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Rotated Lines: A Heatmap representation method for people affected by any kind of color blindness

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Abstract

Heatmaps are not only used for visualizing air temperature over an area, but also for visualizing vital information such as avalanche and flood danger. Regular heatmaps map the value of the visualized variable at each point of the map to color from a given color spectrum. One popular color spectrum for heatmaps is the red-green spectrum. However, this is also the most problematic color spectrum because red-green color blindness quite frequent. Other color coding schemes affect smaller populations, but the general problem still exits. In this paper we present an alternative visualization of heatmap values which relies on angular shading. We show that the efficiency of this method is equal to the standard method for people without color blindness, and people with color blindness can still interpret the map. The fact that Rotated Line heatmaps can be read by people independent of their individual color vision deficiency, makes this heatmap representation technique particularly useful for public information displays.

1 Introduction

Heatmaps are a popular technique for visualizing information on a map. The method is applied in popular media (e.g. for visualizing air temperature over an area, or avalanche danger), as well as scientific visualization (e.g. visualizing the result of an n-objective optimization processes (Pryke et al. 2007), or Microarray analysis (Schena 2002)). The heatmap creation process can be described as follows (cf. Fig. 1). (a) a heatmap raster is created, which defines the resolution of the heatmap. (b) Data of a matrix is transformed into the heatmap raster. (c) The resulting data is normalized. (d) The heatmap values are transformed into colors which are visualized.

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One approach is to use a continuous mapping, such that each value gets a unique color. This approach is popular in scientific visualization. An alternative approach is discrete mapping. This approach often used in cartography and information visualization. Here, the range of values is split into a number of sub-ranges, where each range is assigned a color. The resulting ordered set of colors is called a palette. In this paper we focus on the continuous mapping approach.

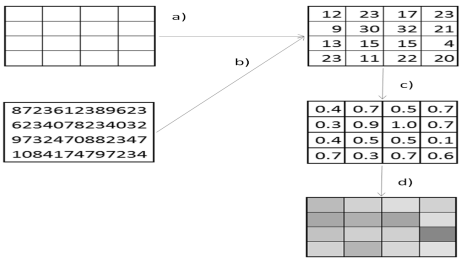

Figure 1 General heatmap generation process

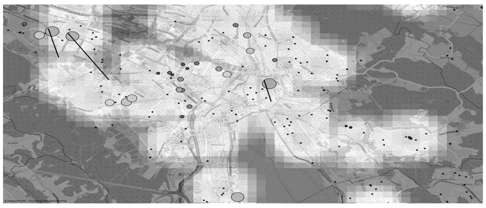
Figure 2 Example of heatmap, 32x32 pixel raster

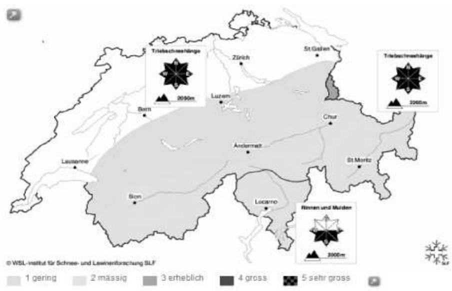

Figure 3 Avalanche information for a normal users

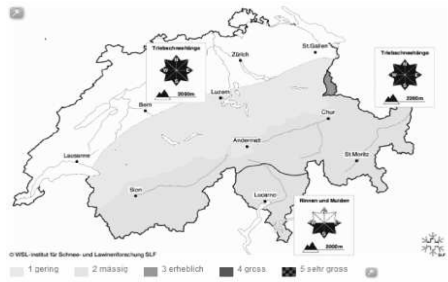

Figure 4 Avalanche information for a protanopia user

Figure 1 displays an overview about this process. Figure 2 shows an example of a generated heatmap with a 32x32 pixel raster. Heatmap values are represented by colors, which makes them not well readable for people with a color vision defect. Particularly problematic is a mapping of values to the red-green spectrum. This is because the loss of green vision and distortion of vision in the red-yellow-green part of the spectrum (Deuteranopia defect) is quite frequent: Up to 8 % of all male and 1% of all females are affected ((Otto Dornblüth 2004), page 551). Providing color blind people with different color transformations is a pragmatic approach for online material, but people with color vision defects such as Monochromacy (Robinson 1997) also known as "total color blindness" (Sharpe 2007) Dichromacy (tritanopia) (Robinson 1997) (blue-green and yellow-violet blindness), and Anomalous trichromacy (tritanomaly) (Robinson 1997) (deficiency in blue-sensitiveness) will still have problems to read the transformed heatmaps.An example from the Website of the Swiss Institute for Snow and Avalanche Research (SLF) illustrates the problem. This website features a heatmap indicating avalanche danger for Switzerland (Figure 3). The website is frequently consulted by people planning their backcountry skiing tours. Figure 4 shows that for a person with a Protanopia defect it is difficult to differentiate between the two given levels of danger. An incorrect interpretation of the information can have far-reaching consequences to the reader of the map. The website does not offer maps with alternative color mappings.

2 Related Work

For choosing color palettes it is helpful to have an idea how human color vision evolved. It has been hypothesized that it developed in three distinct stages: 1. perception of light/dark contrasts (monochrome only), 2. yellow/blue contrasts (usually associated with our notion of warm/cold colors), 3. green/red contrasts (helpful for assessing the ripeness of fruit) (Ihaka 2003).

Three types of color palettes are distinguished: (a) Qualitative palettes, which are sets of colors for depicting different categories, i.e., for coding a categorical variable. (b) Sequential palettes which are used for coding numerical information in an interval where low values are considered to be uninteresting and high values are interesting. (c) Diverging palettes, which are also used for coding numerical information ranging in an interval – however, this interval includes a neutral value. (Zeileis & Hornik 2006)

Wijffelaars (Wijffelaars et al. 2008) presented models to generate sequential, diverging and qualitative palettes. Zeileis et al. presents models to generate qualitative palettes, sequential and diverging palettes (Zeileis et al. 2009) and presents an implementation for the statistical computing software R (Zeileis et al. n.d.). However these methods were not tested on color-blind subjects.

Zeileis (Zeileis & Hornik 2006) describes a color transformation into the yellow / blue color space to support people affected by Deuteranopia. Huang et al. proposed a new re-coloring method for people with Protanopic and Deuteranopic color deficiencies. They use a color transformation that aims to preserve the color information in the original images while maintaining the re-colored images as natural as possible (Huang et al. 2007). These methods provide specific solutions for users with individual color vision defects, but none of the presented methods is able to serve all users independent of potential color defects, additionally these methods may use color palettes which are not intuitive for normal users. This makes them problematic for use in public information displays, such as avalanche maps displays on the slope in skiing resorts.

Alternative approaches to using colors at all are for example the use of shading (ex. choropleth map (Friendly & Denis 2008)) or the use of contour lines (to produce contour maps (Wikipedia 2010)). But these approaches have all additional requirements to the underlying data, like large enough regions of common values must exist for using the shading approach. The possible distinguishable values of shading are also limited as the intensity of the shading must be light as the underlying image may else become unreadable. Shading patterns require much more time to the reader to get an overview of the whole map – increasing with the amount of patterns used – as the reader has no implicit knowledge and training of how to map the pattern to the effective value. The use of contours can also be problematic if applied to a map for displaying values other than contours as this can lead to larger recognition time for the user as the use may be uncommon, e.g. contours for temperature on a geographic map including mountains.

3 Rotated Lines Method

As color blind people can handle contours and shapes much better - depending on their different live experiences (Schaub et al. 2008) - we suggest a new approach which visualizes the heatmap value as the original color value combined with a line – or more lines for better readability, depending on the size of the area per value –, rotated by the heatmap value. Hence, instead of $\mathrm{H_{old}} = \{\mathrm{c}_{0,0}, \mathrm{c}_{1,0}, \dots, \mathrm{c}_{x,y}\}$ where $\mathrm{c}_{x,y}$ = color value for heat map raster point x, y

$$We\ use\ H_{new} = \{(c_{0,0}, angle_{0,0}), \dots (c_{x,y}, angle_{x,y})\}$$

$$angle_{x,y} = \|c\| * MaxAngle,\ with\ MaxAngle = \frac{\pi}{2} \text{ radians and therefore } 0 \text{ rad } \leq \text{ angle } \leq \frac{\pi}{2}\ rad$$

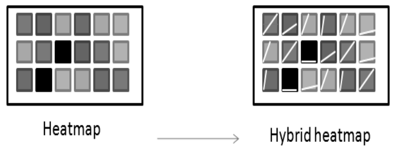

Figure 5 Applying the Rotated Lines method

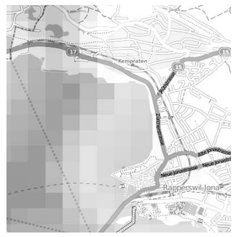

Figure 6 Heatmap in practice using the standard method

Figure 7 Heatmap in practice using the Rotated Lines Method

Figure 5 visualizes this approach. As the figure is only for illustrative purpose, we used some widely different colors for better readability and the values of the colors are not ordered in any way. Figure 6 shows an example of a heatmap in practice using the standard method with the standard colors from red to green. *Figure 7* shows an example of a heatmap in practice using the Rotated Lines Method.

To visualize a line, multiple pixels must be used. This results in a decrease of the maximal resolution of the heatmap. Based on the raster size (one heatmap value is represented within the area of a raster element) of the heatmap, there is a maximal amount of different values which are distinguishably. $\|\mathrm{distinguishable}_{values}\| = \mathrm{d} = \mathrm{raster_x} + \mathrm{raster_y} - 1$, where $\mathrm{raster_x}$ is the amount of pixels of the raster on the x-axis and $\mathrm{raster_y}$ is the amount of pixels of the raster on the y-axis. To represent one heatmap value, the following amount of pixels is used: $\mathrm{resolution_{value}} = \left(\frac{\mathrm{d}}{2}\right)^2$ pixels $[\mathrm{raster_x} = \mathrm{raster_y}]$. For example, a heatmap with a 3x3 pixel raster allows five different values to be distinguishable as shown in Figure 8, whereas 7 values could be distinguished with a raster of size 4x4.

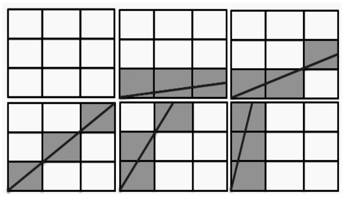

Figure 8 Magnified view of how the 5 possible values of a 3x3 raster are drawn.

4 Validation

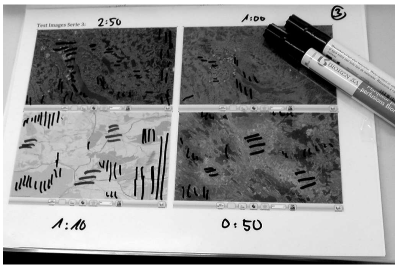

Figure 9 Example of a test assembly where the region are already marked by the test participant.

To test the readability of the Rotated Lines Method we use four different geographical regions. Based on these four geographical regions we created 36 heatmap images, created by 1) the three different method types: a) the standard heatmap method, b) the Rotated Lines Method and c) the Rotated Lines Method without any color information and 2) the use of three of different topological maps (OpenStreetMap, Google aerial map and Bing map) to increase the realism of the test. Test sets were generated so that each test set contained four different heatmap images. The heatmap method and the map provider for an image were chosen randomly. All test sets were printed on photo paper and are laminated on cardboard. In total three test sets were generated. Eleven volunteers (sex: 6 male, 5 females, age: between 18 and 55) participated in the test. None of the volunteers are color blind. Participants were provided with an introduction to the test. Here an example set was presented to them and it was explained how to read the information in the color heatmaps and rotated-line heatmaps. Then the test was started and each participant was given a randomly assigned test set with an overhead transparency placed on top. The participant was then told to go sequentially trough each map in the test set and mark extremely positive and extremely negative regions on each heatmap with a different color marker (c.f. *Figure 9*). We recorded for each heatmap a) the task performance (i.e. time on task), b extreme regions marked correct c) other regions marked correct. As each person has individual working speed, we use relative measures – i.e. comparing the time needed for one method to the time needed for another method – for each participant.

5 Results \ Conclusion \ Discussion

In our test we found the following results. a) We found no relationship between the number of missed regions and the used method, $t(42) = 0.060,\ p < 0.05$. b) Neither did we find a relationship between the number wrongly marked regions and the used method, $t(42) = 0.79$, $p < 0.05$. c) We did however find that the individual performance depends on the used method, $t(42) = 0.00139,\ p < 0.05$. d) The standard heatmap method has a higher performance than the Rotated Lines Method without color information. But between the standard heatmap method and the Rotated Lines method, there is no difference in performance $t(24) = 0.212$, $p < 0.05$. With the Rotated Lines Method we present a new heatmap method for visualizing data for people with any kind of color vision defect. Our test showed that the Rotated Lines Method allows reading the data with equivalent error rate as with the standard heatmap method. For non-color blind people the efficiency of map reading is not degrading when using the new method. We did not test explicitly with color blind people, but we expect that they will perform at least at the level of our observed participants when using the Rotated Lines method without color. Thus their performance will only be slightly degraded compared to non-color blind people. Based on our tests we see no difference in error rates. Our observations during the tests show that with the Rotated Lines Method the heatmap data can be read with more precision than with the standard heatmap method. We reason this as it probably easier to guess the effective value from the angle of the line than from the color. The rotated lines have an absolute value space whereas one is never sure if a color is the darkest or the most saturated. As color blind people can read contours much better, conclude that the Rotated Line method for heatmap visualization provided real benefits for color blind people – while not interfering with the performance of non-color blind people. Thus, the only drawback of the Rotated Line method is a lower maximal resolution of the heatmap. We see useful areas of application for maps with low information density in public information displays. Examples include public displays of air temperature maps, fine particulate air pollution or avalanche information.

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