Poster: Design Elements and the Perception of Information Structure

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Abstract

While there has been significant research on how low-level perceptual elements contribute to a user's ability to compare or discern data points, less is known about how seemingly meaningless properties of a visual scene contribute to the perception of information structure. We present the results of a study in which participants viewed five types of simple data visualizations that supposedly depicted information about the departmental structure of a series of companies. Although the underlying data was the same in each case, we altered simple design elements such as enclosure, connectedness of parts, whether parts were placed within a visible area, and whether the parts themselves were enclosed by borders. Participants were asked to rate each company on a series of semantic dimensions. The results show a significant effect of minor design elements on semantic interpretations of data, and comments by participants further suggest that these effects may be grounded in physical and emotional inferences derived from the appearance of charts.

1 Introduction

Visualization theory has historically focused on the perceptual qualities of individual visual objects. But for all that has been learned about how information is visually encoded in an information visualization, we have very little sense of the impact of the visualization as a whole on how the user thinks about and judges the encoded data. In art and design, it is known that minor choices of visual elements and shapes can have significant effects on how a viewer experiences a visual representation as a whole [2]. Zacks and Tversky [3] show that interpretation of a simple two-point chart as either a trend or two separate data points is more influenced by the type of chart (i.e., bar chart or line graph) than by the type of data.

We theorize that elements that do not carry information about data points, such as borders, connectedness, and background shapes, still carry semantic information about the structure of a dataset, whether intended or not. This can influence a user's interpretation of data in significant ways and must be considered when designing and evaluating visualization methods. Specifically, we believe that semantic judgements of a visualization derived from simple properties of its visual structure can be shown to affect subjective ratings of visualized data in a reliable and systematic fashion. We further hypothesize that while these effects will be present and to some extent consistent across visualization types, semantic effects can also be generated by the visualization type itself, and design elements will affect different visualizations in different ways.

2 Experiment

In order to test our hypotheses, we designed a study to test the effects of visualization design elements on semantic judgements of data in a simple context. This study was meant to test whether a particular set of design elements indeed have a significant effect on semantic judgements, and to what extent these design elements affect various types of simple information visualizations.

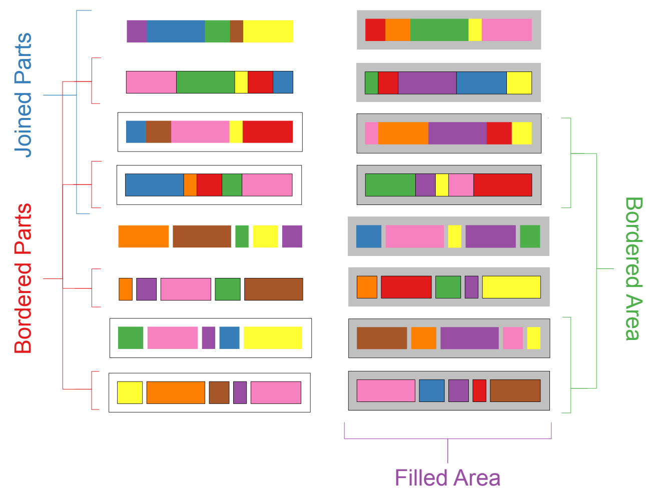

Figure 1: A stacked bar chart in each of the sixteen design configurations used in the study.

We recruited 42 participants via Amazon's Mechanical Turk [1]. Participants performed the study online and were paid a base rate of \$0.20 for their work, which took about twenty minutes. Of the participants, 25 were female (59.5%) and 17 were male (40.5%); their ages ranged from 21 to 62, with an average age of 36.4.

Participants viewed a series of twenty charts which were described as representing the departments of fictional companies. The data proportions were the same for all twenty charts, but the order and coloring of the departments in each chart was randomized to conceal this fact. We used five types of charts to display the relationships of the departments to the company: a pie chart, a waffle chart (or one-level treemap) a horizontal stacked bar chart, a donut chart, and a bubble chart. These visualizations were chosen to represent a range of shapes and relative familiarity, while all being simple enough to evaluate quickly. Having chosen this set of visualizations, we systematically altered them according to four design elements:

Filled area. A gray background was visible behind the main chart which mimicked its overall shape but at a larger size.

Bordered area. A black contour was drawn around the chart at the same size and shape as the filled area.

Bordered parts. Black contours were drawn around each of the individual pieces.

Joined parts. Parts were connected to one another in the manner most natural for a given visualization type.

With two possible states for each of these four variables, there were a total of sixteen design configurations for each of the chart

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Factor	Group	Good place...	Complete	Controlled	Inflexible	Isolated	Rigid	Stable	Structured	Unified	Well-organized
Filled Area	yes	2.97	3.00	2.93	**2.64**	2.66	**2.61**	3.06	3.20	3.00	3.04
	no	3.01	3.03	3.08	**2.88** (+)	2.74	**2.88** (+)	3.03	3.17	2.88	3.15
Bordered Parts	yes	2.96	**2.91**	**3.12** (+)	**2.88** (+)	2.74	2.82	**2.93**	3.21	2.89	3.08
	no	3.02	**3.10** (+)	**2.92**	**2.66**	2.67	2.69	**3.14** (+)	3.16	2.98	3.11
Joined Parts	yes	3.05	**3.20** (+)	**3.14** (+)	2.83	2.62	**2.90** (+)	**3.14** (+)	**3.31** (+)	**3.11** (+)	**3.22** (+)
	no	2.93	**2.83**	**2.88**	2.69	2.78	**2.59**	**2.95**	**3.05**	**2.78**	**2.97**
Gender	female	2.97	3.04	3.03	2.70	**2.58**	2.69	3.06	3.24	2.98	3.13
	male	3.02	2.97	2.98	2.84	**2.87** (+)	2.83	3.02	3.09	2.88	3.04
Chart Type	waffle	2.96	3.14	**3.24** (+)	**3.05** (+)	2.77	**3.06** (+)	3.23	3.45	2.10	**3.36** (+)
	bars	2.95	3.12	**3.26** (+)	2.93	2.63	**2.98** (+)	3.11	3.37	2.89	3.21
	pie	3.08	3.16	3.07	2.63	2.72	2.73	3.17	3.26	3.05	3.18
	donut	3.03	3.02	**2.86** (-)	2.74	2.69	**2.60** (-)	3.11	3.17	3.01	3.04
	bubble	2.94	**2.64** (-)	**2.61** (-)	**2.45** (-)	2.70	**2.36** (-)	**2.61** (-)	**2.66** (-)	**2.68** (-)	**2.69** (-)

Table 1: Means across all factors, except for the non-significant Bordered Area factor. In the case of the two-level factors, differences which are significant at the $p < .01$ level are in boldface and the higher value is marked with a (+). In the case of chart type, a Tukey HSD post-hoc test was used to compare the five categories on a pairwise basis. Values which are significantly higher (at a $p < .05$ level) than at least two other categories at a level are marked with a (+) and values significantly lower than at least two other categories are marked with a (-).

types. Figure 1 shows all sixteen configurations applied to the bar chart. These design elements were chosen because we hypothesized each to have a unique semantic effect on how participants perceived the data. To test this hypothesis, we developed a list of ten semantic variables which could describe a simple dataset in structural terms. On a scale of one to five, we asked participants to rate how much the company presented in a chart was likely to be *a good place to work, complete, controlled, inflexible, isolated, rigid, stable, structured, unified,* and *well-organized*.

We varied two design elements between subjects (filled areas and bordered parts) and two within subjects (bordered areas and joined parts). During the study, participants saw a series of twenty charts described as representing fictional companies. These charts included four versions of each of the five chart types, varied on the two within-subjects variables of *bordered area* and *joined parts*. Participants rated each chart on all ten semantic variables. After this portion was complete, we gave participants the opportunity to explain selected ratings in free text.

3 Results

A summary of the main effects in five of our six variables (three design elements, chart type, and participant gender) is presented in Table 1. All of the design elements except for the presence of a bordered area produced significant differences in at least one of the ten semantic variables we tested. In addition to these main effects, we found a number of significant interactions among our four design elements. Most strikingly, the presence of a filled area and borders around individual parts interfere with one another on all semantic variables except for control, structure, and unity. In general, configurations with a filled area and bordered parts are rated more negatively than those with one or the other design element. We found few significant interactions among chart type and the design elements, suggesting that the effects of design elements are largely constant across the visualization types we chose.

In addition to our hypothesized variables, we also found a number of gender effects; main effects are included in Table 1. We also found significant interactions between gender and chart type for control, flexibility, rigidity, structure, and organization. In general, it seems that men find circular layouts more controlled or rigid, while women show this effect for rectangular layouts. Including a filled area in the chart seems to increase the effect.

4 Discussion

These results suggest that design elements in a simple visualization context can have significant and consistent effects on a user's semantic evaluation of data. Explanations of selected ratings by participants can shed some light on why these design elements have the effects they do. One common theme throughout these explanations was a treatment of both design elements and chart types as offering various potentials for movement or communication. For example, two separate participants explained that they considered the donut chart less stable because it seemed like it might "roll away." This kind of analysis also seemed to underly the evaluations of the bubble chart as unstable and uncontrolled, with participants describing this chart as "floating bubbles that were barely contained within the area" and "scattered." Similarly, charts without joined pieces were often described as "flying apart" or "exploding." This sense of violent movement in the charts with separate pieces may be the reason for their perception as unstable and incomplete. Such physical descriptions also hinted that an interaction between borders and filled areas may be attributed to a sense of blocked communication. These descriptions were occasionally quite elaborate, suggesting that users were drawing complex inferences from their intuitive reactions to the design of a chart.

5 Conclusion and Future Work

This work provides evidence that the influence of elements of visual structure on semantic interpretations of data can be reliable and to an extent predictable. Ultimately, our goal should be to model these effects within a theoretical framework of how people perceive visual structure as information structure. The physical properties frequently described by participants may be a useful basis for such a framework, but much more work is needed to establish a set of correspondences between design elements, the physical properties they afford, and the semantic inferences these cause users to reach.

References

[1] Amazon Mechanical Turk, http://aws.amazon.com/mturk/.

[2] R. Arnheim. *Art and Visual Perception: A Psychology of the Creative Eye*. University of California Press, 1974.

[3] J. Zacks and B. Tversky. Bars and lines: A study of graphic communication. *Memory & Cognition*, 27(6):1073–1079, 1999.