xCoAx 2015
Computation
Communication
Aesthetics
and X

Glasgow
Scotland
2015.xCoAx.org

Data Exploration on Elastic Displays using Physical Metaphors

Mathias Müller
Chair of Media Design, Technische Universität Dresden, Dresden, Germany
mathias.mueller@tu-dresden.de

Thomas Gründer
Chair of Media Design, Technische Universität Dresden, Dresden, Germany
thomas.gruender@tu-dresden.de

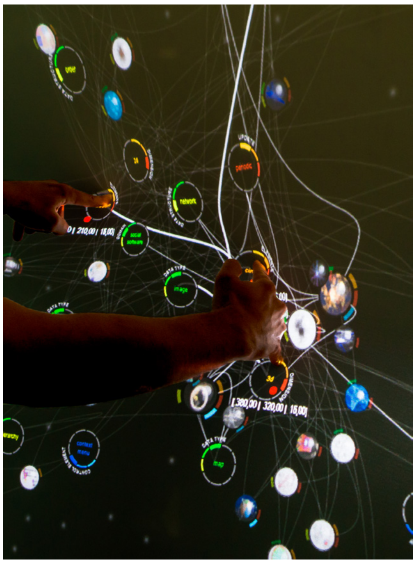
Rainer Groh
Chair of Media Design, Technische Universität Dresden, Dresden, Germany
rainer.groh@tu-dresden.de

Keywords: elastic displays, information visualization, haptic interaction

Elastic displays empower users to interact naturally through pushing and pulling, folding and twisting. While this kind of interaction is not as precise as on other devices, it utilizes interaction metaphors which are easy to learn and understand. We present a system that uses physically based interaction and visualization metaphors to gain a deeper comprehension of the underlying data and its structure. By applying pressure on specific interface elements, associated items are attracted and repelled, the exerted force on the items itself translates into a semantic zoom behavior to display more in-depth information about the specific entity. We present the core concepts of the system, explain the decisions made during the design process and discuss the advantages and disadvantages of the proposed system as well as a short view on further improvements and open research questions.

1 Introduction

Interacting with complex visualizations is a common challenge. Faceting data, selection strategies and the visualization of correlations between data points result in complex user interfaces which lack intuitiveness and the option to explore freely without in-depth knowledge about the underlying concepts and data structures. A possible solution to these issues could be elastic displays which offer an additional dimension of interaction. Elastic displays that deform are a new field in Human-Computer Interaction. Due to their elasticity, these displays allow users to change the surface by pulling, pushing or twisting. Furthermore, elastic displays offer a unique interaction experience through haptic feedback. The elastic membrane may be imprecise when compared to a mouse, but offers a rich multi-modal feedback which facilitates interaction.



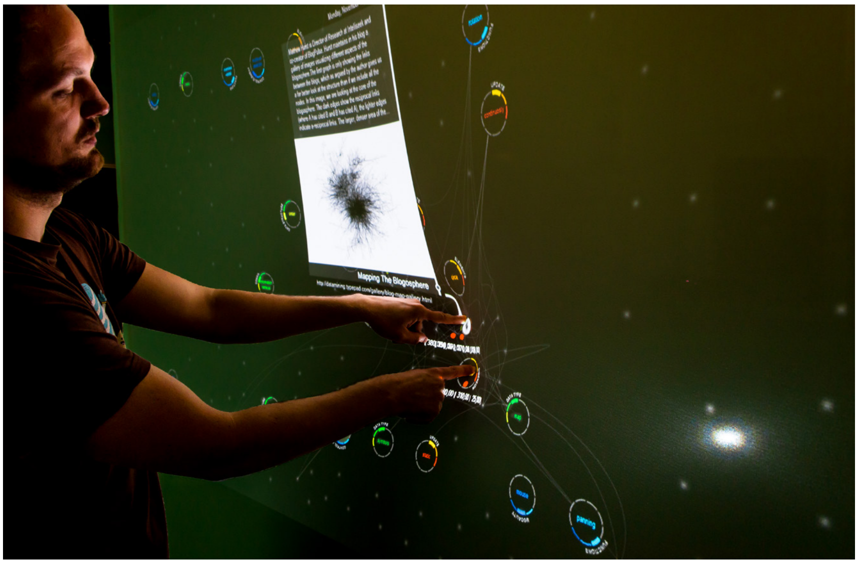


Fig. 1 Exploring different types of visualizations by pushing and pulling into the flexible surface

By extending the direct manipulation paradigm of touch interaction with a large range of different interaction states coupled to the pressure applied on the surface, elastic displays offer a rich and versatile interaction space. The deformation of the surface addresses one of the core problems with current touch devices – they offer basically the two states “on” and “off” for touch recognition. More fine-grained touch interaction can only be achieved with additional devices like pressure-sensitive digitizers or by utilizing the duration of the touch for emulating pressure. The first option is useful in many scenarios, but lacks the versatility of the human hand to form and execute different gestures and again puts a tool between the finger and the interaction surface. The second solution represents a rather weak, indirect substitute for real force sensitive surfaces.

With metaphors based on physical interaction, the interface can generate additional cues to understand the data and connections between elements of the visualization. We argue for using elastic displays to explore complex data sets. We present an approach on data from a database of visualizations using an elastic display called *FlexiWall*. The data is taken from the *DelViz* database, which consists of more than 700 different visualizations classified in hierarchically organized categories of keywords describing the content of the different visualizations.

The goal of this paper is to present a novel approach for playful and intuitive exploration of data sets using advantages of elastic displays.

2 Related Work

In the last years there has been a lot of research focused on elastic displays. *Cassinelli* and *Ishikawa* first published about an elastic display they called *Khronos* projector (Casinelli and Ishikawa 2005). *Peschke et al.* describe an elastic display used as tabletop system (Peschke et al. 2012). In former publications, we classified suitable data types and interaction techniques, based on the experience of both *DepthTouch* (Fig. 2, left) and *FlexiWall* (Fig. 2, right; Franke et al. 2014). The transfer of multi-touch paradigms like gestures, tangible objects and their applicability in the context of deformable surfaces led to the definition of a design space for elastic displays. Gestures and other interaction techniques like gravibles or geometric shapes are introduced in it (Gründer et al. 2013).

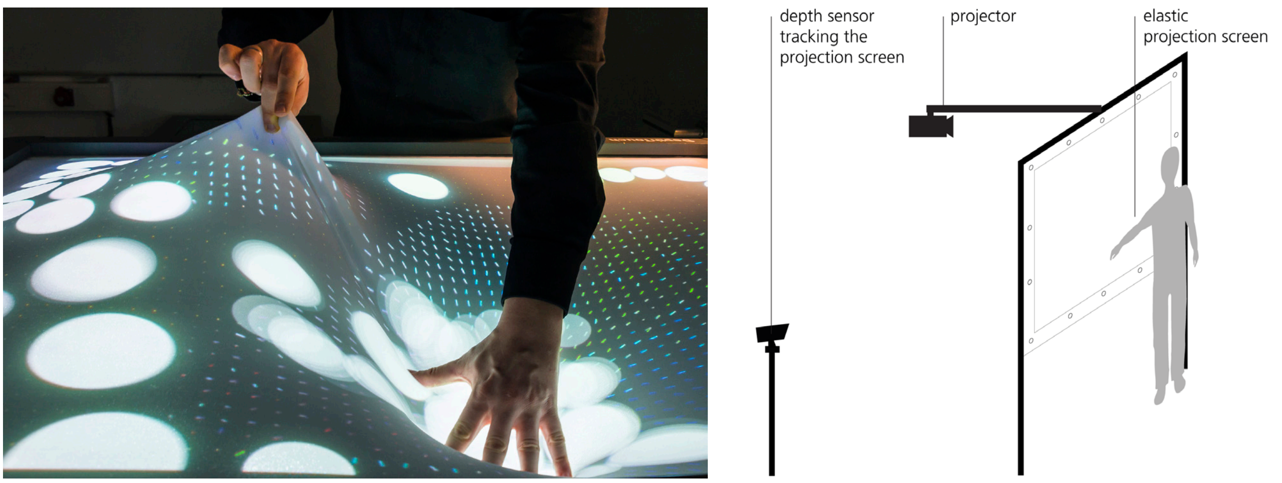


Fig. 2 The DepthTouch prototype in action (left). Core components and system setup of the FlexiWall prototype (right).

Troiano et al. identify gestures used on elastic displays by utilizing the guessability studies method. They find that grab and pull, push with flat hand, grab and twist, pinch and drag and push with index finger are the gestures used most often for the interaction in depth (Troiano et al. 2014) Regarding solutions for common technical issues with elastic displays, Watanabe et al. describe solutions to the projection and warping problems occurring while pushing or pulling the membrane (Watanabe 2008).

Due to the prototypical character and the easy setup, elastic displays have been used in the context of artistic installations and demonstrators, which facilitate playful exploration. Examples for artistic installations are *Cloud Pink* and *Soak, Dye in light* from *everyware* (everyWare01, everyWare02) and *firewall* from *Sherwood* (Sherwood 2012). Use cases apart from the scenarios are described in (Gründer et al. 2013), (Sterling 2012) and (Cassinelli and Ishikawa 2005). One of the rare works describing data visualization on elastic displays is the *ElaScreen*, which utilizes an elastic display system for graph navigation scheme (Yun et al. 2013).

The presented work is based on the *DelViz* system (Keck et al. 2011). They classified data visualizations from the *visual complexity* (Visual Complexity) collection with a faceted approach. They then describe the multi-touch exploration software with focus on the connection of facets and visualizations. As one of the core advantages of elastic displays is their haptic nature, we decided to follow the concept of physically-based interaction by Jacob (Jacob et al.) to mediate correlations of objects and interaction with the visualization. An example for concepts from physics applied to interaction can be found in (Agarawala and Balakrishnan 2006). They describe a system based on physical metaphors. They present a 3D visualization of Desktop Icons. The icons are influenced by physical interaction with a pointer. The pointer is able to grab and throw the icons around.

3 Interaction Concept

We chose to use the *DelViz* classification of visualizations. Every visualization type is described by a set of metadata such as a short description, title, web link and the date it was added. The visualizations are associated with a number of tags representing the most important properties. These keywords are based on three main categories: *Data, Visualization* and *Interaction*, and their associated dimensions (Fig. 3). The tags in the dimensions are competing terms to which the items are matched. However they are not mutually exclusive, e.g. visualizations can combine text and *images*, address both *science* an *economy* domain or employ scrolling as well as *Overview/Detail* functionality. There are complex relations between the items based on their associated tags.

The relations are formed by the items they are assigned to. If items are tagged as *2D* and *static*, those two have a connection. The user is able to filter by several tags or deselect them in order

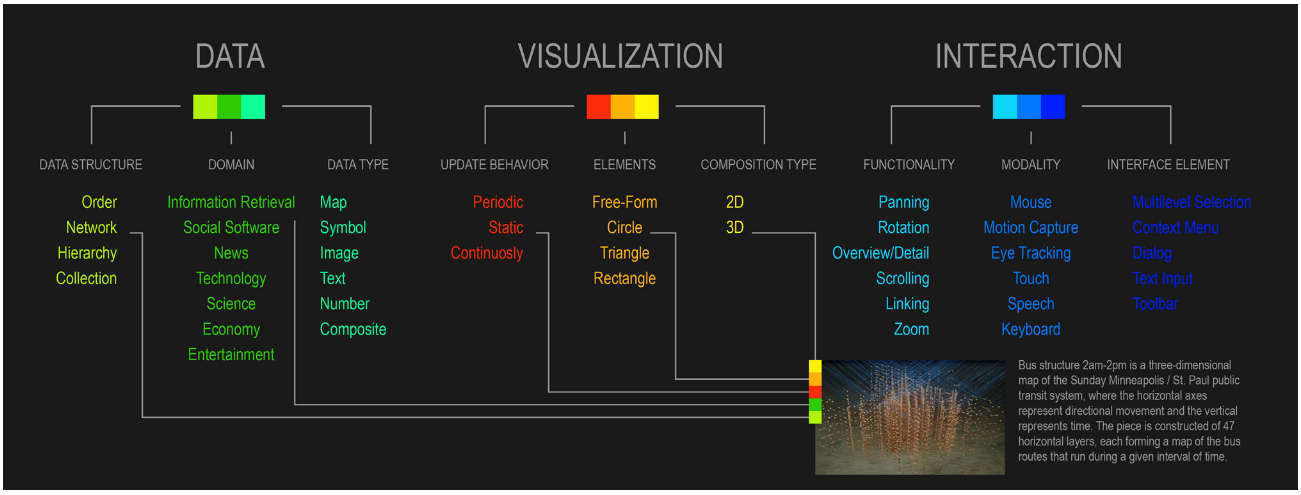


Fig. 3 The *DelViz* classification schema and associated colors used in the prototype with example visualization, associated tags and description (bottom right).

to explore the dataset. According to the selection items are highlighted or diminished. The dataset contains of few major tags, like *2D* or *Network,* which are associated with about two thirds of the items. Other keywords are assigned to only a handful of items, what implies a rather unbalanced tag distribution. The goal is to search and identify visualizations matching given properties, represented by their associated tags. The core concept is to explore items based on weighting several tags. The concept used for the prototype described in this paper originated on the work about the *DepthTouch* (Peschke et al. 2012).

One of the applications of the *DepthTouch* was a simple physical simulation – spheres projected on the surface reacted to the deformation by moving according to the resulting gravitational forces of the deformed surface (cf. Fig. 2). Observations of users show that interfaces based on easy physical concepts like gravitation, mass, spring forces or force fields are playful, easy to understand and to learn. Once people push the surface, the immediate haptic and visual feedback helps to quickly form a mental model of how the interaction works. In contrast to e.g. stacked images which are selectively blended according to the deformation, which require the user to associate the deformed surface to abstract data or image layers, this “natural” reaction to the actions of the user is immediately recognized and interpreted correctly. Users immediately know which actions they have to undertake to achieve a specific goal (e.g. to split a group of spheres by creating “holes” on two opposite sides of the group) because they are used to these simple physical principles from daily life. Therefore our implementation is based on the concept of simulating physical forces to interact with a set of items. The core idea is that for exploration of large data sets filtering and grouping of objects represent basic tasks that can be translated into a simple physical simulation, which allows it to collect objects by pushing into the depth and separating items by creating peaks in the elastic display.

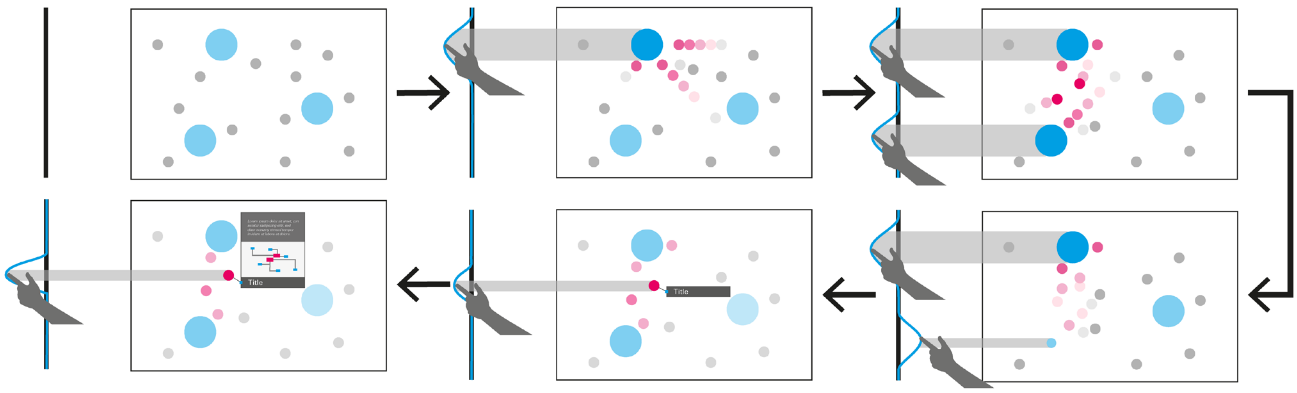


Fig. 4 Tags (blue) and inactive items (grey) are floating on the surface (top left). When pushing a tag into the surface, it attracts associated items, which change their shape to show a thumbnail of the associated visualization (top middle). When two tags are activated by pushing into the surface, associated items are moving toward the gravitational center (top right). Pulling the surface towards the user pushes away and deselects associated items (bottom right). Details about the visualization are displayed using a semantic zoom: the more pressure is applied the more information is shown (bottom middle and left).

Transferred to the *DelViz* scenario, the tags of the dataset represent gravitation centers. Items have "natural" repulsion which prevents them to be influenced by the tags in their normal state. However, when pushing into the surface at the position of the tag, its gravitational force will be increased according to the applied pressure and all associated items are attracted by it. They do not just appear next to the tag but make their way to it. The movement not only indicates the association but also the strength of this association represented by the movement speed of an item. This way the user can tap tags and observe which items are connected. Additionally to the changing movement, the items' representation contains a thumbnail of the associated visualization item and additional information about associated categories. Thin lines represent connections to other tags. Pulling the surface towards the user reverses this force, so that items are pushed away (Fig. 4, second image) and fade out. By applying different pressures to several tags, items are filtered and concentrate around the area next to the gravitational center of all manipulated tags. Items only belonging to one tag will move towards it. Items attracted to more than one gather in their center (Fig. 4, third image). The interaction is based on simple push and pull. Filtering is achieved by applying different gravitational forces to the tags, while the visualization of detailed information and connections between tags and content are retrieved by activating an item. An item again is activated by pushing into it. Items attracted to tags get an image depicting the visualization they stand for, so the user knows that these items can be selected. Fig. 5 depicts the combination of possible states for items.

The presentation of information for each item follows the principle of a semantic zoom. Depending on the amount of pressure applied more or less information is displayed, starting from displaying the title of the visualization and its connections to other tags. Applying more pressure reveals a larger image the visualization and finally additional context information about the visualization, like the description or the associated web address is displayed (Fig. 4, last 2 images). The same accounts for tags. The more pressure is applied, the faster are associated items accelerated towards it. If a pull is affecting a tag, associated items are repelled from it.

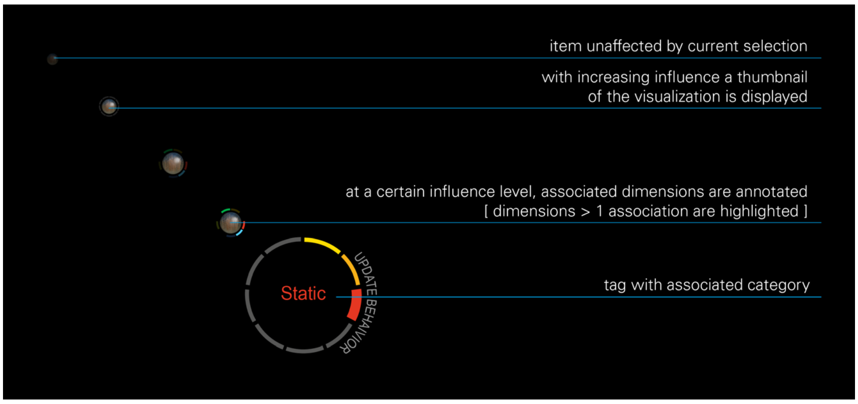


Fig. 5 Different representation of items according to the strength of the force applied to the associated tag.

4 Design Process

One issue with elastic displays is associated with the question how to motivate the user to touch the screen and push, pull or somehow deform it. Based on observations with similar systems, this represents a critical point. Once users have interacted with the system or observed other people how they used the display, the core concepts of the system should be quite easy to understand and become accessible by playing with the system. However, offering affordances for touching and deforming of a screen is quite a difficult task, due to contrasting experiences of users in current systems. We decided to offer subtle signs for interactivity – the items are constantly moving and from time to time specific items start glowing, revealing parts of the connections to surrounding tags. Although this behavior only partially solves the problem of users staying away from the surface, it provides clues how to interact and should arouse curiosity about the system.

Another challenge was to create the physics system for the simulation of item and tag movement. We wanted to create a rather simple system, which feels authentic to the user when interacting with the system. However there are a quite large number of constraints resulting in a number of system parameters which had to be balanced out to guarantee a certain stability and self-recoverability of its initial state after interaction took place. The system basically computes two types of forces between items which are based on their semantics:

(1) Forces between tags: tags sharing a large number of items attract each other. Additionally, Tags belonging to different dimension are pushed away.

(2) Forces between items: As mentioned above, items are pushed towards active associated tags or their gravitational center or pushed away, if the tag is pulled out of the surface.

To prevent the system from getting into a stable state, where tags and items do not move anymore, we added small centripetal forces of random speed to each item. Additionally, the direction is modified randomly to achieve a steady, slightly chaotic flow of the visualization. Collision is based on forces degrading over distance between objects. Similar collision forces prevent items from leaving the screen and push them constantly towards the center. As we wanted to create a flexible system, which acts independent from the visual representation and can also be configured for different associated data sets, these forces need to scale with or adapt to the number of items and tags, the size of their graphical representation, screen size. It is easy to change parameters at the start of the simulation, like object size and intensity of applied forces. Some parameters can also be changed dynamically during the simulation, which enables a wide range of possible effects and visualizations for different aspects of the system.

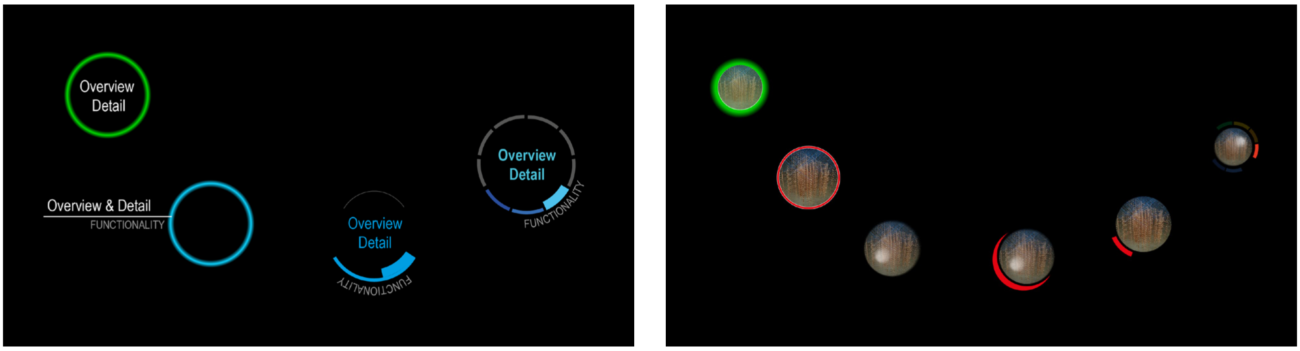


Fig. 6 Design iterations of Tags (left) and visualization items (right). Rightmost items represent the final versions of the item.

The design of tags and visualization items followed the idea of gravitational forces between objects. As forces are acting equally in every direction, the decision to use circles or spheres to represent objects was obvious. However, the question was which information should be displayed on the tags or the items. Tags are associated with a color representing the associated data dimension (cf. Fig. 3). We decided to select three categories for each dimension. As a result, we get nine possible categories a tag can belong to. In the final design, a tag is represented by a circle consisting of nine segments representing the categories. Categories of the associated dimension are drawn in their respective color, other categories are greyed out. The associated category is drawn with a thicker line, its name written outside the circle. The tag name as most important information is written in the center of the circle (Fig. 6).

The representation of items follows the same pattern: The visualization is depicted by a circular thumbnail, surrounded by circle segments representing tag categories, this item is associated with. If an item is associated with two or more tags of a category this segment is drawn in a solid color, in case of one tag it is semi-transparent, otherwise the segment is not drawn at all. The idea behind this visualization is that the user can identify similar visualizations by their characteristic layout of surrounding circle segments (Fig. 5, Fig. 6).

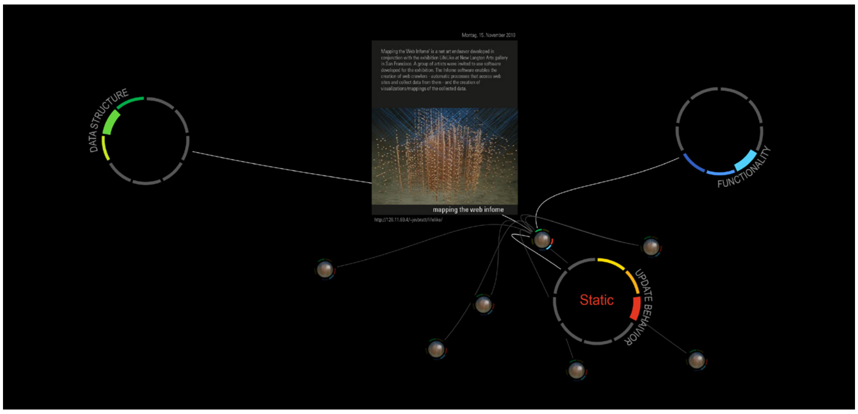


Fig. 7 Display of full details for a selected visualization, including a larger image, metadata and connections to other tags.

The final design also incorporates connection lines drawn from active items to their associated tags (Fig. 7). The idea is that the user gets a fast impression, which tags are relevant for further filtering of items: If a tag is not connected (or only connected by a few lines) with currently active items, pushing these tags will not further diversify the selected set of items. Lines are stronger if an item is connected to multiple selected tags (Fig. 1, right image).

5 Framework

The technical setup of the prototype consists of a standard Windows PC running the application, a large elastic fabric used for back projection, a projector and a Microsoft Kinect as depth sensor. The Kinect is positioned next to the projector and tracks the surface. Each point in the depth image delivered by the Kinect is projected on the associated point of the fabric. The interaction with the elastic surface completely depends on the tracking information delivered by the Kinect, as no other sensing technology is involved in the system (Fig. 2, right image).

We extended our existing *FlexiWall*-Framework (Müller et al., 2014) to achieve a precise tracking of surface deformations. The former implementation of the depth interaction followed a simple principle: Data was organized into several layers and the depth image delivered by the Microsoft Kinect was transformed into a greyscale image, where every color tone represented a specific depth value. Based on this texture, a pixel shader blended the different data layers into each other. As this happened frame by frame, the visualized image responded seamlessly to deformations. As the texture blending is done on the graphics card, this approach is fast and accurate. The problem was that the interaction heavily depends on image content. Only the depth direction was interactive. So it was not possible to drag items over the surface or rearrange things.

The current implementation includes a basic finger tracking, based on the deformation of the surface. The system does not support detection of touch; all computations of physical forces rely upon accurate information about local minima and maxima formed by the current shape of the surface. These are reconstructed by computing the partial derivatives of the depth values in horizontal and vertical direction. For performance optimization purposes, a down-scaled version of the depth image is used for the derivatives.

6 Discussion

The presented system represents a new way of exploring large and extensive data sets by applying a basic physical model as manipulation technique. Facilitated by the possibility to use the deformation of the fabric to sculpt the interaction space, exploring the facets and their content generates a playful experience. On the technical side, the system itself is sometimes lacking in terms of responsiveness and suffers from the small resolution of the Kinect sensor and artifacts resulting from the down-scaling of the depth image which results in a loss of precision for deformation reconstruction. Smoothing the minima and maxima as well in position al and temporal domain does help to increase the accuracy, but at the same time reduces responsibility of the system. This does not severely affect the interaction when selecting tags and filtering entities. However, pushing items to reveal detail- information and stepping through the different semantic zoom states (cf. Fig. 8) can be inconvenient, due inaccurate position detection and tracking lags.

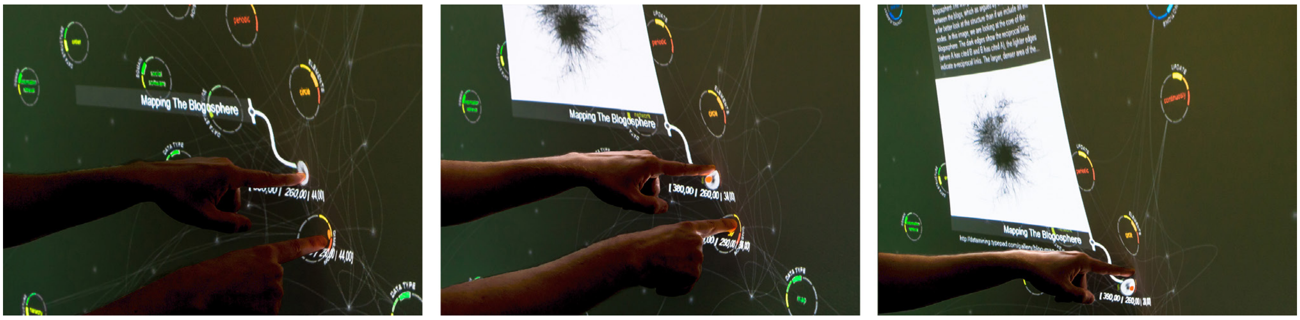


Fig. 8 Semantic zoom for displaying visualization details: when pushing slightly, the name is shown. Applying more pressure the associated image pops up and the description is revealed.

However, most problems are compensated by the additional interaction dimension, which makes it extremely easy to adjust results even if you have to recover a former state after a tracking error. The concept focusses on playful exploration and basic selection tasks which suits the rather imprecise but intuitive interaction style. Users easily learn the concepts of the system by playing with it – due to its reactiveness and limited feature set. As the current implementation recognizes a fair amount of local extrema, collaborative use is another feature (or even requirement, depending on the complexity of the data set) of the elastic surface. As selecting or deselecting three or four tags at the same time is difficult for one user alone and due to the dynamic of the system, the elastic surface necessitates collaboration for complex selection or filtering operations.

7 Lessons Learned

As the technical basics for the *FlexiWall* and its predecessor, the *DepthTouch*, are nearly equal, the application can be deployed for both systems. However, the orientation of the interactive surface plays an important role. As the *DepthTouch* is a Tabletop with an elastic surface, one problem of the current implementation is the orientation of the title and the objects description. People interacting with a Tabletop usually stand around the table, so displaying text is problematic when the position of the user is unknown. The *FlexiWall* as vertical screen benefits from its inherent bottom-up orientation. Text orientation does not represent an issue here. On the other hand, the concept of gravity may be a easier to understand on a tabletop, as the pushing and pulling direction coincides with its direction. Therefore, the abstraction of forces between objects can be easier deduced from the natural direction of gravity.

Material stiffness and size of the elastic surface are further points of interest. Interacting with the large fabric on the *FlexiWall* deforms the whole surface. Fine adjustments or pushing/pulling objects nearby are difficult due to the size of the projection area. A stiffer material helps to increase positional accuracy and reduces the influence on other points. This has an impact on the collaborative use, as small interference between different locations of deformation allows more users to interact with the surface simultaneously and therefore more complex filters to be created.

Observations of test users show that one often demanded feature is the opportunity to preserve distinct states, e.g. save the current deformation to select additional items, or retrieve detail information of all currently selected items without losing the current configuration of tags or items. The core idea is quite obvious, but the consequences are extensive: As state of the physical surface cannot be reserved (or restored later), saving the virtual state breaks this strong connection between the physical display surface and the forces based on its deformation. The question arises whether such a system is still easy to understand, and how large the differences between physical state and virtual state can become, before the user cannot link visual representation and physical/haptic experience anymore.

In combination with demands to save internal states, users often also mention dedicated gestures to trigger complex actions, system command or execute special operations on the data set. The diversity of possible gestures on and with the surface (twisting, bending, flip, bi-manual gestures, speed and size of gesture) offers many options for gestures. Possible (simple) gestures include wipe- gestures to put items to the side or pinch-like gestures to zoom into the visualization. However, these gestures again represent another level of abstraction and have to be learned before being usable. Although gestures add expressiveness to the system, its increased complexity limits the intuitive, playful use of the system.

As mentioned in section 4, the problem of the “first encounter” remains unsolved. Providing affordances for touching and pushing the surface may require physical extensions of the screen. One idea could be magnetic handles (e.g. made of semi-transparent plastic) which are attached to the elastic surface.

A more technical issue is the correction of the image distortion resulting from deforming the screen. While this distortion is not really annoying the users interacting with the system, the discrepancy of visual representation and tracking position poses a severe problem, especially when interacting with items located near the border of the screen.

A final observation relates to the response time of the physical simulation. We decided to break the physical rules at certain points to ensure a fluent interaction. Once selected, Tags remain on their position until the user releases them. The same applies to the selection of content items: Is one of these selected the whole simulation is stopped. These two adjustments are needed to introduce a time delay when the system recognizes a deselection of an object. In order to simplify the recovering from tracking errors, forces on objects are reduced for a small amount of time, so that the user can easily reselect an object if he or the system loses track of an item.

8 Conclusion

In this paper we presented a system to explore faceted data like the *DelViz* data set. As an interaction device we use the elastic displays *DepthTouch* and *FlexiWall*. The advantages of these elastic displays are the haptic feedback and intuitive interaction techniques. Typical gestures like pushing and pulling the fabric are used to select tags and data items, which react corresponding to the underlying physical simulation. Items are attracted or repelled and thus allow a fast understanding of the data and its structure by recognition of movement patterns. The amount of force used on the elastic membrane directly translates to force in the simulation. The more pressure is applied; the stronger tags and items react to each other. Additionally the items present more information as force is used to zoom semantically into items. Further on we discuss the technical properties and problems of the system. It allows fast interaction and comprehension, but lacks the precise detection of movement and discrimination of proximal touches.

We will try to keep the interaction as simple as possible and mainly work on detection and aesthetical problems in the near future. We want to incorporate technical improvements for more precision and try advanced algorithms for better tracking. Afterwards we would like to conduct user studies to validate the exploration concept and especially the advantages and disadvantages of the system.

Acknowledgements.

On behalf of Mathias Müller this work has been funded by the German Federal Ministry of Education and Research (project no. 16SV7123).

References

Agarawala, Anand, and Balakrishnan, Ravin. *Keepin'it real: pushing the desktop metaphor with physics, piles and the pen. In Proc. CHI '06. ACM, New York, 2006: 1283 - 1292.*

Bang, Hyunwoo, and Heo, Yunsil. *Cloud Pink*. http://everyware.kr/home/cloud-pink/. 2011. Last accessed:31-01-2015.

Bang, Hyunwoo, and Heo, Yunsil. *"Soak, Dye in light."*. http://everyware.kr/home/soak/. 2011. Last accessed:31-01-2015.

Cassinelli, Alvaro, and Ishikawa, Masatoshi. *Khronos projector.* In SIGGRAPH 2005 Emerging technologies ACM, New York, 2005.

Franke, Ingmar S., and Müller, Mathias, and Gründer, Thomas, and Groh, Rainer. *FlexiWall: Interaction in-between 2D and 3D Interfaces. In Proc. HCII 2014, Springer, Berlin 2014: 415-420.*

Gründer, Thomas, and Kammer, Dietrich, and Brade, Marius, and Groh, Rainer. *Towards a Design Space for Elastic Displays. In CHI 2013 Workshop: Displays Take New Shape, ACM, New York, 2008.*

Jacob, Robert J.K., and Girouard, Audrey, and Hirshfield, Leanne M., Horn, Michael S., Shaer, Orit, and Solovey, Erin T., and Zigelbaum, Jamie. *Reality-based interaction: a framework for post-WIMP interfaces. In Proc. CHI '08. ACM, New York, USA, 2008: 201-210.*

Keck, Mandy, and Kammer, Dietrich, and Iwan, René, and Taranko, Severin and Groh, Rainer. *DelViz: Exploration of Tagged Information Visualizations.* Berlin, 2011: Informatik 2011 - Interaktion und Visualisierung im Daten-Web.

Lima, Manuel. *Visual Complexity. http://www.visualcomplexity.com/vc/. Last accessed: 31-01-2015.*

Peschke, Joshua, and Göbel, Fabian, and Gründer, Thomas, and Keck, Mandy, and Kammer, Dietrich, and Groh, Rainer. *DepthTouch: An Elastic Surface for Tangible Computing. In Proc. AVI 2012, ACM, New York, 2012: 770–771.*

Sherwood, Aaron, and Allison, Mike. *Firewall*. http://aaron-sherwood.com/works/firewall/. 2012. Last Access: 2014-12-24.

Sterling, Bruce. *Augmented Reality: Kreek Prototype 2.0, Kinect-controlled interface.* By Stephanie Paeper, Daniel Dormann, Lukas Höh and Mathias Demmer (klangfiguren.com). Wired Beyond the Beyond, 2012: http://www.wired.com/2012/05/augmented-reality-kreek-prototype-2-0-kinect-controlled-interface/. Last access: 2015-01-31.

Troiano, Giovanni. M., and Pedersen, Esben. W., and Hornbæk, Kasper. *User-defined gestures for elastic, deformable displays. In Proc. AVI 2014. ACM, New York, 2014: 1-8.*

Watanabe, Yoshihiro, and Cassinelli, Alvaro, and Komuro, Takashi, and Ishikawa, Masatoshi. *The deformable workspace: A membrane between real and virtual space. In* Proc TABLETOP 2008. *IEEE, New York, 2008: 145-152.*

Yun, Kyungwon, and Song, Junbong, and Youn, Keehong, and Cho, Sungmin, and Bang, Hyunwoo. *ElaScreen: exploring multi-dimensional data using elastic screen. In CHI'13 Extended Abstracts. ACM, New York, 2013: 1311-1316.*