Understanding and Improving Drilled-Down Information Extraction from Online Data Visualizations for Screen-Reader Users

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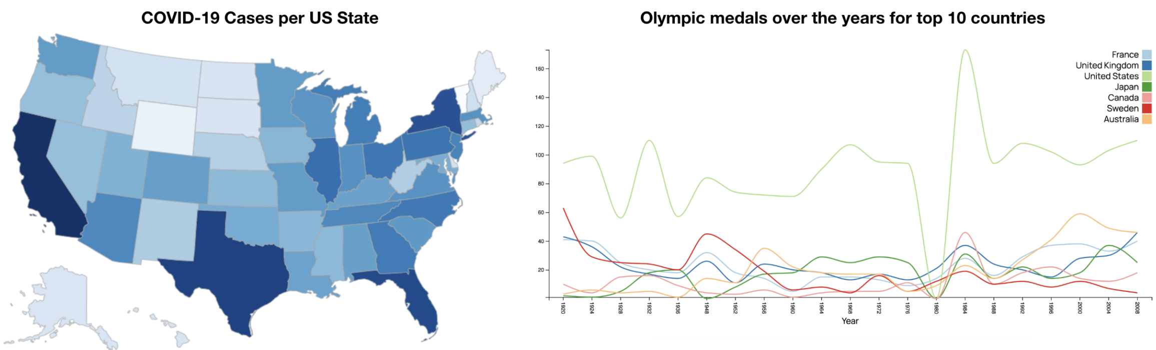

Q: *How is New England compared to Great Lakes?*

A: **Average cases for New England is 1,382,428.3. Average cases for Great Lakes is 452,551.89. Cases for New England are greater than Great Lakes.**

Q: *How many medals did Japan win in 2004?*

A: **Found the following possible results in the data: Medal Count for Japan in 2004 is 37.**

Figure 1: A screen-reader user's interaction with: (*left*) a geospatial map showing COVID-19 cases per US state, and (*right*) a multi-series line graph showing Olympic medals for the top 10 countries over multiple years. For each visualization, the user issues a question ("Q") to our system, VoxLens, which answers the user via their screen reader ("A").

ABSTRACT

Inaccessible online data visualizations can significantly disenfranchise screen-reader users from accessing critical online information. Current accessibility measures, such as adding alternative text to visualizations, only provide a high-level overview of data, limiting screen-reader users from exploring data visualizations in depth. In this work, we developed taxonomies of information sought by screen-reader users to interact with online data visualizations granularly through role-based and longitudinal studies with screen-reader users. Utilizing these taxonomies, we extended the functionality of VoxLens by supporting drilled-down information extraction. We assessed the performance of our VoxLens enhancements through task-based user studies.

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1 INTRODUCTION

Online data visualizations are commonly used on the web to effectively communicate large volumes of data and assist users in extracting information efficiently, helping people make informed life decisions concerning their health, finances, and activities. However, the essential visual nature of data visualizations inherently disenfranchises screen-reader users (over 7.6 million people in the United States). Prior work has reported that alternative textual descriptions ("alt-text") for visualizations are often missing [1, 3]. In cases when alt-text is present, screen-reader users (SRUs) spend 211% more time and are 61% less accurate in extracting information than their non-screen-reader user counterparts [1]. Therefore, it is essential to find ways to make online data visualizations more accessible, efficient, and usable to screen-reader users (SRUs).

Prior tools have contributed to the accessibility of online visualizations but they either focus on simple graphs (e.g., single-series bar graphs) or the extraction of mainly high-level ("holistic") information, such as extrema and averages. Therefore, their granular ("drilled-down") interactions, such as extracting and comparing data points, especially with complex visualizations, remain unexplored. To achieve this goal, we employed a three-step process. First, we aimed to understand the granular information SRUs seek from simple and complex online data visualizations. Then, we utilized these findings to develop taxonomies of the information sought by SRUs during their holistic and drilled-down explorations. Finally, using the taxonomies, we extended the functionality of VoxLens [2]—an open-source JavaScript plug-in that improves the accessibility of online data visualizations using a multi-modal approach—by supporting granular information extraction for SRUs.

We conducted role-based and longitudinal user studies to understand the granular information SRUs seek from online data visualizations. Utilizing our findings, we composed taxonomies of the information sought by SRUs from visualizations. We enhanced the capabilities of VoxLens using these taxonomies. To assess the performance of our enhancements, we conducted a task-based user study. Using our enhancements, SRUs performed 5.6% *more* accurately than non-SRUs. (By contrast, using the original version of VoxLens, SRUs performed 15% *less* accurately than non-SRUs [2].)

2 ENHANCEMENTS TO VOXLENS

Utilizing the taxonomies from our role-playing and longitudinal studies, we enhanced the functionality of VoxLens by supporting drilled-down information extraction from complex visualizations (geospatial maps and multi-series line graphs). We present the design, features, and implementation of our enhancements. We extended the functionality of the *Question-and-Answer* mode, as the other two interaction modes only assist in holistic exploration. We selected the most frequently sought information types from our taxonomies to implement as additional features for VoxLens.

2.1 Overview of VoxLens

VoxLens is an open-source JavaScript plug-in that improves the accessibility of online data visualizations for SRUs using a multi-modal approach [2]. Additionally, VoxLens requires only a single line of code for integration. There are three modes of VoxLens: (1) *Question-and-Answer mode*, where the user verbally interacts with the visualizations; (2) *Summary mode*, where VoxLens gives a summary of the visualization and the information it contains; and (3) *Sonification mode*, where VoxLens enables listeners to interpret data trends by mapping data to a musical scale. Prior to the enhancements presented in this work, VoxLens was limited to only simple visualizations created using two-dimensional single-series data, such as single-series bar graphs.

2.2 Factor-Level Categorization (Multi-Series)

We used the keyword matching algorithm from VoxLens to support categorization by factor levels. Specifically, we searched the user's query to find keywords matching the factor levels. For example, if the user said, "Tell me the housing price for Texas," our algorithm would identify "Texas" as the factor level and calculate the average housing prices in Texas for the past 10 years. We used "average" as the default command based on the findings from our role-playing and longitudinal studies. However, users can specify other statistical measures based on their needs (e.g., "Total housing price for Texas").

2.3 Regional Categorization (Geospatial Maps)

Our participants extracted and compared data points from geospatial maps by categorizing the data by regions within the United States (e.g., east coast); for countries of the world, they grouped the data by continents (e.g., Asia). We further expanded the *state* module based on the National Geographic Society's classification of regions in the United States. As the modules are open-source and engineered to be scalable, developers can easily make necessary adjustments to the VoxLens library to extend the modules to add more regions (and provinces).

2.4 Additional Features

We employed a two-step interaction design for factors and their levels. The first step presents the users with the count for the factor levels and the second step enables them to obtain the list. We also added the functionality to obtain the range of the dependent variable, providing users with the minimum and maximum values. Our participants expressed an interest in obtaining the entire data set. To do so, we appended a table to the end of the visualization, which was visually hidden but accessible to screen readers. Additionally, we extended the vocabulary of VoxLens in our enhancement to recognize more keywords.

3 CONCLUSION

In this work, we conducted role-playing and longitudinal user studies with SRUs to understand their holistic and drilled-down information extraction needs from simple and complex online data visualizations, including multi-series line graphs and geospatial maps. We used our findings to generate taxonomies of the information sought by SRUs in their interactions with online data visualizations. Then, utilizing these taxonomies, we enhanced the capabilities of VoxLens to enable them to extract information from complex data visualizations in a granular fashion. We assessed the performance of our enhancements using a mixed-methods approach through a task-based user study. Our enhancements "closed the gap" between SRUs and non-SRUs with respect to the accuracy of extracted information and interaction times.

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