Easy colorblind-safe typesetting: General guidelines and a helpful LaTeX package

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Abstract

Roughly 5% of people suffer from some sort of color-vision deficiency (CVD) [13]. To create documents that are accessible to anyone, it should therefore be considered how affected people perceive the colors in the documents. In colorblind-safe documents, the contents are presented in a way such that the same information is conveyed to readers regardless of potential CVDs. We first discuss how color is typically used in documents and categorize this into three different use cases that need different color schemes to convey the desired information. We then present some easy to follow rules for typesetting colorblind-safe documents. Finally, we take a look at available colors in LaTeX and how well they are suited for colorblind-safe documents. These considerations have lead to the development of the `colorblind` package, which we will introduce and discuss briefly.

1 Introduction

Human color perception is based on three types of cone cells in our retinas [13], which enable us to distinguish between different wavelengths of light. A variation in the sensitivity of different cone cell types can reduce or shift the color vision of affected individuals. Such differences are called *color-vision deficiencies* (CVDs), and are typically tested for using *Ishihara color test plates* [1]; see an example in fig. 1.

The most common type of CVD is *anomalous trichromacy* [13], where one cone type is less sensitive than the others, leading to aberrant color perception. The extreme case where one cone type is completely absent or dysfunctional is known as *total color blindness* [12].

People affected by a CVD typically have a harder time picking up on information conveyed through color. For example, the most common types of color blindness, deuteranopia and protanopia, make it difficult to distinguish red and green [12].

In this paper we will first discuss how color can be used in documents to encode information. We will discuss general techniques and guidelines to make documents more accessible to people with CVDs. Additionally, we will investigate how well (or rather how badly) the standard colors in LaTeX can be distinguished by people with CVDs. Finally, we will give some remarks on the current state of the `colorblind` package, and goals for its future development.

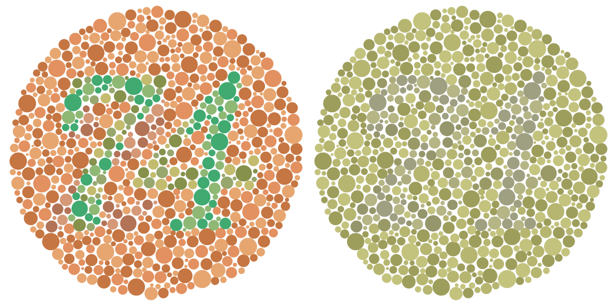

Figure 1: Ishihara test plate number 9. Left side (reads "74") shows normal version, right side (reads "21") shows a simulation of protanopia, a type of red-green color blindness.

2 Colorblind-safe design

When typesetting documents, we should pay attention to which color combinations we use within one visual unit. A visual unit may be a graphic, a table or a paragraph of text. The colors used in a visual unit are called the *color scheme*. In this section, we will first learn about different types of color schemes. After that, we have the necessary tools to formulate some guidelines that we can follow to achieve a colorblind-safe design.

2.1 Types of color schemes

In order to understand how to choose a suitable color scheme, we first have to understand what types of color schemes exist, and when each should be used. Let us consider different cases in which we might want to use colors to convey information. For this, we follow five fictitious students through their 20-week-long semester. At the end of each week they have to take a test which is graded from "1" (good) to "6" (bad). The average of these grades is their overall grade at the end of the semester.

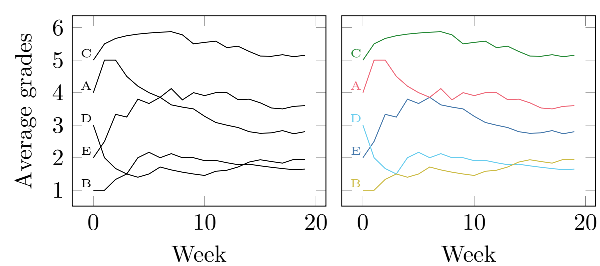

Figure 2: Example graphic showing a typical use case of a qualitative color scheme. Both graphics show the same data, but the right one uses colors to make the lines more distinguishable.

First, we might be interested in how the average grade of each of our students changes during the semester. This is plotted in fig. 2. The left graphic

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does not use color, and it is hard to distinguish the lines, especially at crossings where it is unclear which line goes where. In the right graphic, the lines are colored, which makes it easier to extract the information from the graphic. Now we can ask ourselves: What does the color scheme need to satisfy in order to be helpful? The only reason we introduce color here is to help with distinguishing the lines. Such a scheme is called a *qualitative color scheme* [3], and its only goal is to provide colors that are easily distinguishable, regardless of potential CVDs.

Next, we might be interested in the individual grades of our students. They are given in fig. 3.

A	4	6	5	3	3	3	3	6	1	6	3	5	4	1	4	2	1	3	5	4
B	1	1	2	2	1	2	3	1	1	1	1	3	2	3	4	3	1	1	4	2
C	5	6	6	6	6	6	6	6	5	3	6	6	3	6	3	3	5	6	4	6
D	3	1	1	1	4	3	1	3	1	2	1	2	1	1	2	1	1	1	1	2
E	2	3	5	3	6	3	5	2	3	3	1	1	2	2	1	2	3	4	1	4

Week

A	4	6	5	3	3	3	3	6	1	6	3	5	4	1	4	2	1	3	5	4
B	1	1	2	2	1	2	3	1	1	1	1	3	2	3	4	3	1	1	4	2
C	5	6	6	6	6	6	6	6	5	3	6	6	3	6	3	3	5	6	4	6
D	3	1	1	1	4	3	1	3	1	2	1	2	1	1	2	1	1	1	1	2
E	2	3	5	3	6	3	5	2	3	3	1	1	2	2	1	2	3	4	1	4

Week

Figure 3: Example graphic showing a typical use case of a diverging color scheme. Both graphics show the same data, but the lower one uses colors to make the graphic easier to understand.

In the uncolored graphic, it is difficult to see differences between the students because the grade information is provided only as text. By adding color to this graphic, it becomes easier to interpret since differences between students can be observed without looking at the precise values. Again we ask ourselves, what does a color scheme need to satisfy in order to be suitable for this graphic? This time, the colors should provide a continuous range between two easily distinguishable extremes (in our case blue for good and red for bad grades). The middle color of the scheme (in our case nearly white) should be a neutral color. We call such schemes *diverging color schemes* [3], and their goal is to visualize a range of numbers [min, max] where the mid-point is considered "neutral".

For the third type of color scheme, we consider the weekly number of questions our students ask in class, shown in fig. 4. We add color to this graphic for the same reason as in the previous case of fig. 3 — it helps us to discern patterns in the data. Even though the graphic looks almost identical to the previous one, our choice of color scheme should be different due to a subtle difference in the type of information

A	2	1	3	3	2	0	2	3	1	1	4	0	3	0	0	1	2	2	1	1
B	2	5	6	9	6	6	5	5	7	3	3	4	3	4	3	6	6	4	5	2
C	6	6	13	6	9	3	1	4	6	3	5	6	5	1	4	6	1	6	6	6
D	6	8	7	4	12	6	5	8	7	6	6	4	8	8	4	15	10	6	3	6
E	11	6	10	4	8	6	5	5	5	7	7	5	6	7	7	4	8	7	6	8

Week

A	2	1	3	3	2	0	2	3	1	1	4	0	3	0	0	1	2	2	1	1
B	2	5	6	9	6	6	5	5	7	3	3	4	3	4	3	6	6	4	5	2
C	6	6	13	6	9	3	1	4	6	3	5	6	5	1	4	6	1	6	6	6
D	6	8	7	4	12	6	5	8	7	6	6	4	8	8	4	15	10	6	3	6
E	11	6	10	4	8	6	5	5	5	7	7	5	6	7	7	4	8	7	6	8

Week

Figure 4: Example graphic showing a typical use case of a sequential color scheme. Both graphics show the same data, but the lower one uses colors to make the graphic easier to understand.

presented. Similar to before, the colors visualize numbers in a range [min, max], but this time, the mid-point is not considered neutral. That is why we use a *sequential color scheme* [3], which helps to visualize a range of numbers [min, max] where one end is considered "neutral" (this is often 0), whereas the other is considered "extreme". Importantly, the mid-point of such schemes is not special and often arbitrary (in our example, it would change if the maximum number of questions asked by any student is higher).

2.2 Colorblind-safe color schemes

These three types of color schemes provide the basis for how we use color in documents. In order to write colorblind-safe documents, it is important that the schemes we use provide easily distinguishable colors that retain their meaning under potential CVDs. Various such color schemes exist in the literature [2, 8, 14]. As an example, we focus on the schemes designed by Paul Tol [14], as these make up the most comprehensive set of such schemes that we were able to find. As examples, fig. 5 shows the color schemes used in the example plots from section 2.1. These color schemes typically consist of the main scheme, plus an additional color that can be used for missing data.

2.3 Guidelines

CVDs appear in many different variations and grades of severity, up to monochromacy, where different colors can only be distinguished via their perceived brightness. This means that while the color schemes presented in this paper are easier to distinguish under the most common CVDs, information encoded only in color can never be completely colorblind safe. This leads us to the most important rule in colorblind-safe design [5]:

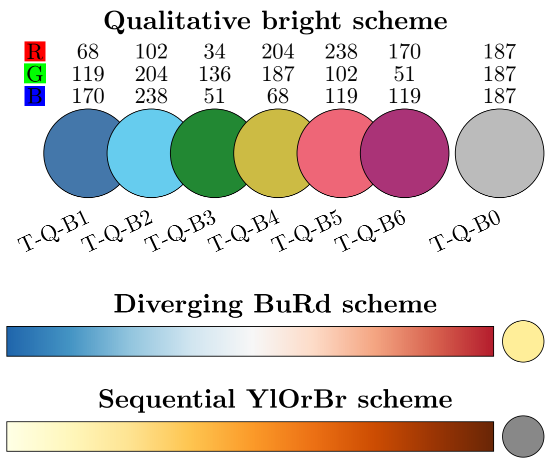

Figure 5: Example color schemes by Tol [14]. For the *qualitative bright* scheme, RGB values are given above the colors, and the color name when using the `colorblind` package is given below them.

Rule 1: Always provide information in more ways than just color.

But how does that rule work in practice? For this, let us revisit the three graphics from section 2.1. In figs. 3 and 4, the information encoded in color is the same as the numbers inside the boxes, so even if the color information cannot be picked up by some individuals, the information is still present as numbers, albeit in a more inconvenient way. These two graphics can thus be considered colorblind-safe. For fig. 2 however, without the color information, it is difficult to distinguish the lines, so we need another way to help the reader make this distinction. To achieve this, we can for example introduce different patterns in the lines, see fig. 6.

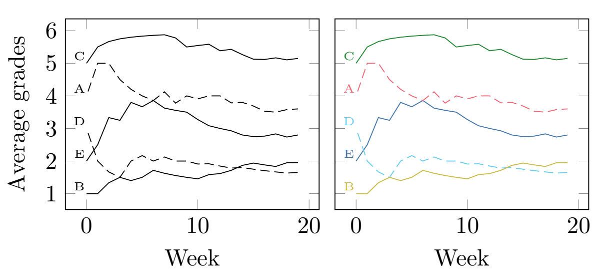

Figure 6: Improved version of fig. 2, where every second line is dashed to make lines distinguishable even when the colors are removed.

If this rule is satisfied in a document, it is by construction guaranteed to be colorblind-safe. However, this does not mean that it is *convenient* for people with CVDs to extract the information, as in the above examples from figs. 3 and 4. In order to achieve the best possible result, a few more rules should be considered when using color.

Rule 2: Stick to a color scheme.
(a) Do not mix colors within a scheme.
(b) Do not use shades of colors.

Colors within colorblind-safe color schemes are designed to be easily distinguishable for people with the most common CVDs, so we should use only colors from one color scheme in any given visual unit. By extension, even colors from the same scheme should not be mixed, since this makes it harder to distinguish them. Even if the result of the mixing is easily distinguishable for people with normal color vision, the same might not be true under certain CVDs. For the same reason, shades of colors (i.e., mixings with black or white) should be avoided, because the brightness of colors is also used to make sure the colors are distinguishable.

Rule 3: Do not use color for information and aesthetics simultaneously.

Color is often also used for aesthetic reasons, e.g., on a scientific poster. This is usually unproblematic, as the color does not convey information in this case. However, if color is used to convey information in a visual unit, avoid using additional color for aesthetic purposes, as this makes it more difficult to extract the information encoded in the color.

Rule 4: Do not use rainbow color schemes.

Due to the many different colors in a rainbow color scheme, they are inevitably difficult to distinguish under CVDs. Therefore, it is best to avoid them. If a rainbow color scheme has to be used at all cost, Paul Tol (and thus also the `colorblind` package) provides both a discrete as well as a continuous version [14], which are optimized to be as distinguishable as possible.

By following these four simple rules, we can ensure that the information encoded in a document is presented in a colorblind-safe way, and that it is reasonably convenient for people affected by CVDs to extract the information. As a side node, following these rules also leads to documents that do not suffer from information loss when printed in black and white, which is usually also desirable.

3 Colors in LaTeX

In this section, we take a look at how we use colors in LaTeX. For this purpose, we first consider the built-in colors of the standard color package `xcolor` [9], and test how well they can be distinguished under CVDs. After that, we propose the use of the new package `colorblind`, which provides many colorblind-safe schemes of all types mentioned in section 2.1.

3.1 The standard LaTeX colors

When using colors in LaTeX, the most convenient way is to use the built-in named colors, like `red` or `green`. This is also what LaTeX packages like Ti*k*Z do [7]. Figure 7 shows the 19 built-in named colors.

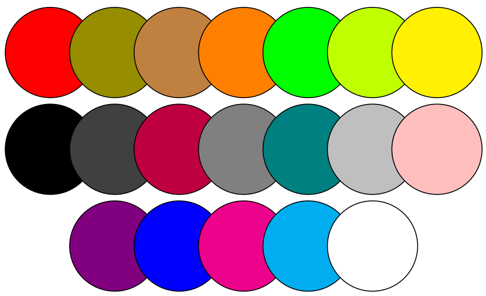

Figure 7: The 19 built-in colors from the `xcolor` package.

These colors are certainly not all easily distinguishable even under normal vision, but we can easily find over ten colors that look like they might work well together.

Now let us consider in fig. 8 how these colors look to a person affected by deuteranopia, a type of red-green blindness. The colors get collapsed into three categories, and the differences within each category are mostly down to different brightness levels. From these colors, there are maybe six distinguishable colors left that we could reasonably use in our graphics, already including black and white. Also we should keep in mind that we have considered only deuteranopia so far; considering other common types of color blindness as well would reduce the number of distinguishable colors even further.

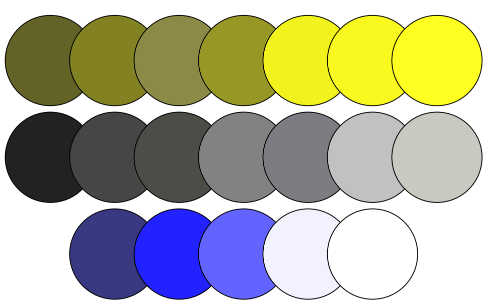

Figure 8: The 19 built-in colors from the `xcolor` package as perceived under deuteranopia, in the same order as seen in fig. 7.

Essentially, we see that the built-in colors by `xcolor` are unsuitable for use in colorblind-safe documents. We therefore need an alternative for choosing our colors.

3.2 The `colorblind` package

There are many ways of obtaining color schemes that are better suited for colorblind-safe documents than the standard LaTeX colors. The most influential of these tools is probably *ColorBrewer* [2]. Such tools make it easy to create color schemes, but to use them in LaTeX, we usually have to define the colors by hand. This is cumbersome, and is probably the main reason why people stick to the standard colors instead of better alternatives.

Thus, we have introduced the LaTeX package `colorblind` [11], which defines color schemes that can be used in colorblind-safe documents. Figure 5 shows examples of the schemes provided by this package. The color names all start with the scheme name, e.g., `T-Q-B` for **T**ol's **Q**ualitative **B**right scheme. The scheme name is then followed by the number of the color, e.g., `T-Q-B0` to `T-Q-B6`. In each scheme, color number `0` is associated with bad/missing data and should be used accordingly.

It might seem inconvenient at first that the colors do not have natural names like *red* or *green*, but there is a simple reason for this. Certain colors (green, red) are often used by people with full color vision to convey certain meanings (good, bad). This meaning is difficult for people with CVDs to pick up. By not using natural color names, it is easier to write colorblind-safe documents that do not make use of said connotations. Additionally, natural color names can be cumbersome, e.g., when slight variations of a color are used. It is annoying having to look up if a color is called blue or cyan.

In addition to these simple color definitions, the `colorblind` package also provides continuous `pgf` colormaps for color schemes that allow interpolation of their colors. These can be activated using the abbreviated form of their color scheme name, e.g., `/pgfplots/colormap name=T-D-BR` for **T**ol's **D**iverging **B**lue-**R**ed color scheme.

4 Future plans for the `colorblind` package

As a last point in this paper, I would like to explain my idea behind the `colorblind` package and discuss how to realize this goal.

The vision I had in mind when starting work on the `colorblind` package was to create a LaTeX package that makes it possible to view elements of a document as they are seen by people with CVDs. This would make it easy to check if a document is colorblind-safe directly during the writing process, as opposed to current CVD simulators [4, 15], which are available only as a post-processing step. By having a CVD visualization enabled during the writing process, common mistakes such as the use of color connotations mentioned above can easily be avoided, leading to documents where colorblind-safeness is not an afterthought, but is achieved naturally.

Such a functionality would be similar to how the `xcolor` command `\selectcolormodel{gray}` converts all colors to grayscale [9]. In fact, the most promising way to implement this feature appears to be the implementation of a new color model for each type of CVD that should be supported. As the `xcolor` package is slowly being replaced by the new `l3color` package within the new LaTeX kernel [10], an implementation of these new color models that builds on `l3color` is advisable, as it is more future-proof. A different approach was used for creating the CVD versions of figs. 1 and 8, where the `\color` command was redefined to convert the colors to a representation of a CVD. Unfortunately, this approach suffers from various limitations and is therefore not viable for regular use.

In addition to this idea of providing CVD simulation directly within LaTeX, future additions to the `colorblind` package will include options to change the default colors of commonly used LaTeX packages to colorblind-safe alternatives, e.g., for `pgfplots` [6].

5 Conclusion

In this paper, we discussed how color-vision deficiencies affect the accessibility of documents. Through some examples, we learned how color can be used in documents to convey information. Then, we provided some rules that help with achieving colorblind-safe documents. Finally, we discussed which colors are typically used in LaTeX and how we can hopefully improve the status quo by providing an easy way to use colorblind-safe colors. The current and planned features of the `colorblind` package can probably be extended by other useful features for colorblind-safe typesetting. If you have any suggestions for this, feel free to contact me.

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