IEEE VIS DC: Tool-making as an Intervention on the Accessibility of Interactive Data Experiences

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Index Terms: Interactive visualization, accessibility, toolkits.

1 Introduction

Data visualizations are a powerful way to gain insight from data, which is an increasingly important activity in the present context of our data-driven world. Decision-making in personal, industry, research, and governmental contexts relies on access to data and visualizations. However, excluding people with disabilities from access to data creates gaps in job opportunities, civic engagement, and quality of life.

Yet making data visualizations accessible for users with disabilities remains a difficult task for designers, especially those without lived experience with a disability. Sighted visualization designers, as one example, must first gain an understanding of ways that their current designs produce barriers for people who are blind, then they must either learn to use new tools or learn to adapt the tools that they have in order to build more accessible artifacts. The design, inspection, and development of non-visual experiences presently requires the practitioner to conduct non-visual tasks using audio-based tools, such as a screen reader.

Our research aims are to study technological interventions on practitioner work in the domain of data visualization, towards more accessible outcomes for people with disabilities who use and interact with the data interfaces and artifacts that practitioners produced. We assert that practitioners who design and develop interactive data visualizations are the last people responsible for the exclusion of people with disabilities. We aim to examine how resources, techniques, and tools can shift the behavior of these practitioners.

However, some of the gaps in our knowledge center on what barriers practitioners themselves face. Do they lack knowledge about what is or is not a barrier that excludes people with disabilities from participating in the use of a data visualization? Would they be more successful with this knowledge? Do practitioners lack the correct building blocks and substrates for creating visualizations that are accessible? Would they be more successful with better tools and materials? Or perhaps do practitioners lack consideration for the ways that end users want to customize or fit their experiences? What if data practitioners are blind and performing analysis for themselves? How would their tooling differ?

In prior work, we explored these gaps. Our initial project, Chartability, provided practitioners with a framework of heuristics for evaluating the accessibility of interactive data representations that they were authoring, so that they would have the knowledge to produce more accessible visualizations. We then developed a software tool, Data Navigator, which provides more robust building blocks for practitioners to assemble non-visual, navigational experiences for users of assistive technologies. Our *Softerware* project explored how system developers can build interactive data representations that end users are able to manipulate and customize to suit their accessibility needs. And our latest project, a novel physical input device called the *cross-feelter*, improved the speed of task completion and quantity of data queries of blind people when exploring and analyzing data.

However, gaps in our knowledge of practitioner needs still remain. In particular, we believe that practitioners without disabilities still face barriers when interpreting their own design and development decisions for users with disabilities.

This document culminates in a proposal for *Skeleton*, a development and de-bugging tool built on top of *Data Navigator*. *Skeleton* will be designed to visually represent non-visual navigation and interaction experiences, which we conjecture will assist sighted designers in rapidly prototyping and fixing custom screen reader experiences for diagrams, maps, and bespoke visualizations. We hypothesize that by enabling visual inspection and iterative design, *Skeleton* will not only speed up the development process but also serve as an educational resource for understanding non-visual data interactions.

2 Related Work

2.1 Tool-making in Human-Computer Interaction

In human-computer interaction, tool-making research spans both the creation of entirely new capabilities and the enhancement of existing systems. One prominent approach involves piggybacking on current systems—leveraging their established functionalities to introduce improvements that streamline workflow or unlock new interactions [14].

Another significant approach centers on the notion of appropriation [48, 7, 6, 39]. Here, research examines how users adapt tools for uses beyond their original intent. In some cases, theory has been developed from the study of emergent and generative tool-use [3, 1], broadly informing future tooling projects as well as general theories of creative human interaction with technology.

Beyond these, tool-making in HCI also includes the development of systems designed to empower users by providing entirely new capabilities, sometimes explicitly named "toolkits" and other times generally just referred to for their ability to enable novel interaction and outcomes [40, 38, 44, 28]. These projects may range from novel software environments that facilitate rapid prototyping and live programming to innovative hardware devices that bridge the gap between digital and physical interactions [38, 18, 20]. The emphasis is not solely on problem-solving but on enabling creative exploration, new possibilties, and even hacking the potential of technologies towards new ends [19].

2.2 Interactive Data Visualization and Data Science

Recent years have witnessed significant advancements in interactive data science and visualization, driven by innovations that enhance both the performance and usability of data tools.

Cross-filtering, as a subtype of cross-linked interaction, has emerged as a powerful technique, enabling users to interact with multiple data dimensions simultaneously [16, 2, 50, 30]. Stress has been placed in recent years on developing fast systems that that reduce latency in user interaction as much as possible [30, 17, 52].

Automated data processing and cleaning have revolutionized workflows by reducing the time spent on manual data wran-

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gling [10]. Enhanced computational frameworks and optimized libraries allow for real-time data manipulation, making interactive visualization more responsive [17]. Coupled with easier-to-use grammars and scripting languages, these tools enable users to generate complex, interactive, visual representations of data [41]. New visualization types and techniques—ranging from dynamic dashboards, faceting, to immersive 3D visualizations—offer novel ways to explore and interpret data [52].

2.3 Data Interaction and Accessibility

Research and standards at the intersection of accessibility and data interaction are both somewhat limited by a strong bias towards visual disabilities [51, 21, 34, 47, 53], leaving the barriers that many other demographics face unstudied. In *Chartability*, 36 of the 50 criteria related to accessible visualization considerations involve visual disabilities [8, 11]. Accessibility research broadly shares this bias, focusing on users with visual disabilities [33].

Since the 1990s, the most prominent and active accessibility topic in data has been color vision deficiency in data visualization [4, 36, 37, 29, 35]. Research projects that explore tactile sensory substitutions to charts have been a topic in computational sciences dating back to the 1983 [12, 31], with tactile sensory substitutions being used for maps and charts as far back as the 1830s [15]. More recent work investigated how to better understand the role of sensory substitution for interactive data visualizations [5, 55, 23, 45].

Some more recent work has explored robust screen reader data interaction techniques [13, 46, 54, 49], screen reader user experiences with digital, 2-D spatial representations, including data visualizations [42, 43, 26, 25, 27, 11], and dug deeper into the semantic layers of effective chart descriptions [32]. A wide array of emerging research projects investigate blind and screen reader users needs, barriers, and preferences, and offer guidelines, models, and considerations for creating accessible data visualizations [43, 5, 11, 24, 22, 54, 9, 55].

3 Preliminary Work

3.1 *Chartability*: Heuristics as a Tool and Resource

> This section was adapted from my published paper: F. Elavsky, C. Bennett, and D. Moritz, ‘How accessible is my visualization? Evaluating visualization accessibility with Chartability’, *Computer Graphics Forum*, vol. 41, no. 3, pp. 57–70, Jun. 2022.

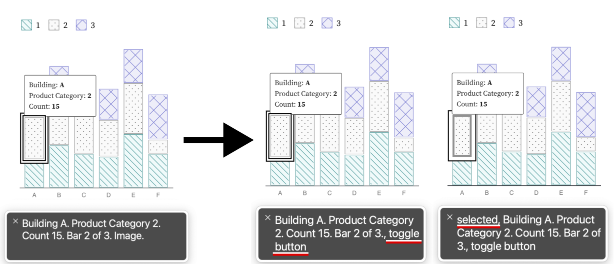

Figure 1: Example evaluation of a visualization: an interactive chart displaying only “Image” as semantic information to a screen reader is instead changed to show the correct semantics “toggle button” (middle) as well as provide instant feedback, “selected” (right) during interaction.

Novices and experts have struggled to evaluate the accessibility of data visualizations because there are no common shared guidelines across environments, platforms, and contexts in which data visualizations are authored. Between non-specific standards bodies like WCAG, emerging research, and guidelines from specific communities of practice, it is hard to organize knowledge on how to evaluate accessible data visualizations.

We present Chartability, a set of heuristics synthesized from these various sources which enables designers, developers, researchers, and auditors to evaluate data-driven visualizations and interfaces for visual, motor, vestibular, neurological, and cognitive accessibility. In our work, we outline our process of making a set of heuristics and accessibility principles for Chartability and highlight key features in the auditing process.

3.1.1 Preliminary Results

Working with participants on real projects, we found that data practitioners with a novice level of accessibility skills were more confident and found auditing to be easier after using Chartability. Expert accessibility practitioners were eager to integrate Chartability into their own work. Reflecting on Chartability’s development and the preliminary user evaluation, we discuss tradeoffs of open projects, working with high-risk evaluations like auditing projects in the wild, and challenge future research projects at the intersection of visualization and accessibility to consider the broad intersections of disabilities.

3.2 *Data-Navigator*: Accessibility Tooling for Visualization Toolmakers

> This section was adapted from my published paper: F. Elavsky, L. Nadolskis, and D. Moritz, ‘Data Navigator: An Accessibility-Centered Data Navigation Toolkit’, *IEEE Transactions on Visualization and Computer Graphics*, pp. 1–11, 2023.

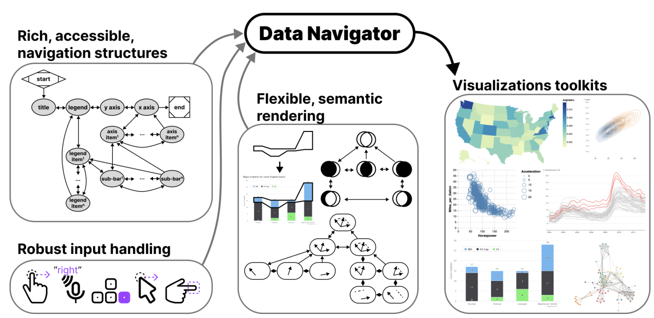

Figure 2: Data Navigator provides data visualization libraries and toolkits with accessible data navigation structures, robust input handling, and flexible semantic rendering capabilities.

Making data visualizations accessible for people with disabilities remains a significant challenge in current practitioner efforts. Existing visualizations often lack an underlying navigable structure, fail to engage necessary input modalities, and rely heavily on visual-only rendering practices. These limitations exclude people with disabilities, especially users of assistive technologies.

To address these challenges, we present *Data Navigator*: a system built on a dynamic graph structure, enabling developers to construct navigable lists, trees, graphs, and flows as well as spatial, diagrammatic, and geographic relations. *Data Navigator* supports a wide range of input modalities: screen reader, keyboard, speech, gesture detection, and even fabricated assistive devices.

3.2.1 Preliminary Results

We present 3 case examples with *Data Navigator*, demonstrating we can provide accessible navigation structures on top of raster images, integrate with existing toolkits at scale, and rapidly develop novel prototypes. *Data Navigator* is a step towards making accessible data visualizations easier to design and implement.

3.3 *Softerware*: Building Tools for Accessibility and Personalization

This section was adapted from my paper, currently under review with CG&A: F. Elavsky, M. Vindedal, T. Gies, P. Carrington, D. Moritz, and Ø. Moseng, 'Towards *softer*ware: Enabling personalization of interactive data representations for users with disabilities', *Computer Graphics and Applications* (to appear at *IEEE VIS 2026*), 2025.

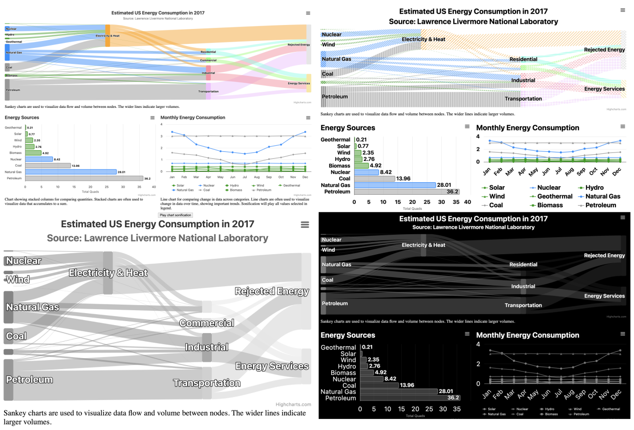

Figure 3: Sometimes one design is not enough. Our design (upper left) and three different designs by low vision users. All low vision users chose larger text, but then diverged: redundant-encoding enabled (upper right), high zoom and greyscale on white (bottom left), and then dark mode (enabled externally) with greyscale (bottom right).

Accessible design for some may still produce barriers for others. This tension, called access friction, creates challenges for both designers and end-users with disabilities. To address this, we present the concept of *softerware*, a system design approach that provides end users with agency to meaningfully customize and adapt interfaces to their needs.

To apply softerware to visualization, we assembled 195 data visualization customization options centered on the barriers we expect users with disabilities will experience. We built a prototype that applies a subset of these options and interviewed practitioners for feedback. Lastly, we conducted a design probe study with blind and low vision accessibility professionals to learn more about their challenges and visions for softerware.

3.3.1 Preliminary Results

We observed access frictions between our participant's designs and they expressed that for softerware's success, current and future systems must be designed with accessible defaults, interoperability, persistence, and respect for a user's effort-to-outcome ratio.

3.4 *Cross-feelter*: Tool-making for Blind Data Science

This section was adapted from my paper, currently under review with IEEE VIS: F. Elavsky, Y. Li, P. Carrington, and D. Moritz, '*Cross-feeltering*: A principled tactile design approach for blind linked data interaction', *IEEE Transactions on Visualization and Computer Graphics*, 2025.

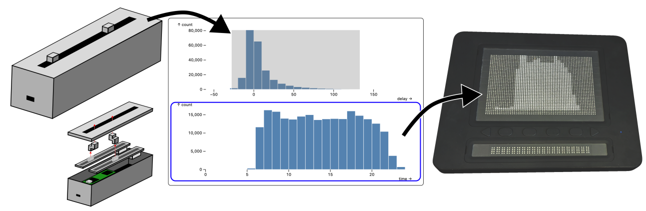

Figure 4: Interaction and perception in one space while being able to perceive output in a separate space is the cornerstone of cross-filtering. Our prototype *cross-feelter* (left) can manipulate a visual cross-filter on one visualization (middle) in order to produce output in a separate visualization, as a tactile graphic (right).

Cross-filtering is a widely-used interactive data science technique that helps sighted users visually filter, build hypotheses, find correlations, compare distributions, and explore relationships quickly. However, blind individuals face substantial challenges when cross-filtering due to the limits of screen readers, which enable input and output on only one discrete element at a time; a time-consuming process that limits ideation and exploration.

We propose a tactile interaction approach that enables users to perceive the input they are providing while also focusing their attention on a separate output space, such as a screen reader, tactile display, or sonification. We mirror existing principles in visual cross-filtering, such as providing cross-linked input and output and facilitating fast, dynamic, user-driven interaction.

We present a novel prototype device called the *cross-feelter* that demonstrates our design approach as well as an analytical environment for testing our device. We evaluate our approach in a within-subjects study with 15 blind individuals who either have existing (7) or no (8) professional data expertise.

3.4.1 Preliminary Results

In our quantitative evaluation, we find that using our prototype with a braille display compared to a screen reader and braille display greatly improves speed (+90%) and quantity of computational (+188%) and spoken (+54%) exploratory queries produced by our participants. Users also self-report that our approach greatly improves enjoyment and reduces perceived stress and anxiety when working with data, especially among our participants without prior professional data analysis experience. We conclude with further use cases of tactile cross-interaction that our design approach enables.

Our work expands cross-filtering into non-visual modalities, demonstrating how tactile interaction can inherit the analytical power of linked visualizations for blind data scientists.

4 (Proposed Work) *Skeleton*: Visual Tooling for Non-visual Data Experiences

In our previous work we built Data Navigator, a tool for assembling non-visual data interfaces. Despite the existence of this tool, key gaps still persist: Ironically, making visualizations accessible in non-visual ways poses accessibility barriers for *sighted* practitioners, who may not be able to easily understand, build, and debug screen reader experiences for people who are blind.

This research proposes *Skeleton*, a tool that visualizes non-visual navigation paths, semantic structures, and screen reader interactions in data visualizations. By rendering these invisible experiences visually, Skeleton seeks to bridge the cognitive gap for sighted practitioners, enabling them to more easily inspect, debug, and author accessible experiences during development.

4.1 Approach

First our approach will be to investigate existing tooling that explores making non-visual experiences visual, and if any existing

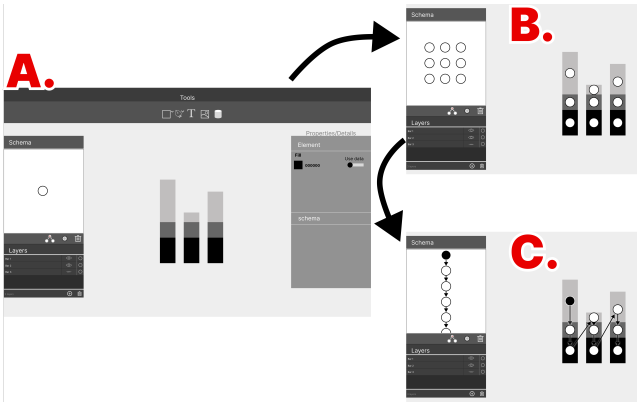

Figure 5: Low-fidelity design draft of *Skeleton*'s main user interface components and interactions. A. *Skeleton*, our graphical user interface for creating and debugging screen reader navigation experiences of data visualizations. B. Users can add nodes wherever they want over the chart, manually or automatically with algorithmic assistance. C. Users can then "draw" edges between nodes, which signify navigation paths through the visualization.

projects explore this with accessibility and software development goals in mind.

Second, we will develop a graphical user interface for *Skeleton* that builds on *Data Navigator*'s underlying graph-based substrate for scaffolding navigable, interactive data structures (see Figure 5).

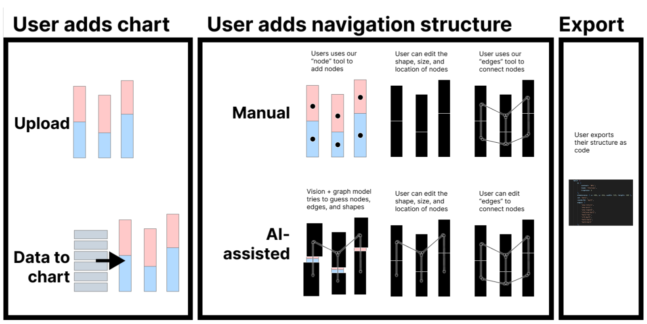

Figure 6: Design draft of user flow in *Skeleton*: adding a chart or data, adding nodes and edges manually or with AI-assistance, and code exporting capabilities.

Users will be able to edit nodes manually (see B. in Figure 5) by directly clicking on visual "add nodes" interface elements and then directly clicking on their visualization where those nodes should exist. The exact location of nodes is shown in the main element inspector while the schema (abstract representation) of those nodes will be reflected in a schema inspector (shown on the left in Figure 5). Nodes that are selected in either view will be shown in high contrast (black) as selected in both views.

And users will be able to add edges using our edges drawing tool. This will enable users to drag a visible line to connect between nodes or add connections between all nodes in a selection. Edges can be drawn between nodes in both the main view or the schema inspector (see C. in Figure 5). Rules for navigation (direction, etc) will be automatically generated, up to a limit, but users will always be able to edit these features using the Details Inspector (shown on the right side of the interface).

Our interface tool will allow 2 different kinds of input: (**1**) data, in a standard JSON format (array of objects) or (**2**) as a rasterized image (png, jpg, etc). If users upload data, they can choose to render a simple visualization from it using vega-lite. Users will then be able to choose to either manually or "automatically" build navigation (with AI-assistance). Even when using assistance, users will always be able to tweak and override the model's decisions (see: Figure 6). Lastly, users can export the code generated by the system for use in their own environments.

4.2 Evaluation

Our research will address three questions: (**1**) What conceptual barriers arise when practitioners use visual tools to design non-visual experiences? (**2**) How can visual representations of non-visual interfaces improve practitioners' design decisions? (**3**) How might practitioners identify and resolve accessibility barriers during visualization authoring?

To evaluate our work, we will provide a sandbox prototyping experience to 12 sighted designers and observe how they work to make their own diagrams, maps, and bespoke visualizations accessible to navigational assistive technologies, in addition to performing a debugging task for a screen reader experience of our design. We will then conduct a qualitative interview with our practitioners, using our sandbox session as a probe to help us learn more about what ways a visual tool that constructs non-visual experiences could be improved.

5 Questions for the Panel

- How might I best frame the dual purpose of Skeleton as both a development/de-bugging tool *and* an epistemic aid for understanding non-visual data interactions?
- Are there examples in HCI or VIS where visual representations have been successfully used to help practitioners understand *non-visual* experiences? How might I learn from or differentiate Skeleton from them?
- Do you see any methodological or conceptual risks in designing accessibility tools *primarily for sighted developers*?
- How can I effectively evaluate whether Skeleton supports not just efficiency, but *critical reflection* and learning about accessibility among practitioners?
- Given the speculative and systems-level implications of Skeleton and Softerware, how might I build a stronger bridge between tool-making and theory-building in my dissertation?
- In which ways, if at all, should I prepare to discuss my work in light of LLMs, which have become utterly ubiquitous in scholarly imagination of HCI "tools" and systems?

6 Conclusion

Our proposed research will provide empirical insights into practitioner challenges in accessibility-focused design and the role of visual aids in mitigating them. It will refine *Skeleton* to better align with practitioners' workflows, enhancing their capacity to build inclusive visualizations. A theoretical framework will also emerge, emphasizing bidirectional translation between visual and non-visual experiences in authoring tools, which we hope will inspire other environments (such as within PDFs and web development) to follow suit.

By equipping practitioners with tools to visualize and address the design and development of non-visual experiences of data, this work aims improve design practices, foster better design collaboration between sighted and blind individuals, and inspire new technological developments in accessibility tooling. Our outcomes could transform how accessible data interfaces are created, fostering greater equity in data-driven decision-making for users with disabilities. Aligning with broader goals of digital inclusion, our research ensures that data's transformative potential is accessible everyone, including people with disabilities.

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