Poster

Classifying user interface accessibility for colourblind users

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CCS Concepts

• **Computing methodologies** → *Perception;* • **Human-centered computing** → *Accessibility systems and tools;*

1. Introduction

Colour vision deficiency (CVD, colourblindness) is the failure or decreased ability to distinguish between certain colours even under normal lighting conditions. There are an estimated 300 million people worldwide with CVD, with approx. 1 in 12 men (8%) and 1 in 200 women (0.5%) [Cli23]. CVD affects an individual's ability to perform everyday tasks in both personal and professional settings [TPT*04]. It is an X-linked genetic disorder with varying degrees of prevalence in different populations. [FAAO22]

With displays utilising increasing colour gamuts, user interface (UI) designers have adapted conventions to use colour to guide and graphically convey key information to the user. E.g. green is often associated with 'yes' and red with 'no'. Objects of the same colour satisfy the popular Gestalt principle of similarity, whereas different colours can be used to help an object stand out or even to mark figure-ground articulation [Tod08]. However, these dimensions are reduced or even lost to someone with CVD.

UI designers have taken various approaches to tackle the issue of CVD with some decreasing the aesthetics by using a reduced colour palette (high-contrast mode), some integrating colour-blind awareness into their design process, others hoping that automatic post-processing enhancements (*daltonisation*) [SLF16] will correct for CVD.

The Web Content Accessibility Guidelines (WCAG) [wca18] outline some best practices for maintaining accessibility; however, it is uncertain to what extent current UIs follow these. In this work, we analyse a number of popular websites and software packages with a range of use cases to establish how much of their functionality is available to CVD users. To gain a strong understanding of how each industry manages CVD, we chose the most popular websites and software packages from prominent industries within the space such as Productivity, Education and SaaS. Specifically, we discuss relevant WCAG criteria, we simulate various types and severities of CVD on screenshots of UIs, analyse how much functionality is lost and compile our results into a rating of "UX experience and aesthetics kept" where there is a strong user experience and aesthetic similar to a non-CVD user would experience and to "core lost functionality" where the functionality central to the website or

software package is inaccessible and unusable due to it's lack of accommodation for CVD users.

2. Background

Human vision is generally understood to be trichromatic, with three types of retinal cone cells (L, M, and S) responding differently to wavelengths of light (Fig. 1). CVD can occur as a result of certain cone cells being absent, not working or having an abnormal response. Severe colourblindness occurs when two or three types of cone cells are absent (monochromacy, achromatopsia). Milder colour blindness occurs when one type of cone is absent (L: protanopia, M: deuteranopia, S: tritanopia), or even when all three are present, but one cell has an abnormal response (L: protanomaly, M: deuteranomaly, S: tritanomaly). In fact, this last type of CVD is the most frequent, with reduced ability to distinguish between greens and reds being the most prominent [MSM15] due to the spectral similarity of the M and L cones.
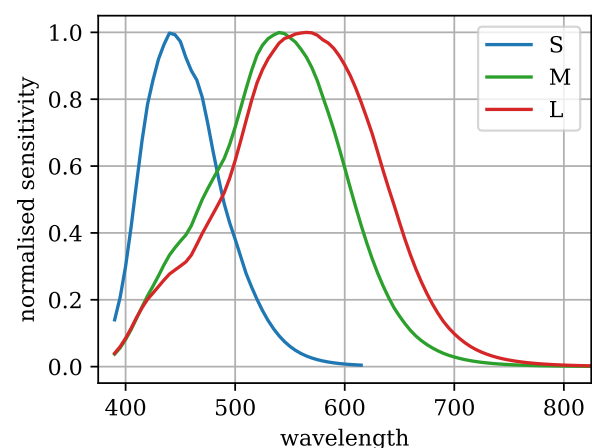

Figure 1: *Normalised spectral sensitivity of the three types of retinal cone cells as a function of light wavelength. Note the similarity of the M and L cones. Source: Stockman and Sharpe [SS00].*

3. Analysis

As a representative user study would need to involve a high number of participants with varying degrees of colour blindness, we

Table 1: *Tabular results of our user interface classification.*

adopted a simulation-based approach, which is reproducible by people without CVD. Specifically, we first collated a dataset of 56 screenshots of 30 popular standalone software and websites, enabling colourblind modes and themes where available. Then, we used the CVD simulation by Machado et al. [MOF09, Smi18] to simulate 5 levels (20%, 40%, 60%, 80%, 100%) of protanomaly, deuteranomaly, and tritanomaly. The screenshots often contained too much information to be processed automatically. As such, the final classification was performed by the authors, observing the following relevant success criteria in WCAG 2.1 [wca18]:

- 1.4.1 Use of Color (Level A): encourages providing information conveyed via colour through other visual means
- 1.4.5 Images of Text (Level AA): encouraging text being used to convey information rather than images of text

Figure 2: *Screenshot processed with simulated CVD simulation [MOF09]. Contrast across UI components can often be reduced.*

- 1.4.11 Non-text Contrast (Level AA): visual presentation of UI components and graphical objects having a contrast ratio of at least 3:1
- 1.4.6 Contrast (Enhanced) (Level AAA): visual presentation of text and images of text has a contrast ratio of at least 7:1

During our initial investigation, we found that while text contrast (1.4.6) and non-text contrast (1.4.11) were often maintained in the CVD-simulated screenshots, neighbouring UI elements became harder to distinguish (Fig. 2). Hence, we computed CIE dE2000 colour differences [LCR01] between main UI components in the original and the CVD simulated screenshots to quantify distinguishability across elements. For some complex UIs with multiple coloured elements, such as a timetable in Excel, this approach was not feasible and we applied subjective judgement. Furthermore, we also inspected the screenshots side-by-side to understand whether the aesthetics might be reduced. We then classified each UI into a table, where rows represent levels from high user experience (aesthetics and functionality kept) to lost core functionality (Table 1).

4. Discussion

While analysing UIs, we noticed that a key difference was whether the UI provided its own CVD theme (in contrast to adapting to the operating system's (OS's) reduced-palette high-contrast mode). We observed that UIs with dedicated CVD themes were more successful at meeting WCAG guidelines and maintaining aesthetics. We also found that while text alternatives for colour differences is a WCAG success criterion (1.4.1), not all existing UIs were compliant. All analysed UIs maintained the majority of their core functionalities. UIs without a dedicated CVD theme hope that the OS's high-contrast mode will maintain their functionality. Indeed, we found that enabling high contrast mode resulted in an overall improvement in the text readability across all software in Category 3, but this strategy has low potential to maintain aesthetics and does not impact image and video elements. Perhaps an OS-level daltonisation approach would be more successful.

5. Conclusions and Future Work

We analysed a number of popular websites and software packages to establish how much of their functionality is available to CVD users. Specifically, we used existing techniques to simulate the effects of CVD on a number of screenshots and then manually classified each into a rating of "core lost functionality" to "UX experience and aesthetics kept".

In the future, we hope to investigate how the process could be automated, and calibrate our results with a subjective user study. We also hope to expand and release our dataset of screenshots.

References

[Cli23] CLINTON: Color blindness in clinton in clinton, ct, May 2023. URL: https://www.clintoneye.com/color-blindness.html. 1

[FAAO22] FAKOREDE S. T., AKPAN L. G., ADEKOYA K. O., OBOH B.: Prevalence and population genetic data of colour vision deficiency among students from selected tertiary institutions in lagos state, nigeria. *Egyptian Journal of Medical Human Genetics 23*, 1 (2022), 1–8. 1

[LCR01] LUO M. R., CUI G., RIGG B.: The development of the cie 2000 colour-difference formula: Ciede2000. *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur 26*, 5 (2001), 340–350. 2

[MOF09] MACHADO G. M., OLIVEIRA M. M., FERNANDES L. A. F.: A physiologically-based model for simulation of color vision deficiency. *IEEE Transactions on Visualization and Computer Graphics 15*, 6 (November/December 2009), 1291–1298. 2

[MSM15] MAREY H. M., SEMARY N. A., MANDOUR S. S.: Ishihara electronic color blindness test: An evaluation study. *Ophthalmology Research: An International Journal 3*, 3 (2015), 67–75. 1

[SLF16] SIMON-LIEDTKE J. T., FARUP I.: Evaluating color vision deficiency daltonization methods using a behavioral visual-search method. *Journal of Visual Communication and Image Representation 35* (2016), 236–247. 1

[Smi18] SMITH N. J.: Colorspacious. URL: https://pypi.org/project/colorspacious/. 2

[SS00] STOCKMAN A., SHARPE L. T.: The spectral sensitivities of the middle-and long-wavelength-sensitive cones derived from measurements in observers of known genotype. *Vision research 40*, 13 (2000), 1711–1737. 1

[Tod08] TODOROVIC D.: Gestalt principles. *Scholarpedia 3*, 12 (2008), 5345. 1

[TPT*04] TAGARELLI A., PIRO A., TAGARELLI G., LANTIERI P. B., RISSO D., OLIVIERI R. L.: Colour blindness in everyday life and car driving. *Acta Ophthalmologica Scandinavica 82*, 4 (2004), 436–442. 1

[wca18] Web content accessibility guidelines (wcag) 2.1. *W3C World Wide Web Consortium Recommendation 05 June 2018* (2018). 1, 2