Interacting with Layered Physical Visualizations on Tabletops

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Abstract
Physical visualizations only recently started to attract attention from the InfoVis and HCI communities. They are well suited for playful exploration and stimulate curiosity but are often limited by their fixed appearance and lack interactivity. In this paper we discuss our early experiments in designing physical visualizations made of transparent acrylic glass using a laser cutter. We also present our initial considerations how these physical visualizations can be used for interactions on tabletops.

Author Keywords
Tangible User Interfaces; Physical Visualizations; Digital Fabricaton; Interactive Surfaces

ACM Classification Keywords
H.5.m. Information interfaces and presentation: Miscellaneous.

General Terms
Design; Experimentation; Human Factors

Introduction
Tangible user interfaces (TUIs) [3] employ the evolved human ability to sense and manipulate physical objects to support a direct engagement with the digital world. These physical objects either represent digital objects

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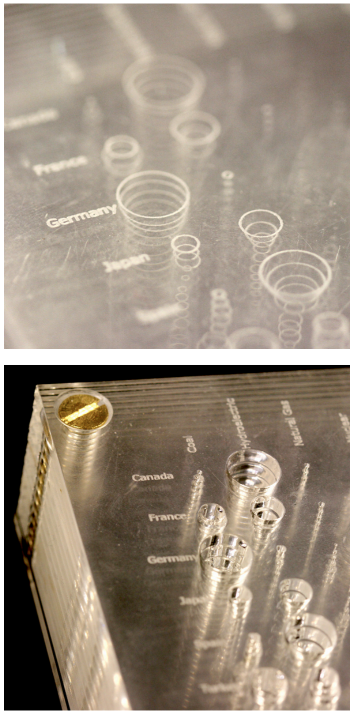

Figure 1: Two alternative physical visualizations, where each data case is represented by a carved circle (top) or hole (bottom). The x axis represents energy sources, the y axis countries and the z axis time.

or can be used as tools for data manipulation. In the field of Information Visualization (InfoVis) several systems have been proposed to help users navigate and explore datasets. However, the physical objects that are involved in such systems are models (e.g. architectural models), not visualizations [4]. In other instances they are only used as an input device [4].

Physical visualizations (PVs) are visualizations in which data is mapped to a physical form [4]. Artists and designers have produced a large variety of physical representations of data [1]. Vande Moere [10] argues that PVs have the quality of evoking user fascination and curiosity. They can turn data exploration into an educational, enjoyable experience.

In this paper we explore the design space of PVs and how they can be used on interactive surfaces. We focus on layered physical visualizations made of transparent acrylic glass. As the most PVs are limited by fixed visual appearance, the combination of PVs and tabletops is a promising approach to data exploration. The PVs can be used to awaken interest and to get a first overview of the data. Placing the PVs on a tabletop enables the showing of greater details as well as a deeper exploration of the data. We report our initial findings in building PVs for a range of different datasets and in various form factors. Furthermore, we present interaction techniques for PVs on tabletops.

Related Work

In recent years, various research systems and prototypes were proposed which apply tangible user interfaces and data exploration. Konchada et al. [5] explored the potential of physical 3D rapid prototypes combined with virtual reality visualizations and used sketch-based gestures to control the parameters of the visualization. Piper et al. [7] presented Illuminating Clay, a system which enables the real-time computational analysis of landscape models. The authors highlighted the benefits of combining the sense of touch of physical models and the dynamic capabilities of computational simulations.

The most common type of PVs are data sculptures. Vande Moere [10] explored the physicality of information visualization and introduced different degrees of ‘data physicality’. These vary in the level of abstraction of how data is mapped and perceived by human senses. Jansen et al. [4] presented the first study that evaluated the efficiency of physical visualizations, by comparing physical 3D bar charts to their on-screen counterparts. The conclusion was that the physical touch and the perfect visual realism of physical objects seem to be an essential cognitive aid for information retrieval tasks. They point out that further research is needed, e.g. more visual mappings and other modalities should be studied.

Many TUIs use tangibles that are made of transparent material. Frisch et al. [2] offer good overview on translucent tangibles on tabletops and their advantages. This work emphasizes the promising approach to blended interaction that transparent tangibles represent, as visualizations can be seen through or even inside a physical object. Less space on the interactive surface is occupied, if the virtual data is shown below the translucent tangible instead of around it. Furthermore the transparency allows stacking of tangibles as well as touch interaction through the object.

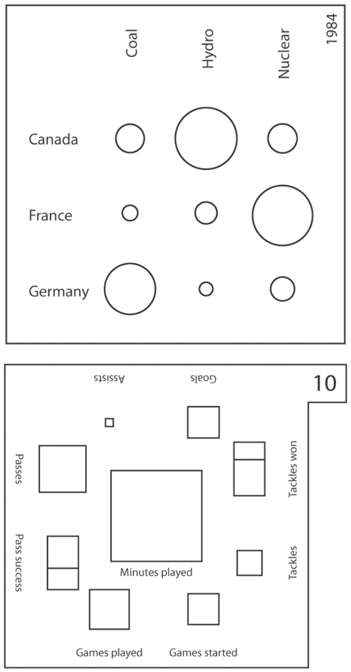

Figure 2: Top: Simplified matrix visualization of one layer of the country indicator dataset. Bottom: Visualization example for the soccer data. Each side of a layer has a specific mapping to one kind of variable (e.g. passes or tackles). The number in the right corner represents the player number.

Layered Physical Visualizations

The construction of PVs can include various materials and fabrication tools. We used transparent acrylic glass and a laser cutter to build our prototypes. Because of the transparency light effects can be realized by illuminating the PV and in addition digital content can be displayed below it [2]. The laser cutter enables rapid prototyping with high precision for creating accurate PVs.

Two examples of our PVs can be found in figure 1. This type of PV provides a good overview of the dataset and assists analytical InfoVis tasks such as finding extreme values or anomalies. Other tasks such as sorting or clustering would require more sophisticated mechanical constructions or the disassembling and reassembling of the PV.

Our prototypes are a starting point and only a specific instance of a larger design space. In the following we will discuss the chosen datasets, visualizations and the construction of the PVs.

Datasets

We used two different datasets for our prototypes. The first was a country indicator dataset from Gapminder[1] with three dimensions: country, energy source and time. The second was a sports dataset with two dimensions: soccer player and their statistics such as minutes played, number of goals or pass success.

Visualizations

We focused on well-established 2D visualizations, thereby the PV can be easily interpreted. Figure 2 (top) shows the matrix visualization of one layer of the country indicator dataset, in which the x axis represents energy sources and the y axis represents countries. Time is represented by the z axis, which is expressed in the single acrylic glass layers. The data cases can be represented by holes or carved shapes (e.g. a circle or square) in the respective layer. In figure 2 (top) the width of the circle represents the percentage of energy production from the respective source by the respective country for a given year. A visualization example for the soccer data is shown in figure 2 (bottom). In this prototype a single soccer player is characterized by one layer. The different statistical variables are visualized by rectangles. Again, the width of the rectangle represents the value. If the value is expressed as percentage (e.g. pass success) the visualization has a border that represents 100 percent.

Construction

There are several possibilities for a fixation of the individual physical layers. Figure 3 shows three variations. If only one screw (figure 3 top) is used to hold the layers together, it is possible to rotate them independently from each other. One problem in this variation is that the orientation of the visualization changes with the rotation and comparisons of the single layers are difficult. If two screws are used (figure 3 middle) a sliding mechanism can be achieved. Figure 3 (bottom) shows the third variation, in which the single layers are fixated with tape at one side, similar to bookbinding. By turning over a layer, a horizontal or vertical flipped visualization is attained.

It is worth noting that a fixed construction is also possible, in which none of the layers can be articulated. The other extreme would be independent layers without any fixation. As tangibles in the basic forms of blocks

[1] http://www.gapminder.com

and plates [2] are well known, this paper will not take these variations into further account.

Interacting on Tabletops

Interaction with PVs on tabletops is similar to that of standard tangibles. It supports common interaction techniques such as repositioning the PV by moving it across the surface or rotating the object. As our PVs convey complex visual information and can be articulated, additional interactions are possible.

Following the visual information seeking mantra by Shneiderman [9] the PV allows a first overview of the data and the tabletop is used to show further details. Depending on the side of the PV that lies on the surface, different information about the complete dataset can be displayed. In the country indicator dataset for example, the exact values could be displayed in a table. As the z axis represents the time, turning the entire PV around can change the chronological order from ascending to descending and vice versa. In the soccer data visualization each side of a layer has a specific mapping to one kind of variable (e.g. passes or tackles). Again, depending on the side that lies on the surface, detailed information regarding these variables can be shown.

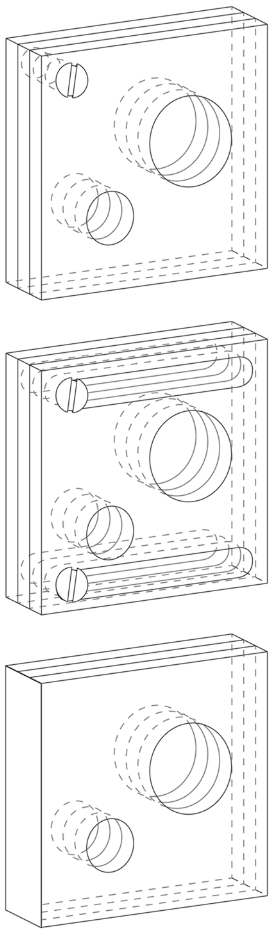

Figure 3: Top: Fixation of the layers with one screw. Middle: Fixation of the layers with two screws. Bottom: Fixation of the layers with tape on one side.

The possibility to articulate single layers allows a filtering of the dataset. By rotating or sliding one layer out of the physical block (see figure 4) the digital information can be adapted according to that specific layer. In our examples further details about a particular year or a soccer player may be visualized.

In addition more than one layer can be articulated (see figure 4). This interaction technique enables a comparison of the data represented by the chosen layers. The differences may be displayed on the tabletop. An alternative result would be the union of the single layers. In the example of the soccer dataset each layer embodies the data of one soccer player. Hence, how many goals the chosen players scored together may be visualized or if one player assisted another.

Taking the angle of the rotation into account or how far a single layer is pulled out can be used to realize more sophisticated interactions and results. To differentiate for example between the union and the comparison of the layers these characteristics could be utilized.

As our PVs are made out of transparent acrylic glass they can be illuminated with light from the display. In this variation the tabletop is used for the input and the PV functions as an output device. After selecting or filtering data on the tabletop only the corresponding layers of the PV are illuminated. Using different colors for illuminating the layers is another possibility. In the soccer dataset for example all layers that represent a player that scored more than a specified amount of goals may be illuminated in one color, all other layers in another.

Conclusion and Future Work

In this paper we presented our first approaches in designing layered physical visualizations and explored how these could be used for tabletop interaction. In particular, we discussed different datasets, visualizations and the fabrication of the PVs using transparent acrylic glass and a laser cutter. Furthermore, we described interaction techniques that

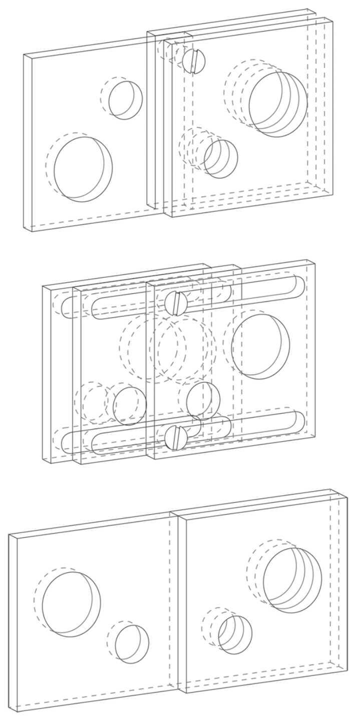

Figure 4: Possibilities to articulate the PV. Top: Rotating. Middle: Sliding. Bottom: Flipping.

would take advantage of the visual information encoded in the single layers of the PV.

The purpose was not to build a system for data analysis experts. In our opinion, PVs on tabletops are a promising approach in the area of casual InfoVis [8]. PVs are well suited for a playful exploration and can awaken interest to take a deeper look into a dataset. The tabletop in turn has a large screen to show further information and details on demand.

As in most TUIs, the size of the PV is fixed. Moreover, the visual information that is cut or carved into the acrylic glass is unchangeable. A further challenge in comparison to traditional tangibles is the development of suitable visualizations that can be cut or carved into the acrylic glass.

Our next step is the actual implementation of the software for the interactive tabletop. The tracking could be realized by using transparent markers [2]. One challenge is the thickness of the single layers, which is probably too thin to attach markers. We would like to evaluate the PVs and the interaction techniques in a lab-based user study as well as in field studies in public places or museums.

For future work we want to extend the design space of PVs by using different datasets and form factors. Using more than one PV on the tabletop and letting more than one person interact with the system in a collaborative way may be further directions of interest. Last, but not least the recognition of touch input on the PVs could be implemented, e.g. tapping on a specific layer or even treat the acrylic carving as an interactive surface [6].

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