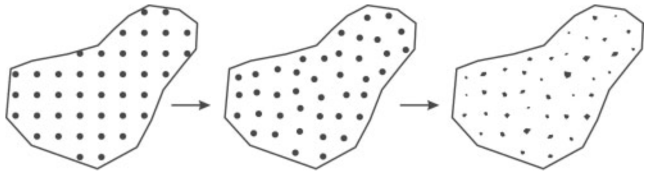

Figure 3. Randomized dot pattern (Hurni *et al.*, 1999)

of slope are not included, and stones are all of equal size and shape.

Gondol *et al.* (2008) reported on ongoing attempts to automate the representation of rocks and scree areas for the French national mapping agency IGN. They combined the pattern filling and the gully symbolisation by Hurni *et al.* (1999). When the slope angle of the hill is steeper than 50%, small dot symbols are placed along slope lines that are extracted automatically from a terrain model. The size of dots increases slightly in downward direction. In areas with a slope flatter than 50%, the pattern filling method is used. This method is fully automatic, but scree patterns are rather monotonous, as the size and density of dots is not modulated with the illumination from the top left.

This paper presents a method for the automatic mapping of scree. This research project was mandated and evaluated by the swisstopo, Switzerland‘s national mapping agency. The resulting method and Scree Painter, a dedicated software application developed during this project, will be used for future editions of the official printed Swiss map series.

DESIGN PRINCIPLES FOR SCREE MAPPING

Cartographers of the manual era knew which etching needle to use for placing scree dots and judged the density of stones based on their aesthetical experience and a few rules of thumb. They ignored the precise geometrical dimensions, such as the diameter of dots or the number of dots per square centimetre, as these measures were simply of not much practical use. Before a digital method can be developed, however, the graphical design principles and geometrical dimensions for scree drawing must be identified.

We derive these principles from manually created topographic maps by swisstopo, as the main goal is to transfers their particular manual scree mapping style to the digital realm. Other national mapping agencies and private map publishers also show scree symbols on their maps, but drawing inspiration from official Swiss maps for digital

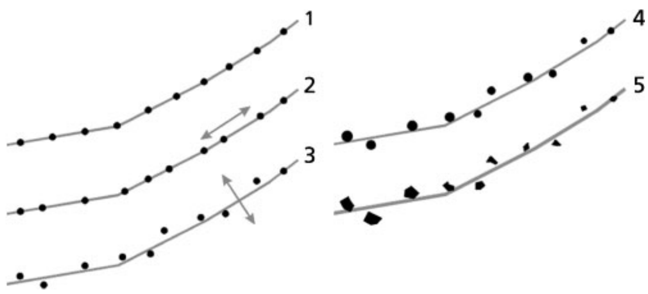

Figure 4. Symbolisation of gully lines in five steps (Hurni *et al.*, 1999)

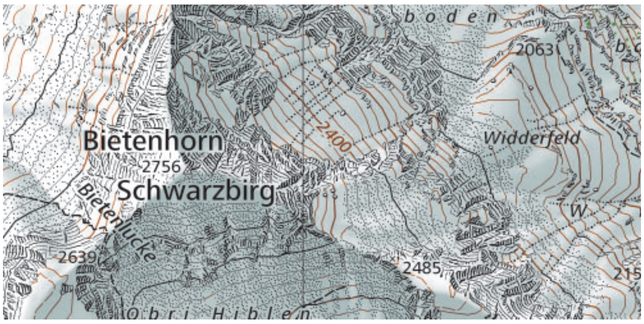

Figure 5. Scree pattern by error diffusion: all dots are of identical size and some are too close to other map elements (Kartenprobe 2005 Alpen, OPTINA LK, 1 : 25 000 by swisstopo, unpublished)

terrain mapping seems obvious, as these maps have set a standard that is internationally renowned for its graphical clarity and elaborate mapping style. Tufte (1990: 82) notes that 'the Swiss maps are excellent because they are governed by good ideas and executed with superb craft'. The depiction of mountainous terrain on Swiss maps is regarded as exemplary by Knowles and Stowe (1982: 108) who suggest that they are 'distinguished by their very fine draughtsmanship and in particular by the manner in which relief is shown'; Keates (1996: 257) compares the treatment of relief by various mapping agencies and finds that 'the most sophisticated and elaborate representation is the Swiss, using contours in three colors …, detailed rock drawing and hill shading'; Hodgkiss (1981) writes: 'it is … in the depiction of mountain and glacier landscapes that the Swiss excel'. Hence, the design principled described in this section were derived in collaboration with cartographers of swisstopo and are partially based on publications by Imhof (1982), Spiess *et al.* (2002) and swisstopo (2008). We concentrate on design principles for mountain slopes and glacial moraines covered by scree. More simple representations, such as stone quarries, clay pits and gullies, are neglected in this discussion, as efficient methods for their digital production already exist as described in the previous section.

Areas covered by scree are often relatively small, and scree patterns are therefore most prominent on large-scale maps. swisstopo maps show scree at 1 : 25 000, 1 : 50 000 and 1 : 100 000, and on very small patches at 1 : 200 000. The dimensions and numbers presented hereafter apply for maps at 1 : 25 000, but the design principles are valid for all scales and an Appendix summarizes the numerical values.

Representing terrain with a three-dimensional illumination effect

For the Swiss mapping style, a continuous three-dimensional appearance of the terrain is of primordial importance. The map should show the main structures of the terrain surface at a glance, while still providing detailed information about the morphology of the terrain when focusing on a small section of the map. A virtual light source from the top left is used to generate a three-dimensional illumination effect that helps the map-reader perceive the third dimension. On swisstopo maps at 1 : 25 000, the illumination effect is generated by modulating the brightness of the shaded relief, the rock drawing and the scree pattern. An additional faint yellow tone highlights areas fully exposed to the virtual light. It is the interplay of these four elements that generates a three-dimensional illumination effect.

Scree stones on shaded slopes are larger and denser than scree stones on illuminated slopes. The result of this brightness modulation can be observed on the glacial moraine mapped in the right part of Figure 6. When viewed from afar, the individual dots cannot be distinguished, but the shape of the moraine clearly stands out due to the pronounced contrast between the bright and the dark slopes, which is due to the adapted size and density of scree dots.

The density and arrangement of scree dots can also be varied to accentuate important details of the terrain's morphology, such as very small valleys, deposition fans and gullies that are impossible to show with contour lines or the shaded relief alone (Figure 6). Comparisons with orthophotos of the same areas, however, show that the representation of gully lines, scree covered slopes and large boulders is not a precise rendition of nature. No one-to-one relation exists between the gullies and boulders on the terrain and on the map. Indeed, these elements emphasize local features of the topographic surface and provide a symbolic rendering of an interpretation of the terrain's morphology that is derived from areal stereophotos, terrestrial photos and field checks (Gurtner, 2004). This

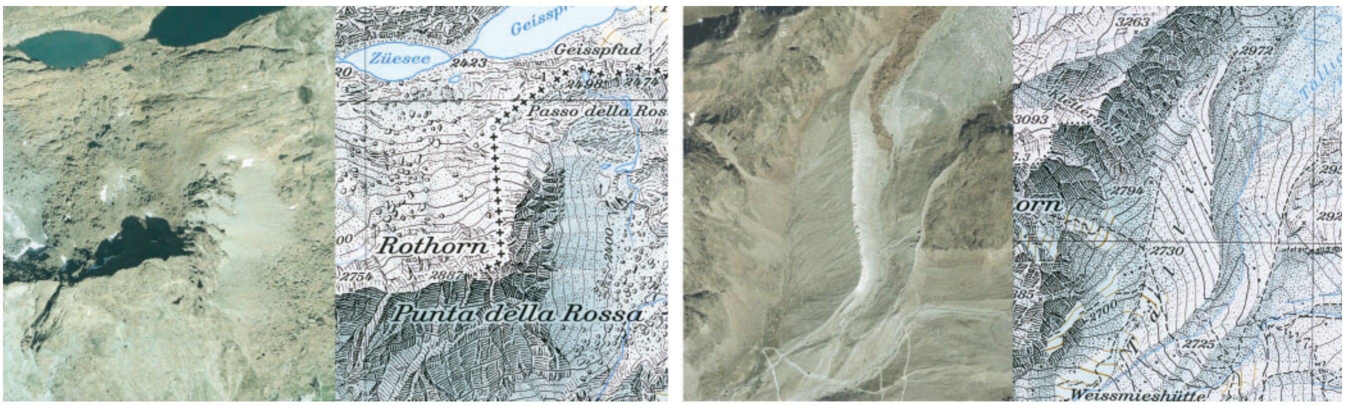

Figure 6. Generalisation and symbolisation of scree and boulders. The scree pattern varies with the exposition towards a source of illumination from the top left: Swissimage orthophoto, swisstopo; and maps 1290 Helsenhorn 2008 (left) and 1309 Simplon 2007 (right), 1 : 25 000 by swisstopo

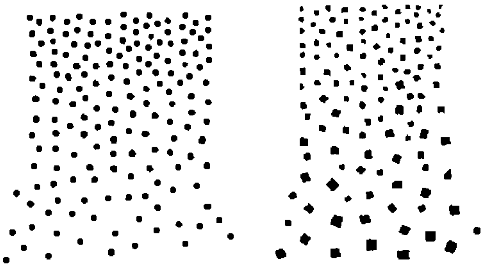

Figure 7. Gravity effect: the size of scree stones increases towards the lower end of slopes (swisstopo, 2008)

generalisation is inevitable even at large scales for a map to be unambiguous and easy to read.

Shape and size of scree stones

Large boulders are represented by relatively large hollow symbols, as can be seen on the map of the north-oriented slope of the Rothorn in Figure 6 (left). The symbols are not filled to avoid any potential confusion with other solid map elements of similar size, for example, buildings that are symbolized by filled black polygons. The diameter of boulder symbols can reach up to approximately 1.5 mm. Boulder symbols are irregularly shaped and cast a tiny shadow represented by a thicker line on the lower right side to simulate the illumination effect from the top left. The cast shadow also gives boulders graphical weight despite being hollow. Because of their limited number and visual importance, they are individually designed. Generally, only few boulders are placed on a mountain map, at locations where they are identified by field checks and the interpretation of aerial photos.

Scree fields on mountain slopes are a much more common map element. They are symbolized by irregularly shaped dots having four to eight corners. Their minute size varies with the exposure to a fictional light source between approximately 0.01 mm on sunlight slopes and 0.22 mm on shaded slopes. The size of dots not only varies with the exposition towards an illumination from the top left, but it also varies with the relative position on mountain slopes, as suggested by Imhof (1982). The increased size mimics the effect of gravity, which induces a larger momentum to heavier stones that run over a longer distance (Figure 7). However, this graphic trick is sparsely used, as it is rather difficult to consistently apply over the area of a complete mountain map.

Distribution and density of scree stones

Scree stones should be irregularly distributed and avoid an arrangement in a checkerboard pattern (Figure 8). The mean distance between dots varies with the exposure towards the virtual illumination between approximately 0.05 mm for stones on shaded slopes and 0.2 mm on sunlight slopes. This can results in up to 1000 stones per square centimetre in shaded areas (with a distance of 0.05 mm, a theoretical number of 2500 stones could be reached, but scree dots have to share space with contour lines and other map elements). Scree is a type of land cover that has a low graphical priority. Dots should not overlap

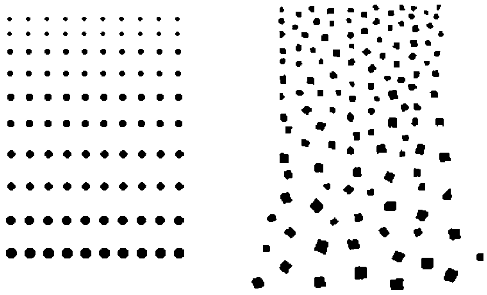

Figure 8. Irregularly distributed stones avoid a checkerboard pattern (swisstopo, 2008)

other map elements or be placed too close to other elements. The minimum distance between scree dots and contour lines must not be too large either, as a disturbing halo would be generated otherwise (Figure 9). Text labels, however, must be masked unsparingly to ensure easily readable type (Figure 10).

swisstopo maps represent scree slopes by a mix of randomly distributed dots and dots arranged in flow lines. These flow lines indicate the direction of flow of the scree and are formed by stones jittered along the line. Stones in flow lines are about 1.5 times larger than normal scree dots. Flow lines are placed along concave micro-valleys or gullies to graphically stress these terrain details, which are important to hikers and alpinists, for example. Since flow lines are graphically heavy elements, they are used more often on shaded slopes, and only sparsely applied on bright slopes.

Scree dots are occasionally arranged in special patterns to show outstanding morphological features, for example, rock glaciers. Rock glaciers are masses of angular debris that move downslope due to the deformation of internal ice (Benn and Evans, 2008). They have a tongue-like or lobate surface, as shown in the successful rendition in Figure 11.

SCREE MAPPING ALGORITHM

This section presents an algorithm and a software application developed for the automatic symbolisation of scree. The algorithm fills polygons with small dots according to the design principles presented in the previous section. It varies the dots in size and density with the brightness of a shaded relief image and generates flow lines from a digital elevation model.

The distribution of dot symbols is based on the Floyd–Steinberg dithering algorithm (Floyd and Steinberg, 1976), which is applied to the shaded relief image. Floyd–Steinberg

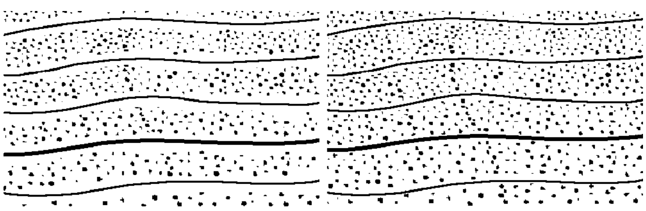

Figure 9. Oversized (left) and accurate (right) distances between scree and contour lines (swisstopo, 2008)

Figure 10. Masking of scree and rock drawing to improve type readability (enlarged) (Spiess *et al.*, 2002)

dithering is commonly used to reduce the number of colours in an image, for example, when converting a greyscale image to a binary black-and-white image. Floyd–Steinberg dithering transfers the quantisation error of each pixel (i.e. the difference between the original image and the new binary image) to the neighbouring pixels, while not affecting the pixels that already have been quantized. As previously mentioned, swisstopo experimented with Floyd–Steinberg dithering (Figure 5), but the resulting scree dots do not sufficiently modulate the terrain because they have a constant size of 1 pixel.

We have extended the Floyd–Steinberg dithering algorithm to scree mapping by randomly displacing each dot, placing each dot at a minimum distance to other map elements, varying the size of scree dots with the grey value of the shaded relief, generating irregularly shaped dots instead of square pixels and enlarging dots at the lower end of slopes. Additionally, the dot pattern is interspersed with flow lines.

The standard Floyd–Steinberg dithering algorithm stores the result in a binary raster image, where individual pixels are set to white or black depending on the grey values in the input image. Our modified algorithm does not generate a raster image, but creates a small vector polygon for each scree dot, which allows for manipulating the size, shape and position of each dot. Figure 12 illustrates the various steps of the algorithm. First, the shaded relief image is resampled to a cell size that is large enough to densely pack dots at the darkest positions of the shaded relief (Figure 12a). The Floyd–Steinberg dithering algorithm is then applied to the resampled image, which results in denser dots where the shading is dark, and sparser dots where the shading is bright (Figure 12b). The density of dots can be adjusted by altering the brightness of the shaded relief before the algorithm is applied. Our modified Floyd–Steinberg algorithm then randomly displaces each dot to avoid a regular checkerboard pattern (Figure 12c). Additionally, it ensures that dots are not placed too close to other map elements (Figure 12d), and modulates the size of each dot with the grey value of the shaded relief (Figure 12e). The shape of dots is randomized (Figure 12f), and finally dots are enlarged when they are placed at the lower end of a slope to imitate the effect of gravity (Figure 12g, at the foot of the right slope).

For illustrative purposes, the top row of Figure 12 shows the Floyd–Steinberg dithering, the random displacement of dots and the masking with other map features as three independent steps. In reality, however, these three steps are integrated. The Floyd–Steinberg dithering proceeds row-wise from top to bottom and parses the columns in zigzag order. If it finds that the current pixel is dark enough to place a dot, a small randomly generated displacement is applied to

Figure 11. Scree dots arranged to represent a rock glacier (map enlarged by 200%): Swissimage orthophoto by swisstopo; and map 1218 Zernez 2005, 1 : 25 000 by swisstopo

the coordinates of the centre of the pixel to avoid a checkerboard pattern. The candidate position is then tested against all other map elements. If the dot would overlap another map element or would be placed too close to another element, a new candidate position is computed by applying another random displacement, and this new candidate position is again tested against all other map elements. This procedure is repeated until an empty position to place the dot is found, or until the maximum number of iterations is reached. Auxiliary grids for accelerating this conflict detection between a candidate position and all other map features are discussed in a later section.

The size of dots varies with the brightness of the shaded relief. We found that a linear mapping of the greyscale value to a dot diameter yields good enough results. Random convex dot shapes are simple to generate (Figure 13). A regular polygon with a random number of four to eight corners is first rotated by a random angle, and then the central angles and the chord lengths are randomized.

In the final step of the algorithm, stones at the foot of slopes are enlarged to imitate the effect of gravity that lets larger stones roll over a longer distance until they reach a flatter area. Attempts were made to automatically identify such areas based on slope derived from a terrain model. Unfortunately, results of this simplistic approach were not satisfactory: automatically enlarged stones did appear in flatter areas, but not necessarily at the foot of hills. For a fully automatic solution, a more advanced method would be needed that takes the terrain morphology into account. An alternative solution is to enlarge stones using an additional mask that is painted by the cartographer with raster graphics software. The idea is simple: when a stone is placed where the georeferenced mask is dark, it is enlarged by a certain scale factor, and if the mask is white, the size of the stone is not changed. We have found that the best results are achieved if the scale factor varies according to a random function providing values with a Gaussian bell distribution. Hence, most dots on the dark mask area are only slightly enlarged, but a small number is greatly enlarged.

This interactive mask-based method for enlarging stones proved to be effective and very quick to execute, because the cartographer can change the size of many stones with a single, coarsely placed brush stroke on the mask image.

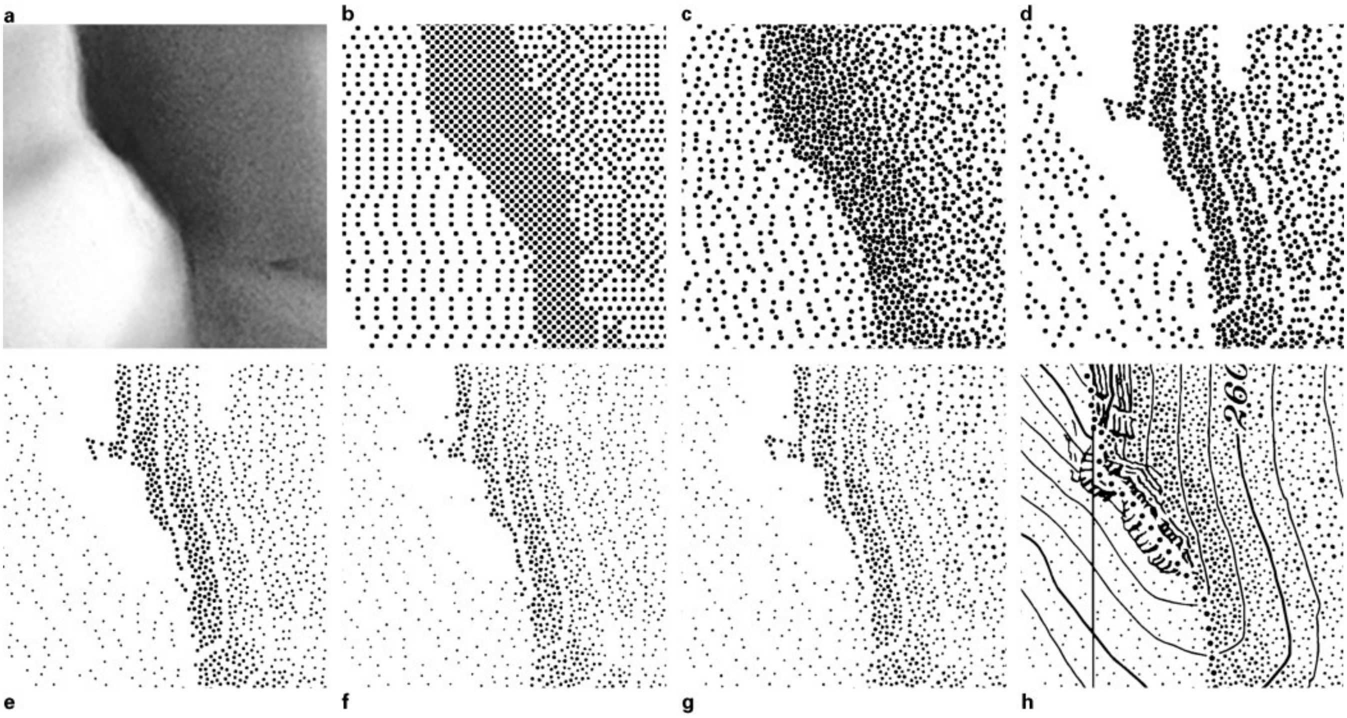

Figure 12. Steps of the modified Floyd–Steinberg dithering algorithm for scree mapping (map enlarged): (a) shaded relief, (b) Floyd–Steinberg dithering, (c) random displacements, (d) masking by other elements, (e) size variation, (f) shape variation, (g) larger stones at foot of hills, (h) final map

Gully and flow lines

To illustrate the slow but steadily flowing character of scree, normal scree dots are interspersed with dots arranged in lines. The same graphic device is used to symbolize gully lines (Figure 2). When the geometry of these gully and flow lines is known, their automatic symbolisation with dots placed along the line is simple to accomplish, as described before. This section describes how the geometry of flow lines can be computed from a digital elevation model.

The geometry of flow lines should meet the following requirements:

- they should follow the line of maximum slope (so-called slope lines);
- they must not be too short;
- they should be embedded in micro-valleys and not be placed on convex terrain forms;
- they must keep a minimum distance to each other; and
- they should not be placed in almost flat areas.

To find lines satisfying these criteria, first, a large number of candidate slope lines are extracted from an elevation model, following the terrain along the path of steepest slope. This is the path that a drop of water would take when flowing downhill. The standard slope line algorithm is modified such that the line tracing stops when either the line reaches an area that is flatter than a threshold slope, or when the line reaches a convex terrain shape. From the many slope line candidates, those shorter than a threshold value are discarded at this stage.

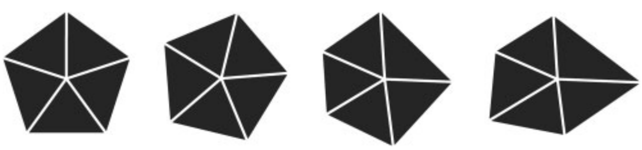

Figure 13. Constructing a dot (from left to right): regular polygon, randomly rotated, randomized angles and randomized chord lengths

The plan curvature coefficient is used to decide which of the remaining candidate lines is placed on the map. The plan curvature coefficient measures the rate of change of aspect along a contour (Willson and Galant, 2000). It is computed for each cell of the elevation model that a candidate line crosses, and the values are summed for each cell crossed. This results in an accumulated plan curvature index that rates each line – a line that is long and follows a deeply carved valley will have a higher index value and *vice versa*.

After computing the accumulated plan curvature index for each candidate line, the lines are first ordered by their index values and then added one by one to the map if the distance to all other previously added lines is large enough. This ensures that priority is given to long lines that follow deeply engraved valleys. Figure 14 shows flow lines generated with the described method, symbolized by vector lines (left) and by dots arranged along the flow lines together with regular scree dots (right).

Symbolized flow lines are graphically outstanding elements that are especially visible on illuminated slopes where the density of scree dots is low. Our digital method therefore varies the density of flow lines with the brightness of the shaded relief.

Auxiliary grids for conflict detection

Frequent distance tests are necessary for generating dot patterns and for finding flow lines, because candidate dots and candidate flow lines must keep a minimum distance to

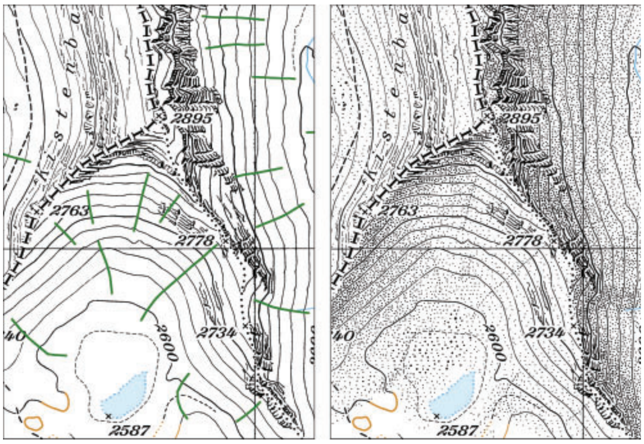

Figure 14. Flow lines extracted from an elevation model symbolized by green lines (left) and dots (right): map 1193 Tödi, 1 : 25 000, 2009, by swisstopo

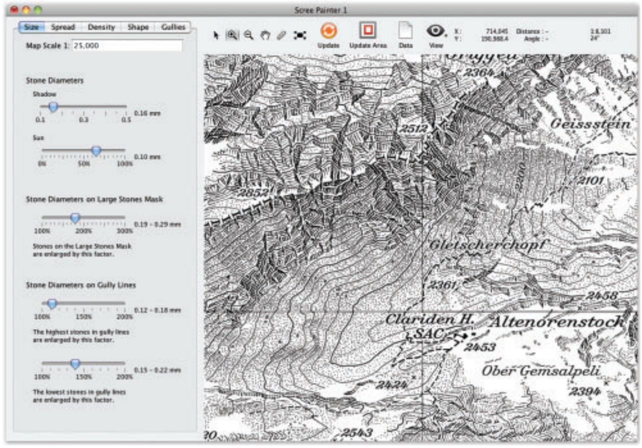

Figure 15. Screenshot of Scree Painter

other map elements. Distance evaluations are potentially very expensive in computational terms when many map elements are involved, which is typically the case for topographic maps. To accelerate these computations, invisible auxiliary grids are used. The auxiliary grids contain binary values, i.e. they indicate whether an element exists at the position under consideration.

To test whether a candidate dot would be placed on an existing map element, the auxiliary grid is initialized with a rasterized version of the map, i.e. all map elements are converted to a binary image. At this rasterizing stage, type on the map can be masked to ensure that scree dots are not placed too close to type elements (Figure 10). It is then algorithmically simple and quick to test whether a candidate dot would be placed on grid cells t74hat are already occupied by other elements or whether the dot would be placed too close to other elements.

A similar idea is used to keep flow lines at a minimum distance from each other. At the beginning, the auxiliary grid is left blank and lines are added to the grid one at a time by using standard rasterizing algorithms for converting vector lines to raster images. Lines are rasterized with a width corresponding to the minimum distance between two flow lines. To test whether a candidate line is distant enough to all other lines that have been accepted, the candidate line is first rasterized to a temporary grid. Then, all overlapping cells of the two grids are compared, and when two corresponding cells are occupied, the candidate line is rejected, as the minimum distance is not respected.

Scree Painter

The digital method developed for scree mapping was implemented in Scree Painter, a free open-source software application, programmed in Java that is available for all

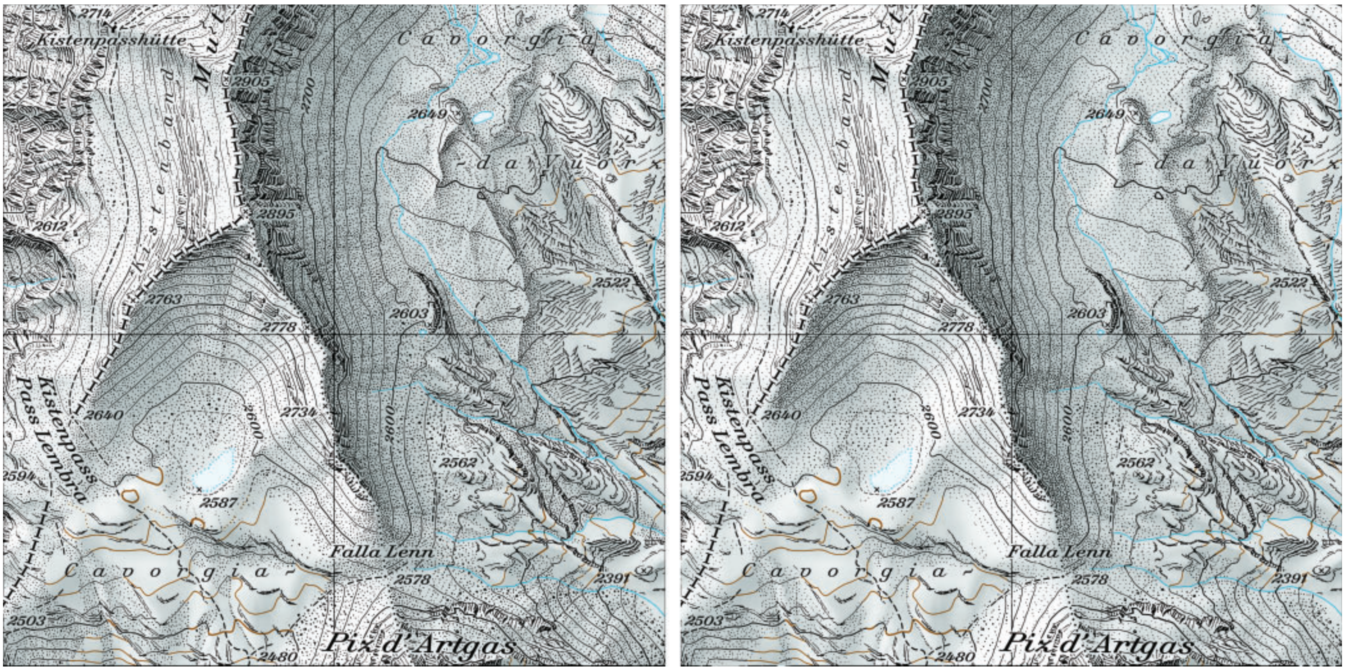

Figure 16. Comparison of manual (left) and automatic (right) scree rendering (map 1193 Tödi, 1 : 25 000, 2009, by swisstopo)

Table 1. The parameters describing the geometric attributes of scree patterns on the map series at 1 : 25 000 of the Federal Office of Topography (swisstopo)

Values varying with the brightness of the shaded relief (first value for bright slopes, second value for dark slopes)	
Stone diameter (mm)	0.10–0.16
Stone diameter on flow lines and gully lines (mm)	0.12–0.22
Distance between stones (mm)	0.05–0.2
Diameter of enlarged stones at foot of hills (mm)	0.2–0.4 (with higher probability for small diameters)
Constant values	
Minimum distance to other map elements (mm)	0.05
Maximum random displacement of stones (mm)	0.07
Stone symbol	4–8 corners with random convex shape

major operating systems. Scree Painter offers a graphical user interface for configuring the parameters necessary for scree mapping, e.g. the size of the largest and smallest stones, the gradation curve applied to the shaded relief, the placement of gully lines, etc. (Figure 15). Scree Painter can be downloaded from http://www.screepainter.com, where sample data and a manual are also available (Jenny, 2009).

After starting Scree Painter, the following input data have to be provided: a shaded relief, vector polygons to fill with scree, an elevation model (which is required for finding flow lines) and a mask image that specifies areas that must not be covered by dots. Scree Painter can also interpret a raster mask image for enlarging stones at the foot of hills, and another mask image for delimiting areas where a second gradation curve is applied. This second mask is used to locally strengthen the contrast of the shaded relief, which in turn will adjust the density and size of the derived scree dots. This feature is useful to enhance the contrast along ridges or glacial moraines by quickly placing a few strokes on the mask with raster graphics software.

Scree Painter generates flow lines as described in the previous section. Occasionally, the density or geometry of the lines must be adjusted to better reflect the local terrain morphology. In such cases, the lines can be exported, edited with a GIS and read again with Scree Painter to be symbolized with dots.

Figure 16 compares scree produced manually and by Scree Painter. Scree Painter generated 16,500 dot symbols in less than 2 s for the section shown. A comparison of the manually and the digitally produced samples shows that scree is more irregular in the manual sample and that certain small terrain details are more prominently visible. This is due to the fact that the developed algorithm modulates the size and density of stones with the shaded relief – if the shaded relief does not show a terrain form clearly, it will not be represented by the dot pattern either.

CONCLUSION

The Scree Painter software, which integrates the described digital method for scree mapping, can generate scree patterns that are comparable to manually produced renderings in a very short time. Scree Painter offers a graphical user interface for configuring all parameters necessary for scree mapping, and integrates options to correct the distribution of flow lines and to adjust the density and size of scree dots using masks in raster format. These masks can be edited with standard raster graphics software to interactively accentuate the representation of important details, such as mountain ridges or glacial moraines. Only exceptional terrain forms that occur very rarely (such as lobate rock glaciers or deltas of mountain rivers) require the dots to be placed individually by a cartographer for high-end mapping.

swisstopo has generously agreed to release Scree Painter as free open-source software, which might inspire other national mapping agencies and private mapping companies to apply this method for their printed maps.

APPENDIX: DIMENSIONS FOR SCREE MAPPING

The following list (Table 1) summarizes the parameters describing the geometric attributes of scree patterns on the map series at 1 : 25 000 of the swisstopo. Values are approximate.

BIOGRAPHICAL NOTES

Bernhard Jenny is a post-doctoral researcher at the Institute of Cartography of ETH Zurich, where he also did his PhD studies. He studied Geomatics, Surveying and Environmental Sciences at EPFL Lausanne, Switzerland, and also holdsz a post-graduate certificate in computer graphics of ETH Zurich. His research interests include cartographic terrain representation, web mapping, the visualization and analysis of map distortion, and the design of world map projections. Ernst Hutzler studied communications engineering at the University of Applied Sciences in Konstanz, Germany, and is now a software developer at the Institute of Cartography of ETH Zurich. He specialized in the development of cartographic extensions and plug-ins for vector graphic software, such as Adobe Illustrator. Lorenz Hurni is Professor at the Institute of Cartography, ETH Zurich. He is the editor-in-chief of the Atlas of Switzerland, the Swiss national atlas, and the Swiss World Atlas, the official school atlas. His current research focus is on cartographic data models, tools for the production of printed and multimedia maps, as well as interactive, multidimensional multimedia map representations.

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