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Evaluating Perceptual Judgements on 3D Printed Bar Charts

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Abstract

Visual depth is a limiting factor for the interpretation of 3D data visualizations rendered in 2D environments. It is well documented that the accuracy of data comparisons is worse for 3D charts, but these studies are almost entirely focused with 2D projections. Our study brings these graphs into a 3D environment and compares the effectiveness of 3D printed charts to their 2D rendered counterparts. Primilinary results do not show a difference in judgment accuracy between charts, .

Keywords *Graphics; 3D bar charts; 3D printing*

1 Introduction

The goal of our research is to replicate partial results from **?** and extend their study to multiple mediums of data visualizations. Current research into 3D data graphics is mostly limited to 2D projections and shows that 3D graphs are less accurate at portraying numeric information than 2D graphs **??**. In certain contexts and conditions, there is some research suggesting that 3D graphs may better encode information **?**.

Here, we provide the process of replication and modernization of testing perceptual judgements to 2D graphs, 3D graphs projected in 2D environments, and 3D printed bar graphs.

1.1 Selected Components From Cleveland and McGill

Cleveland and McGill provided a theory and tested for the ordering of perceptual importance for the elements of length, position, and angle. Their first experiment, referenced as the position-length experiment, used five types of bar charts. Two of these were grouped bar charts and the other three were stacked bar charts. Each chart had two bars used for comparison and participants were asked to determine which bar was smaller and give their perceived ratio of the smaller bar to the larger bar. The two grouped bar charts are for the perceptual element of position along a common scale, where one has zero distance between bars and the other has a fixed distance between bars. These grouped bar charts will be referenced as adjacent and separated graph types in this paper, respectively.

Our study replicates the procedure for the comparisons of the two grouped bar charts, but with an objective of detecting differences between 2D graphs, 3D digital graphs, and 3D printed graphs.

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2 Methods

Our study is designed to replicate part of the position-length experiment as closely as possible. In this section, we will discuss the replication process and the design of our modified version of the position-length experiment.

2.1 Replicating Cleveland and McGill

The first step of replicating the position-length experiment was to determine the values used for comparison. These values for bar heights are linear on a log scale and are given by

$$s_i = 10 \cdot 10^{(i-1)/12}, i = 1, ..., 10$$

The ratio of heights between the bars that were compared by Cleveland and McGill were 17.8, 26.1, 38.3, 46.4 (twice), 56.2, 68.1 (twice), and 82.5 (twice). The exact numeric comparisons were not disclosed, but the comparison values were subjected to the constraints of having the same ratios and that no value was used more than twice.

Each graph is presented so that there are ten bars. Within a graph, only two bars are marked for identification. Cleveland and McGill did not specifically state the random process for generating the remaining bars of the grouped bar charts, so the remaining bar heights were generated from a scaled Beta distribution with parameters that limit the amount of obsessive noise around the bars used for comparison. The aspect ratio of the plots are approximately 4:3.3, which was determined by measuring the pixels of a figure in Cleveland and McGill's paper.

2.2 Designing Graphics

Due to limitations, creative adjustments were made from Cleveland and McGill's study to closely match both types of 3D charts (digital and 3D printed) to our 2D charts. The graphs share a common layout across the three chart types. There are two groupings of five bars and each grouping is identified by either "A" or "B". Circles and triangles are used to identify the bars that are to be compared by participants.

Figure 1: A 2D graph, 3D graph, and a prototype 3D printed graph showing the same set of data.

3 Equations

Weibull distribution has the virtue of being a mathematically tractable model and is versatile in terms of its applications in reliability, life data analysis, actuarial science and others. Apart from being a potential model in survival analysis and reliability engineering, it has a vast domain of other applications.

Equations are always parts of sentences, so they need to have appropriate punctuations. To evaluate the distribution of a normal variable, one use

$$\Pr(Z \leq t) = \Phi\left(\frac{Z-\mu}{\sigma}\right), \tag{1}$$

Table 1: Analysis results for real data. Point estimates (EST) from both two-piece method and marginal method are reported. Standard error of point estimates are evaluated by parametric bootstrap (SE).

Season	Parameter	Two-piece method		Marginal method	
		EST	SE	EST	SE
Summer	λ_1	2.841	0.459	1.090	0.280
	λ_0	0.179	0.014	0.158	0.015
	σ	1.335	0.106	0.999	0.104
	$\sigma_\epsilon(\times 10^{-2})$	1.854	0.087	1.879	0.078
Winter	λ_1	6.225	0.825	4.720	0.711
	λ_0	0.118	0.010	0.114	0.009
	σ	1.506	0.095	1.454	0.089
	$\sigma_\epsilon(\times 10^{-2})$	0.908	0.036	0.934	0.043

where Z follows a $N(\mu, \sigma^2)$ distribution. Equations can be referenced by `\eqref`. When $\mu = 0$ and $\sigma = 1$, the Z in Equation (**??**) becomes a standard normal variable.

Multiline equations can be presented with the `align` environment. For example,

$$\begin{aligned} g_\mu(\phi) &= 0, \\ g_\mu(X) &= 1. \end{aligned}$$

An equation that is not referenced should not be labeled. The starred version of the `equation` and `align` are for this purpose.

4 Tables

We recommend LaTeX package `booktabs` for professional looking tables. Its toprule and bottom-rule are thicker than midrule.

A professional table contains no vertical lines.

Table **??** is an illustration.

5 Figures

Vector graphics do not lose clarity when being scaled. Make your figure in pdf format when you first generate it and keep in mind its sizes in the article to avoid over-scaling. Do not simply convert a jpeg or png image to a pdf.

6 Code

The document class `jds` provides several commands to decorate

- inline code, such as `print("Hello world!")`;
- programming language, such as R, Python, and C++;
- software package, such as *stats*, *utils*.

7 Guide for Authors

The following requirements must be followed as closely as possible. A technically acceptable manuscript that fails to follow these requirements may be returned for retyping, leading to delay in publication.We only accept submissions in PDF format. The Latex file must be provided after the manuscript is accepted.

7.1 Submission of Papers

Submission of a manuscript must be the original work of the author(s) and have not been published elsewhere or under consideration for another publication, or a substantially similar form in any language.

Authors are encouraged to recommend three to five individuals (including their research fields, e-mail, phone numbers and addresses) who are qualified to serve as referees for their paper.

8 A Placeholder Section

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9 Citing References

The citations are in the author-year format with the `chicago` bibstyle.

A bibfile contains all the citations in bibtex format is prepared (see `JDSbib.bib`). Some characters in the title of the references needs to be protected so that the style file does not alter it. For example, in the bibtex entry for **?**, the "B" in "Brownian" and the "E" in "estimation" following the colon are protected. A book reference (e.g., **?**) should have an address field.

Citations can be in either text or parenthesis format style with `\citet` or `\citep`, respectively. For example, **?** is a seminal work on quantile regression; The Laplace distribution has applications in many fields (**?**).

10 Discussion

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