A Framework for Color Design of Digital Maps: An Example of Noise Maps

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Introduction

Colors have been used in cartography "to label (color as noun), to measure (color as quantity), to represent or imitate reality (color as representation), and to enliven or decorate (color as beauty)" (Tufte 1990, p. 81). In thematic mapping, such as traffic noise maps, color especially is used to represent quantity. Colors are therefore arranged in a color scheme to represent a range of ordered values. Used properly colors then have the power to reveal the structure within the data, but they can also contribute to misinterpretation if used carelessly.

Principles for so-called sequential and diverging color schemes that are used to represent ordered values have been introduced (Harrower and Brewer 2003) and put into practice in *ColorBrewer*, a library for color schemes. *ColorBrewer* laid a theoretical and practical basis for color design in cartography and also indicates the suitability of schemes for users with color vision deficiencies (CVD). Although color design has been addressed in depth and cartographers have described its complexity, examples on the internet show that guidelines are still neglected, especially by untrained map makers. Rainbow color schemes, e.g., are still used in maps and scientific visualizations although their unsuitability was pointed out (Light and Bartlein 2004). Also, the difference between qualitative and sequential schemes has been stressed and the importance of a perceptual order of the color patches has been highlighted (Brewer 1994). The reason why guidelines are ignored is sometimes simply because map-makers, often non-cartographers, do not know *ColorBrewer* or similar libraries and standard software does not give cues to suitable schemes based an data characteristics. However, for some applications,

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like noise mapping, there might not be a suitable, ready-made color scheme. Reasons for this are, e.g.:

- Ready-made palettes are finite (Wijffelaars et al. 2008) and color specifications in *ColorBrewer* should never be treated as ironclad guarantees since color reproduction, whether on screen or in print, is an inexact science (Harrower and Brewer 2003, p. 33).
- *ColorBrewer*, e.g., offers sequential schemes for up to nine classes, but due to a low contrast caused by the high number of groups some colors are quite hard to distinguish, which is especially a problem if the enabling of a correct identification of classes is the objective.
- Nature of data varies strongly for different applications (Harrower and Brewer 2003) and can be ordered (ordinal, interval, ratio scale), with a neutral point, or qualitatively (nominal). Transformed scales, as in our use case logarithmic scales, are also ordered, but it should be considered that, in this case, arithmetic operations are not valid and that higher values contribute more to a mean value. To our knowledge, no guidelines or recommendations are available how this characteristic can be reflected by color schemes.
- Spatial distribution of data can be regular vs. irregular, ordered vs. unordered, or coarse vs. finely detailed. This can lead to different perceptual effects: "The more complex the spatial pattern of the maps, the harder it will be to distinguish slightly different colors" (Harrower and Brewer 2003, p. 32). Schemes with lightness steps only, hence, are not appropriate for more than five or six classes.

With the increasing number of devices, and therefore variety of screen sizes, resolutions, use cases and contexts, color design becomes even more complex. The major challenge of color design for online maps is that output devices present colors differently. Consequently colors have to be optimized to suit a variety of devices, such as computer screens, tablets and smart phones.

Due to this high number of criteria influencing the suitability of schemes, guidelines are highly dependent on use cases, user tasks, respective data and aims that are achieved. Starting with fundamentals, such as color perception and scheme types we thus introduce a framework that concentrates guidelines and combines them with criteria that facilitate the decision on a suitable color scheme. As a proof of concept, we give an outline of the guideline's relevance for the design of noise maps.

Fundamentals of Color Design

Color Perception

How color is perceived depends on many things: "All colors, whether they are seen as direct or reflected light, are unstable. Every change in light or medium has the potential to change the way a color is perceived. [...] Not only are colors themselves unstable, ideas about colors are unstable as well" (Holtzschue 2011, p. 11). Not only physiology, also psychology and cultural background effect how people see and interpret color. The subsequent paragraphs outline the most important principles.

Color Contrast

Color contrast is a result of the perceived difference of at least two colors. The *World Wide Web Consortium* (W3C) defined straightforward recommendations on color contrast in their "Web Content Accessibility Guidelines". Comparable rules are not available for maps because they do not just consist of background and text that have to be balanced. It is necessary to consider the different kinds of contrast.

Classical contrasts are the ones between two colors: light and dark, warm and cool or complementary colors (red/green, yellow/purple, blue/orange). Special contrasts are quality and quantity contrast (Itten 1987). The first occurs when colors of different saturation or purity are combined. The latter describes the effect when contrastive saturations are used for objects of different sizes. Itten (1987) suggests to use colors only in harmonic proportions otherwise it results in an *effect of depth* and warm or saturated colors appear further in the front than cool or unsaturated colors. Especially saturated yellow, orange and red have the characteristic to be salient, therefore they should only be used for values that are meant to be highlighted and in lesser amounts in contrast to blue and green. Figure 1a illustrates, how yellow and orange stand out in contrast to other colors in the map. Hence "the intensity of color which should be used is dependent on the area that that color is to occupy" (Ihaka 2003).

The described contrasts together cause simultaneous-contrast that effects the appearance of colors in dependence on adjacent and background colors. Light colors surrounded by light colors look darker than surrounded by dark colors. An object surrounded by an unsaturated or complementary color appears more saturated than on saturated background (Lübbe 2012). This effect is hard to avoid and predict because the spatial patterns in maps differ significantly.

Effects on Perceived Object Size

Schumann and Müller (2000) describe that the perceived purity of a color is dependent on the object size: A small colored area on black background is perceived more saturated than a bigger area of the same color on black background. In contrast, the color of an object has effects on the perceived object size too because lighter colors stimulate retinal cells more due to higher light reflection (Schumann and Müller 2000, p. 85). Consequently colors can facilitate misinterpretation if the area size needs to be estimated for interpretation.

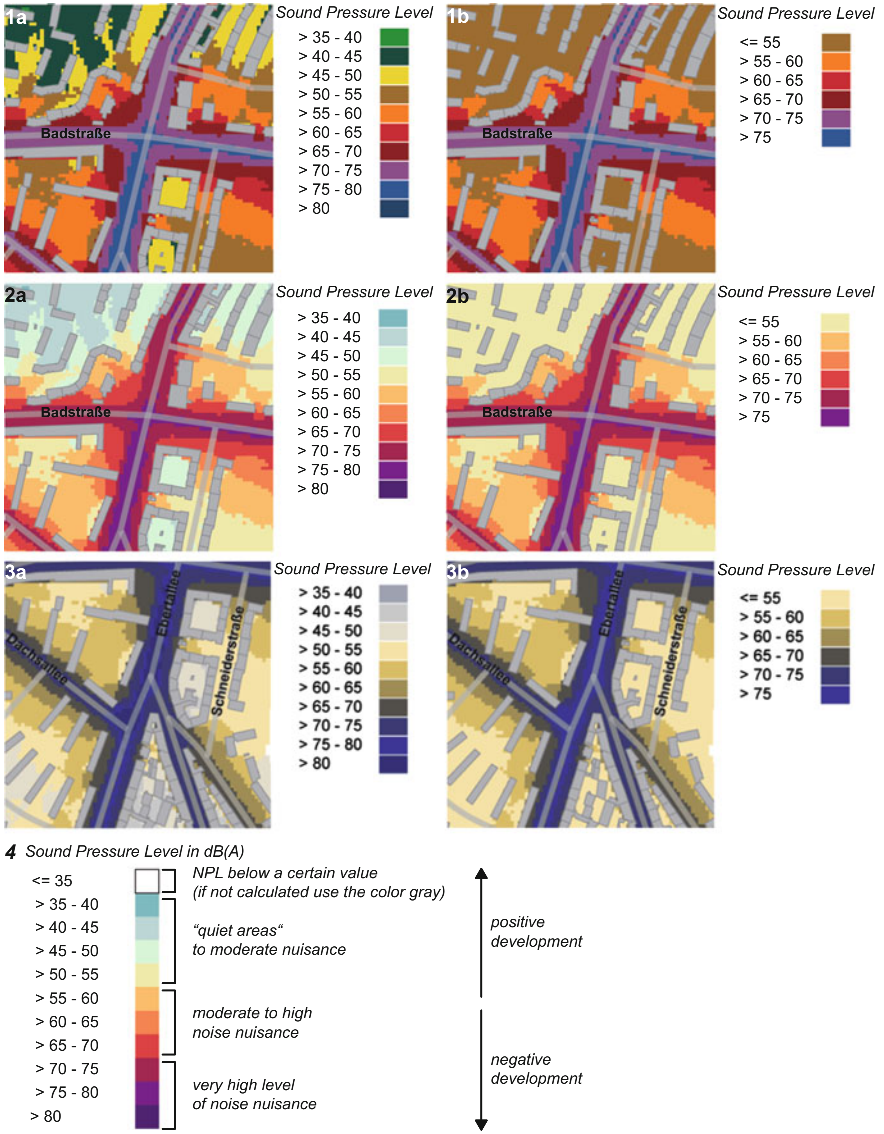

Fig. 1 A map in the color scheme according to DIN 18005-2 with ten classes (**1a**) and six classes compliant to German law (**1b**); the map in the new scheme with ten (**2a**) and six classes (**2b**) and as people with CVD (protanopia) see the new colors (**3a**, **b**). Please consider that the scheme has *only* been optimized for digital use. A color illustration and color codes can be found on the website www.coloringnoise.com

Color: Highly Associative and Emotional

Color is generally connected with mood and emotions, especially hue has strong effects on associations. This is because experiences of everyday life are connected to sensory impressions. A popular example are the connotations of red and green: While red is used to issue a warning, green is assigned a positive semantic (Fischer 2012). Blue and yellow do not have any comparable effects and are less stimulating than red and green (Goldstein et al. 2008). A study on the effects of color schemes on the estimation of nuisance in maps did not show any effects of blue and green schemes in contrast to schemes in warm colors (Weninger 2013). Only vivid schemes with hue-steps lead to higher estimations.

For online maps, as they are accessible from all over the world, it is advisable to consider the cultural aspect of color too. The color for mourning, for example, is black in European countries and white in India.

In psychology effects of color have been studied in depth, nevertheless the consideration of the emotional and affective components in cartography is a recent research area. The *Society of British Cartographers* highlighted the importance of emotion in one of five principles for good map design as early as 1996: “Engage the emotion to engage the understanding” (Jones 2010, p. 150). Griffin and McQuoid (2012) and Klettner et al. (2013) have elaborated on emotion and Fabrikant et al. (2012) present a framework to study emotional responses on map design, under consideration of different color schemes. In the proposed framework associations, connotations, and emotions are seen as crucial aspects of sound map design.

(Situational) Color Vision Deficiencies

Color vision deficiencies (CVDs) and their practical consequences are well known to the scientific cartographic community. As indicated in *ColorBrewer* not all schemes are suitable for people with color vision deficiencies. Programs such as *Adobe Illustrator*, *Photoshop*, and *Color Oracle* (Jenny and Kelso 2007) have a special proof mode. Nevertheless practical examples show that it is still not general knowledge that especially red and green should not be used in combination because 4 % of users have difficulties to distinguish these two colors or are not able to do so at all. Men are much more likely to be affected because of heredity, 8 % have to live with it (Lübbe 2012).

Strictly speaking CVDs are not a perceptual issue but a physiological one, because they are caused by a misfunction of one cone-type and therefore one of the three primary colors—red, green, or blue—cannot be perceived leading to protanopia, deuteranopia, or tritanopia. However, Schumann and Müller (2000, p. 97) claims that deviations from “normal” color vision are quite common and lead to problems distinguishing colors. Besides people that have been diagnosed with CVD, inherited or caused by a disease, color vision deficiencies can also occur if cone photolabile pigments show anomalies which results in a deformed spectral sensitivity curve (Welsch and Liebmann 2012). Affected people therefore perceive colors slightly differently. Additionally, CVDs appear more often during screen handling for a small field of vision (FOV) for up to 2° even though persons concerned do not have any CVD with a FOV around 10° (Schumann and Müller 2000). Results of an experiment showed that 23 % percent of participants were not able to identify numbers on two Ishihara plates while only 13 % of the participants indicated that they in fact had some type of CVD (Weninger 2013). We explain this as a result of *situational* CVD caused by different devices and thus various patterns of use, screen contrast, visual angles and FOV. The issue of *situational* color vision deficiencies and its consequences on map design, according to our best knowledge, has not been studied in cartography, but suggests important insights to support web mapping for inclusion.

Scheme Types

Brewer (1994) identifies two kinds of schemes besides qualitative schemes: sequential and diverging. Diverging schemes have a positive and a negative end which are divided by a neutral point. Sequential schemes can represent ordinal or numeric data in a perceptual order and consist of one or more hues in different lightness steps. If multiple hues are used in combination it has to be assured, preferably by means of a change in lightness *and* saturation, that they can be brought in a perceptual order. Multi-hue schemes with at least one hue-transition are especially reasonable for more than five to seven classes.

As mentioned before, color is highly associative. Therefore the specification of different kinds of scheme types is important to find a suitable scheme for a use case. We therefore suggest a further subdivision of sequential schemes on the basis of some of Imhof's scheme types (Imhof 1965). This characterization is an important basis to decide on the level of abstraction that is described as one decision criteria (see section "Criteria for Decision Support"). His research into relief presentation involved a comprehensive analysis of color schemes as well. Relief presentation as the representation of classified heights is comparable to the presentation of other thematic contents, like physical distributions and phenomena that are usually represented with a low level of abstraction. Amongst other types Imhof defined the following ones:

- **Contrasting schemes**: Contrasting colors are supposed to enhance distinguishability. The amount of contrast of single-hue schemes is defined by the lightness of the first and darkness of the last class in connection with the number of classes. Many single-hue schemes therefore do not contrast much. In addition, the amount of contrast of multi-hue schemes is determined by factors described in section "Color Contrast". It should be adjusted in line with the color design guidelines and decision criteria, that are illustrated in the subsequent section.

- **“The more of a phenomenon, the darker the color”**: This type is based on Imhof’s “the higher, the lighter” example, resulting in a presentation that appears three-dimensional. In thematic cartography this is usually inverted.
- **Modified spectral schemes:** Spectral schemes are popular in visualization—61 % of the papers of the IEEE Visualization Conference from 2001 to 2005 without medical figures made use of the spectral scheme (Borland and Taylor 2007)—nevertheless they are to challenge:

  > Perceptually [...] this scale does not appear linear. Equal steps in the scale do not correspond to equal steps in color, but look instead like fuzzy bands of color varying in hue, brightness and saturation. When mapped onto scalar data, this colormap readily gives the user the erroneous impression that the data are organized into discrete regions, each represented by one of the rainbow colors. This can lead the user to infer structure which is not present in the data [...] (Bergman et al. 2006, p. 119).

  If only parts of the spectral scheme are used and modified—for example saturation and lightness balanced—it can be an interesting option for some use cases with a big data range or a logarithmic scale, as our practical experience showed.

Color Design Aspects for Digital Maps

Color Design Guidelines

Levkowitz (1996, p. 97) defines general guidelines for color design: Colors of a scheme should:

1. “preserve the order of the original values”;
2. “convey uniformity among values they are representing, and representative distances between them”; and
3. “create no artificial boundaries that do not exist in the original data”

The first rule is established in cartography and basis for sequential and diverging schemes. The other two rules are reasonable, but it is difficult to put them into practice, especially for non-cartographers. Especially representative distances is an aspect that has not been further defined in cartography, therefore it is the aim to contribute to this discussion (refer to guideline 2). Moreover, Levkowitz’s guidelines focus on the data and neglect the complexity of perceptional and user issues that go along with color. Color is a physical stimulus that causes physiological as well as psychological reactions. In respect thereof we describe design guidelines that help to develop effective color schemes:

1. To represent partially or fully ordered data colors should build a **harmonical hierarchy** (Jones 2010, p. 46), i.e., lightness *and* saturation should in- or decrease systematically at one end of the scale. Harmonical hierarchy is achieved in single-hue sequential schemes, or multi-hue sequential schemes

that consist of hues that have a perceivable order, like yellow to dark–red, yellow to purple, or yellow to dark–blue. The addition "harmonical" refers to the necessity to balance the scheme considering the saturation and object size (cf. section "Color Contrast").

2. **Match values or class distances and color distances**: The distance of elements or represented classes is next to ordering (see above) and continuity type one data characteristic (Andrienko and Andrienko 2006). Class ranges can be equidistant, i.e., all classes have the same size, or they can be different according to quantiles or natural breaks. Perceptual uniformity is often described as an aim within cartographic science. In color systems like Munsell (1905) or CIE L*a*b the Euclidean distance between any two colors fits with the perceptual distance. For equidistant classes this approach is appropriate, but not for the representation of classes with different ranges or logarithmic scales. Logarithmic data is special, it appears to be equidistant although classes of the antilogarithms would not be. Equidistant schemes could give a wrong impression and classes with higher values would be underrepresented. This has to be considered in the representation. At this point, however, we cannot give any straightforward recommendations about color distances.
3. **Consistency of colors** on a variety of output devices is a major aim. It is the aim to use colors that can be recognized regardless of object size, adjacent colors, or device in use and enable a correct assignment of the object colors to the color patches in the legend. However, we have described many effects that counteract this objective (cf. section "Color Perception"), therefore we recommend the use of different hues in a harmonical hierarchy and fewer steps in lightness per hue—in contrast to single-hue palettes with a high number of classes—to support the recognition of colors.
4. **Avoid colors that are not suitable for (situational) color vision deficiencies.** To consider (situational) CVDs is crucial to facilitate the accessibility of digital maps (cf. section "(Situational) Color Vision Deficiencies"). Already small improvements of the scheme, without completely changing it, turned out to have positive effects (Kröger et al. 2013). Also a reduction of the amount of classes and the use of colors with strong contrast can work against CVD.

Criteria for Decision Support

Each use case is different and therefore a consideration of the specific objective, data characteristics and context is needed. Consequently we propose criteria that support the decision for or development of a color scheme and help to set priorities. Within the development process several criteria can be considered, but there need to be priorities. Although the underlying color design guidelines are the same for each use case, the aim to achieve a high distinguishability leads to other recommended color schemes than the aim to highlight patterns. At this point we cannot present a complete list, but an initial concept.

The basic question for color design—and of course map design in general—is: *What is the aim of the map-maker? What aspect(s) shall be highlighted in compliance with the aim? And what color choice is evoked by the character of the phenomenon that is presented?* Options are:

1. **The user task:** The tasks users are to complete by means of a map are a crucial decision criterion for map design. Andrienko and Andrienko (2006) give a comprehensive overview of tasks for exploratory data analyses, such as:
   a. In **lookup tasks** users are searching for an individual value in the map, such as a sound pressure level of 65 dB(A), or looking up the value of an attribute in a defined place. To complete these tasks it has to be ensured that colors can be distinguished.
   b. For **pattern identification** patterns in the data based on data-interpretation according to the objective are highlighted:
      i. Highlight a critical value, e.g., by means of a contrast-increase or a hue-step. Resulting schemes are sometimes similar to diverging schemes which makes the exceedance of a value striking (see section "Color Contrast").
      ii. Induce a three-dimensional effect by highlighting, e.g., one end of the scheme by means of color effects (see section "Color Contrast").
2. **The level of abstraction:** This facet determines if the color scheme is consistent with the natural color of the occurrence or an associated color, in line with the characteristics of the sensory perception or if it is an abstract choice. We distinguish:
   a. *Realities and physical distributions and phenomena*: e.g., altitude levels, or population density. Because these phenomena have some kind of visual appearance the representation should be less abstract. Representations are more intuitive if an association between their visual appearance and the representation is facilitated. Therefore, e.g., high densities are usually presented by means of darker color, giving the intuitive impression of *more* color meaning *more* subjects or objects per area.
   b. *Phenomena that have a physical, but not visible presence* in space and are measurable and perceivable, such as sound or air pollution. In this case the association between the phenomenon and the representation is not based on their visible appearance, but on other characteristics based on the user's sensory perception, e.g., annoyance for environmental noise. Consequences for color design in such use cases have been described in section "Color: Highly Associative and Emotional".
   c. *Data that do not have any physical presence* in space, e.g., inflation, national debt, energy consumption, age of the population etc. The representation of these examples is most abstract, they do not cause any sensory perception, unless visualized. Hence the choice of a hue does not have to be intuitive, but it will be helpful to consider certain color connotations.

3. **Engage the emotion:** This objective is the most vague of the mentioned herein. Latest research in cartography argues that the way data is presented effects the emotions of users, such as trust (Skarlatidou et al. 2011). In usability engineering user satisfaction is also considered as one of the three parameters according to ISO 4291-11. We regard this facet as crucial in cartography for the following reasons:
    a. to foster positive effects on look and feel; or
    b. to raise attention and increase the recognition value; or
    c. to foster trust in the information; or
    d. to make it persuasive.

However, at this point we will not present straightforward rules as to emotion can be engaged by means of color, besides the aspects of association and connotation (cf. section "Color: Highly Associative and Emotional"). Further research is needed to evaluate if the results of studies on psychology, online marketing etc. are applicable to map reading and data interpretation as well. Nevertheless we would like to stress the importance of this aspect and that it is worthwhile to spend time on the choice or development of a color scheme.

Applicability to Noise Mapping

Strategic Noise Maps According the Environmental Noise Directive

Noise mapping has been obligatory in Europe since 2002 when the European Union adopted the *Environmental Noise Directive* (END). Noise maps have to be drawn up every 5 years by the member states for major roads, railways, airports, and agglomerations. Color represents the sound pressure level in the logarithmic scale dB(A) as equal loudness contours (also isophones) in 5 dB classes. Although these maps are the basis for informing the public [Directive 2002/49/EC, art. 9(2)] examples throughout Europe lack appropriate and satisfactory cartographic presentation. Especially the color scheme is subject of debate (Alberts and Alferez 2001; Schiewe and Weninger 2013) [Fig. 1 (1a, b)]. It is based on the ISO 1996: 2 of 1987. Although the scheme was left out when the ISO standard was revised in 2007 it is still defined in the German Industrial Standard DIN 18005-2 and used in countries such as Austria, Denmark, France, or Italy (Alberts and Alferez 2001). The problem of the scheme is that the colors cannot be put into a perceptual order because the seven hues vary strongly in lightness and can therefore not be intuitively assigned to dB(A) values. Also the signal color red and saturated yellow and orange are used in the middle of the scheme which overemphasizes these values in contrast to the very high values of the range. Moreover, the scheme includes red and green and is therefore not suitable for people with CVD.

Requirements for the Color Scheme

We recommend strongly to define requirements before the development of a scheme. These should consider the color design guidelines specified in section "Color Design Guidelines" and should give an indication of the criteria for decision support (section "Criteria for Decision Support"). In our use case described herein, prerequisites were the class range and the number of classes determined by EU and national law.

Alberts and Alferez (2001) suggest the following considerations for the END-scheme: The scheme should cover a wide range of noise bands from 40 to more than 80 dB(A); noise bands below 50 dB should be in green colors; the bands over 65 dB(A) in red; it should be suitable for different noise indicators like L_{day}, $L_{evening}$ and L_{max} and noise bands of 5 or 10 dB; colors should differ sufficiently; rather topographic objects should be transparent instead of noise bands; color codes such as HEX and RGB should be provided.

We agree with the considerations above, but we add more detailed requirements based on our color design guidelines. Thus the colors of the scheme should be:

- **Distinguishable** for people with CVD as well as when used for areas of different size, in different scales and a variety of screens;
- **consistent** and therefore facilitate a matching of colors used in the map with colors of the map legend;
- **logically assignable to the characteristics of the noise data**; i.e., that presented noise levels should not be under- or overestimated, hotspots and silent areas should be determined by the users without referring to the map legend and colors should facilitate an association with the categories of noise levels.

According to our criteria for decision making the priorities are therefore to highlight a critical value (1.b.i) and to induce a three-dimensional effect (1.b.ii). The level of abstraction is 2.b., hence the colors should be in association with the annoyance levels.

Designing a Color Scheme

The design was carried out iteratively in three steps. Several empirical user studies have been conducted throughout the development process. The first version of the scheme was designed according to cartographic standards as a sequential scheme with two hue-steps (yellow/orange, orange/red), but it did not satisfy noise experts because the different shades could not be distinguished in cases where ten classes were visualized, which is done frequently in Germany. After a discussion with experts from the *German Standardization Organization* requirements were defined not only with a focus on cartographic rules but also with focus on the specific use case and practical requirements. In the second design, therefore, more hue-steps were introduced to support distinguishability and the association of the colors with the annoyance levels. An experiment, including the developed scheme, proved the hypothesis that class and color distances should be matched (cf. guideline 2) (Weninger 2013). Especially Brewer schemes in orange, green, blue, and red, that appear approximately uniform, lead to an underestimation of the sound pressure level, in contrast to schemes with hue-steps. Consequently, we recommend the use of schemes with hue-steps. Moreover, further discussions of the results showed light colors, representing low noise levels, were too saturated and, therefore, too salient. In the third design [Fig. 1 (2a, b) and (4)] a special focus was put on the gradation of saturation. To achieve that areas representing high values are more salient they have to be more saturated than the other colors. The adjustment of saturation was achieved by re-designing the scheme in the Munsell color space, which defines colors by the parameters hue, saturation and lightness (Munsell 1905). This way an increase of saturation and a decrease of lightness for higher values can be facilitated which results in a systematic color order and thus hierarchy. It also helps to induce a three-dimensional effect to highlight hotspots. The five hues—blue–green, yellow, orange, red, purple—are used, which results in a maximum of three lightness steps per hue. The hue-steps in combination with high contrasts are meant to represent a big data range to indicate the logarithmic scale. They also enhance differentiation and thus counteract effects of simultaneous contrast. Each hue stands for a certain level of noise nuisance to support recognition of levels. In the style of a traffic light scheme, which is seen clearly to communicate the exceedance of a value, a diverging scale was implied, using light yellow as a neutral point between moderate nuisance and higher levels of nuisance. By means of the diverging scheme the positive and negative extreme values are highlighted. A bluish green was used to help people with CVD to discriminate green and red.

Conclusion and Outlook

We gave an overview of the manifold perceptional and psychological effects on colordesign, such as color contrast, effect of depth, effects on the perceived object size, the emotional and associative aspects of color, and (situational) color vision deficiencies. While in recent cartographic work often the technical aspect of color design, for example, automatically generating palettes are the focus (Steinrücken and Plümer 2013) we emphasized perceptional issues in the development of guidelines and decision criteria that especially consider digital maps. In particular different kinds of color contrasts and the emotional aspect have been covered in more detailed.

Our hypothesis is that a big variety of output devices and manifold patterns of use, which are characterized by different lightning conditions, screen sizes and visual angles, effect color perception and thus color design. One of the major aspects here is the consideration of color vision deficiencies, both inherent and situational, in the design of a color scheme.

(continued)

Due to the high complexity and interaction of effects it is almost impossible to come up with straightforward rules or a set of color schemes that fits every use case. Thus, we state that the design of color schemes cannot solely be done on the basis of four design guidelines, but this has to be supported by the use of decision criteria. They are necessary to further define the use case specific objective of the map, user tasks and to adjust the scheme to the respective requirements.

The guidelines for color design—(1) harmonical hierarchy, (2) match value or class distances and color distances, (3) consistency of colors, and (4) avoid colors that are not suitable for (situational) color vision deficiencies—are based on research in color science and cartography. The design of a color scheme to represent sound pressure level in maps showed its relevance and proved there was need to come up with decision criteria to choose a final scheme. The decision criteria are in a preliminary state and have to be refined by considering a variety of use cases. Of particular importance is the consideration of emotional responses and the effects on trust; initial foundations for this have been laid by Skarlatidou et al. (2011) and Fabrikant et al. (2012). Additional research on color distance and the combination of effects of hue, lightness and saturation on the association of colors with respective data values and the interpretation of maps is needed to establish clearer rules. Results of the latest user study on the association of the proposed color scheme showed the essential role of connotations with hue and the amount of red/blue that is decisive if a color is interpreted being warm or cool. Results also gave an indication of the perception of color distances, but systematic experiments are needed to analyze patterns.

As soon as the guidelines and decision criteria have been refined by adapting them to other use cases and considering existing factors for color design as described in Slocum et al. (2009), a comprehensive framework can be presented. It will not only list several aspects, but it will also connect them with straightforward recommendations and illustrations in a decision tree. Then this framework can supplement prevalent mapping tools like *ColorBrewer*.

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