Developing a Verbal Assistance System for Line Graph Comprehension

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Abstract. Statistical graphs have been designed for accessible use by visually impaired users. Haptic devices provide an appropriate interface for haptic exploration of statistical graphs. However, haptic exploration of statistical graphs reveals a more local and sequential inspection pattern compared to visual exploration. This difference between haptic exploration and visual exploration is usually attributed to different characteristics of the exploration processes, such as bandwidth of information extraction. To facilitate information extraction from statistical graphs, alternative sensory modalities have been employed. In particular, line graphs have been represented by sound, thus leading to *sonified* graphs. Despite their demonstrated facilitating effects, sonified graphs have limitations under complex line representations. One method of overcoming those difficulties is to develop a verbal assistance system for haptic line graph comprehension. In the present article, we summarize our studies on designing and developing a verbal assistance system for haptic line graph comprehension. We present the findings in a set of studies conducted with blindfolded and visually impaired participants.

Keywords: Haptic Graph Comprehension, Verbal Assistance.

1 Designing Graphs for Accessibility

1.1 Accessibility for Visualizing Data: Haptic Graphs

Data visualization aims at presenting or representing data so that users gain access to an appropriate means that facilitate thinking, reasoning and communication. Statistical graphs comprise an effective and efficient tool set for data visualization. Today's frequently-used statistical graphs, such as line graphs, bar graphs and pie charts find a wide range of use in various settings, from news media to classroom settings and scientific articles. Among those various types of statistical graphs, *line graph* is the most frequently used one. Depending on the variability of its basic graphical constituents, such as the framework, the specifier (i.e., the line proper), and alphanumeric labels [1], line graphs are of different types. For instance, a line graph may involve verbal annotations, or it may include multiple lines. But in its most

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simple and also most frequently used form, a line graph is a representation of a visual continuum, which conveys information about time course of trends, processes (e.g., *increase* and *decrease*), durative and punctual states [2], as exemplified in Figure 1 (a sample population graph of a bird species).

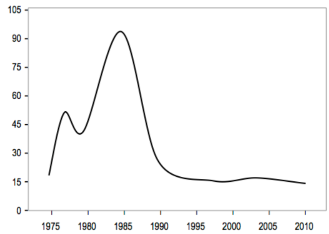


Fig. 1. A sample line graph that represents the population of a bird species

From the perspective of graph comprehension, statistical line graphs are different from graphs of mathematical functions in that the line (proper) serves for different purposes. In particular, in a function line graph, the line represents value mappings between the two axes, whereas in a statistical line graph, the line usually serves for visual continuum (without always representing a value mapping). This is because these visual line graphs are typically generated from data (in technical terms: tables or relational databases) by assigning markers to data points and filling in between the data points by means of straight or curved line segments. Therefore the lines are usually not veridical representations of the data. Instead they are visual elements that connect data points. When the lines are removed from a visual line graph, the remaining data points still represent a visual continuum, which is indeed a construction of the human visual system (cf. the Gestalt principle of visual continuity). Those characteristics of line graphs make them an appropriate means of reasoning and communication about time course of events represented by the graph line. Given their capabilities in representing time course of events, line graphs are the most frequently used type of statistical graph recently [3].

Designing accessible line graphs has been subject to research in various fronts. Haptic graphs were developed for exploration in single sensory modality (i.e., haptic exploration). However, compared to visual exploration of line graphs, haptic exploration exhibits a more local and sequential inspection pattern. Although sighted people do not have difficulties in inferring the visual continuum out of a data-point graph (in single sensory modality), haptic line graphs reveal different characteristics with respect to information extraction by haptic exploration. This difference between haptic exploration characteristics and visual exploration characteristics is usually attributed to different characteristics of the exploration processes, such as, bandwidth of information extraction. Those limitations of single-modality (i.e., haptic-only) exploration led to the development of multimodal graphs, which were able to simultaneously represent two sensory modalities (i.e., haptic and audio) [4, 5, 6]. *Sonified graphs* have been an outcome of this endeavor for designing multimodal accessible graphics. In sonified graphs, statistical data are represented by the pitch of the sound, e.g. a tall bar produces a high-pitch sound, while a short bar produces a low-pitch sound [6].

Sonified graphs have revealed demonstrated facilitating effects in perception of haptic graphs of certain types. On the other hand, given the complexity of cognitive processes in comprehension of line graphs—a closer look at graph comprehension processes reveals that it starts with the perception of the depiction as an external representation, goes through segmentation of lines and points, inspection of alphanumerical labels on the graph frame and it ends with internal, conceptual representations about the domain of discourse [7]—further assistance is necessary than sonified graphs can provide. In previous studies, we proposed that verbal assistance systems may provide the appropriate assistance that may facilitate graph comprehension processes, with a specific focus on provided verbal assistance for the shape of graph line. In the following section, we present a review of those studies that aim at designing and developing a verbal assistance system for haptic line graph comprehension.

1.2 A Verbal Assistance System for Haptic Line Graph Comprehension

Verbal assistance systems have proved to be useful in various types of diagrammatic representations, such as “you are here” maps. The development of a verbal assistance system for line graphs requires an interdisciplinary approach, which involves the identification of appropriate positions and timing for the verbal assistance on a haptic graph, as well as the analysis of the lexicon of verbal assistance by means of user studies, among others. We have been conducting experimental research on verbal assistance in line graph comprehension and comprehension of line graphs and text since the past several years [8, 9, 10, 11, 12, 13, 14, 15]. Below, we present a summary of the findings obtained in those studies.

In Habel, Alaçam, and Acartürk [13] we reported a comparative analysis of production of human referring expressions (within the context of communication through line graphs) between visual context and haptic context. The results revealed that the shape of the graph line (proper) has a major influence on identifying referents by distinguishing it from its distractors. In particular, graph segments with geometrically specific salient features (such as a graph segment with *smooth inflection points*) are more difficult to acquire in the haptic modality than in the visual modality. This is possibly due to the sequential and local perception with a narrow bandwidth of information extraction in the haptic modality, as well as due to the low resolution of daily-use haptic devices.

In a more recent study, we employed the Wizard of Oz technique to analyze the efficiency and effectiveness of verbal assistance in haptic graph comprehension. In a joint activity setup one blind-folded participant (the haptic explorer) explored haptic graphs and the other participant (the verbal assistant) provided verbal assistant when required by the haptic explorer. We analyzed the production of referring expressions by the participants [14], as well as their sketches [15]. The analysis of referring expressions in the dialogues provided valuable insight about how the haptic explorer comprehends the data, parses it for naming, recognizes which graphical elements are salient and which are hard to distinguish from the others. The results revealed that geometrically distinct shape properties of graph lines (e.g., points of high curvature) are helpful for segmentation, and shape-dependent variances may lead to differences in the types of referring expressions. For example, two distinct maximum points of a graph are usually described in terms of individual properties for each peak. However, the graph readers show a tendency to describe the graph with three peaks by highlighting the general trend without focusing on individual details. We have also found that verbal assistant has a crucial role in the haptic explorer´s comprehension of graphs since they introduce more graph domain oriented concepts in the course of the dialogue with the haptic explorer. Finally, the analysis of the post-exploration sketches showed that sketches for verbally assisted graphs are more similar to stimuli-graphs than the graphs explored without verbal assistance. This finding shows that appropriate verbal assistance facilitate comprehension of haptic graphs. In particular, we observed that haptic graph comprehension improves when the content of the verbal assistance is enriched by modifiers, such as 'this is the biggest curve' or 'this point is one of the maxima' [14].

Our long-term goal is to realize an automatic verbal assistance system that has the capability to provide instantaneous support for haptic explorers during their course of exploration. Empirical studies are needed to understand the underlying principles of haptic graph exploration, as well as the differences in terms of graph reader's need. Those experiments are usually performed in blind-folder users or visually impaired users. In the following section, we present our findings in an experimental study of haptic line graph exploration with visually impaired participants.

2 An Experimental Study on Haptic Line Graph Exploration: Visually Impaired Users

2.1 Participants, Materials and Design

Eight visually impaired participants (three partially sighted) participated in the experimental study. The participants were teachers from an elementary school for visually impaired, in Turkey. The category of blindness was identified by various parameters, such as onset-time of blindness (congenital-early or late) and level of deprivation (total, severe blind or partial sighted), [16]. In the present study, we include into the analysis only congenitally blind participants with or without partial sight.[1] The experiment was conducted in single sessions. Each session took approximately 1 hour. The sessions were audio and video recorded. The experiment was conducted in Turkish, the native language of all participants. Before the experiment, a warm-up session was conducted to familiarize the haptic explorer with Phantom Omni® Haptic Device (Figure 2).

For the familiarization of the participants to the haptic interface, they first explored a character set consisting of two letters (L and G) and two digits (2 and 3). Those characters were chosen due to their resemblance to graph line segments. The

[1] Late-blind participants are also of interest since they have domain knowledge, and mathematical skills acquired via visual modality. However, this study was left for a further follow-up study.

Fig. 2. Phantom Omni® Haptic Device

experiment session started after at least three trials with the characters.[2] After the familiarization session, the participants were informed that the graphs represented populations of bird species in a lagoon. The (smooth) graphs employed in the present study (see Figure 3, for examples) were taken from a public report on bird-population in Bolinas Lagoon [17]. In the experiment session, each participant was presented five haptic line graphs with smooth edges (two additional graphs were employed for haptic graph familiarization). The graphs were presented in random order. The participants performed haptic graph exploration by moving the handle of the haptic device, which can be moved in all three spatial dimensions (with six degree-of-freedom). In haptic graph representation, the graph line was represented by engraved concavities on a horizontal plane; therefore the haptic explorers perceived the graph as deeper with respect to other area on the surface. The numerical labels were not represented, therefore the participants were asked to comment on the graph based on the line shape only. The participants did not have time limitation. After the experiment session, the participants were asked to present single-sentence verbal descriptions of the graphs to the experimenter. They were also asked to fill in a spatial term survey that contained the words or phrases used by the verbal assistant in the previous experiments [14].

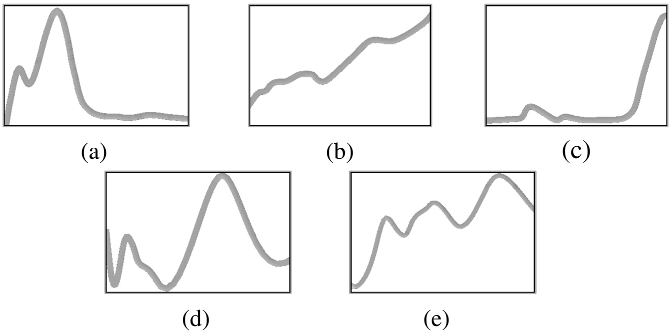


Fig. 3. Five different haptic graphs

The participants used a Likert scale to rate the meaningfulness of the terms, using 1 (*less meaningful*) to 5 (*most meaningful*). They were also asked to verbally explain the meaning of the terms in the questionnaire. Only basic assistance or *alerts* that

[2] The participants were not asked to predict the character since they use Braille alphabet, and thus those characters may not be in their repertoire.

aimed to help participant to locate him/herself on the reference frame (e.g., "you are at the start point", "you are out of the line") was provided by the experimenter during the course of haptic exploration. The line graphs represented populations of bird species. Each graph had a different pattern in terms of the number and polarity of curvature landmarks, length and direction of line segments.

2.2 Results

In this section, we focus on the differences between totally blind participants and partially sighted participants in terms of their conceptualization of the events represented by line graphs (e.g., an increase in bird population). The motivation of the analysis is that the identification of the differences between those two conditions may provide information for the design of the verbal assistance content for the two user groups. Since the haptic representation of the line graph by the haptic device is implemented by the engraved line on a horizontal space, depth information is irrelevant, therefore it was kept constant. The depth only served for preventing the stylus of the haptic device going outside of the graph frame, thus facilitating the tracing action. The participants were informed about the workings of the haptic device and the structure of the task space. Two totally blind participants exhibited a tendency to interpret the depth information as a parameter for trend information. This is possibly due to participants` dominant perceptual habits. This finding suggests that a more detailed training session should be designed for totally blind participants so that the interface introduces itself as in a coherent manner for the haptic exploration.

A qualitative analysis of all the exploration patterns and the utterances produced by the participants showed that the *points of high curvature* are easy to detect for all the visually impaired participants. The haptic line graph interface was led to a successful interpretation, most of the time, of trend changes (in terms of the changes in bird population) that are represented by those points of high curvature in the graphs (henceforth, *landmarks*). On the other hand, totally blind participants had difficulty in detecting *line segments* compared to partially sighted participants. This finding was accompanied by less adequate interpretation of population events by the totally blind participants compared to the partially sighted participants. This is possibly due to higher prior knowledge of the partially sighted participants with line graphs.

Table 1 presents excerpts from verbal utterances produced by a single participant. The utterances show how the participant links the concept of "population increase" to haptic movement. In the graph presented in Excerpt.1a there exists an abrupt change in the direction of exploration movement from horizontal to vertical, and additionally the graph ends with a landmark that is also the global maximum of the graph. Therefore the participant instantly linked that "Loc1" point to population increase. However, in the exploration of the graph in Excerpt.1b, the participant first attempted to find a landmark to detect a possible maximum point. Since the graph line continues with an increase, she interpreted the distance between the upper border and the line by taking the middle point as a reference point ("Loc2"). This finding and similar findings that we obtained in the experiment show that landmarks are relatively easier to haptically explore compared to line segments with low trend changes.

Table 1. Locations of haptic stylus on the explored graph and accompanying verbal utterances for two instance by same participant

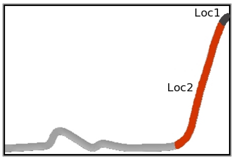
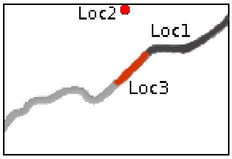
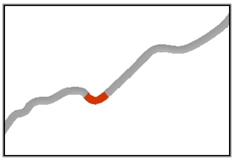
Excerpt.1a	Excerpt.1b
	
E: This is upside, right? (Loc1) A: Yes E: It is upside, then the population increases as it goes upward. (Loc2 and Loc1)	E: Lets look at the upside (Loc1) E: I am not out, right? (Loc2) A: Yes, you are out (Loc2 and horizontal movement on upper border). E: Then, there is no increase here (Loc1 and Loc3) E: I mean, if that is end point, then I am trying to find the upside since I don't find a line upside, it means that the population did not increase (entire graph).

Figure 4 presents an excerpt from a partially sighted participant. Although there is a misconception about one of the local points (red line section in Figure 4), the details and scaling can be considered as quite good. The verbal protocol shows that it is a challenging task to distinguish between global maximum/minimum and local maximum/minimum for haptic explorers, possibly due to the local sequential character of haptic perception.



10% increase at the start. Then, it seems as if it gets 20% more. Then there is clutter. Then it sinks towards the bottom 5%. It increases from 5% to 40%, it continues on the 40% level. But, there is a slight thing here, %42 or %43. I believe there is a slight increase here. There is not, it is flat. Then it seems that it increases towards 45% and here, it is completed.

Fig. 4. A participant´s verbal description of the population in terms of percent changes

A closer look at the vocabulary of the utterances by the haptic explorers also reveals similarities and differences between partially sighted and totally blinds. Both user groups employ a common vocabulary set, including the terms for the following concepts: "increase, decrease", "left, right, down, upside", "here, there, this, that", "slow, steep, small, big", and "something" (as a deictic pointer). Table 2 presents a list of additional vocabulary items, employed by the users during the course of haptic exploration.

Table 2. Vocabulary used by total-blind and partially sighted participants

Total Blind	Partially Sighted	
• Difference	• Difference	• Inclined towards down
• Change	• Change	• Curve/bend
• Increase or change	• Point	• Cavitation/ bump/bulge
• Stay same	• Horizontal line	• Deep
• Point(s)	• Diagonal	• Fork
• Hole	• Stable course	• Letter J
• Different point	• From right to left	• Hit the ceiling
• Like a hill	• Something which is not pyramid but a steep slope(geographical term)	• Sink to bottom
• Point	• Slope / incline	• With long intervals
• With constant intervals	• Slight round	• At constant intervals
• Narrow		• Border

An analysis of the vocabulary terms reveals that totally blind participants verbally describe landmarks (i.e., trend changes) by using domain-independent terms, such as “difference, change”, without providing direction or polarity information. Partially sighted participants, on the other hand, employ a domain-dependent and graph-oriented terminology, in addition to the domain-independent terms. Moreover, the vocabulary of partially sighted participants involved “horizontal, diagonal” and “stable, inclined” for line segments, and “curve, bend, bulge, cavitation, deep” for landmarks. The vocabulary terms that belong the jargon of statistical graph were also observed (e.g., “hit the ceiling” and “sink to bottom”).

The answers to the spatial-terms questionnaire revealed another major difference between the two user groups in terms of the use of navigational terms. All participants rated the terms “upward” and “downward” with high scores (in terms of its relevant to graph exploration). The terms “backward” and “forward”, however, received lower scores from the partially sighted participants. The haptic graph line is a directed line (i.e. the x-axis represented the year from the past up to now). Therefore the terms “backward” and “forward” correspond to left and right respectively. The totally blind participants, however, rated those terms with high scores. This finding may again be interpreted as an outcome of the prior knowledge of partially sighted participants in line graphs.

The findings obtained in the present study are also compatible with the previous blind-folded experiments in that smooth and low-curvature segments are haptically less salient regions of the graph, which are explored by smooth and relatively effortless movement of stylus. Therefore these regions can be considered as candidate locations for verbal assistance. The prior knowledge of line graph is of crucial importance in haptic comprehension, as in visual comprehension of line graphs. The findings suggest that, the design of a haptic interface for graph comprehension should be more informative for the use of totally blind users. This information can be provided by an introduction session about graph concepts and their relation to domain concepts (e.g., bird population) before the exploration starts.

Finally, the participants stated that they did not have difficulty in getting familiar with the device. All participants stated (during the experiment or after the experiment) that it becomes easier to stay within the engraved line as they proceed with the exploration. Being less anxious about the device and the stylus, they were able focus on the task at hand. Overall, these finding suggest that a verbal assistance system for haptic line graph comprehension reveals a potential use by visually impaired persons.

3 Conclusion

Our previous studies have shown that haptic exploration of line graphs exhibits different patterns compared to visual exploration, thus leading to differences in difficulty of conceptualization of the events represented by the graphs. A verbal assistance system has the potential to facilitate haptic graph comprehension, as long as appropriate verbal assistant is provided to the haptic explorer [13]. The design and development of a verbal assistance system should take into account different types of visual impairment because as stated by Tomaso and Cattaneo [16], comprehension differs between totally blind users and partially sighted users.

In the present article, we aimed at studying the similarities and differences between the two user groups. In an experimental investigation, we recorded and analyzed the exploration patterns of totally blind participants and partially sighted participants, as well as their utterances during the course of exploration. The major finding of the study is that partially sighted users may have more developed prior knowledge of line graphs compared to totally blind users. Providing the same verbal assistance may lead to a suboptimal use of the system by different user groups. Therefore, an effective assistive system that meets the different needs of diverse target groups should adapt itself to user's prior knowledge of line graphs. In particular, a verbal assistance system for totally blind users should introduce general graph comprehension concepts, as well as the verbal assistance about the specific graph under exploration.

In future studies, we plan to conduct the experimental investigation with a larger participant group to arrive at a better generalizability of the results. In particular, we plan to extend our experimental investigations to late-blind users, who acquired graph comprehension competence by means of visual modality.

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