The Multi-Color Contrast Checker (M3C)

Improving visual accessibility of digital interfaces according to WCAG 2.1

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Abstract—**Accessible and readable contrast of text and graphical elements is a key requirement of the universal design of digital interfaces for people with and without disabilities. Many manual and automatic tools have been developed to help designers and developers measure color contrasts, but these tools are limited when it comes to assessing the contrast of three or more colors, the contrast of non-textual elements, as introduced by the Web Content Accessibility Guidelines (WCAG) 2.1, and contrasts for people with visual deficiencies, including Color Vision Deficiencies (CVDs). This paper proposes an open-source, worldwide accessible, and universally designed web-based tool called Multi-Color Contrast Checker (M3C). Our tool provides three novel main functions: (1) A multi-color contrast checker that assesses two *or more* colors according to their compliance with WCAG 2.1. (2) A color contrast example area that visualizes the effects of the chosen colors on concrete visual example elements typically found in digital interfaces. (3) A CVD simulator for three common types of CVDs. The tool has been assessed for correctness, accessibility, and user experience in both expert and user evaluations, which have confirmed the tool's usefulness in increasing awareness and knowledge of good color contrasts.**

Keywords - Universal design; accessibility; color contrast; Web Content Accessibility Guidelines; WCAG; user evaluation; readability; color vision deficiency; simulation.

I. Introduction

Luminance and color contrast significantly impact the readability and accessibility of visual information in digital interfaces [1][2]. Insufficient contrast affects many user groups, including people with visual impairments, such as people with Color Vision Deficiencies (CVDs) [3][4][5], as well as many elderly [3]. CVDs may prevent users from extracting visual information from a digital interface [5]. Recommendations for accessible contrasts have been integrated into international standards for accessibility, such as the Web Content Accessibility Guidelines (WCAG) [6][7][8][9]. WCAG 2.0 and 2.1 have become part of national and international laws and regulations by requiring compliance with websites, apps, and other ICT solutions [10][11][12]. WCAG defines minimum requirements for the contrast between text and background colors (Guidelines 1.4.3 and 1.4.6 in WCAG 2.0 and later [8][9]) and in non-text elements necessary to understand the content including icons, buttons, parts of a map, charts, etc. (Guideline 1.4.11 in WCAG 2.1 and later [8][9]).

These guidelines aim to make text and graphical elements easy to perceive, ensuring that the content of an application is readable and accessible to individuals with visual impairments. There are numerous application possibilities for WCAG: WCAG can guide designers and developers to choose color combinations with good contrast during development. Likewise, WCAG enables supervisory authorities and interest organizations to assess if colors in an interface are accessible. However, many relevant stakeholders lack awareness and knowledge of WCAG [13][14][15][16]. Moreover, existing color contrast checkers based on WCAG 2.0 [17][18] analyze contrast between two colors (mostly text and background), but lack support for complex multi-colored graphical elements like information graphics, as required by the introduction of non-text content in WCAG 2.1. Existing tools require all relevant color combinations of a multi-colored palette to be checked manually one-by-one. Additionally, there is a lack of example visualization tools that demonstrate how color contrast in complex graphical elements impacts an individual's visual experience of the digital interface. As a result, the success criteria in WCAG can remain somewhat theoretical, leading to developers and designers not adequately considering individuals with visual variations during the design and development process. Last, the needs of individuals with CVDs are often overlooked, even though research shows that CVD simulations can enhance understanding of the experience of people with CVDs among individuals with normal color vision [19][20].

We aim to enhance the accessibility of visual information in digital interfaces by facilitating compliance with the color contrast success criteria defined in WCAG 2.1. We present a web-based tool to support developers, designers, decision-makers, authorities, and civil society organizations in analyzing and visualizing accessible contrasts for simple and complex color combinations that meet the WCAG 2.1 requirements. Additionally, the tool increases awareness of the most common types of CVD. Compared to other tools our solution supports combinations of more than two colors, provides typical UI examples, and simulates the most common CVDs for the chosen colors.

In this paper, we discuss in Section II related color checkers. Section III presents the concept and implementation of the Multi-Color Contrast Checker (M3C). Section IV introduces methods to assess the universal design of the developed tool. In Section V, we discuss their results including some suggestions for future research and development before concluding the article in Section VI.

II. Related solutions

The W3C maintains a list of tools that can measure color contrasts in digital interfaces [21] that possess some notable limitations. Only a few tools compute contrast between multiple colors like, for example, Accessible Brand Colors [22]. Many color checkers only calculate contrast between two colors like, for example, Color Check [23], Clapperton's Colour Contrast Checker [24], Monsido's Color Contrast Checker [25], Color Contrast Checker by UserWay [26], Colors Tester [27], ColorTester [28], Rumoroso's WCAG Contrast Checker [29], WCAG Contrast Checker by Acart Communications [30], contrast finder [31], Contrasts - WCAG Farbkontraste [32], Color Contrast Accessibility Validator [33], Visual Contrast Checker and Colorblind Simulator [34]. In addition, most of these contrast checkers support only textual elements and their backgrounds [22][23][24][27][28][30][31]. A few color checkers provide CVD simulation [24][32], while others can *only* be used for CVD simulation [35][36]. Some tools do not have an explicit connection to the success criteria of WCAG [23][30][31], while some have only limited free functions [27][34] or are limited to specific operative systems or apps [29][32].

Popular tools not on the W3C list include WebAIM's Contrast Checker [18], Colour Contrast Analyser [37], Color Contrast Checker & Analyzer [38], and Firefox' native Accessibility Inspector [39]. Three of them check for both text and non-textual elements [18][37][39], and only one includes a simulation of different CVD types [39].

Many existing tools calibrated for calculating contrast, specifically between text and background colors per WCAG 2.0 guidelines, fall short of accommodating the expanded color usage for non-text elements in user interfaces introduced by WCAG 2.1. The current tools largely neglect practical visualization of color combinations in various graphical interface elements and lack consideration for color-deficient users. Additionally, tools offering broader functionalities are generally neither universally available nor commercially free. Hence, there is a notable absence of an open-source tool that effectively enables computation and practical demonstration of multiple color contrasts, while also providing CVD simulations. Moreover, there is a necessity for scientific research on strategies to ensure that such a tool is universally designed.

III. The Multi-Color Contrast Checker (M3C)

To facilitate and increase compliance with WCAG 2.1, we propose a web-based tool, called *Multi-Color Contrast Checker (M3C)*, which is openly available at https://norskregnesentral.github.io/m3c/, easy to understand and use, accessible, and universally designed for people with and without disabilities. The tool consists of a multi-color contrast checker, a color contrast example area, and a CVD simulator.

A. The Multi-Color Contrast Checker

The multi-color contrast checker (cf. Figure 1) calculates contrasts between multiple colors. The user can make a color palette by choosing colors found in a text, background, non-textual element, or graphics manually from a color wheel (in RGB or HSV), by entering a hex color value, or by using a pipette on a graphical element visible on the screen. The contrast checker enlists all possible combinations of the chosen colors and assesses whether each combination meets the success criteria 1.4.3, 1.4.6, and 1.4.11, as defined in WCAG 2.1 for texts (both minimum and enhanced), as well as non-textual elements [8]. Information about WCAG 2.1 and color contrast according to WCAG 2.1 is included in the tool. The numerical results of the contrast computations are presented in a matrix, along with indicators for whether the success criteria are met on level AA or AAA (cf. Figure 1). Contrast computations are defined in WCAG 2.1 [8]:

$$(L_1 + 0.05) / (L_2 + 0.05) \tag{1}$$

Where L_1 and L_2 represent the relative luminance of the lighter and darker colors respectively according to the sRGB standard [40][41]. The tool also includes a "Get started" section that offers accessible example color palettes inspired by Color Brewer 2.0 and Color Hunt [42][43][44].

B. The Color Contrast Example Area

The color contrast example area (cf. Figure 2) demonstrates the practical implications of contrast and readability of the chosen colors. It provides concrete examples of typical UI elements and visualizes how distinct color combinations affect these elements' readability. The example area uses vector graphics that can individually adapt the colors of the various parts of the graphic. In the current implementation, we included four UI elements: text on background, a calendar graphic, a pie chart, and a button.

C. The Color Vision Deficiency Simulator

The Color Vision Deficiency (CVD) simulator (cf. Figure 1) replicates the three most common types of CVDs, protanopia, deuteranopia, and tritanopia, based on the formulas provided by Brettel et al. [45][46]. The CVD simulator automatically adjusts the colors of the palette and in the example area to mirror perceptions of a person with CVD. Concurrently, all contrast calculations are updated to reflect the simulated colors, enhancing the understanding of contrast perception for a person with CVD.

D. Implementation

The code of the application is hosted on and deployed by GitHub [47][48]. The tool has been programmed in the JavaScript library React [49] including the libraries i18next for internationalization [50], color-contrast-checker for contrast calculations [51], and adaptations of libDaltonLens for CVD simulations [52][53]. The CSS libraries flexbox and grid enabled a responsive user interface for variable screen sizes. The tool has been evaluated on computer screens, mobile phones, and tablets [54]. The tool has been developed in an agile process with several iterations consisting of planning, execution, review, and retrospective [55] including a review by other developers during each cycle. We conducted a round of user evaluation aimed at accessibility and user experience on the first prototype in January 2023.

IV. Accessibility and User Experience Evaluations with Experts and Users

A. Methods and Participants

We used tools, checklists, and user evaluations to assess the accessibility and user experience of the web tool. To begin with, the code was periodically tested concerning rudimentary technical accessibility using the Chrome and Firefox extensions of the WAVE Web Accessibility Evaluation tools [56]. Next, we conducted an expert evaluation according to the WCAG 2.2, including screen reader testing. We chose evaluation using WCAG 2.2 to make the tool more robust for the future, due to WCAG's backward compatibility with previous versions.

We conducted user evaluations of our first prototype in January 2023. This prototype contained all functions on a single page, requiring the user to scroll up and down to each section. The prototype also lacked the CVD simulation and internationalization modules. The evaluations were inspired by inclusive-design approaches and strategies for the assessment of digital artifacts' user experience [57][58][59][60]. The evaluations employed a think-aloud strategy to identify bugs and other issues [57][60], and we defined a set of tasks that the participants had to complete in the presence of the test leader. Practical, technical, and content-related tasks were included, aiming at the functionality, accessibility, usability, and user-friendliness of the tool. The test leader encouraged the participants to comment while completing the tasks. Where necessary, the test leader asked clarifying questions. Additionally, we interviewed the participants about their expectations, their first impressions, and impressions after testing, including grades for satisfaction, the tool's easy-to-use factor, and perceived usefulness.

User evaluations were conducted with one female and seven male developers, both locally (5) and remotely (3) using our experience from previous remote evaluations [61]. Seven of the participants did not mention any disabilities, while one reported some degree of low vision. Some of the participants had corrected-to-normal vision otherwise. The average level of experience with universal design among the participants was low (2.4 on a 5-point Likert scale). We evaluated multiple operating systems including Windows (6), Linux (1), and macOS (1), as well as different browsers including Chrome (4), Firefox (3), and Edge (1).

B. Results

The WCAG testing resulted in the discovery of 12 accessibility issues. The expert and automated testing resulted in the detection of 61 issues in total, of which 41 were usability issues, 13 were accessibility issues, and 7 were other issues. The issues were then triaged together with the accessibility issues and mostly implemented.

The participants reported a medium satisfaction grade (3.25 on a 5-point Likert scale). They reported that the first version of the prototype was neither / nor easy-to-use (3 on a 5-Point Likert scale). Finally, participants gave the tool a high usefulness rating (4.25 on a 5-point Likert scale).

Participants found the prototype of the tool lacking in essential information about its purpose, funding, and creators, and criticized the absence of guidance and tutorials making it non-intuitive and difficult to comprehend. The front page was deemed cluttered and overwhelming with numerous elements, and the interface's bright, sharp colors made it appear unrefined.

Participants praised the interface for its clean, spacious design, clear hierarchy, and color categorization of the sections, appreciating the immediate, universal color changes and well-categorized sections. The color contrast calculations matrix and interactivity of the example area were valued for providing clear overviews and hands-on visual manipulations, respectively. The summary feature highlighting good and bad color contrasts and the presentation of WCAG requirements were deemed useful, with both the matrix and summary commended for showing all possible color combinations.

Participants recommended making the system more logical by utilizing unused space, emphasizing essential elements, and refining icon usage. Suggestions included implementing tabs to minimize scrolling and optionally presenting WCAG guidelines alongside the contrast ratio table. The need for multi-language support and a feedback mechanism for reporting issues and suggesting improvements was emphasized. Additionally, participants desired a "dark mode" and increased interactivity in the example area with more than two colors, as well as guidance for choosing accessible color combinations from the start.

V. Discussion

The tool's accessibility and user experience have considerably improved for the current version. Tabs have been added to make the app's structure clearer by avoiding empty space, giving clear headers, and putting focus on a single section at a time while hiding others. We updated the WCAG explanation and placed it in a separate tab for clarity. We integrated internationalization and translations in English. We added background information about the project and its contributors and added the possibility to submit feedback through GitHub's issue feature. Last, we implemented the CVD simulation feature.

User feedback generally indicated a positive reception, with users gaining familiarity with WCAG and appreciating the insights offered by the new CVD feature in understanding the needs of individuals with CVDs.

The proposed tool targets developers, designers, decision-makers, regulatory authorities, and civil society organizations. The tool can support these stakeholders' work by assessing if a chosen palette for a digital user interface conforms with the WCAG 2.1 success criteria. In practice, the tool can be utilized for all digital interfaces with visual information such as websites, web applications, digital learning materials, and self-service machines, as well as computer games, XR apps, or IoT devices, but this list is non-exhaustive. The tool also promotes knowledge and awareness of the universal design of ICT applications by providing information about good color contrasts and WCAG. The application is built modularly, allowing for easy expansion, and adding new features, such as support for additional languages, simulations, or more graphical examples.

The tool underwent user experience and accessibility evaluations including WCAG checks and user testing to ensure that it is universally designed. It can, for example, be operated by only using the keyboard or using a screen reader. We also utilized the tool to assess the accessibility of the colors employed on the website itself. The application is deployed and freely available on GitHub, enabling all users worldwide to benefit from the tool. Also, the source code may be downloaded and extended as desired. Users can provide feedback and report issues or requests for future features. At the same time, the current research has its limitations related to the lack of quantitative performance comparisons with other tools, as well as demonstrating real-world impact by including user studies or metrics quantifying improvements in accessibility and WCAG compliance.

We aim to enhance our website's accessibility and user guidance by implementing several upgrades: translating it into additional languages, including German, Chinese, Nynorsk, and Sámi, to appeal to a global audience; refreshing and augmenting examples; and introducing a tutorial through a succinct video demonstration. Additionally, we plan to incorporate a color palette picker, designed to facilitate accessible color selection in compliance with WCAG 2.1 while adhering to other functional and aesthetic needs—ensuring it meets user expectations related to, for instance, corporate design, and allowing user control over parameters such as hue, saturation, and brightness. Furthermore, we will assess the tool's efficacy and its contribution to increasing WCAG knowledge and awareness through questionnaires and head-to-head comparative evaluations, thereby establishing its innovations and added value compared to existing tools.

VI. CONCLUSION

We introduced the Multi-Color Contrast Checker (M3C), a novel tool designed to enhance the accessibility and readability of visual information in adherence to WCAG 2.1 contrast success criteria. M3C, which is openly available and free-to-use (1) enables multi-color contrast checking, (2) visualizes color contrast effects on graphical interface elements, and (3) simulates various types of Color Vision Deficiency (CVD). Besides aiding developers and designers in making informed color selections, it also facilitates assessments of color palettes against WCAG 2.1 criteria.

We employed diverse evaluation methods, including user experience and accessibility testing, to ensure that the tool itself is universally designed. Future developments will incorporate additional languages and a color palette chooser, guiding users toward accessible color selections within existing aesthetic, functional, or corporate design constraints.

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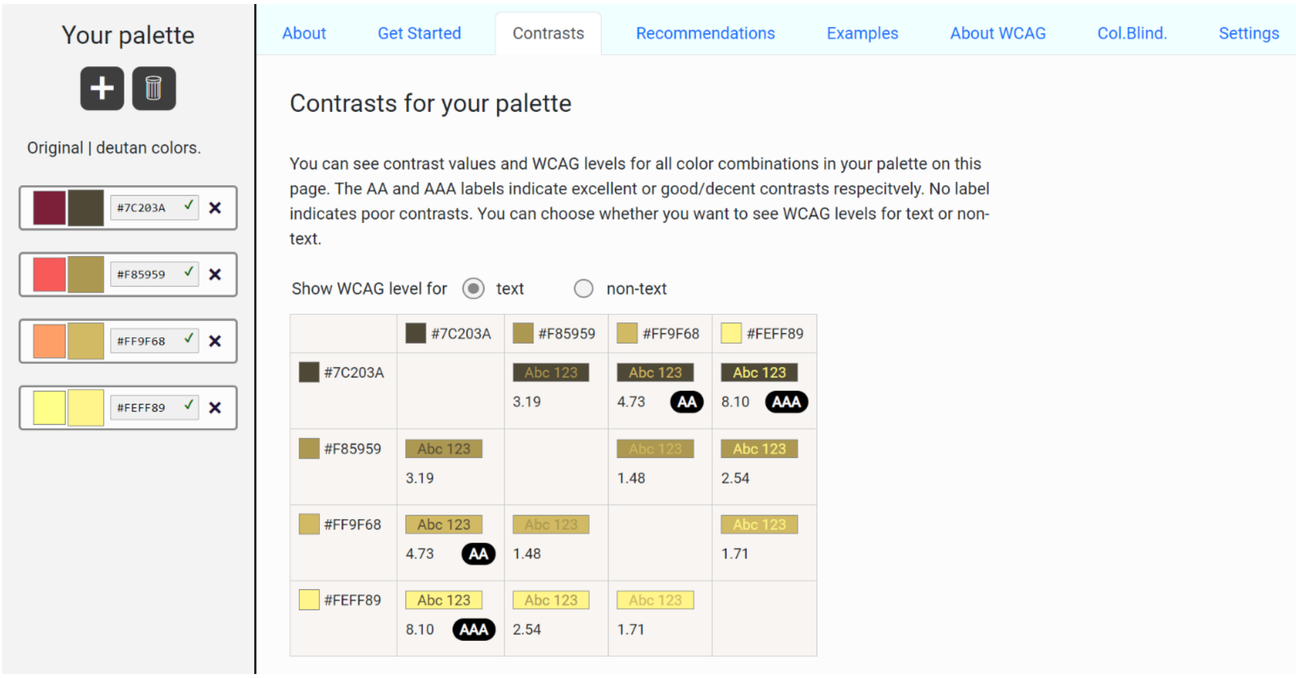

Figure 1. The Color Contrast Checker shows the color contrast calculations and conformance with WCAG 2.1 for textual elements. In this example, colors have been adapted according to an individual with deutan CVD.

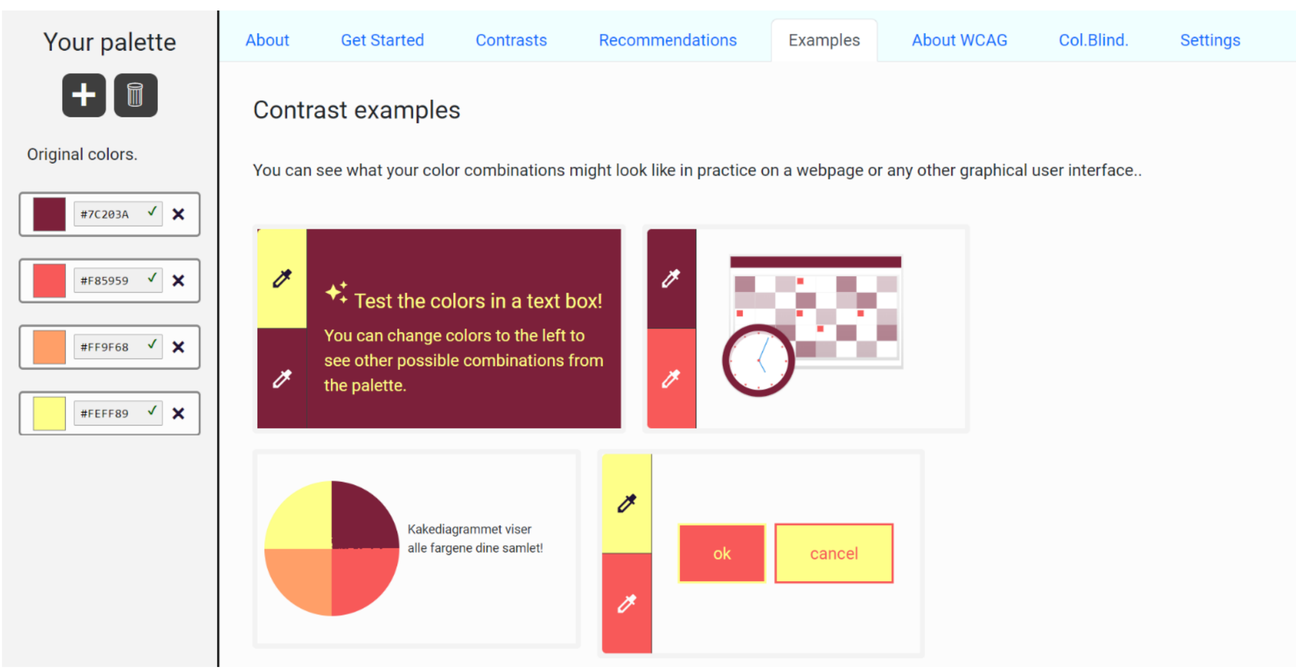

Figure 2. The Color Contrast Example Maker shows how the chosen colors of a palette might graphical elements on a digital interface including text on background, an information graphic, a pie chart, and buttons.