Exploring a Shape-Changing Bar Chart

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Abstract
Data visualizations have the ability to help us analyze and reason about complex datasets. Current data visualizations, however, are mainly screen-based and rarely physical, dynamic and interactive. This paper focuses on the role of shape-changing displays in showing physically dynamic data. We describe our explorations of a physically dynamic bar chart, a shape-changing display prototyping tool, and a reflection of the implementation challenges that we faced.

Author Keywords
Shape-changing displays, emerging technologies, actuation, information visualization, bar charts.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
By using vision to think [2], data visualizations enable users to perform tasks such as compare values, detect patterns, and understand trends. Although data visualizations are typically optimized for 2D screens, the rich and tangible qualities of physical visualizations are becoming more familiar within the information visualization community. This paper describes an exploration of a physically dynamic bar chart using a custom-built prototype: EMERGE (Figures 1 and 2). In addition, we describe the ShapeClip tool, which is

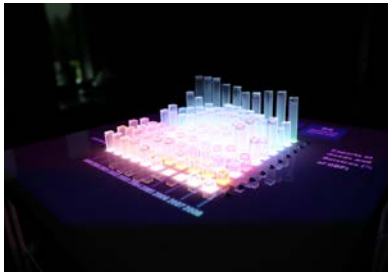

Figure 1 – The EMERGE bar chart showing LED-lit rows of push rods.

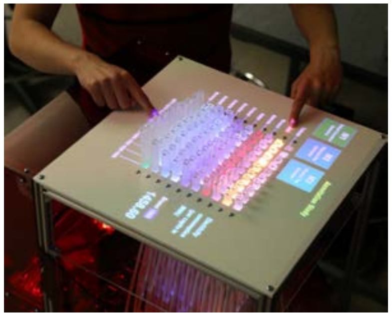

Figure 2 – Study participant interacting with the EMERGE system.

designed to enable rapid prototyping of shape-displays. Finally, we discuss implementation challenges based on first-hand experiences and provide guidelines for designers of shape-displays.

Related Work

Recent interest has grown in developing physical visualizations ([8], [12], [16]). Physical visualizations aim to extend the benefits of visualizations by using the haptic qualities of physical objects to exploit humans' inherent tactile perception capabilities. Jansen and Dragicevic's curated a list of physical visualizations[1] shows examples more than six millennia old. These visualizations are mostly used to show quantity in physical form, for instance by mapping a number to physical height. Other approaches include audio, texture, and enclosures to show quantity [13].

Previous research has examined the efficiency of physical visualization [7] and approaches for designing physical visualizations [15]. Jansen et al. found hand-held 3D printed physical visualizations improved users' efficiency at information retrieval tasks, with physical touch and visual realism being important advantages [7]. Stusak and Aslan examined various physical visualization prototypes and found that these representations can support analytical tasks through mature design, emphasising the importance of stability and affordances [15].

While static, physical visualizations are useful and attractive, they must be fabricated before use. Shape displays typically have a physical equivalent of pixels, either binary (on/off) or continuous (being able to show a range of values). Typical examples include Sublimate [10], Relief [11], Lumen [14], Feelex [6], Taxel [9], inFORM [3], Tilt Displays [1], and Physical Charts[2]. These physical pixels are often implemented via motorized pins that can extrude from a surface.

Exploring Physically Dynamic Bar Charts

Our goal was to investigate data analysis tasks and interactions with physically dynamic bar charts. We developed the EMERGE prototype (see Figures 1 and 2), which consists of a 10×10 array of actuated plastic rods that are individually linked to 100 motorized potentiometers. Each column is illuminated by a dedicated RGB LED. Additionally, a Microsoft Kinect® and projector were mounted above the system to project information (i.e. axes, labels, and controls) and detect touch interaction on the surface surrounding the rods. This was achieved by using the Ubi Displays toolkit [4] to map the projection and detect touch.

We carried out a user study with 17 participants (6 female) that explored interactions with EMERGE to perform visualization tasks based on Heer and Shneiderman's taxonomy [5] for visual data analysis. We explored 14 interaction techniques using tasks such as annotation, filtering, organization, and navigation. The insights from the study highlighted design implications for interacting with EMERGE, and also the usefulness of shape-changing displays for data physicalization. For instance, the study highlighted the importance of the tangible quality of the actuating push rods for tasks such as annotation and filtering. In

[1] http://www.aviz.fr/phys (last accessed 21/01/2015).

[2] http://research.microsoft.com/en-us/um/cambridge/projects/physicalcharts/ (last accessed 21/01/2015).

addition, we found that it is important to integrate familiar interactions, e.g. from touch-screens and include functionalities such as switching from data overview to more fine-grained control. We also found that participants were at times hesitant to interact with and startled by EMERGE, highlighting the unfamiliarity of such devices.

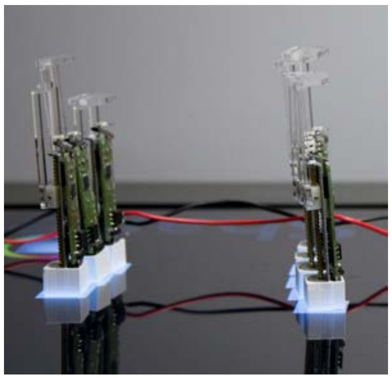

Figure 3 – ShapeClips placed on LCD screens, which are used to control their heights.

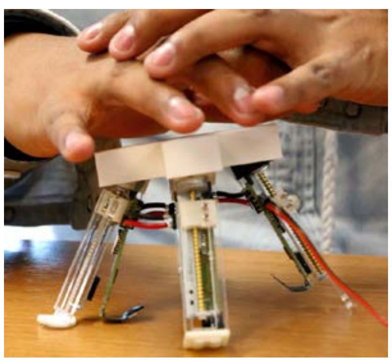

Figure 4 – demonstration of actuation ShapeClips by blocking natural light.

ShapeClip: Enabling Rapid Prototyping

One of the limitations of EMERGE is its size and the complexity of its implementation. These systems can take months to develop, thus hindering the focus on application development and explorations. The goal of ShapeClip is to counter these limitations. This is achieved through the removal of hardware barriers: (1) engineering complexity, (2) fixed actuator arrangements, (3) control circuitry, (4) low failure tolerance, (5) large build-footprints and, (6) scalability challenges. Interactive motion designs can be produced with no programming knowledge, embedded firmware, cross-platform support, or software tools.

To construct a ShapeClip, c*lips* are placed on a *control surface* (i.e. LCD Screen, see Figure 3). Alternatively, natural light can be blocked to enable actuation (Figure 4). Light Dependent Resistors (LDRs) in each Clip sense changes in screen brightness to adjust actuation height and output color. Touch events can be 'forwarded' to capacitive surfaces using thin wires that run down the length of the Clip to copper tape on the base. This approach enables individual Clips to be added, removed, repositioned, and re-oriented at runtime.

Standard Clips are constructed from a bespoke circuit board containing an ATmega328p (compatible with the Arduino tool chain), two LDRs, a stepper motor (as used in DVD drives), a corresponding 3D printed base, and a WS2812B LED for RGB color output. Clips can forward touch events to capacitive screens using copper tape and thin wire, or stream data from an optional force sensor attached at the top. Each standard Clip weighs ≈30g, and is 20×20×80mm when closed, and costs ≈USD$15. Individual Clips draw between 60–540mA at 5V, enabling small groups to be powered via USB. An independent on-board power circuit separates motor voltage from logic in order to increase the travel speed above the standard 80mm/s. Clips are 'clipped' together with pin connectors that double up as a power transmission method.

Implementation Strategies

The development of EMERGE and ShapeClip has generated knowledge that informs future builds, warns of common pitfalls and design limitations, and highlights opportunities for refinement. These are discussed as follows.

Design: The design process must include CAD packages like Autodesk Inventor to reduce design time, error, enable digital trial and error, and provide spatial validation. Access to tools such as 3D printers is essential for testing the suitability of different components. Laser cutters are also useful in constructing accurately measured components. Budget, parts-ordering and delivery must also be considered.

Engineering: Large amounts of time can be spent testing various parts such as the linkages used for EMERGE, and we found that higher cost equates to better quality. Efficient debugging tools are essential and should be done on a computer rather than on the microcontroller. Other considerations include catering for heat from motors, and expecting manufacturing errors, and thus the need for multiple iterations.

Maintenance and Usage: It is essential to consider disassembly and part-replacement, as over time parts can deteriorate and become faulty. Using transparent materials can also help monitor hardware. We also found that using glue (e.g. hot glue) can cause more long-term problems.

Conclusion

This paper provided a validation of shape-displays for use in data physicalization, described a rapid development approach for these devices, i.e. ShapeClip, and presented guidelines based on first-hand implementation experiences.

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