Points, Lines and Arrows in Statistical Graphs

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Abstract. Widely used statistical graphs (such as line graphs and bar graphs) are usually accompanied by graphical entities other than the graph proper. Those graphical cues, such as point marks and arrows serve for communicative purposes by bringing certain aspects to the foreground over the others. The present study discusses the results of an experimental investigation, in which the participants produced sketches of graphical cues on different types of graphs, given sentential expressions of states and processes. The outcomes of the study have the potential for serving as guidelines for the development of software tools that produce graphical cues.

Keywords: statistical graphs, graphical cues, diagrammatic communication.

1 Introduction

Statistical graphs (e.g., line graphs, bar graphs) are abundant in communication settings and problem solving settings of daily life. They are used in newspapers and in web blogs, in annual reports of institutions and in management reports, in academic settings such as lecture notes and in scientific articles. The investigation of statistical graphs (henceforth, graphs) from a scientific perspective has attracted interdisciplinary interest. An early study at the intersection between cognitive psychology and usability research is an identification of the 'basic level graphic constituents' and acceptability principles (i.e., design guidelines) for charts and graphs by S. M. Kosslyn [1]. Kosslyn uses the notion of 'basic level' analogous to the conception of the term in categorization hierarchies, thus introducing a general classification of the components of a typical graph (or chart) in addition to keeping a high degree of similarity among different types. All the components of a graph or a chart are presented on the *background*, the first basic component. The background is often blank and it does not play a significant role in communication information. The *framework* represents the domain variables (in graphs), without specifying particular information about the mapping between the values. The *specifier* specifies the mapping between the parts of the framework. The lines in a line graph and the bars in a bar graph, in other words the graph (proper), are the specifier. Finally, the *labels* comprise alphanumerical expressions and depictive labels that contribute to the interpretation of the specifier or the framework. For example, in the time-domain line graph in Figure 1 (a two-year graph for the S&P 500 stock market index) the rectangular grid constitutes

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the background and the framework; the graph line is the specifier (i.e., the graph proper). The alphanumerical expressions on the framework and the depictive labels on the graph proper—in this case a circle and an arrow—constitute the labels. The depictive labels, also called graphical cues, are the major focus of the present study. [1]

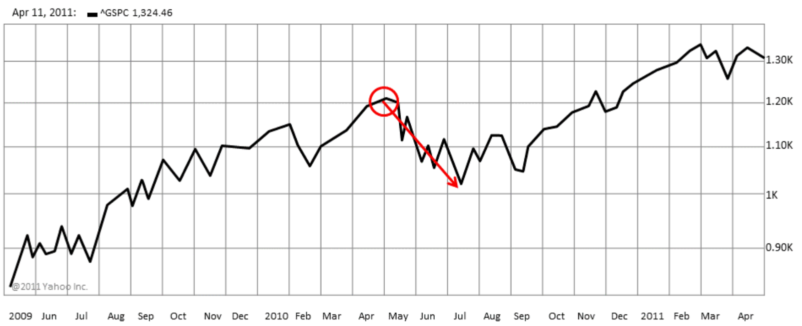

Fig. 1. A sample time-domain line graph. Excerpted from and redrawn based on the article "Bull Market Coming to an End?" by Sara Nunnally, Smart Investing Daily, retrieved on Sep. 6, 2011, http://www.smartinvestingdaily.com/articles/smart-investing-042511.html

Graphical cues and alphanumerical labels on the graph proper facilitate comprehension of the reader (or the interlocutor in a communication setting) by highlighting a whole graphical entity, a part of it, and/or domain entities that are referred to by the graphical entities. Human perception in un-cued visual displays is largely directed by perceptual salience of graphical entities. Entities with larger size and brighter colors or unusual shapes tend to be more conspicuous than others [2]. In closed contours, perceptual salience is often determined by a set of critical points (in the terminology of geometry) such as maxima, minima, inflection points [3], discontinuities in curvature and endpoints, among others [4]. These points have the potential for predicting attention and possibly eye movements [5]. Adding graphical cues updates the "natural perceptibility profile" of the display so that perceptibility is better aligned with thematic relevance [6].[2] In time-domain graphs, graphical cues and verbal annotations bring certain aspects of states and processes to the foreground over the others, such as temporal aspect [7] and causal relationships [8]. The use of 'schematic figures' as graphical cues, such as arrows in diagrams, and their influence on comprehension and verbal descriptions have been the subject of research in diagrammatic communication [9], [10], [11], and the relevant domains. In the domain of instructional science, for instance, the role of graphical cues in learning has been investigated in multimedia

[1] In the present study, the term 'graphical cue' is used for graphical entities that emphasize comprehension-relevant aspects of other graphical entities in visual displays. In the domain of computer science, the term 'annotation' is used to mean the same type of graphical entities. In the domain of instructional science, the terms 'signaling' and 'scaffolding' are used in addition to 'cueing'.

[2] Thanks one reviewer for emphasizing the relationship between graphical cues, perceptibility and thematic relevance.

learning material that involves picture and text. ‘Signaling’ is introduced as a technique to foster learning in multimedia material, e.g. [12], [13], as well as in animations without text, e.g. [6]. From the perspective of software development and HCI, although graph-drawing tools in statistical and mathematical software packages are abundant, the methods for designing and producing graphical cues (i.e., annotations) are very limited in the current state of the art, mostly relying on designers’ experience and practice rather than research-based design guidelines. The present study reports an experimental investigation of graphical cues by analyzing cues produced by humans in terms of their types and their use in different graph types. The findings are interpreted within the theoretical framework of acceptability principles for charts and graphs proposed in [1], thus leading to a set of basic design guidelines for graphical cues.

2 Experiment

2.1 Participants, Materials and Design

Sixty participants from the Middle East Technical University, Turkey, participated in the experiment (mean age = 21.6, *SD* = 1.9). The participants were native speakers of Turkish, the language of the experiment. Each participant was presented 21 graph-sentence pairs. Each pair involved a graph (the population of a bird species) and a sentence that emphasized a certain aspect of the information represented by the graph (see Figure 2 for sample stimuli).

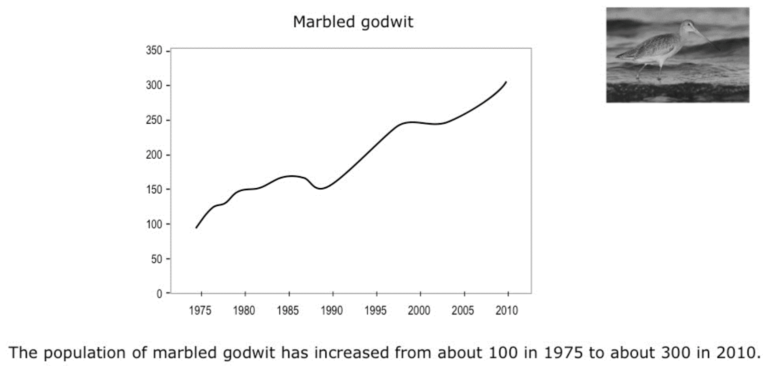

Fig. 2. A sample graph-sentence pair, designed based on a bird consensus report by PRBO Conservation Science (http://www.prbo.org). The stimuli were designed and reconstructed where necessary, according to the purposes aimed at the experimental investigation.

The experiment design involved one between-subject parameter (the graph type) and one within-subject parameter (the content of the accompanying sentence, i.e. the sentence type). The graph type parameter involved three experimental conditions (smooth line graph, straight line graph with sharp corners, bar graph). Accordingly, the participants were randomly divided into three groups (20 participants per group) and each group of was presented one of the three graph types. The graphs represented the same statistical data. The within-subject parameter was the type of the accompanying sentence in the presented stimuli. The accompanying sentence represented either a punctual or durative state (‘*For the past 15 years, canvasback population has been about 30 birds*’) or a process such as an increase or decrease with(out) explicit numerical values (‘*Ruddy duck number has decreased to about 50 in 2010.*’), fluctuate (‘*The number of sanderling on the lagoon has fluctuated from about 20 birds to about 120 birds in the past 35 years*’), peak (‘*The number of white-winged scooters peaked at about 90 birds in 1985*’) or cause (the cause sentences were increase / decrease process sentences; however, they involved a causal terminology). The stimuli were presented in printed form and the participants produced graphical cues for graphs on paper. The participants were instructed to improve a seminar presentation by marking and labeling according to the accompanying sentences.

2.2 Results

Each participant produced graphical cues for the 21 sentence-graph pairs, thus producing a total of 1260 protocols in the experiment. The graphical cues that were produced by the participants were classified into four groups.

- 0-D: Point-like markings, such as asterisks, stars, dot-circles and dash lines.
- 1-D directional: Straight and curved lines with a single arrowhead.
- 1-D nondirectional/bidirectional: Lines with no- or double-arrowheads.
- 2-D: Region-shapes such as ellipses, circles, rectangles and squares.

In the following sections, the analysis of graphical cues and the projection lines are reported.[3]

Graphical Cues on the Graph Proper.
The types of graphical cues on the graph proper were analyzed by a Friedman test, which was conducted to evaluate differences in medians among the cue types. The test was significant, χ^2 (3, N = 60) = 70.3, $p < .01$, and the Kendall coefficient of concordance of .39 indicated strong differences among the cue types. The participants produced more 0-D graphical cues than 1-D directional cues, which was followed by 1-D nondirectional/bidirectional cues and then 2-D cues. A comparison between the groups showed that the participants in the bar graph group produced more 1-D nondirectional/bidirectional cues than both line graph groups. In addition, the participants produced different types of cues depending on the sentence type in the stimuli. They produced more 0-D cues when the graph was accompanied by a process sentence in which the domain value was explicitly stated. In the durative states, the participants produced less 0-D cues but more 1-D nondirectional/bidirectional cues and 2-D cues.

[3] The participants also produced alphanumerical annotations, which were numerical expressions of the domain value and time, as well as verbal expressions that were mostly causal statements, where applicable. The investigation of alphanumerical annotations is left for future research and it is not analyzed in the present study.

Finally, in the increase/decrease processes, the participants produced more 1-D directional cues than the other cue types.

Graphical Cues on the Axes.
The participants produced less graphical cues on the axes (M = 9.85) compared to the graphical cues on the graph proper (M = 22.6) per participant. The analysis of the produced graphical cues on the axes revealed significant differences for different types of cues, χ^2 (7, N = 60) = 99.3, $p < .01$ (Kendall coefficient .24). The participants produced more 0-D cues (on both the x axis and the y axis) than all the other types of cues. In addition, they produced more nondirectional/bidirectional 1-D cues and more 2-D cues on the y axis than on the x axis. Graphical cues on the axes were more frequently produced by the bar graph group than the two line graph groups. Concerning the relationship between the cue type and the type of the accompanying sentence, the participants produced 0-D cues on the x axis in the durative states (to highlight the duration of the state), whereas in the increase/decrease and in the fluctuate processes, they produced the 0-D cues on the y axis (to highlight the domain values).

Projection Lines.
The projection lines serve for facilitating the construction of the mapping between a point on the graph proper (e.g. a point on the line or the tip of a bar) and the relevant axis. In the experiment, the smooth line group produced more vertical projections compared to the straight line group (the participants in the bar graph group produced almost no vertical projection lines because the bars themselves served for vertical mapping to the x axis). Moreover, the participants produced horizontal projection lines if the domain value was explicitly stated in the accompanying sentence. Finally, the participants produced more vertical projection lines in the durative states than they produced in the increase/decrease processes.

3 Discussion

The results of the experimental investigation showed that the production of graphical cues by the participants was influenced by several factors, such as the type of the accompanying sentence (state vs. process), the occurrence of an explicit domain value in the sentence and the type of the graph (bar vs. line). In particular, when the graph was accompanied by a durative state sentence, the participants produced more nondirectional/bidirectional lines and region shapes on the graph proper and they used more vertical projections on the framework. On the other hand, when the graph was accompanied by a process sentence, the participants produced more arrows than nondirectional/bidirectional lines. A second finding was that the participants who produced graphical cues in line graphs produced more arrows for process sentences compared to the participants who produced graphical cues in bar graphs. Third, the occurrence of a numerical value in the accompanying sentence resulted in more point marks on the graph proper and more horizontal projection lines compared to the absence of an explicit value in the sentence. Finally, the participants who produced graphical cues in smooth line graphs produced more projection lines than the participants who produced cues in straight line graphs. It is likely that straight line graphs with sharp corners convey information about specific numerical values more efficiently compared to smooth line graphs.

Participants' systematic production of graphical cues for bringing certain aspects of states and processes to the foreground over the others shows that time-domain graphs are interpreted not only as visualizations of domain values but also as visualizations of states and processes, and possibly they are interpreted as hints to causes and effects in the domain of discourse [7] [8]. The graph-as-data-visualization conception of graph design tools, in the recent state of the art, underestimates the potential use of graphs in reasoning and communication, thus leading to a lack of research in designing graphical cues. The results of the experiment suggest that a systematic analysis of graphical cues has the potential to fill this gap in graph design research.

4 Conclusion and Future Work

Among many factors that underlie the competent uses of a graph, graphical cues are design elements that facilitate reasoning as well as communication by statistical graphs. The findings in this small-scale study suggest the following guidelines for the design of graphical cues in time-domain graphs. Larger-scale usability studies would provide a complete list of design guidelines for cued graphs.

1. Processes (e.g., fall, rise, fluctuate) should be highlighted by arrows whereas durative states (e.g., remain) should be highlighted by nondirectional/bidirectional lines.
2. A line graph (instead of a bar graph) should be used to emphasize a process.
3. The emphasis on explicit numerical values in the graph can be facilitated by the use of point marks and projection lines.
4. Smooth line graphs should be avoided if the designer aims to highlight specific information on the graph.

Additional guidelines, such as 'the arrows should not be drawn on top of the graph proper but near it' (cf. Figure 1) would help the end user to produce more usable graphs. These guidelines provide the basis not only for designing graphical cues but also for the graphical tools that provide end users with the toolkits for designing graphical cues. The future work should address the following topics. The reported experiment investigates graphical cues from a production perspective. In particular, the participants were free in their producing graphical cues in contrast to being provided an inventory of graphical items for their selection, cf. [14]. The future work should analyze participants' choice given an inventory of graphical cues in addition to addressing the interpretation of graphical cues on graphs from a comprehension perspective. A relevant research topic is the interaction between dynamic gestures, different types of static and dynamic graphical cues and referring expressions in spoken communication environments. The analysis of alphanumerical annotations is a complementary research topic to the analysis of graphical cues in written communication environments and in reasoning.

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