Dynamic Color Adjustment in Visualizations: Improving Accessibility for Sighted, Low Vision, and Colorblind Users

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Abstract

Visualizations rely heavily on color palettes and types to efficiently deliver information. However, people with different vision impairments have varied needs. This research proposes a dynamic adjustment framework that enables real-time, user-driven customization of visualization colors and types, enhancing the accessibility across diverse user groups. A literature review was conducted, and the framework was presented through a dashboard generated using Streamlit in Python. Colorblind-friendly sequential palettes are enabled, including Cividis, Magma, and Plasma. For visualization types, it supports choropleth maps, bar charts, and tables. While formal user testing remains future work, existing accessibility principles suggest that this customization can improve information clarity for diverse vision groups.

This work contributes to a framework for adaptive visualization with a working dashboard, and insights for future improvements. Future work should include real user testing and the integration of this framework into existing visualization libraries and applications.

Keywords

Data Visualization; Accessibility; Colorblindness; Low Vision; User-Centered Design

1 Introduction

The three choropleth maps in Figure 1 illustrate the same data for 2011 US Agriculture Exports by states with different color palettes. The left one uses a rainbow color palette from purple to red, the middle one uses red from light to dark, and the right one only places data on top of each state without coloring. For people with normal vision, all three maps are clear, but the middle one makes the most logical sense. However, people with protanopia, a type of colorblindness, often struggle to distinguish red shades. For those users, the first two maps appear confusing, so they prefer the right one.

Visualizations are among the most compelling media for communicating complex data. However, they heavily rely on chosen color and type, which may exclude people with visual impairments like low vision (LV) and color vision deficiencies (CVD). 295 million people around the world have moderate-to-severe vision impairment [1]. Many visualizations fail to address their needs. In addition, sighted people often find accessibility-oriented visualizations less informative. The majority of visualizations seen today are pre-designed. Users in different vision groups have no control over color selection or type adjustment.

This leads to the main research question: How can a real-time, user-driven color adaptation framework be designed to improve accessibility in visualizations for users with normal, low or color-deficient vision, compared to static color schemes?

2 Related Work

Previous approaches using predefined color schemes or automated recoloring algorithms failed to be adaptive and flexible. This framework will contribute toward filling this gap by allowing dynamic color adaptation with a view to enhancing access by a diverse audience in an active user-driven manner.

Prior work has targeted visualization accessibility with special concern for colorblind viewers. Tools like ColorBrewer provide static color palettes optimized for colorblindness [2]. Automated recoloring algorithms [3] adjust images to improve color differentiation.

However, these approaches are limited in several ways. For example, they primarily focus on CVD, while ignoring the needs of low-vision individuals who may require high-contrast colors, non-color cues, or other accessibility features. In addition, these methods rely on predefined rules or batch processing, limiting flexibility for real-time, user-driven customization. Moreover, they lack integration with existing visualization tools, further limiting their practical applicability [4].

This project builds on these efforts by proposing a dynamic, user-driven framework that integrates multiple accessibility features and allows users to tailor visualizations to their specific needs. A dynamic approach in this research means users can adjust visualization settings as needed instead of relying on pre-defined type and fixed color schemes. This can be considered a combination of all color schemes for people with different vision impairments. No matter which color scheme and visualization type users prefer, they can customize them on their own.

3 Research Methodology

The project has been conducted in two phases: Design (with justification) and Application.

3.1 Design & Justification

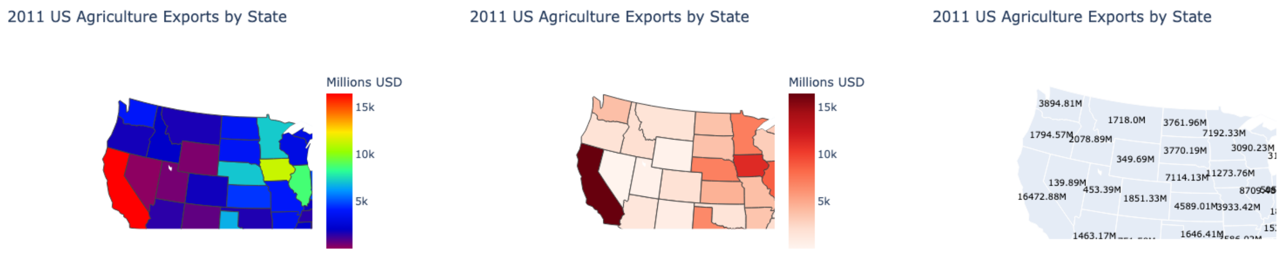
In the first phase, the framework for dynamic color and visualization type adjustment was developed. It also includes a set of design principles for accessible visualizations and a prototype interface for real-time customization. For the same visualization, different users can switch between different color palettes and choose the one most informative for them. Similarly, dynamic visualization type adjustment allows different users to switch between visualization types, such as choropleth maps and tables, to meet their needs.

3.1.1 Color Palettes

There are five color palettes designed, and each of them was carefully selected based on scientific recommendations and studies for different vision problems. The following is not only an explanation of color choices but also a description of impairment types.

- **Normal Vision:** It's natural to consider the default color palette for people without vision deficiency. As suggested by ColorBrewer [5], *px.colors.qualitative.Set1* in the Plotly library provides bright and distinguishable colors suitable for the most common case.

- **General Colorblindness:** Follow the guidelines of the Netherlands Cancer Institute (NKI), a set of distinguishable colors,



(a) Map using the `rainbow` colormap.

(b) Map using the `Reds` colormap.

(c) Map without colors.

Figure 1: Comparison of US Agriculture Exports by State using different visualization techniques.

called Color Universal Design (CUD), has been developed for various types of color blindness. [6].

- **Deuteranopia and Protanopia:** People with Deuteranopia and Protanopia are unable to perceive "green" or "red" light, respectively. The Cividis palette developed by Nuñez et al. maintains a linear brightness gradient and has been suggested to be more informative for red-green colorblind individuals through computational analysis [7].
- **Tritanopia:** Tritanopia is a type of "blue-yellow" color blindness. Patients have difficulty distinguishing colors containing blue or yellow. Magma developed by van der Walt and Smith, provides a scientifically optimized color scheme for people with Tritanopia [8].
- **Low Vision:** According to the Perkins School for the Blind, high contrast color schemes are preferred for low-vision people [9]. Plasma, which was also developed by van der Walt and Smith, has high contrast between warm and cool colors, which is a good choice for enhancing the readability for low-vision individuals [8].

Figure 2 presents the selected color palettes designed for accessibility, and table 1 summarizes the palette sources and target groups.

Table 1: Summary of Color Palettes and Their Intended Vision Groups

Palette Name	**Source**	**Target Group**
Set1 (Plotly)	ColorBrewer	Normal Vision
CUD	NKI Guidelines	General Colorblindness
Cividis	Nuñez et al.	Deuteranopia, Protanopia
Magma	van der Walt & Smith	Tritanopia
Plasma	van der Walt & Smith	Low Vision

3.1.2 Visualization Types

Using the correct type of visualization enables clear and concise communication [10]. Choropleth maps, bar charts, and tables are the three chosen types of visualization. Many other visualization types exist, but by incorporating these three types, the design covers most use cases. The comprehensive design of these three can

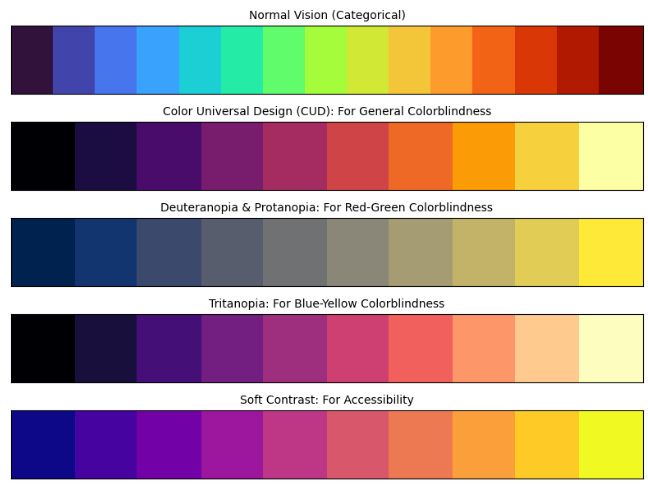


Figure 2: Comparison of colorblind-friendly sequential palettes used in the study.

provide important insight for the development of other visualization techniques.

- **Choropleth Maps:** Unlike regular maps, choropleth maps use color to represent an aggregate summary of a geographic characteristic within spatial enumeration units [11]. It is suitable for displaying regional variations in data if designed with sufficient contrast.
- **Bar Charts:** Bar charts can provide a simple way to summarize numerical values of different categories. They effectively display categorical comparisons but are not suitable for delivering geographic information. It can be colored by category in stacked bar charts or a single color for simple cases.
- **Tables:** Tables present data in grid format. They are not intuitive when presenting geographic data or trends, but for a blind person who requires a screen reader, this is the most suitable type [12]. Even for low-vision people who may not need screen readers, there are many challenges in accessing bar charts as shown by Sampath et al. [13], so providing tables as an option is crucial to improve accessibility for them.

Without optimized color palettes, information delivery is limited and the visualizations are unreadable for people with color vision deficiencies. A low-vision or blind user may prefer tables over maps and charts, while a sighted person benefits from visual representations. The key improvement of the study over previous ones is empowering users with decision-making control. While providing scientifically proven color and type choices, end users have the freedom to try out and decide which one they prefer the most.

3.1.3 Customization in Accessible Data Visualization

A key question is why a "dynamic" approach is important. Previous studies have analyzed the needs of different vision groups, but the research focuses on letting users to determine their own preferences. This adaptability ensures that the information is more engaging.

In general, Bureau of Internet Accessibility emphasizes that accessibility features should be added to core design [14]. The second principle "Flexibility in Use" in The 7 Principles paper by Center for Excellence in Universal Design (CEUD) also highlights this [15]. This principle says it is important to provide choices in methods of use to meet diverse user needs.

Specifically, for dynamic settings in visualization, Elavsky et al. discussed the need for improving accessibility in data visualization. Their solution Data Navigator enables more structured and customizable interfaces for people with disabilities [16]. Similarly, Gorniak et al. examined the conversational AI-driven tool VizAbility, which enhances accessibility by allowing users to interact with visualizations using natural language [17]. In addition, MIT Vision Group talked about the customization when designing screen readers for low vision and blind users, they emphasize that user control is a key to making screen readers more effective [18]. This paper extends that idea by giving users flexibility in designing visualizations.

3.2 Application

In the application stage, the framework is implemented as an interactive web application using Python and Streamlit, a Python package for creating user-friendly front-end webpages for visualizations [19]. Alongside Streamlit, standard libraries like Pandas and Plotly are used for data processing and plotting. The application is developed with the following key components:

- **Dashboard Layout:** The main part of the dashboard is the visualization, with necessary titles and legends. The left sidebar, which can be hidden contains two selectors. Users can choose one color palette and one visualization type. There are also some default settings in Streamlit that users can interact with, such as toggling light/dark mode or exporting visualizations.
- **Data Processing:** The GeoJSON dataset provides population data for the Canadian provinces [20]. It has been preprocessed using Pandas and GeoPandas.
- **Visualization Techniques:**
  - Choropleth Maps: It is the default visualization type. Folium, a graphing library in Python, is used to dynamically shade provinces based on population size and the chosen palette.
  - Bar Charts: Implemented with Plotly Express, it uses blue for bin coloring. Blue provides sufficient contrast against the light or black background. For Tritanopia, blue may not be ideal in general, but this is not a significant problem since only one color is used, and the color is not delivering any information.
  - Tables: Displayed using Streamlit's default table, offering a structured but less intuitive view for the dataset. It does not clearly convey differences in population levels, even when sorted in ascending or descending order.
- **Color Palettes:** Previously designed color palettes for choropleth maps are incorporated into the selector in the sidebar.

Figure 3, 4 and 5 demonstrate the dashboard [21].

4 Results

The standard contributions include:

1. A framework for dynamic color adaptation in information visualizations,
2. An interactive dashboard that supports real-time user customization,
3. Practical guidelines for integrating accessibility into visualization tools.

Specifically, this dashboard allows users to choose from colorblind-friendly and low-vision friendly palettes. While formal user testing was not performed, it builds directly on the well-established principles and prior research [2, 16, 17]. Research by Bureau of Internet Accessibility and CEUD found that fixed accessibility designs are not enough to meet individual needs [14, 15].

Visualization technicians do not need to develop visualizations repeatedly with different colors, while maintaining accessibility across user groups. In addition, information is usually only delivered in one type of visualization, but types like choropleth maps are hard for low-vision or blind users to read. This application provides the option to switch between maps, bar charts, and tables, supports people who struggle with color differentiation.

These results support the research question that user-driven customization provides a more adaptable approach to access data visualization compared to static color schemes across user groups.

5 Limitations & Future Work

This project has several limitations. First, it lacks a functional prototype. Second, user testing is limited. The framework will not be evaluated with low-vision or colorblind users within the scope of this project. Third, the framework focuses on specific types of visualizations, such as bar charts and choropleth maps. News organizations often include image-based content, making these images accessible for different vision groups is beyond the scope of this research. Additionally, this project does not address accessibility for blind users.

To address these limitations, future work should implement a working prototype and conduct formal user studies with low-vision and colorblind users. Simulated validation such as using colorblindness simulators can provide initial insights as well. Researchers should also consider supporting blind users and extending the framework to cover a wider range of visualization types, including images. AI-driven palette recommendation could also provide personalized suggestions based on user profiles or interaction history when users are unsure where to start. Most importantly, accessibility for people with vision impairments should be integrated into the core designs. These improvements will ensure that data visualizations are more inclusive and flexible.

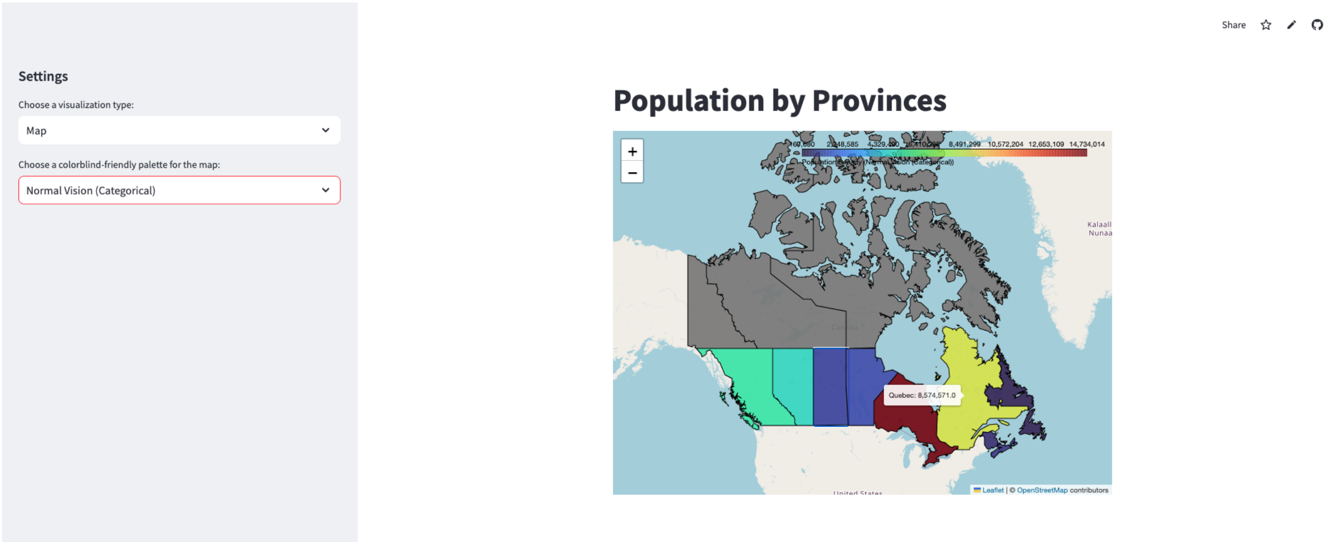


Figure 3: Interactive choropleth map of population by provinces in Canada.

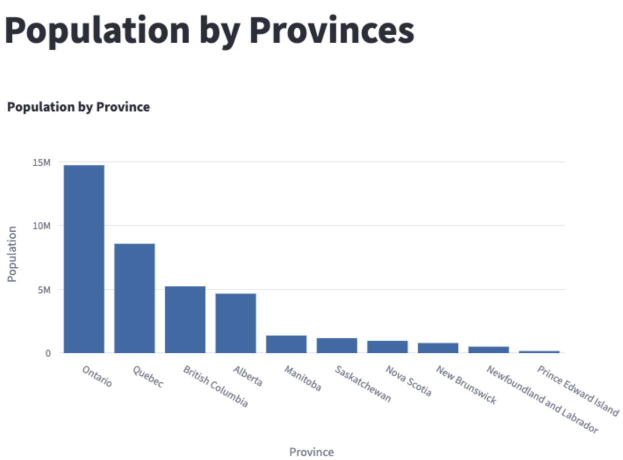


Figure 4: Bar chart visualization of population by provinces.

Population by Provinces

Province	Population
Ontario	14734014
Quebec	8574571
British Columbia	5241058
Alberta	4666101
Manitoba	1386335
Saskatchewan	1178681
Nova Scotia	969383
New Brunswick	794300
Newfoundland and Labrador	510550
Prince Edward Island	167680

Figure 5: Tabular representation of population by provinces.

6 Conclusion

This study introduced a dynamic color adjustment framework that enhances visual accessibility by allowing real-time, user-driven customization of colors and visualization types. It aims to improve the accessibility of visualizations across vision impairment groups. Through literature review, the static color schemes and visualization types this research builds directly on are effective in accessibility improvement. While formal user testing remains future work, previous research supports the hypothesis that a dynamic, user-driven adaptation improves accessibility over static color schemes.

Future work should include the development of a working prototype, real-world user testing, and support for more visualization types. Additionally, integrate the framework into common libraries and tools such as Power BI. AI-driven recommendation systems may also be explored to provide personalized suggestions.

By shifting the focus from pre-defined accessibility solutions to interactive user-driven customization, this novel approach highlights the importance of flexibility in delivering data visualization. Making accessibility features more adaptive and intuitive ensures that visualizations remain clear and comprehensive for all users, regardless of their visual abilities.

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