Exploring the Potential of Physical Visualizations

Simon Stusak
Human-Computer Interaction Group
University of Munich (LMU)
simon.stusak@ifi.lmu.de

ABSTRACT
Although physical objects have been used for information presentation for a long time, physical visualizations only recently started to attract interest in the HCI and InfoVis communities. While physical visualizations have the quality to evoke user fascination and curiosity, our understanding of their benefits regarding data exploration and the creation of effective representations are still limited. This paper describes several projects in the area of physical visualizations, all with the goal to explore their potential and limitations. First findings show that a promising direction of physical visualizations is the area of personal data, where they can offer a more creative and mindful way to look and reflect on ones' data.

Author Keywords
physical visualization; information visualization; digital fabrication; tangible user interaction.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors; Design; Experimentation.

INTRODUCTION
The emerging interest in digital fabrication and the technical progress in research areas such as shape-changing interfaces lead to the questions how such novel techniques can be integrated into everyday life and how they can complement traditional 2D displays. While technologies for shape-changing interfaces are rapidly evolving, our understanding of their clear benefits is still limited.

This thesis focuses on the area of information visualization with the goal to investigate how information can be visualized in a material form and uncover its potential but also highlight challenges and limitations. Artists and designers have produced physical representations of data in various forms and companies already used them in the early 20th century [2]. While it is widely recognized that they engage playful exploration and can foster curiosity, their analytical value and the creation of effective physical visualizations remain to be explored.

This paper starts with a short introduction into related work and a specification of the main research questions. The main part describes several projects in which material representations for a range of different data sets and in various form factors based on several materials were designed and built. All had the goal in common to explore how physical visualization can be designed, to investigate how people use and interact with them and to establish a basic understanding of their potential and limitations. First findings revealed the area of *calm* or *slow visualizations* to be a promising field for further research, since the nature of physical visualizations as long lasting and "always on" objects seem to offer a more mindful and reflective look at data, especially in the case of personal data.

TEI '15, January 15–19, 2015, Stanford, California, USA..

ACM 978-1-4503-3305-4/15/01...$15.00.
http://dx.doi.org/10.1145/2677199.2691604

RELATED WORK
Hiroshi Ishii [3] developed the vision of Tangible User Interfaces (TUIs). He argues that people have sophisticated skills for sensing and manipulating the physical environment. However, most of these skills are not employed in interaction with the digital world. TUIs are built upon those skills and provide physical form to digital information. Physical visualizations are part of this vision as they offer to explore and receive information through multiple sensory channels

Jansen et al. [5] present the first information visualization study comparing physical to on-screen visualizations. They compared physical 3D bar charts to their on-screen counterparts and showed that moving visualizations to the physical world can improve users efficiency at information retrieval tasks. The ability to be touched and the perfect visual realism of physical objects seem to be an essential cognitive aid. Their findings provide empirical motivation for further studies, which focus on other modalities (e.g. paper or touchscreens) and different tasks. In addition they extended the information visualization pipeline model by adding further levels to integrate beyond-desktop visualizations such as shape-changing displays and physical visualizations [4].

Vande Moere and colleagues [11, 12] reviewed and discussed a large variety of data sculptures. They point out the limitations of the screen medium and the advantages of information presentations that can be touched, carried or even possessed. He argues that physical visualizations can address a broader audience and extend the area of casual and ambient information visualization.

A first model of physical representation of data was developed by Zhao et al. [13]. Their data sculpture domain model is split into four relevant areas: *information visualization*, *tangible user interfaces*, *visualization art* and *interactive art*. The model is defined by the two attributes *focus (artistic - functional)* and *manifestation (virtual - physical)*.

METHOD AND RESEARCH QUESTIONS

The main goal of this research is to investigate how physical visualizations can contribute to the process of data exploration and what value they have dependent on different tasks and goals. What are the design challenges for visualizations in material form and what are the key points to create effective physical visualizations? This further leads to questions about the interplay between physical and traditional digital visualizations, their individual strengths and how they could complement one another. How for example should visualization systems be designed that try to take advantage of a multisensory approach and use vision and haptics to communicate information?

I started with a practical approach, inspired by the research through design method [14], by designing and building material representations for a range of different data sets and in various form factors. The intention and expected final output is a series of prototypes and a documentation of the design process, which can help to specify a problem space, context of use and set of target users.

To consider suitable approaches to evaluate physical visualizations and to find first indications for possible benefits a literature research was conducted. Besides areas from computer science, such as *information visualization*, *tangible user interaction* or *projection augmentation*, I also looked into research fields from psychology, e.g. *memory and cognition* or *motivation and persuasion*.

PROJECTS

This section describes several projects I am currently working on. For the fabrication a laser cutter and a 3D printer were used, which both enable rapid prototyping of physical visualizations with an adequate precision. Various materials from paper and cardboard, to wood and acrylic glass, to plastics were used for the data-driven artifacts. So far, we focused on static physical visualizations to keep the design and creation process rather simple.

Beyond Physical Bar Charts [7, 8]

To investigate the creation of effective and usable physical visualizations we used an iterative design process. We started with sketches on paper, created first low fidelity prototypes out of cardboard and built the final visualizations with acrylic glass and a laser cutter. Figure 1 (left) shows the static variation of the so-called *thread star plot*, which combines a bar chart and a star plot, both well-known 2D visualizations, into one compact physical object. Furthermore we built an interactive type by attaching hook-and-loop fastener at the edges of the acrylic glass (figure 1 right) to enable filtering and reordering of the data. A conducted user study revealed that a mature design is crucial if the physical visualizations are aimed at supporting analytical tasks. Especially stability and affordances are essential properties. [7]

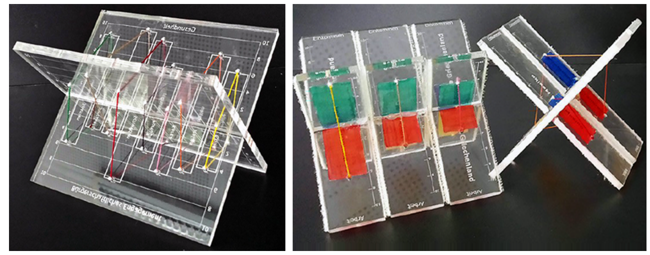

Figure 1. Static thread star plot (left); Interactive thread star plot (right) [7].

We furthermore examined to which extent physical visualizations can support well-know analytical tasks from the domain of information visualization. An analysis based on the taxonomy of Amar et al. [1], which lists tasks such as "filter", "sort" or "determine range", showed that many analytics tasks can be supported by physical visualizations. However, to support all analytical tasks more sophisticated physical visualizations that offer for example mechanical manipulation are required. [8]

Paper-Based Visualizations

The goal of the paper-based visualization projects was to explore which effects come into play, when people build their own physical visualizations. We developed three paper-based visualizations using the data of the TEI 2014 conference (see figure 2 left) and included them into the conference bags. Although the qualitative feedback during the conference was positive, the number of completed questionnaires were marginal.

Figure 2. Paper-based visualizations for the TEI conference 2014 (left) and the soccer world championship 2014 (right).

In similar spirit we designed a visualization for the soccer world championship 2014 (see figure 2 right). The result of each game is represented by two paper pyramids colored in the corresponding national flags. The scored goals of each team are visualized by the height of the pyramid. We shared pictures and source files through social media. While again the qualitative feedback was positive, nobody tried to build the visualization for themselves or developed it further to realize, for example, a different data mapping.

Augmenting Physical Visualizations [6, 10]

Physical visualizations are often limited by their fixed appearance and lack interactivity. To minimize these disadvantages we tried to fuse the digital world with the physical.

One project combined physical visualizations and interactive tabletops. The general motivation here was to use the physical visualization for a first overview of the data and to awaken interest and than use the tabletop to show further information or details on demand. Placing and manipulating the physical visualization (e.g. repositioning or rotating) on the tabletop enables a deeper exploration and interaction of the data set. [6]

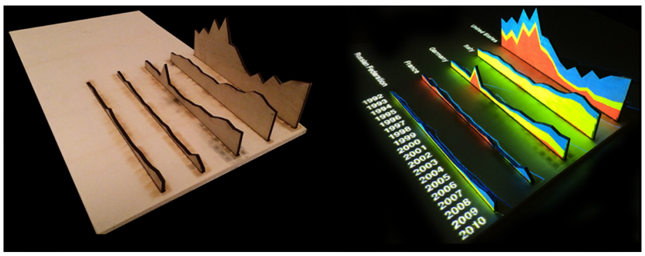

Figure 3. Physical Area Chart (left); Projection Augmented Physical Visualization (right) [10].

Another project investigated the potential of augmenting physical visualizations with projections. Figure 3 shows a concrete prototype of a wooden physical area chart (left) and its augmentation (right). The creation process revealed some initial insights as the importance of the accuracy of the physical model and the resolution of the projection. The exploration showed that projection augmentation can enhance physical visualizations, by for example projecting guides that help to overcome problems which arise through perspective distortion. As the design of projection augmented physical visualizations involves multiple dimensions such as the visualization itself (e.g. material, fabrication), the projection (e.g. position, purpose) and the input modality (e.g. touch, disassemble and reassemble, remote) our early prototype is just a starting point for a more systematic exploration of this fascinating design space. [10]

Activity Sculptures [9]

The *Activity Sculptures* project explored the impact of physical visualizations on running activity. Figure 4 shows four examples how the final sculptures looked like. The sculptures were modular, rewarding each running session with a part of the sculpture. The sculptures had in common that with better performances the size of the single pieces increased. Furthermore the performance influenced their shape, going from an angular and sharp appearance to appearing smoother and in our opinion more aesthetically pleasing. As underlying data standard measurements of running activity such as average speed, duration and distance were used.

Figure 5 offers an overview of the process we used to produce the sculptures. The running data was tracked with a popular mobile tracking application (Endomondo, Runkeeper, Nike+ Running and Runtastic) and saved in the cloud (fig. 5-1). The data was then gathered either through an export on the according website and mail (fig. 5-2a) or by API calls (fig. 5-2b).

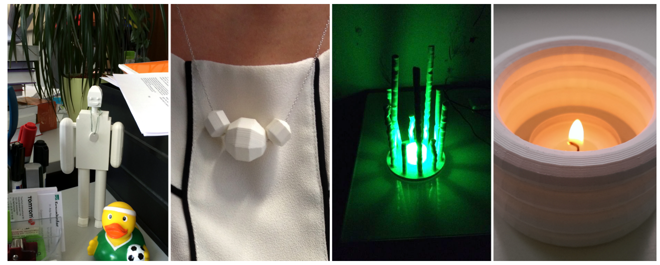

Figure 4. Four Activity Sculptures of running activity: a figure, a necklace, a lamp and a jar [9].

Based on the captured data, a digital version of the sculptures as 3D printable STL files were generated by using web technologies. We then used an Ultimaker Original to 3D print the single parts of the sculptures (fig. 5-3). Each piece of the Activity Sculptures was either handed out in person (fig. 5-4a) or by letter (fig. 5-4b).

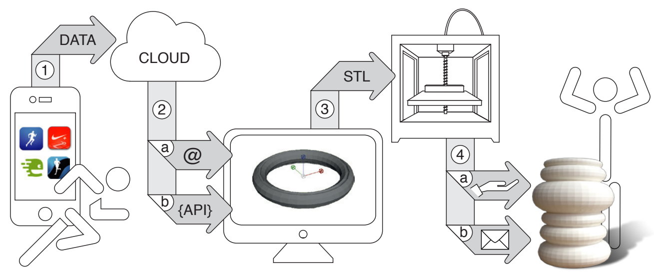

Figure 5. The fabrication pipeline of the Activity Sculptures [9].

A three-week field study with 14 participants with various levels of running activity was conducted. Semi-structured interviews at the beginning and end of the study revealed a great acceptance of the general idea of the Activity Sculptures. Most of the participants were convinced of their ability to improve motivation and self-reflection. We further observed their potential to offer a more creative view at ones activity (playfulness), as participants started to change their running habits in order to impact the shape and aesthetics of the final sculpture pieces.

FUTURE WORK

As the area of personal data representation seems a promising field for the use of physical visualizations we are thinking about a follow-up work on the Activity Sculpture project. One idea is to reward runners of public events such as marathons with physical visualizations. Another one is changing the concept of one sculpture for each person to one sculpture on which more people collaborate, which could be espeically interesting for running teams.

Haptic memory refers to the recollection of data acquired by touch and thus seems to be a promising direction for further research in the area of physical visualizations. We are planning an experiment to compare digital and physical visualizations regarding interpretation accuracy and long-term recall.

We are also working on physical visualizations with more sophisticated mechanical constructions and would like to experiment with non-rigid, elastic parts or even liquids.

REFERENCES

1. Amar, R., Eagan, J., and Stasko, J. Low-level components of analytic activity in information visualization. In *Information Visualization, 2005. INFOVIS 2005. IEEE Symposium on*, IEEE (2005), 111–117.
2. Dragicevic, P., and Jansen, Y. List of physical visualizations. tinyurl.com/physvis, 2013. [Online; accessed 04-Sep-2014].
3. Ishii, H. Tangible bits: Beyond pixels. In *Proceedings of the 2Nd International Conference on Tangible and Embedded Interaction*, TEI '08, ACM (New York, NY, USA, 2008), xv–xxv.
4. Jansen, Y., and Dragicevic, P. An interaction model for visualizations beyond the desktop. *Visualization and Computer Graphics, IEEE Transactions on 19*, 12 (2013), 2396–2405.
5. Jansen, Y., Dragicevic, P., and Fekete, J.-D. Evaluating the efficiency of physical visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 2593–2602.
6. Stusak, S. Interacting with layered physical visualizations on tabletops. In *Work-In-Progress in conjunction with the 8th ACM Conference on Tangible, Embedded and Embodied Interaction (TEI '14), February 16-19, 2014, Munich, Germany*, TEI '14, ACM (New York, NY, USA, 2014).
7. Stusak, S., and Aslan, A. Beyond physical bar charts: An exploration of designing physical visualizations. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '14, ACM (New York, NY, USA, 2014), 1381–1386.
8. Stusak, S., Tabard, A., and Butz, A. Can physical visualizations support analytical tasks? *IEEE Conference on Information Visualization (INFOVIS)* (November 2013).
9. Stusak, S., Tabard, A., Sauka, F., Khot, R. A., and Butz, A. Activity sculptures: Exploring the impact of physical visualizations on running activity. *Visualization and Computer Graphics, IEEE Transactions on 20*, 12 (2014), 2201–2210.
10. Stusak, S., and Teufel, M. Projection augmented physical visualizations. In *Proceedings of the 2Nd ACM Symposium on Spatial User Interaction*, SUI '14, ACM (New York, NY, USA, 2014), 145–145.
11. Vande Moere, A. Beyond the tyranny of the pixel: Exploring the physicality of information visualization. In *Information Visualisation, 2008. IV'08. 12th International Conference*, IEEE (2008), 469–474.
12. Vande Moere, A., and Patel, S. Analyzing the design approaches of physical data sculptures in a design education context. *Visual Information Communications International (VINCI09)* (2009).
13. Zhao, J., and Vande Moere, A. Embodiment in data sculpture: a model of the physical visualization of information. In *Proceedings of the 3rd international conference on Digital Interactive Media in Entertainment and Arts*, ACM (2008), 343–350.
14. Zimmerman, J., Forlizzi, J., and Evenson, S. Research through design as a method for interaction design research in hci. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2007), 493–502.