Survey of Color for Information Visualisation Guidelines for Choosing the right Colors in Information Visualisation

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Abstract

Since information visualization becomes more and more important, choosing the right colors for representing various data becomes a key element of information visualization. How to deal with people who have color vision deficiency and how to express specific data like amount of trees or wedges of people. The survey presents a short overview of how to choose the right color and what colors should be used.

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Chapter 1

Introduction

Nowadays information visualization becomes more and more important. To get an overview of a specific field very fast charts and figures can be used to describe massive amounts of data. With an increasing amount of data categories also the number of necessary colors will increase and therefore it is very important to choose the correct colors, to not confuse the audience [Stone 2002]. This survey is kind of a guide, which colors should be used and what has to be kept in mind if colors have to be chosen. Nevertheless in every culture colors have different meanings and express different things and emotions. Therefore this paper is a guideline for people creating information visualizations with an audience mostly in western regions. The first section covers colors in general, what are its properties and how can they be differantiated. The following chapter focuses on the human visual system containing basic information about the human eye and color vision deficiencies. The next chapters are focused on color accessibility, more specifically how to create information visualizations with people who have color vision deficiency in mind and how to use colors in a way to underline important information visually and express them in a correct way. The last chapter describes some tools which help finding the correct colors for information visualizations or even tool, which check chosen colors for their accessibility.

Chapter 2

Colors in General

If a person is asked about a color, the response will typically be a hue, like orange, green, yellow, blue etc., if the color is light or dark or vivid, muted, colorful and grayish. With this information a perceptual model can be generated as can be seen in Figure 2.1. The edges of this model have equal length, which means it is uniform [Stone 2002].

2.1 Light

To represent light, a spectral distribution function or short spectrum is used, also shown in Figure 2.2. Each color is defined by a different wavelength. The spectrum ranges from 370–730 nanometers for visible light. The y coordinate of the function describes the power or in other words the brightness of the certain color. Values below 370 nanometers and higher than 730 nanometers are defined as ultraviolet and infrared light [Stone 2002].

2.2 Lightness | Brightness | Intensity | Luminance

Lighntess, *brightness*, *intensity* and *luminance* are terms which get often used to describe a color as dark or light. They all sound the same but have different meanings [Stone 2002]:

- **Brightness**: Brigthness is usually associated with lights or light emitting sources as an absolute value.
- **Lightness**: Lightness is often associated with reflecting surfaces as a relative value to an already defined white area.
- **Intensity**: Intensity can be measured with its units light power. Every wavelength has its own intensity. It can be calculated by taking the integral of the *spectral distribution function*.
- **Luminance**: Luminance describes how much intensity is perceived regarding the eye's sensitivity. To calculate the luminance the *luminous efficiency function* as you can see in Figure 2.3 is needed. The function has its peak at 555 nanometers, which is in the yellow green spectrum. This means that the eye is more sensitive to green/yellow light. To get the luminance, the spectrum of a certain color has to be multiplied with the luminous efficiency function and its integral is the resulting luminance. In other words if there are two lights, one is yellow and the other one is violet and both have the same intensity the yellow one will appear much brighter since its luminance is much higher regarding the luminous efficiency function.

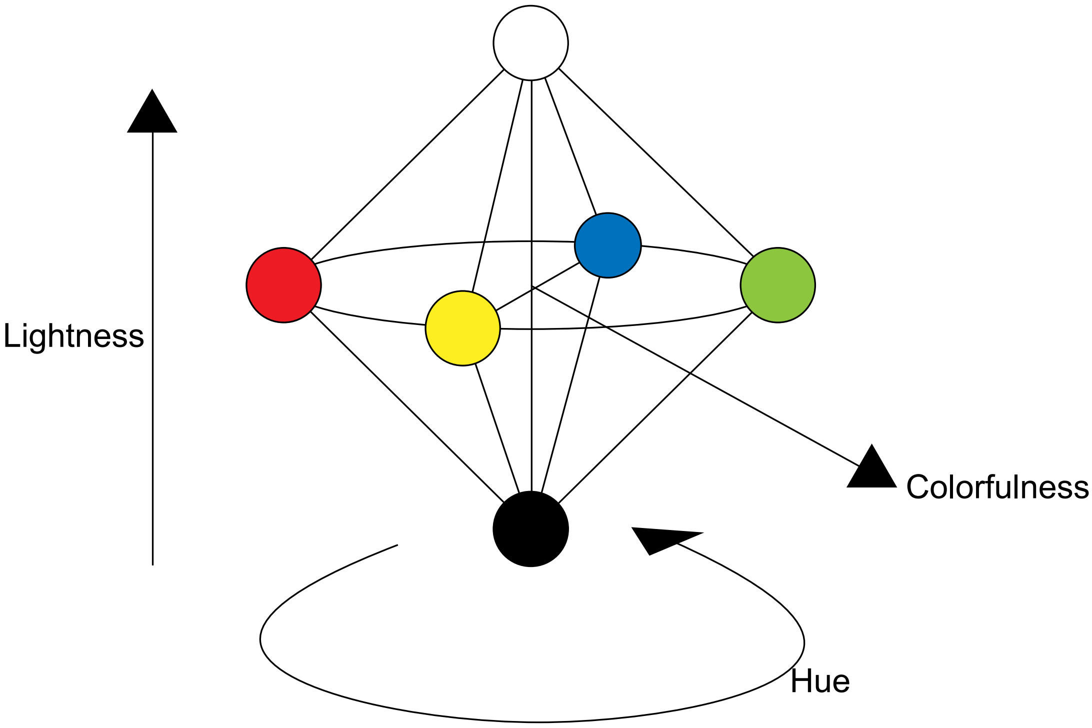

Figure 2.1: Perceptual model of colors [Image from [Stone 2002] redrawn by the author of this paper]

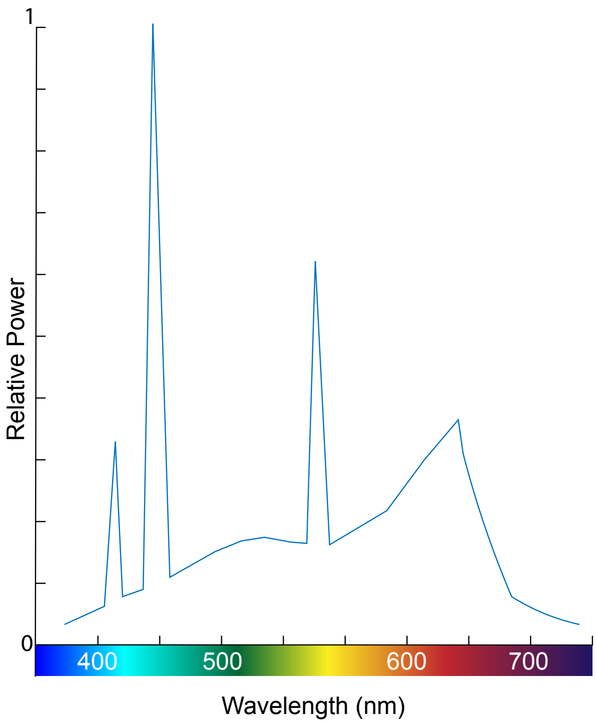

Figure 2.2: Spectral distribution function [Image from [Stone 2002] redrawn by the author of this paper]

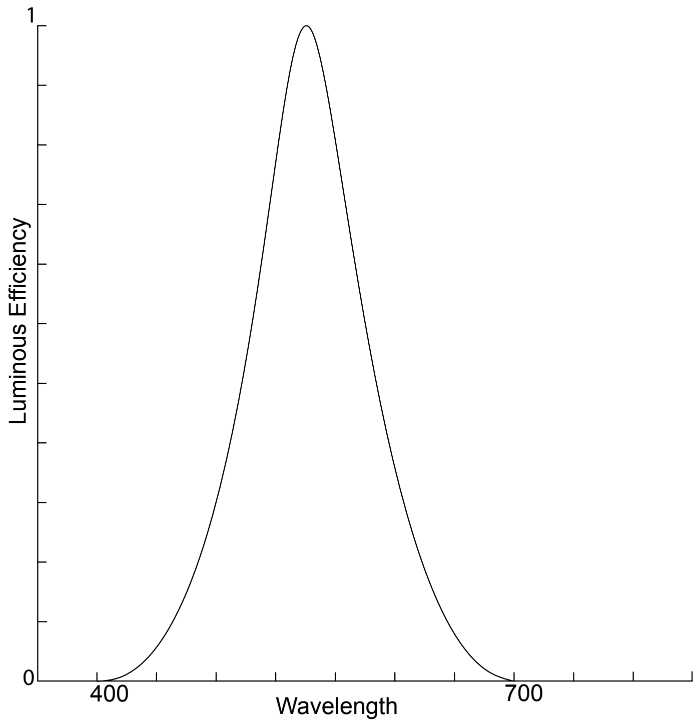

Figure 2.3: Luminous efficiency function [Image from [Stone 2002] redrawn by the author of this paper]

2.3 Colour Spaces in Digital World

A perceptual model is good to represent colors for humans, but if a computer should be able to understand and to interact with colors, a representation is needed. There are many different color spaces, which can be represented in a technical way. [Logvinenko 2015]. Typically they consist of 3 to 4 values. Figure 2.4 shows a bar chart in different colors and its values in some specific color spaces[Stone 2002]. One of the most common ways to express colors is through the RGB color space. [Poynton 2003]. To represent a color in RGB color space a unit cube as shown in Figure 2.5 can be used. It starts n the lower left corner at (0,0,0) which represents black and goes to the upper right corner with value (1,1,1) which represents white. Three of the remaining vertices represent the primary colors red, green and blue and the other three vertices describe cyan, magenta and yellow. To combine two colors they can be simply summed up to get the desired color. Values greater than 1 or smaller than zero will be not within the cube anymore and therefore the values will be limited from 0 to 1 in most of the cases [Stone 2002].

Figure 2.4: This image shows a bar chart in different colors and its values in specific color spaces. [Image created by the author of this paper]

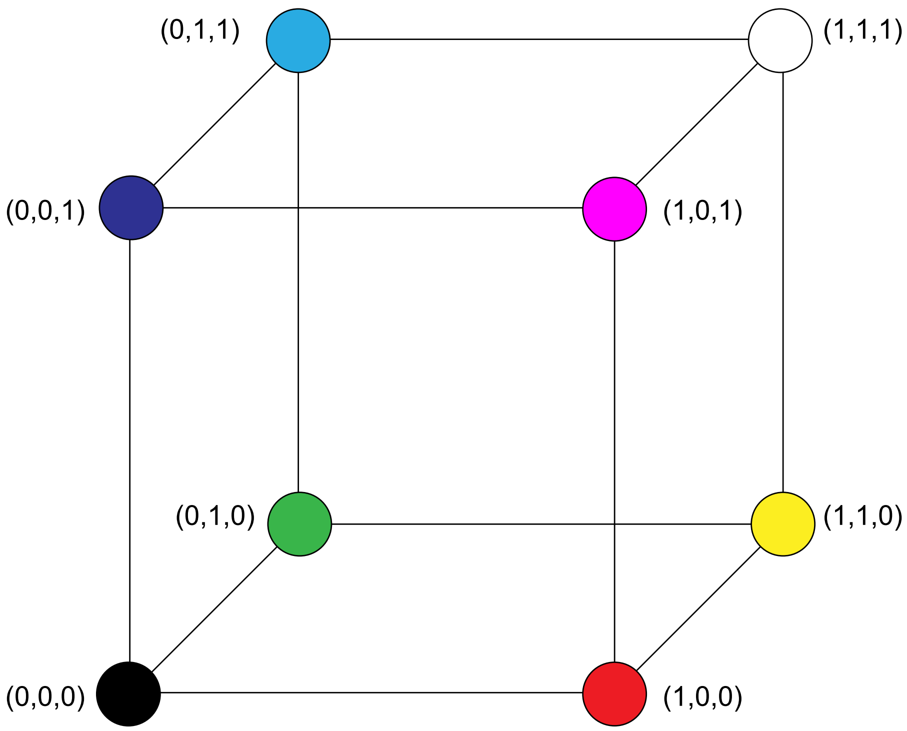

Figure 2.5: RGB Color Cube with its normalized RGB values in each vertex [Image from [Stone 2002] redrawn by the author of this paper]

Chapter 3

Human Visual System

The human visual system consists not only of the eyes but many other parts like the optic nerve or the visual cortex. Color vision starts in the eyes and these organs are the main focus of this part. The human eyes are marvellous sensory organs with a large number of components as depicted in Figure 3.1.

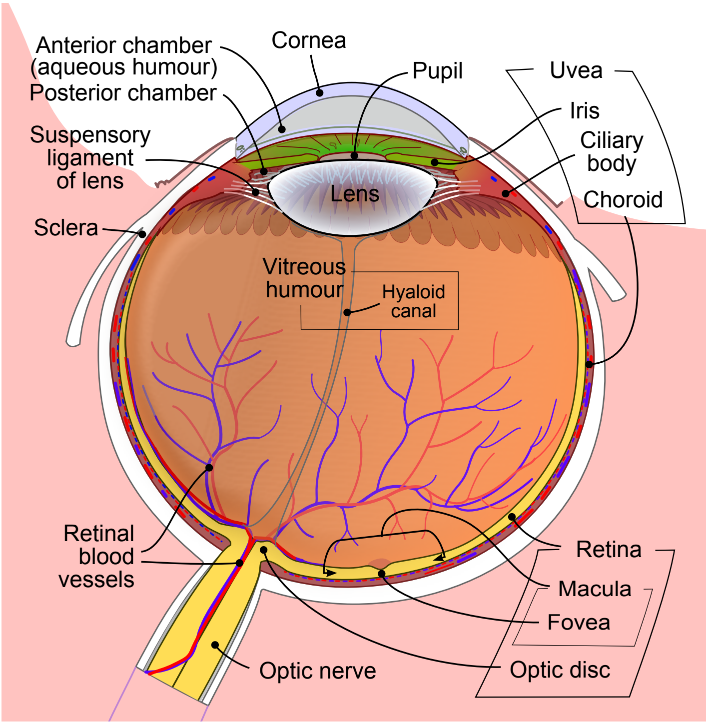

Figure 3.1: Illustration of human eye [Image from Wikimedia[Rhcastilhos. and Jmarchn. 2007] Used under the terms of Creative Commons CC BY-SA 3.0]

3.1 The Retina

One part that is very important for the human visual system is the retina. The retina is the light-sensitive, innermost layer of the eye. Within the retina there are several layers of photoreceptor cells. These photoreceptor cells can be divided into two categories, the rods and the cones. The rods are mainly for light vision, meaning they provide black-and-white vision. The cones function best in relatively well-lit conditions as opposed to the rods and provide color vision. These photoreceptor cells have a distinct distribution in the retina and therefore different parts of the retina are mainly responsible for certain types of vision.

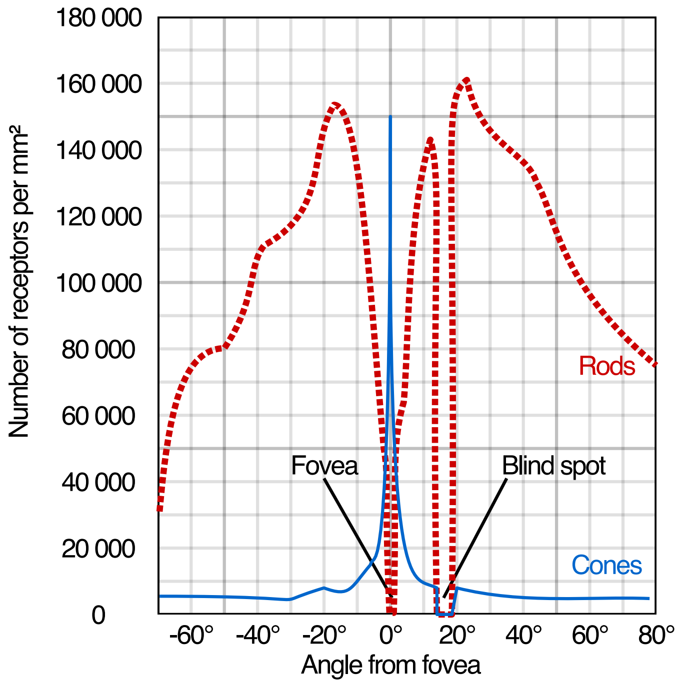

Figure 3.2: Human photoreceptor distribution [Image from Wikimedia [Cmglee no date] Used under the terms of Creative Commons CC BY-SA 3.0]

Figure 3.2 illustrates the distribution of rods and cones in the retina. The highest concentration of cones is in the fovea, the spot in the center on the retina directly opposed of the pupil. The density of cones rapidly decreases with the distance from the fovea and hardly any cones at the edge of the field of view. Rods on the other hand are more evenly spread across the retina with a lot more cells even at the edge of the field of view, but rapidly decreasing in density when close to the fovea. Directly in the fovea there are no rods at all, as well as in the so-called blind spot on the retina where the optic nerve enters the eye. This distribution of rods and cones is responsible for the fact that peripheral vision is monochromatic.

3.2 Color Vision

The human visual system is capable of color vision, especially trichromatic color vision because there are three different types of cones. The different types of cones are called S, M, and L, for short, medium and long wavelengths because each type corresponds to a different wavelength of light that excites them. Short wavelengths are perceived as blue, medium wavelengths as green and long wavelengths as red. All of these wavelengths are between approximately 380 nanometers and 780 nanometers of the electromagnetic spectrum. This small part is called the visual spectrum.

Cone type	Name	Range	Peak wavelength
S	β	400–500 nm	420–440 nm
M	γ	450–630 nm	534–555 nm
L	ρ	500–700 nm	564–580 nm

Table 3.1: Peak wavelengths of the different cone types taken from [Hunt 2005]

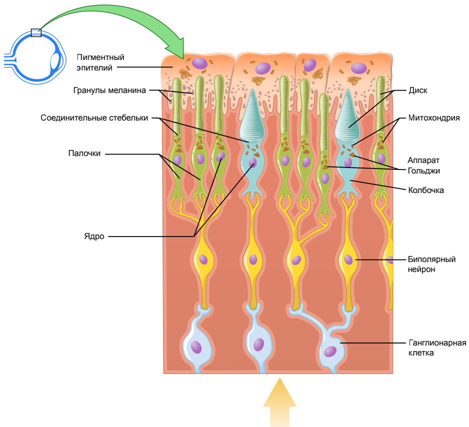

Figure 3.3: Illustration of the two types of photoreceptor cells. [Image adapted from Wikimedia[College 2013] Used under the terms of Creative Commons CC BY-SA 3.0]

3.3 Color Vision Deficiency

If there is any abnormality within the eye regarding the cones then a person suffers from color vision deficiency or even color blindness. There are two major types of color vision deficiency or partial color blindness: the so-called red-green color blindness and the so-called blue-yellow color blindness. If a person suffers from a partial color blindness then the person has a difficulty distinguishing either red and green or blue and yellow, as the names suggest. Total color blindness on the other hand means that a person is unable to see any color, so only black-and-white vision. A typical way to test if a person suffers from color vision deficiency is the Ishihara test.

Color vision deficiencies can be distinguished by the cones causing them. If one type of cones - S, M or L - are missing completely then it is called Tritanopia, Deuteranopia and Protanopia respectively. If there is only a defect of the cones then the color vision deficiency is called Tritanomaly, Deuteranomaly and Protanomaly respectively.

Type	Men%	Women%
Protanopia	1.0	0.02
Deuteranopia	1.1	0.01
Tritanopia	0.002	0.001
Cone monochromatism	very rare	very rare
Rod monochromatism	0.003	0.002
Protanomaly	1.0	0.02
Deuteranomaly	4.9	0.38
Tritanomaly	rare	rare
Total	8	0.4

Table 3.2: Types of color vision deficiencies types taken from [Hunt and Pointer 2011]

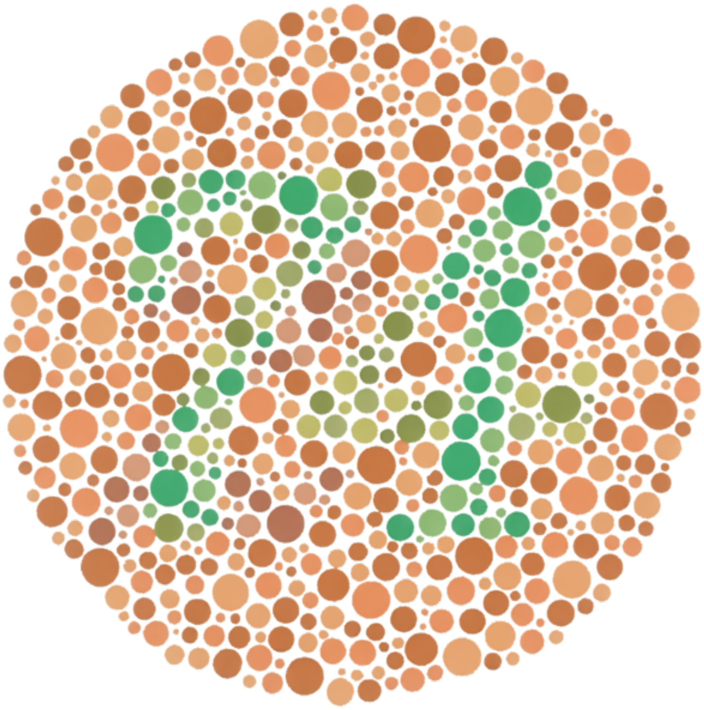

Figure 3.4: The Ishihara test is a typical way to test for color vision deficiencies. The number 74 should be clearly visible with normal color vision. People suffering from dichromacy or anomalous trichromacy may read it as 21. [Image from Wikimedia [Cmglee no date] Used under the terms of Creative Commons CC BY-SA 3.0]

Ethnic Group	Men%	Women%
Caucasians	7.9	0.42
Asians	4.2	0.58
Africans	2.6	0.54

Table 3.3: Percentage of people suffering from color blindness by ethnicity taken from [Machado et al. 2009]

Chapter 4

Color Accessibility

Accessibility in the digital world describes the approach to use designs that can be used and understood even by people with disabilities. Techniques to comply to accessibility can contain auditory feedback, haptic feedback or some form of screen reader. This paper will focus only on color vision deficiencies as targeted disabilities and only on improving the color schemes used for information visualizations. Guidelines for color accessibility start with choosing a good color palette which has a high contrast between the chosen colors and ranges up to redundant encoding of information. All of these important aspects will be discussed in the next chapters.

4.1 Color Palettes

Finding the correct color palette for an information visualization is not that easy. Although there are already many color palettes available on the internet many of these are designed for user interfaces and not for presenting data. Sometimes there are just too few colors on the chosen palette or the palette consists of a gradient color set which has not enough variations and so the colors become indistinguishable. The best way to circumvent these limitations is to create a new color palette. However there are some rules to consider when creating a personal color palette. It should provide enough variation in both brightness and hue. Using intuitive colors instead of static colors, which achieves a natural association. Choosing a gradient set of a color makes it easier to pick the desired amount of colors and still provides a good variation in brightness and hue for the data [Samantha Zhang 2015]. A good starting point are the Brewer Palettes by Cynthia Brewer [Brewer 2017].

4.2 Contrast

One of the most known terms in the topic of color is contrast. It appears on the TV settings or when dealing with photography. Colors do not have a contrast by themself, but rather in relation with other colors. Contrast is the difference between two colors, so the higher the ratio the easier it is to distinguish them. Increasing or decreasing the contrast can make a picture better or worse, which is illustrated in Figure 4.1, where in the left column the contrast is decreasd from top to bottom, while in the right column the contrast increases [Wikipedia contributors 2019b].

For visualization it is always important to be able to either read a text on some colored background or to distinguish between two colored areas side by side. There are guidelines which give specific minimum contrast ratio values to make it easier for the user to pick the correct colors. This guideline is called the "Web Content Accessibility Guidelines" (WCAG) and is primarily for all developers of web content and covers a lot of different aspects. For the purpose of contrast there are two standards in this guideline, AA and AAA. When it comes to legible text on a background the required contrast ratio for AA has to be 4.5 (larger text 3) and for AAA it is 7 (larger text 4.5) [Cooper et al. 2008].

The creators of a visualization do not need to calculate contrast ratios by themself to figure out the correct colors because there are plenty of Web Applications available, one of them will be discussed in chapter 6 about Tools.

Figure 4.1: Contrast Change - Top left shows the original, left column decreases in contrast and right column increases. [Image taken from Wikimedia Commons [Commons 2018]. Used under the terms of Creative Commons CC BY-SA 3.0]

4.3 Redundant Encoding

Redundant encoding describes a technique to not only convey the information via a color but also with some other visual feature like a shape. The next chapters describe some redundant encoding techniques which can be applied in some form or another to most information visualization types like bar charts and line graphs.

4.3.1 Shapes

Shapes are sort of the prime example for redundant encoding by visual features. Shapes are mainly used in scatter plots to distinguish different classes of the data points. Redundant encoding with shapes as a second visual feature can lead up to a 13-18% faster processing compared to either of the single visual features as Christine Nothelfer [Christine Nothelfer 2016] found out when she conducted her studies in this field. These numbers are for people with normal color vision. For people with a color vision deficiency using two visual features with redundant encoding may be the only way to understand the information within a visualization. A basic example for redundant encoding is shown in Figure 4.2.

Another example where redundant encoding of color and shape is beneficial is the repetition discrimination task [Vickery and V Jiang 2009] where a subject is asked which object or group of objects is repeated. An illustration of this experiment can be found on Christine Nothelfer's blog. [Nothelfer no date].

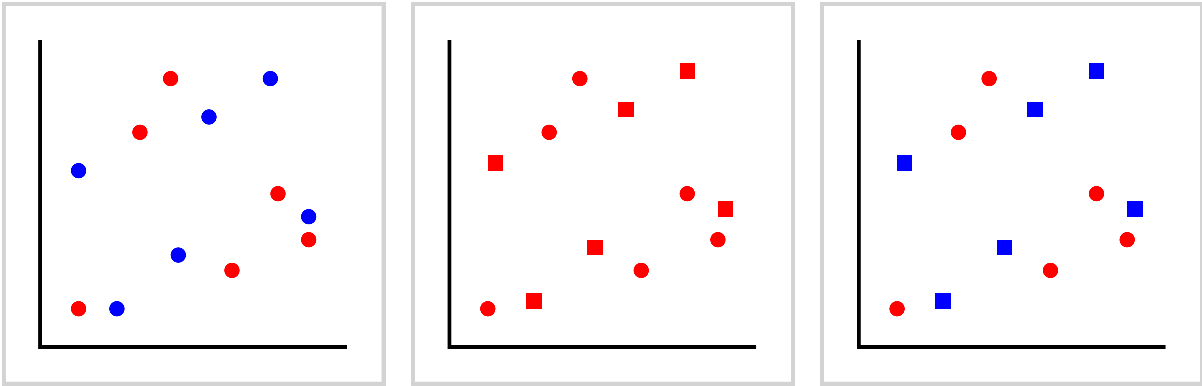

Figure 4.2: An example for redundant encoding within a scatterplot and two classes of data points. [Image from [Nothelfer no date] redrawn by the authors of this paper]

4.3.2 Patterns

Another approach to ensure accessibility of an information visualization is to overlay colors with patterns. This technique can only be used with larger areas of color like bar charts. The good thing about overlaying colors with patterns is that the original color choices are not altered and therefore to do hamper with the color perception of people without color vision deficiencies[Sajadi et al. 2013]. The patterns can be of shape or form like straight lines, crosshatch patterns or even simple geometric forms like circles and rectangles. Basically any pattern can be used as long as it is not too obtrusive and hinders people with normal color vision to understand the information visualization. Some examples for patterns can be found in Figure 4.3.

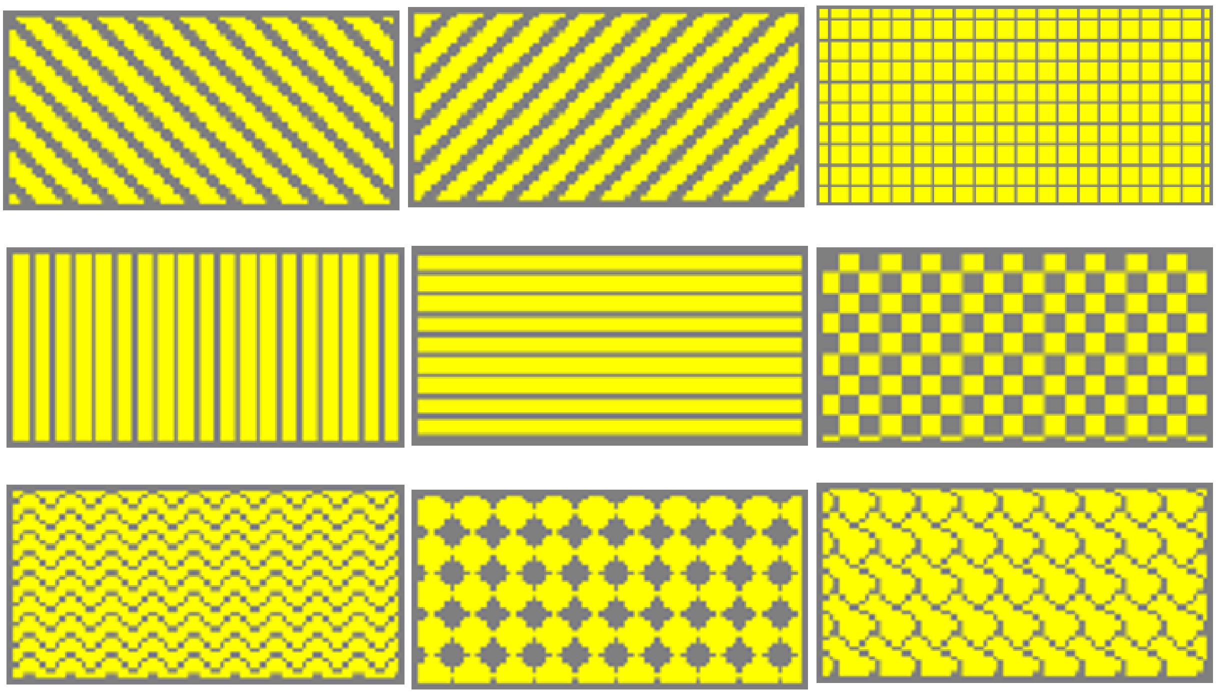

Figure 4.3: An example for redundant encoding of colors overlayed with patterns. [Image drawn by the authors of this paper]

4.3.3 Line Styles

A third technique for redundant encoding especially for line graphs is to use different line styles like solid, dashed or dotted lines in combination with color. In most cases the lines in a line graph are rather thin and therefore patterns cannot be applied in a way that helps to distinguish them. Line styles are good way to improve distinguishability between them even without the "Focus and Context" method described the chapter 5. A small example of different line styles is illustrated in Figure 4.4.

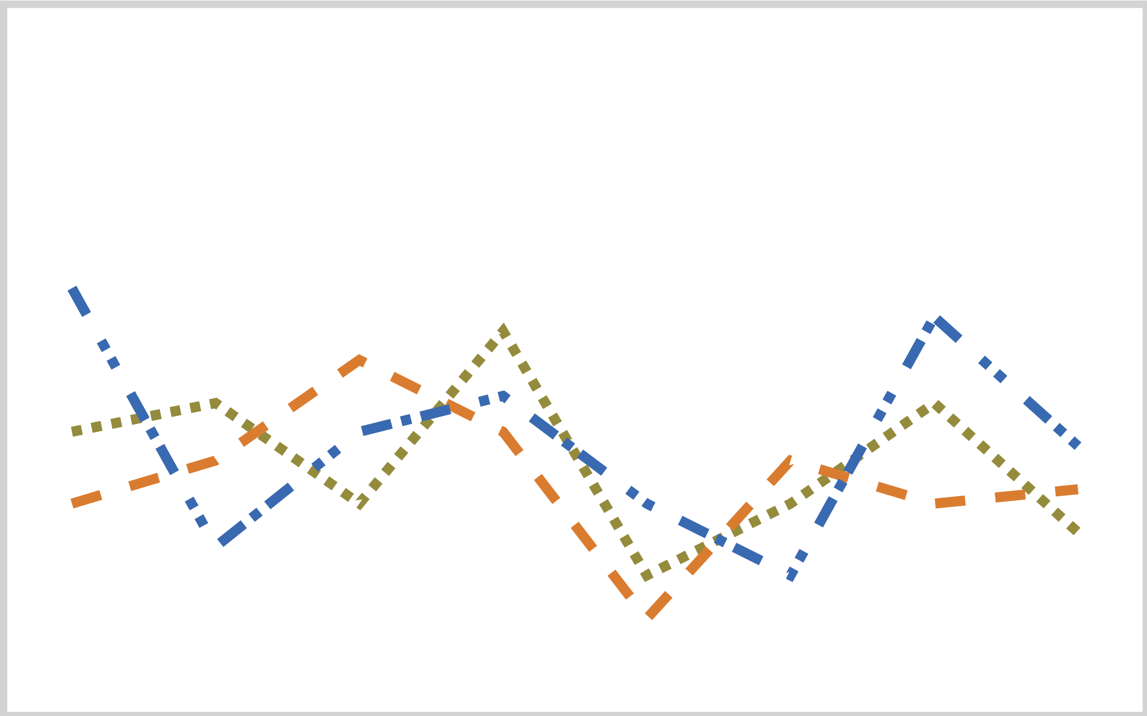

Figure 4.4: An example for redundant encoding in a line chart with different line styles. [Image drawn by the authors of this paper]

Chapter 5

Best Practice for Information Visualization

Charts and other data visualizations are often presented in color for better understanding. Different colors and types of visualizations can make complex data easier to comprehend [Samantha Zhang 2015]. Being involved with the data that should be visualized gives a head start in the iterative process of trying out different styles and figuring out the best way to visualize the data. Each color has a different effect in the eye of the reader and can quickly distinguished for example red from green. That is why data visualization is a unique form of art that arouses the interest and focuses attention on a statement. What is visualized in color is internalized faster by the reader. For example take a line chart where all but one of the lines are put in the background by making them grey and highlight one of them in a visible color. This colored line becomes the focus point of the chart and draws the attention.

5.1 Color Consistency

To make better information visualizations it is important to use the same colors for the same variables. For example if there are multiple charts with the same data always use the same color for specific variables throughout your information visualization. It can be confusing to the audience when there are different colors for the same variables. When choosing only one color for all charts stick to the same color is the best choice, otherwise the visualization will be too colorful and quite hard to understand [Lisa Charlotte Rost 2018a]. The Figures 5.1 and 5.2 show an example of how to use the same colors for the same variables in different charts.

5.2 Amount of Colors

Colors are useful to make it easier for the audience to understand the data but it gets harder to read the more colors are chosen. According to experts on the subject of colors for data visualization seven to ten colors are a good number to make the charts not too colorful [Lin et al. 2013] but still visually appealing. If there are more than ten colors the readers will not be able to decipher the values fast enough. To prevent this the data can be grouped into categories or extend the chosen color palette by using different brightness or adjust the hue of some of the chosen colors. The Figures 5.3 and 5.4 show an example of how to avoid using too much colors by grouping values it into categories.

5.3 Gradient Colors for Continuous Values

Using gradient colors is a useful teqhnique when visualizing continuous variables, for example showing the wages of people. An example for that kind of visualization is illustrated in in Figure 5.5. Gradient colors are also useful to show patterns on a map. Always choose bright colors for low values and dark colors for high values because it is more intuitive for people to associate this with a scale of values. Gradient colors are not really suited for categories to visualize because the audience might imply a ranking

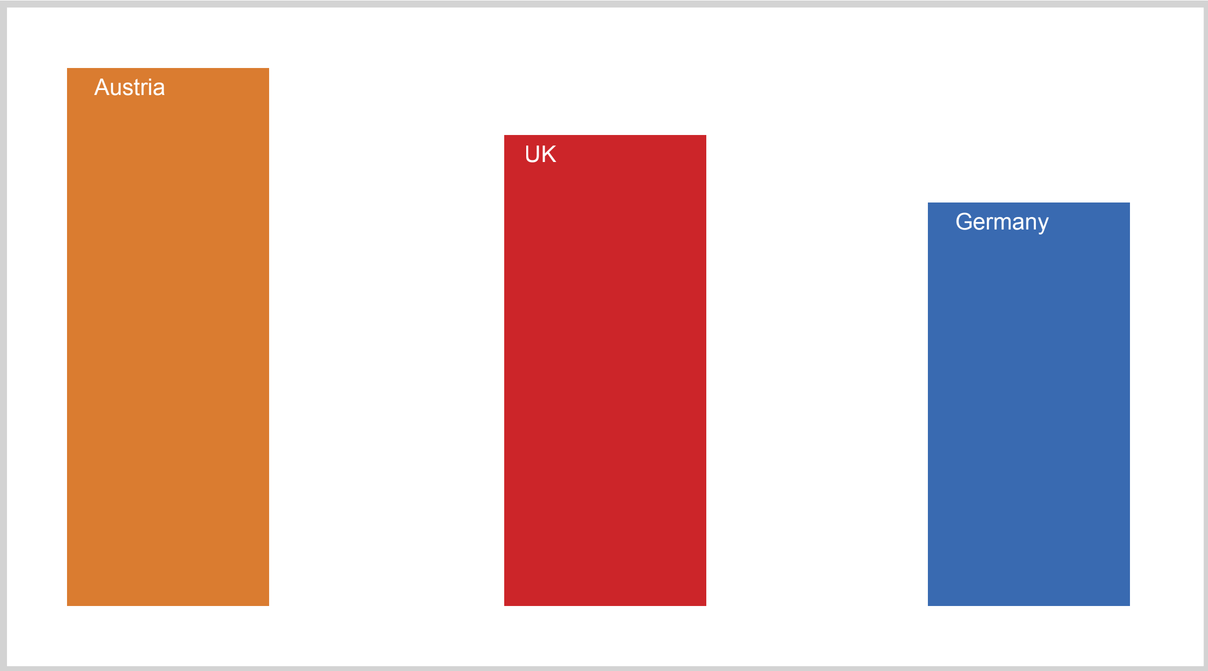

Figure 5.1: Choose a color for a specific variable and stick to the color throughout the visualization [Image drawn by the author of this paper]

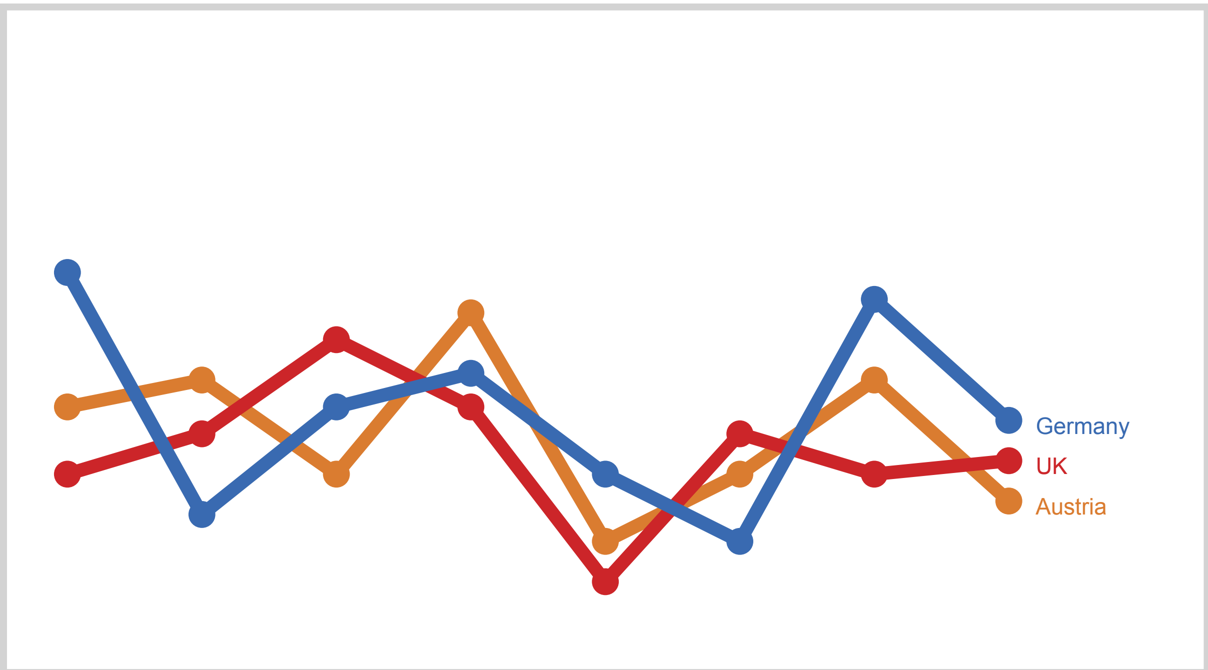

Figure 5.2: Stick to the same colors for the same values in following charts [Image drawn by the author of this paper]

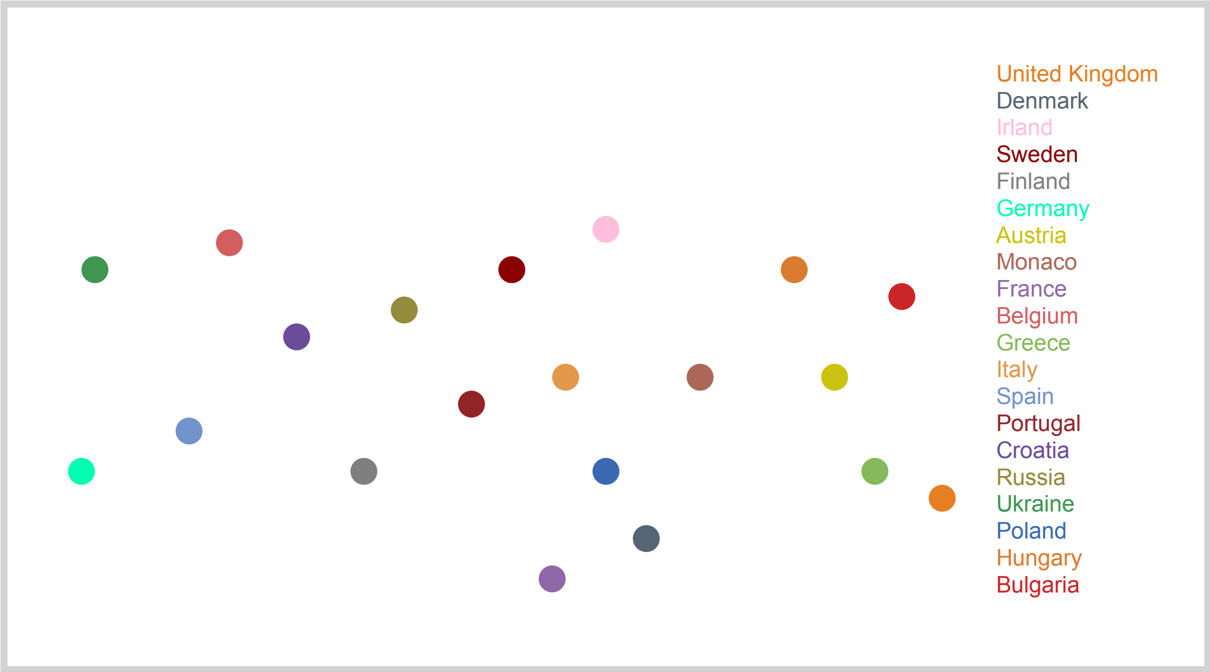

Figure 5.3: Countries of europe with one color for each country which makes it hard to understand (too colorful) [Image drawn by the author of this paper]

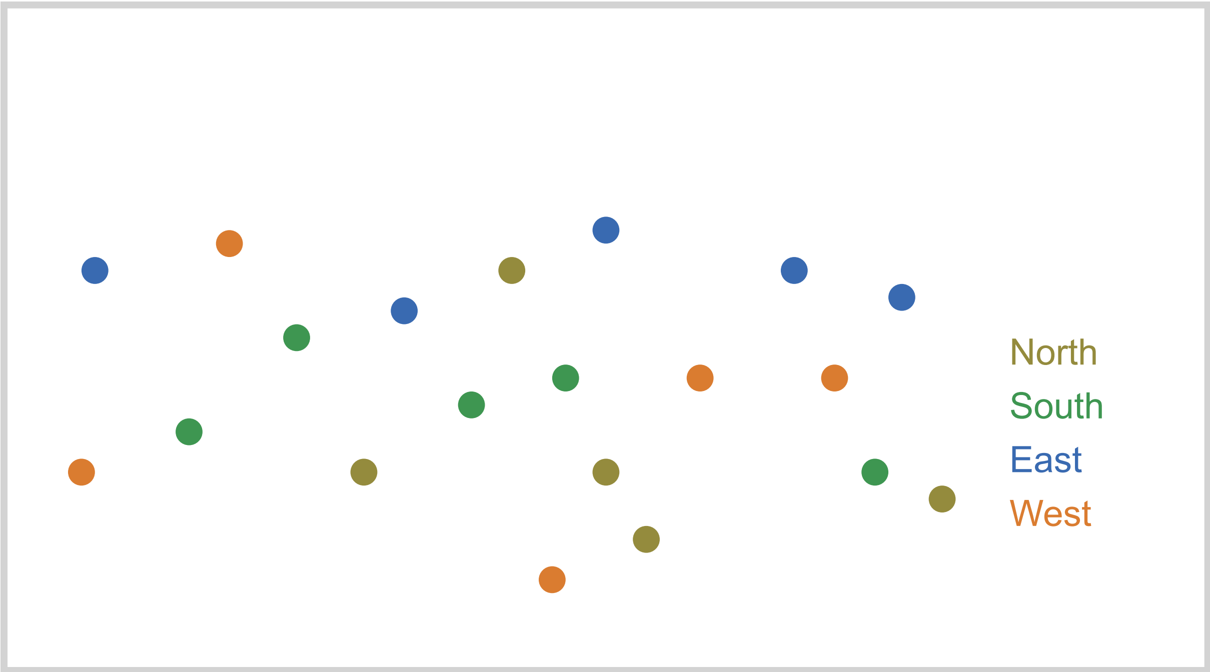

Figure 5.4: Better solution by grouping the countries into categories [Image drawn by the author of this paper]

Figure 5.5: The upper bar is a bad example of using gradient colors, the second bar illustrates the correct usage, bright colors for low values and dark colors for high values [Image drawn by the author of this paper]

of the categories [Lisa Charlotte Rost 2018b]. When the data can be displayed as categories, distinctive colors are a good choice [Lisa Charlotte Rost 2018b]. Split the color palette into bins which makes it easier to decipher the values and see the differences between them. Finding good colors which draw the attention the audience can often be a problem, so there are some helpful tools to generate distinguishable colors using various methods which will be discuss in more detail in the following section.

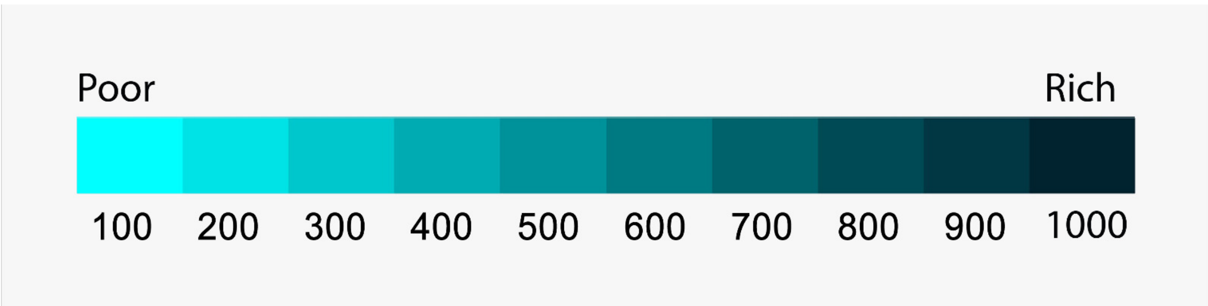

Figure 5.6: Shows a more detailed bar chart using distinctive colors [screenshot taken by the author of this paper from the Web Application Chroma.js Color Scale Helper[Aisch, Gregor and others 2013] and added]

5.4 Intuitive Colors

All colors are associated with specific cultural and psychological concepts and therfore have several meanings. In the western culture the color red is well-suited for displaying negative deviations. In contrast the color green is cognitively positively occupied and can be used to represent positive deviations. In China on the other hand red has positive connotations and is associated with success and warmth. To

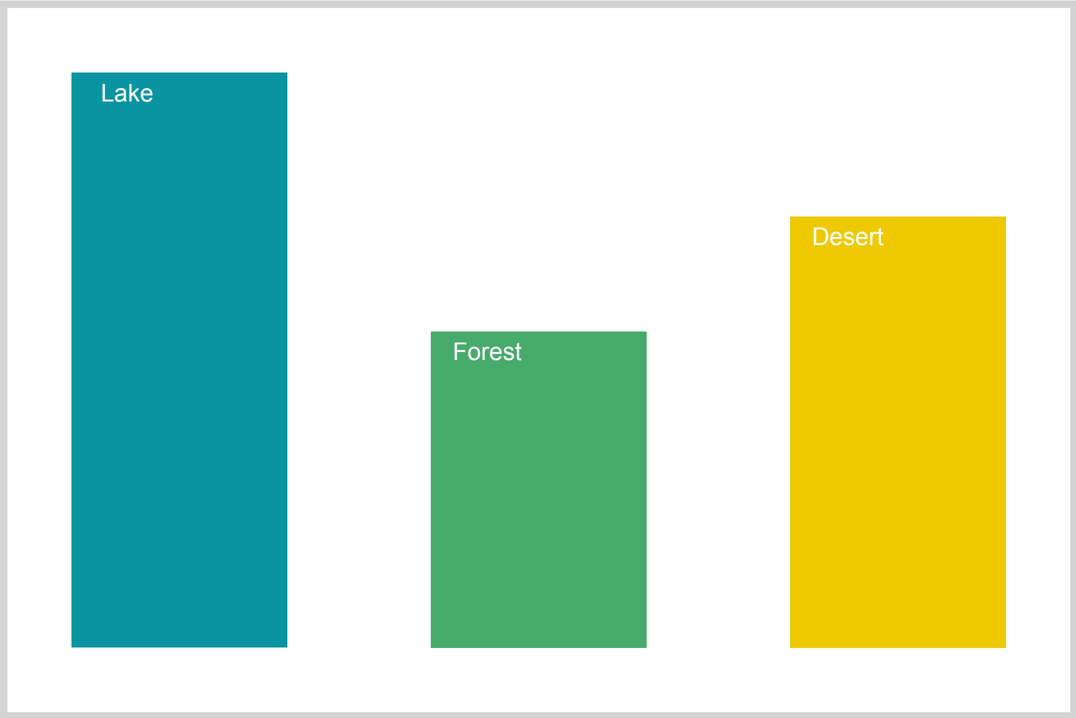

Figure 5.7: Use colors that people associate with certain things (natural colors) [Image drawn by the author of this paper]

choose the correct color palette use colors that the audience associates directly with the data. Learned colors like green = good/nice or red = bad/evil/anger or natural colors like green = grass/forest, blue = lake or yellow = desert are good examples for intuitive colors. Keep in mind that choosing only red and green for charts can lead to misinterpretations especially for people with color vision deficiencies. [Lisa Charlotte Rost 2018a].

5.5 Focus and Context

Consider the color grey as one of the most reliable and important color options in information visualizations [Andy Kirk 2015]. There are several methods that utilize the color grey in information visualizations. A good example is to use it for less important values to make the more importand colored parts stick out even more or for general context data to highlight other parts 5.8. Grey can still be remarkable so play a bit with the transparency of the colors and make the grey parts a bit brighter or choose a warmer version of grey (combination of grey and orange/yellow). Another important part is the contrast in combination with text. If there is some text on the charts make sure that the audience is able to read everything on the screen even with bright colors or smaller text. A high contrast ratio between background and text is necessary to ensure legibility. There are many tools to calculate good color contrast ratios between background and foreground.

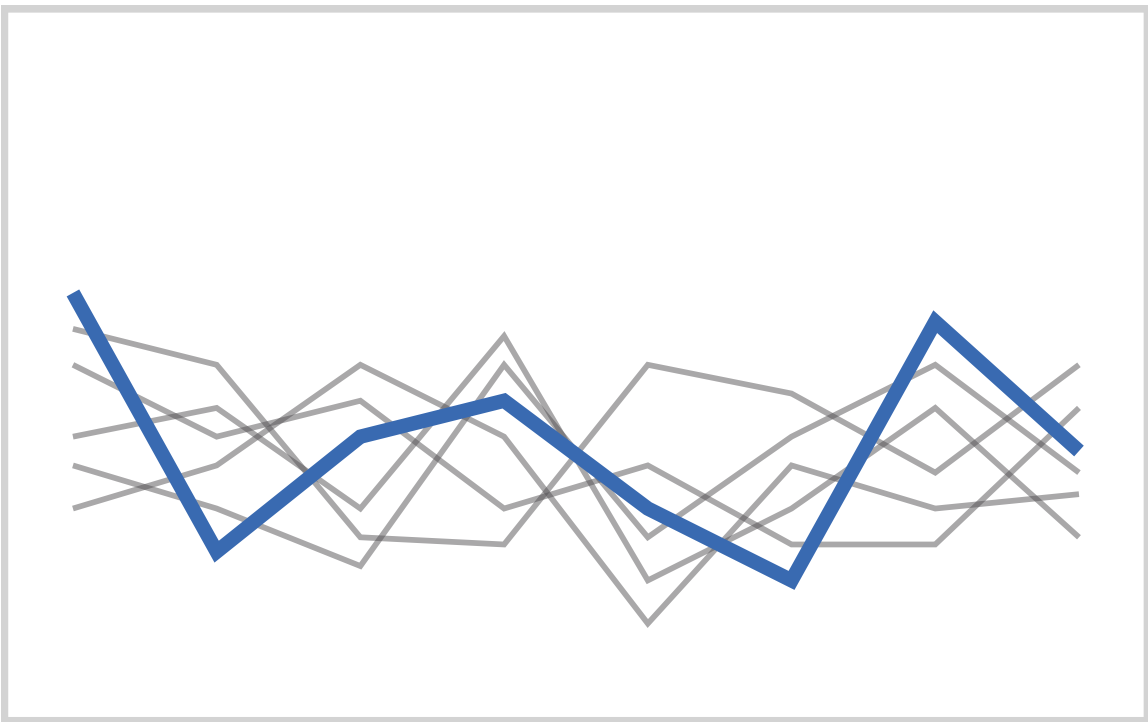

Figure 5.8: Using grey to highlight the important values of the chart [Image drawn by the author of this paper]

Chapter 6

Tools

Finding the correct colors for information visualizations or texts is always a hard task. To make life easier, there are plenty of tools which help creators to decide on a color palette. From basic libraries to easy-to-use applications, this chapter will have a look at some of them.

6.1 Chroma.js

Chroma.js is one of the biggest javascript libraries when it comes to color manipulation. Chroma.js is able to import and export a wide range of color spaces and to manipulate them in different ways. The biggest reason why this library is helpful for information visualizations is the ability to create multi-hued color scales. Instead of separating a gradient of two colors into steps which causes neighbouring colors to be indistinguishable, Chroma.js gives the opportunity to use the Bezier interpolation to create color steps. For this method to work correctly the user needs to add at least one intermediate color point to make a curve possible [Aisch, Gregor 2013].

The author of this library, Gregor Aisch, created an online tool to generate color steps, without the need of using the library itself. Figure 6.1 shows a screenshot of the tool with the name "Chroma.js Color Scale Helper". The Bezier interpolation ensures that the intermediate points, here "orange" and "deeppink", will never be one of the color steps, but instead the curve approaches them slightly. This tool is a great way, to generate color steps for your personal visualization, without the need of using the corresponding javascript library [Aisch, Gregor 2013].

6.2 D3.js

Data-Driven Documents (D3) is a javascript library for creators of information visualizations. One of the features of this library are the available color palettes, which are called "category10" and "category20". Category 10 gives the user 10 colors, which are easily distinguishable, as long as the viewer has no color vision deficiency. In contrast, category 20 is widely disliked in the community which is understandable when inspecting all the available colors in this palette, shown in Figure 6.2 with the source code shown in listing 6.1 and 6.2. The 10 extra colors are just desaturated versions of category 10 and some are really hard to distinguish. This is why D3 changed their approach since version 4 of their library. Those two categories are still available but they are way harder to access now. The focus now lies on the ColorBrewer application of Cynthia Brewer [Brewer 2017] which gives some color schemes to use [Wikipedia contributors 2019c].

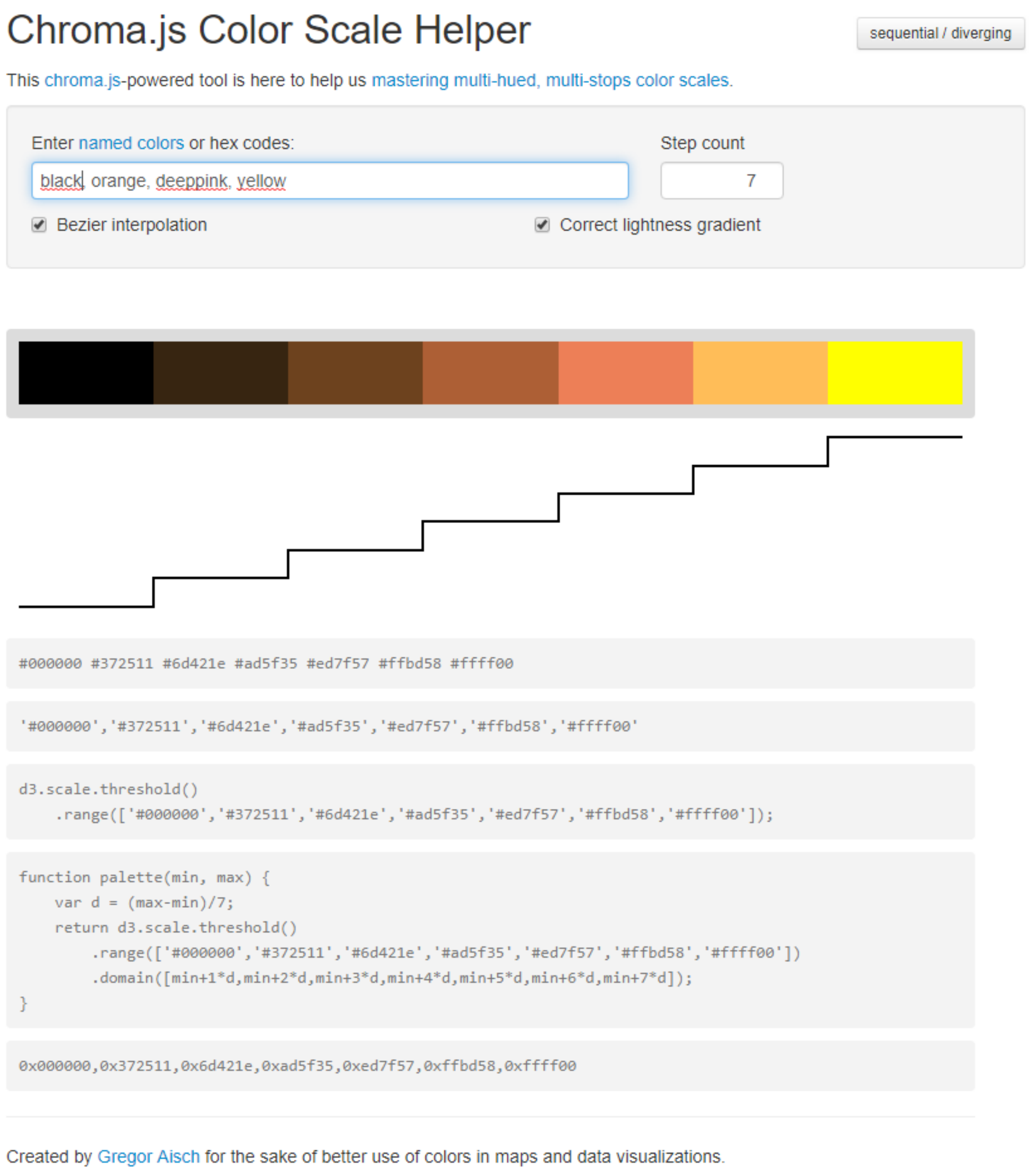

Figure 6.1: Example of color steps using Bezier interpolation [Screenshot taken by the author of this paper from the Web Application Chroma.js Color Scale Helper[Aisch, Gregor and others 2013]]

```
var cat10 = d3.scale.category10();
var cat20 = d3.scale.category20();

d3.select("#cat10")
  .append("svg")
  .attr("width", 500)
  .attr("height", 50)
  .selectAll("circle")
  .data(d3.range(10))
  .enter()
  .append("circle")
  .attr("r", 9 )
  .attr("cx", d3.scale.linear().domain([-1, 10]).range([0, 500]))
  .attr("cy", 10)
  .attr("fill", cat10);

d3.select("#cat20")
  .append("svg")
  .attr("width", 500)
  .attr("height", 50)
  .selectAll("circle")
  .data(d3.range(20))
  .enter()
  .append("circle")
  .attr("r", 9)
  .attr("cx", d3.scale.linear().domain([-1, 20]).range([0, 500]))
  .attr("cy", 10)
  .attr("fill", cat20);
```

Listing 6.1: D3 Categories - category.js

```
<!DOCTYPE html>
<html>
<head>
  <script src="http://d3js.org/d3.v3.min.js"></script>
  <meta charset="utf-8">
  <title>D3 Categories</title>
</head>
<body>
  <h1>D3 Categories</h1>

  <p>Category 10</p>
  <div id="cat10"></div>

  <p>Category 20</p>
  <div id="cat20"></div>

  <script src="category.js"></script>

</body>
</html>
```

Listing 6.2: D3 Categories - index.html

Figure 6.2: Category 10 and 20 of D3.js [Image created by the author of this paper using the D3 library]

6.3 Color Safe

Contrast is an important property when it comes to colors. Therefore it is very important for information visualizations, whether it comes to labels inside a bar chart or having two bars side by side. To help with finding the correct color for a text on a colored background there are plenty of Web Applications available on the internet. One of them is called "Color Safe"[D. Berg and A. Rapp 2015].

This application uses the Web Content Accessibility Guideline Standards, AA and AAA, [Cooper et al. 2008] for their calculation of contrast ratios. Initially the user has to select the background color and all the text settings, like font family, font size and font weight as well as the WCAG Standard to determine how high the contrast ratio should be, as shown in Figure 6.3. As soon as the "Generate Color Palette" button is pressed the application calculates the contrast ratio to every other color and discards the ones which are lower than the selected WCAG Standard. After that the user reaches another view seen in Figure 6.4, where all the available colors for the text are shown which are above the defined ratio. The colors can be filtered and selected, and by clicking on the color space value of the color, this value gets copied to the clipboard [D. Berg and A. Rapp 2015].

6.4 Colorgorical

Finding the correct colors for an information visualization can be really tricky sometimes, which makes the Web Application "Colorgorical" immensely useful. The user is able to receive a color palette with a selected number of colors in no time. Limiting the hue by selecting the desired hue angle, changing the lightness range or adding specific colors, which should definitely be in the visualization are the main settings, that can be changed. Another important slider is the Perceptual Distance which, if increased, favors colors, that are more suitable for the human eye. When the selected hue is too small for the amount of colors the user wants, the application even informs the user, that there are not enough colors with the current settings. Figure 6.5 shows the interface with some example results [Gramazio et al. 2017a].

Everytime the "Generate" button is pressed, a lot of calculations are done in the background. An overview of the process is shown in figure 6.6. At first either a color from the selected starting colors is chosen or a random one inside the selected hue and added to the palette. This palette now enters a loop, which runs n times, where n is the number of requested colors. In this loop, a score gets calculated for

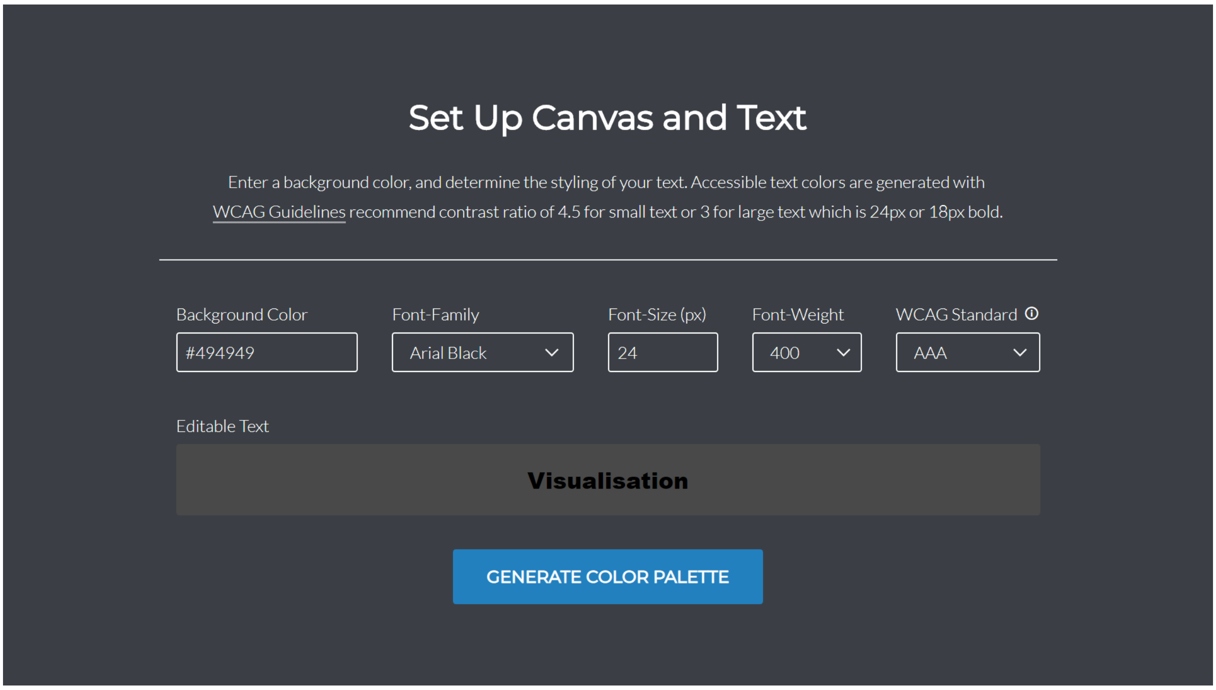

Figure 6.3: The setting page of Color Safe [Screenshot taken by the author of this paper from the Web Application Color Safe[D. Berg and A. Rapp 2015]]

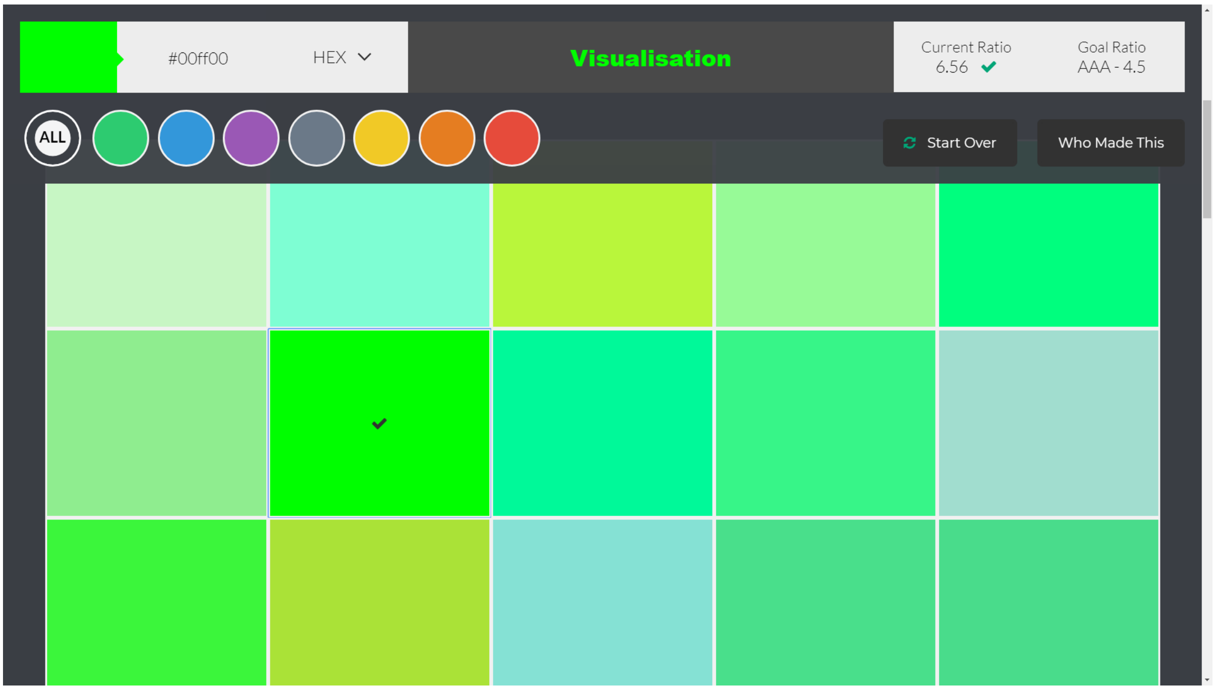

Figure 6.4: Results of the selected settings [Screenshot taken by the author of this paper from the Web Application Color Safe[D. Berg and A. Rapp 2015]]

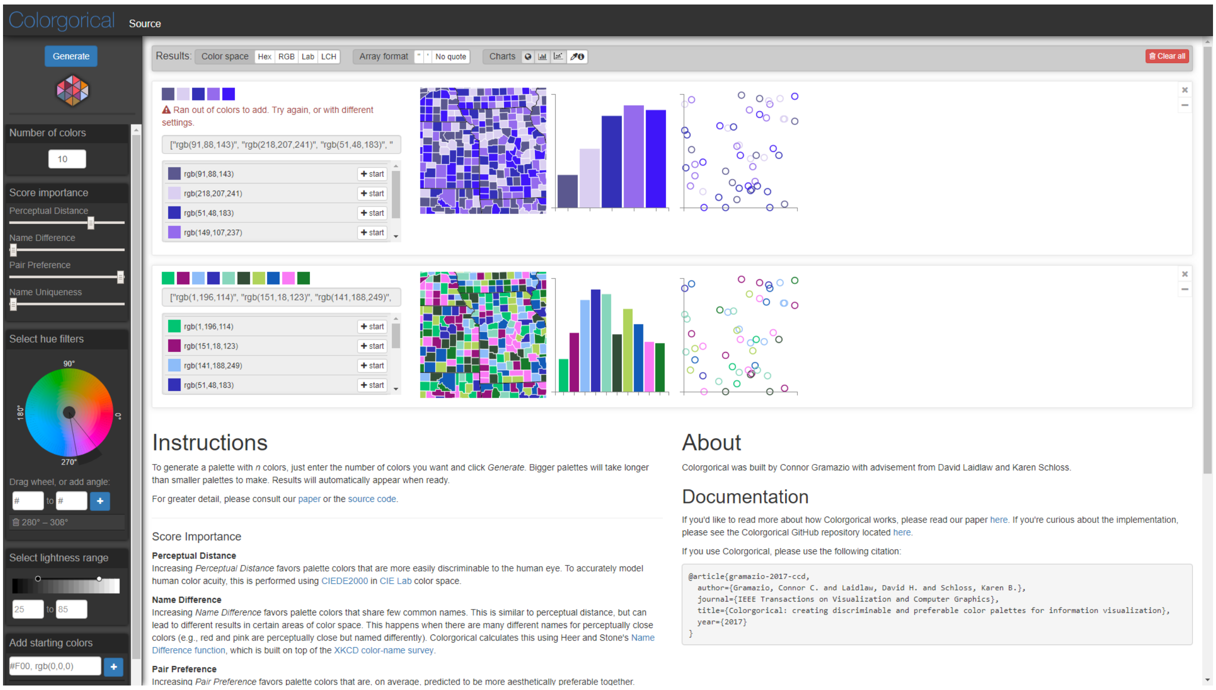

Figure 6.5: Interface of Cologorical with some results [Screenshot taken by the author of this paper from the Web Application Colorgorical[Gramazio et al. 2017a]]

every not added color that is available in the selected hue range, in regard to the already added colors. The main part of the score is the perceptual distance which is performed by using the formula of CIEDE2000 [Wikipedia contributors 2019a] to get the color difference. At the end the color with the highest score to all already added colors gets added. This continues until the amount of requested colors is reached or there are no more colors left which results in an error [Gramazio et al. 2017b].

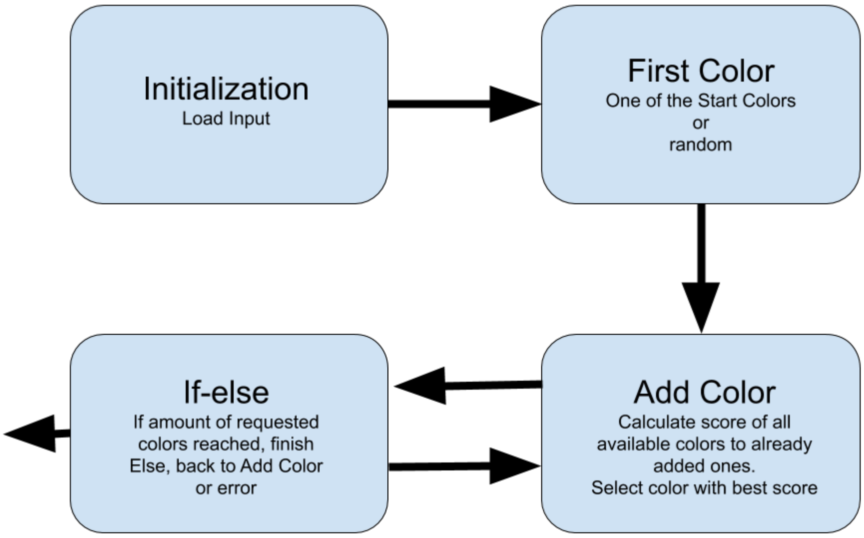

Figure 6.6: Process of finding the color palette [Redrawn by the author of this paper from the original in [Gramazio et al. 2017b, page 4]]

Chapter 7

Conclusion

The objective of this survey is to provide some insight in the domain of colors in general and especially for information visualizations. A big aspect of colors is the accessibility of them for people with color vision deficiencies. To prevent misinterpretations due to disabilities this survey describes some techniques for designing information visualizations with a focus on color accessibility via redundant encoding. Some techniques for redundant encoding are well-suited for certain types of information visualizations like shapes are good for scatterplots, patterns are good for larger areas of color like bar charts or maps and line styles can be used in line graphs even alongside the Focus and Context method. Furthermore this survey presents some tools to help in choosing a good color palette. Unfortunately there is no definitive guideline for colors in information visualization because the best colors for a specific visualization is highly dependent on various factors like the type of data to be visualized or the targed audience. Some of the presented tools are a good starting point for choosing a good color palette and in combination with some other techniques for color accessibility can lead to a beautiful and comprehensive information visualization.

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