Investigating Physical Visualizations

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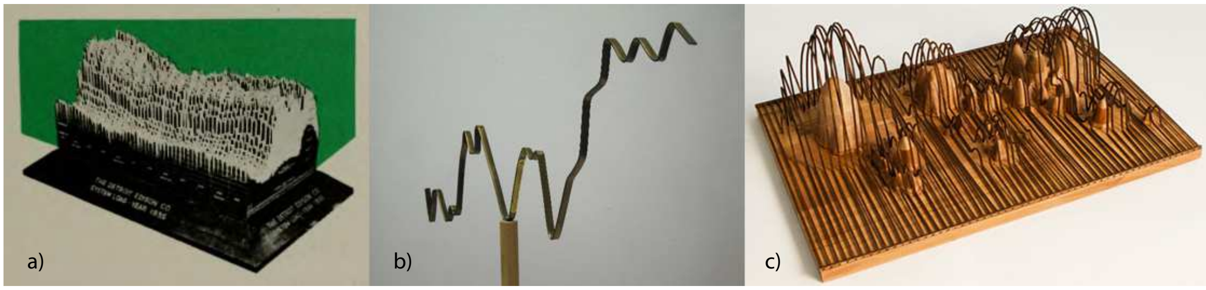

Figure 1: Examples of physical visualizations: a) electricity consumption by Edison electrical company (1935), b) *Consumer Confidence*, a physical 2D graph by Joshua Callaghan, c) *fundament* (world GDP and derivatives volume) by Andreas Nicolas Fischer.

ABSTRACT

Physical visualizations have been around for several decades and remained mostly unnoticed. They recently became popular in the form of *data sculptures*, due to a proliferation of data-driven artefacts produced by the art and design communities, and to a wider availability of rapid prototyping facilities such as fab labs. It has been recently suggested that such physical data representations are suitable for demonstrative, artistic or communicative purposes. But can physical visualizations also help carry out actual information visualization tasks? We describe the design of the first user study whose goals are to assess the efficiency of physical visualizations compared to on-screen visualizations – with a focus on the challenges posed by 3D visualizations – and to better understand how people use physical data representations to answer visual questions.

Index Terms: H.5.0 [Information Systems]: Information Interfaces and Presentation—General

1 INTRODUCTION

Physical visualizations have been created for at least several decades. They have become more popular in the form of data sculptures, and the wider availability of rapid prototyping machines such as 3D printers facilitates the creation of accurate data visualizations.

Most work so far focused on design aspects, such as metaphors used to map data variables to physical form or material properties. Several advantages especially for social aspects and educational purposes have been postulated [9]. However, we believe that physical visualizations could also be useful to carry out infovis tasks building on results in the area of tangible user interfaces and studies on "tangible thinking" [5]. Companies have already used physical visualizations for business intelligence purposes (e.g., Fig. 1a).

We are interested in how physical visualizations compare to virtual (screen-based) visualizations in terms of performance at infovis tasks. So far there is virtually no work in the field of infovis on this question. Most notably Dwyer [3] performed a pilot study with a physical visualization. However, he compared a physical model of a 3D time-series visualization with printouts of the same data plotted as 2D graphs in a small-multiples layout, and used the physical model only as a "simulation" of a perfect 3D display. Our experiment compares visualizations that are designed to be as similar as possible between on-screen and physical modalities, enabling us to better attribute findings to differences in modalities and not to different visual mappings.

2 2D VERSUS 3D

Physical visualizations are inherently 3D, as are all objects in the real world. However they can represent either 2D or 3D visualizations. Figure 1b) shows an example of a 2D graph where the third dimension is simply extruded and does not encode any information. We do not expect to find large differences between virtual and physical 2D visualizations. Accordingly we exclude physical 2D visualizations for the purpose of this study but use a virtual 2D representation as a baseline.

Overall 3D visualizations are controversial due to inherent problems such as occlusion, perspective distortion, and navigation [6]. Still, new 3D visualizations are regularly being proposed, some studies suggest advantages for specific applications [2], and some visualizations such as 3D histograms are widely used, including in scientific literature (e.g., [8]). However, this controversy is about 3D *virtual* visualizations. Given promising results from research in tangible interaction and the identified properties of affordances, embodiment, and epistemic actions, we could assume that for physical representations the aforementioned problems of 3D visualizations are mitigated, as we are used to deal with them everyday in real life. But so far there is no study on this in the field of infovis.

3 RESEARCH QUESTIONS

We set out to investigate how physical 3D visualizations compare to their virtual counterparts in terms of task efficiency. As a first step, we will solely look into differences in overall performance when carrying out infovis tasks. Then, we will dissect observed differences to identify strategies used to cope with occlusion, distortion and navigation.

4 EXPERIMENTAL DESIGN

We will run two controlled experiments to answer our research questions. The first one will compare user performance between modalities with different infovis tasks, in order to figure out whether physical visualizations can provide any advantage. The second experiment will not focus on time and error measures for solving tasks but, based on the results and observations from the first study, on *how* subjects solve them and how strategies differ among modalities.

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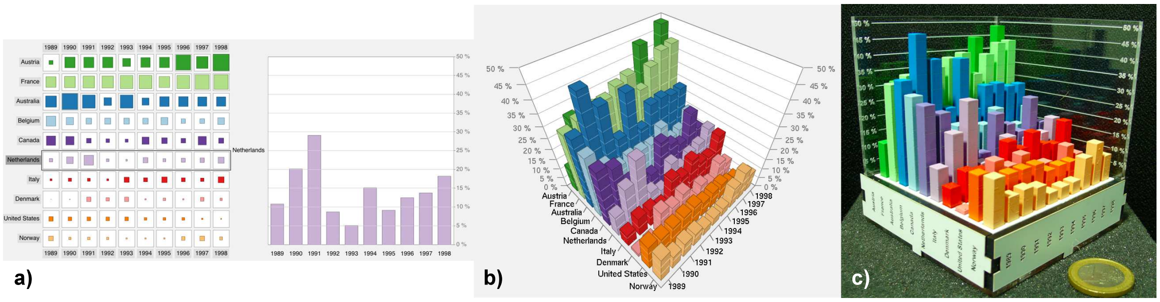

Figure 2: Visualizations used in the experiment (these examples show education aid rates for 10 countries over 10 years.) a) 2D matrix representation with 2D projection, b) virtual on-screen model, c) physical model.

4.1 First Experiment

We decided to use 3D histograms for our first experiment as they are a commonly used 3D representation (e.g., recently for the Google Zeitgeist 2011 visualization and in many newspapers and scientific articles), they require low "visualization literacy", and they can represent many data types such as time series or matrices while being prone to problems such as occlusion and perspective distortion.

The underlying datasets are country indicators accessed from the Gapminder database[1]. Each visualization represents the value of one indicator (e.g., suicide rate) for 10 countries over 10 years (equal distanced but with varying intervals between datasets).

In addition to the physical (Figure 2c) and virtual on-screen (Figure 2b) modalities, we added two modalities as control conditions: a) a 2D matrix visualization where rows and columns can be selected and shown on the side as a 2D histogram (Figure 2a), and b) a stereoscopic rendering of the 3D on-screen version. Although our focus is not to compare 2D with 3D, we decided to include 2D as a comparison baseline. If all 3D conditions turn out to be much worse then 2D, it could imply that using a 3D visualization is a bad idea, whether virtual or physical. The stereoscopic condition serves as a control providing binocular depth cues instead of relying on structure from motion alone, and will assess the relative importance of providing stereoscopic cues.

Tasks. Our tasks are derived from a task taxonomy [1]. To keep the length of the experiment manageable we used preliminary data gained from pilot studies to converge on 3 different tasks that cover a range of elementary actions: 1. indicate the range of indicator values for one country, 2. sort one year ascending, 3. find three data points (country-year pairs) and determine which one has the lowest value.

Hypotheses. We use two measures: task completion time and error rate. We do not expect to find sizable differences in terms of error rates but rather use this measure to make sure that speed accuracy tradeoffs are consistent across modalities. Effect sizes are estimated from an initial pilot study involving four subjects.

1. The 2D visualization will outperform the 3D visualization in all modalities by no more than 50% in time.
2. For the 3D visualization, the physical modality will be 15–20 % faster than both on-screen modalities.
3. The stereoscopic modality will be slightly faster than mono.

4.2 Second Experiment

The purpose of the second experiment will be to understand how the differences found in the first experiment can be explained. To record the additional data necessary to build a model of how subjects solve visual tasks using the different modalities, we will employ more elaborate sensing. The on-screen condition requires only simple logging of mouse movements. Comparable data for the physical models requires to embed multidimensional sensors (e.g., a 9DOF Razor IMU[2]).

[1] www.gapminder.com

[2] http://www.sparkfun.com/products/10736

5 Discussion

Even assuming physical visualizations can facilitate infovis tasks, there is an obvious cost-benefit aspect to using them: physical objects can take time to build and are typically static. In contrast, computers are everywhere, visualizations can be easily shared and dynamically modified, and software supports powerful interactions like dynamic filtering, searching, and brushing and linking.

Nevertheless, the cost of building a physical visualization needs to be compared with the benefits of using it, which is also a function of the time spent using it and of the total number of users [7]. For example, a retail store could produce physical 3D histograms every year to help its customers compare new camera models. Moreover, physical visualizations became easier to build with machines such as laser cutters and 3D printers, and will likely become easier and easier to build, so there will be more and more situations where using them will be realistic. In addition, we will probably soon see physical visualizations that are augmented to support dynamic data update and interactive features like dynamic queries or details on demand. There is more and more work on interactive physical representations and shape displays, e.g., [4]. While this is an exciting area of work, it is currently technology-driven with virtually no user study. There is still a need for experimentally assessing the benefits of using physical information representations, and studying static visualizations is a sensible starting point. If clear benefits are found for these, this will partly justify past work and motivate further work on shape displays and other sophisticated, interactive physical information representations.

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