Designing Communicative Visualization for People with Intellectual Developmental Disabilities

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ABSTRACT

Visualization research has paid little attention to individuals with intellectual developmental disabilities (IDDs). This lack of attention is problematic due to the fact that the consumption of visualization relies on a significant number of cognitive processes, including the ability to read and process language and retain information, and these processes often operate differently for people with IDDs. We argue that visualization should be used to communicate with and by IDD populations, who are currently unsupported. We identify three elements of visualization design that may improve how people with IDDs communicate with data based on prior efforts and empirical findings to examine the influences of chart types, data continuity, and chart embellishments on this communication. In doing so, we hope to establish preliminary steps towards bridging the gap between IDD individuals and data in support of their self-advocacy and self-determination, and thus recognizing this underserved group in the conversational visualization design space.

Index Terms: Human-centered computing—Visualization

1 INTRODUCTION

Visualization research offers numerous theories and guidelines to ease the access to encoded data [9, 13, 15, 29]. However, these theories are often designed for people with strong cognitive skills including the ability to read and process language and retain information. Intellectual and developmental disabilities (IDDs) are disorders that are usually present at birth and that negatively affect the trajectory of the individual's physical, intellectual, and/or emotional development [3]. Over 7 million people in the US are suffering from IDDs [4]. These IDDs impair cognitive processing in ways that may make traditional visualizations difficult to use. As a result, IDD populations cannot use existing visualization tools for data communication and are excluded from many of the benefits of data-driven reasoning and communication. While prior studies have found that the cognitively impaired would benefit from using visuals to reduce cognitive load and enhance their learning process [10, 22, 33], there are no thorough guidelines or tools for how visualization might achieve this goal. Effective communication between this underrepresented group and data visualization remains unexplored.

People with IDDs have the right to advocate for themselves, which means they must have a say in decision-making in all areas of their daily lives and in public policy decisions that affect them. Team efforts from IDD self-advocates, caregivers, policy makers, researchers, and family members have been made to promote this participation. Communication remains at the heart of these efforts and is the key to better community. Efficient communciation with data will largely improve the abilities of people with IDDs to engage in self-advocacy and help related parties to make intelliegent and informed decisions. Nevertheless, we have no clues so far about how to design better visualizations to translate data into accessible information for IDDs.

As first steps towards remedying this divide, this position paper argues for preliminary aspects of visualization design that should be examined to support visual communication for IDD users. We identified three areas building on a series of discussions between visualization designers and clinical psychiatrists: chart selection, continuity, and semantic embellishment. We examined the role of the visual as the dominant channel of human perception and communication, and highlighted its benefit to the target audience. We reviewed existing studies and findings on the influence of chart types, data contunity, and chart embellishments from graphical perception. We then discussed the design possibilities to adapt visualizations to better fit the needs of this group. We argue that we should improve how we use visualization to communicate with and by IDD individuals and we hope to elicit more conversations and discussions to design inclusive visualization to support their self-advocacy. When it comes to human beings, there is no such thing as ”normal”. We believe that inclusive visualization design is to design for diversity and to learn from this diversity to make visualization itself better.

2 VISUALIZATION AND INCLUSIVE DESIGN

Visualization for Communication Visualization used in communication allows people to fluidly leverage data to support their arguments [21]. To that goal, efforts have been made to design better visual graphics to convey quantitative information [8, 13, 41], and to evaluate the communication accuracy and efficieny of different visual elements [11, 38], and to prioritize and explore the explanatory side of visualization for effective presentation [27]. Designing expressive and narrative visualizations has also been evolving as a recent focus around this topic. Various narrative strategies have been discussed and data-driven authoring tools have been developed to allow users to build expressive visualizations, which highlighted the opportunities of using a storytelling approach for engagement, memorability and ease of interpretation [18, 20, 26, 40]. However, all of this work has focused on communication for traditional populations. As a result, people with IDDs aren't able to partake or use visualizations to their full advantage. This is especially problematic when the data is being used to make an argument about decisions affecting their lives and well-being.

Inclusive Visualization Design Born out of the digital environments, inclusive design has been widely applied in many areas including visualization. Inclusive visualization pushes the boundaries of visualization literacy, targeting a broader range of people, who often have a restrained set of abilities. For instance, Lee et al. developed VLAT, a visualization literacy assessment test to measure non-expert users' visualization literacy [30]. Alper et al. advanced our understanding of children visualization literacy through the development of *C'est La Vis*, an interactive tool for teaching visualization [7]. Choi et al. recognized the inaccessibility of web-based visualizations for visually imparied users, and built a

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Google Chrome extension to automatically extract information from charts [14]. Fang et al. compared the usability and emotional reactions across different interfaces among older adults and younger adults, their study uncovered some information design suggestions for aged users [16]. Visualization toolkits have started to developed general rules of thumb for the design of accessible visualization to be used with assistive technologies [1, 2]. The CFPB has defined an accessible design manual in alignment with the Section 508 Standards to incorporate web accessibility into data visualization design [2]. Charting libraries like amChart started to provide screen reader compatible visualization solutions [1].

However, these works focus on people with traditional cognitive processing abilities, excluding those with intellectual disabilities. According to the American Association on Intellectual and Developmental Disabilities (AAIDD), there are over 7 million people with IDDs in the US, who have difficulty equally participating in society and making informed decisions [4]. We talked with stakeholders in this community and learned about their efforts to leverage visualization to improve the self-advocacy of individuals with IDDs. Traditional tools like Tableau and Power BI were too complicated and inaccessible to this population, while paper based approaches like sketching didn't work as the data scaled. While visualization is getting more inclusive, this population and research area received very little attention. Building on research in this area and conversations with people in the AAIDD community, we identify three design factors that may help create more inclusive communicative visualization: chart type, continuity, and embellishments.

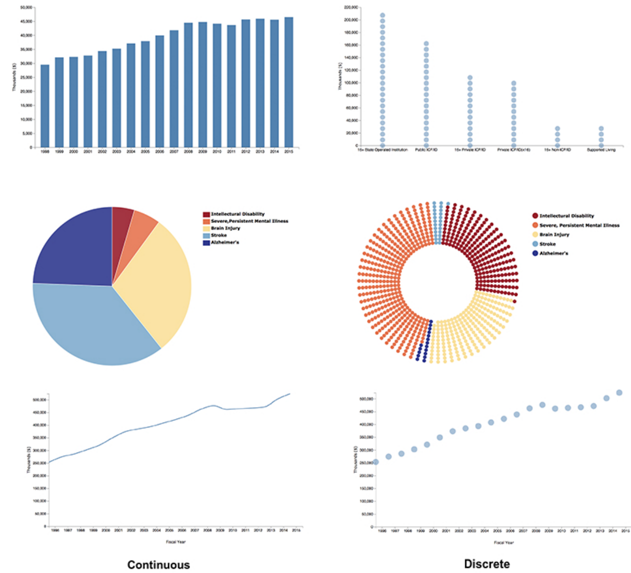

Figure 1: Data Continuity: Pairs of Continuous and Discrete Charts.

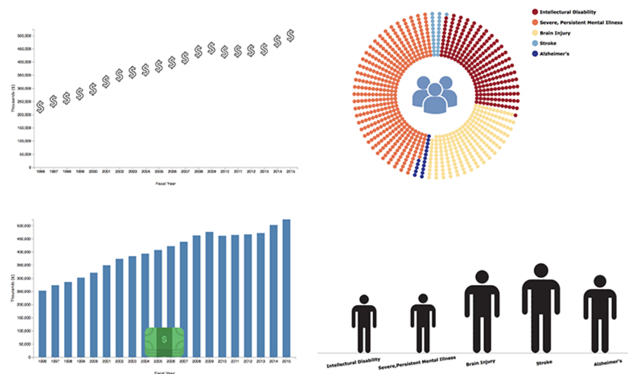

Figure 2: Chart Embellishments: People with IDD may better comprehend the underlying message of a graph when supplemental pictorial icons enforce the semantic meaning of the data.

3 Chart Types and Visual Communication

Visualization frequently presents data that is otherwise too complicated or too numerous to be described in other forms [24]. A well-designed communicative visualization typically conveys a clear message in a simple and easy to digest form. Grounded in the principles of cognition and perception, empirical studies map chart types to the tasks they support as well as the information they best communicate [5, 6, 21]. For example, bar charts are considered strong for comparing data across discrete categories [44], line charts are used to show resulting data relative to a continuous variable [44], pie charts are good for understanding the part to whole relationship in data and so forth [28].

However, preliminary discussions with advocates in the IDD community suggest that these results may not hold for the IDD population: the kinds of charts that work best for people with IDDs may not communicate data in the same way as they do for traditional populations. For example, when looking at the part-to-whole relationship of data, pie charts didn't work as well as stacked bar charts. The problem with pie charts is that they forces us to compare areas (or angles) of slices, which is usually hard and not intuitive. Instead, people within the AAIDD community noted that individuals with IDDs tended to find stacked bar charts, which use length to encode data, as more intuitive representations of proportions. This brings to light some interesting questions: Would certain chart types be more accessible than others? What visual channels are IDD people using when decoding data? How might we improve the current mapping of chart types to visual tasks to better fit into their cognitive pipeline?

To address these questions, we reached out to clinicians and advocates who work with IDD populations to understand the challenges people with IDDs face when interpreting common visualizations. Out of the informal interviews we had with stakeholders and practitioners among the IDD community, we identified chart type as one of the variables that may require new design perspectives for visualizations to better communicate across IDD populations. We hypothesize that different chart types will have different levels of communicative effects in support of the data interpretation and decision-making for individuals with IDDs. This population often leverage different cognitive strategies to reason about textual and mathematical information [32]. For example, visual cues can supplement both reading and mathematical problem solving; however, experiments in mathematics suggest that the ability to use spatial visualizations is correlated with overall mathematical abilities, with students with cognitive disabilities exhibiting significantly worse performance using visualization in problem solving than those with high mathematics abilities [42]. However, disabled students comprehended narrative structures better when coupled with visualizations and images [25] and showed improvement with supplemental pictoral imagery than traditional students [43]. Further, prior experiments suggest that people with IDDs may process visual information differently than traditional populations [36]. Taken together, these results suggest that people with IDDs may interpret visual information differently when used in conjunction with quantitative reasoning as used in visualizations. We anticipate that this difference could cause IDD individuals to interpret the same visualization in different ways, leading to differences in design hierachies for effective visualizations. Visualization research should take concrete steps to confirm and revise mappings of visualization to task to better support data communication for IDD populations.

4 Data Continuity and Visual Communication

Visualizations can represent quantities either discretely (e.g., a dot plot with a point at each measured sample) or continuously (e.g., a line graph encoding a series of discrete samples). Isotypes represent a popular and intuitive method of discretely communicating potentially large quantities of data using a small number of countable symbols [34,35] (Fig. 1). Isotype visualization has gained increasing attention and interest in the area of visual communication, especially in infographics design. Haroz et al. tested the effectivenss of pictographic reprentation and found its positive impacts on memory for the information just viewed, the speed of finding information, and the engagement and preference in seeking out those visualizations [19]. As suggested in this study, when data is countable, users generally find it more memorable and intuitive to extract the information. Our discussions with AAIDD professionals suggest that these benefits may be even more pronounced for individuals with cognitive impairments and that isotypes and other discrete representations may significantly improve visualization for IDD audiences.

We recognize data continuity as another variable in the accessible visualization design space. We argue that the countability of discrete visualizations will likely help IDD individuals better reason with data communicated through a visualization. However, the aspects of visual communication facilitated by allowing people to "count" the elements of a visualization may take many forms: Would they find discrete bar chart easier to use than the continuous one? Would they find it easier to recall the value represented by counatble points?

While discrete visualizations often have less expressive power as single, uniformly-sized marks represent multiple values, they also take advantage of our abilities to count elements. In our discussions with AAIDD professionals, this ability to count likely facilitates comparative analyses by simplifying the comparison task from comparing continuous quantities to readily enumerable values. It is simply easier to count a handful of circles in two different columns than to project the length of a bar to an axis and compare the relative differences of the projected values. Research in mathematical processing for children with intellectual disabilities support this as well: while their abilities to generalize abstract quantities is limited [17], for some disabilities, their approximate number system (the ability to roughly interpret how many objects are present in a scene) may be comparably efficient to traditional populations [12]. This suggests that discrete visualizations that transform abstract area or length judgments to concrete numerosity judgments may better communicate quantitative data than continuous visualizations.

5 Chart Embellishments and Visual Communication

Effective visualization tends to encode the most necessary information with minimalist design, as with Tufte's Data-Ink ratio [41]. However, this minimalist style may make it difficult for individuals with IDDs to connect data to meaning: abstract symbols lack semantic connection to the underlying data and many people with IDDs struggle to map abstract concepts to concrete values [17]. Recent studies suggest that chartjunk and other embellishments may have some utility for supporting cognitive processing in general audiences [23]. Borkin et al. conducted an experiment to understand visualization memorability, they found that visualizations with low data-to-ink ratios and high visual densities (i.e., more chart junk and clutter) were more memorable than minimal visualizations. Hullman et al. found that non-efficient visual elements may benefit comprehension and recall on the part of users [22]. These studies suggested the implications for using chartjunk to benefit visual perception. Other studies looked at embellishment strategies tied to specific chart types, for example, Skau et al. evaluated the impact of visual embellishments in bar charts, and identified the most important visual cues for bar charts to impact the visual communication [38,39]

We anticipate that the benefits of icons, chartjunk, and other semantic chart embellishments help overcome cognitive barriers individuals with IDDs face with minimalist, abstract visualizations. In reading comprehension tasks, access to relevant images coupled with actively sketching visualizations of narrative progress significantly increased story understanding in students with reading disabilities [25]. Principles of Universal Design recommend coupling pictoral and text representations in GUIs to enhance accessibility [37], and coupling word and relevant pictoral cues significantly improves recall for individuals with cognitive disabilities [31]. We anticipate that the pictoral cues supplied by icons and chartjunk likely help overcome limitations in processing abstract information from visualizations (Fig. 2). Designers can use this added cuing to more effectively communicate a specific message about data to an IDD audience.

6 Conclusion

In this paper, we argue that visualization design should be adapted to better consider individuals with intellectual developmental disabilities (IDDs). Current visualizations are often inaccessible to IDD populations, significantly disadvantaging them in a world increasingly driven by data. Building on conversations with AAIDD professionals and research in accessibility, we anticipate that simple changes from traditional design guidelines—considering new mappings of design to task, emphasizing discrete representations, and integrating semantically-meaningful embellishments—all may improve how effectively visualizations communicate data to IDD audiences. However, our understanding of the failures of visualization for IDD populations is grounded in anecdotal evidence and experimental studies in education and developmental studies. We are currently conducting quantitative studies to evaluate these elements as well as different design choices. Moreover, we will also be using qualitative research techniques like interview, observations, and case studies in the interest of building a solid understanding about the target audience in terms of their data interpretation patterns and preferences. At the heart of visual communication, we envision that storytelling strategies that can engage the target audience and closely connect them with the data should be developed throughout the exploratory visual analysis. We want to shed light on this unexplored design space, and raise broader attention to the individuals with IDDs and encourage more visualization research to be done to improve their self-determination and decision-making process.

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