TouchViz: (Multi)Touching Multivariate Data

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Abstract

In this paper we describe TouchViz, an information visualization system for tablets that encourages rich interaction, exploration, and play through references to physical models. TouchViz turns data into physical objects that experience forces and respond to the user. We describe the design of the system and conduct a user study to explore its use, finding that it supports many different models of data exploration and encourages users to have fun exploring data.

Author Keywords

Visualization; Multitouch; Information Visualization; Exploratory Interfaces; Exploration; Physics; Tangible

ACM Classification Keywords

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

General Terms

Human Factors; Design; Measurement; Performance

Introduction

Information literacy has become an increasingly important part of society. Decisions in almost any setting depend upon accurate interpretations of data. Whether a person might take action based on business data, understand scientific findings, or simply choose a healthy food, the types of data people confront every day are often heterogeneous, multivariate, and complex. This makes one's ability to interpret and understand data a crucial component of their success [9].

Along side this growth of information and the need for strong information literacy, information visualization technology has evolved. Systems such as D3, ManyEyes, and Tableau are regularly used (and abused) to convey and interpret information. These tools provide users the ability to explore data through traditional desktop metaphors. By incorporating techniques such as dynamic querying or brushing [3,8], systems enable rich interactions that aid users in their quest to understand data.

However, these techniques remain primarily within the realm of traditional, directed interactions on a desktop. While these systems can be used for data exploration, in the case of highly multivariate data, it is difficult to examine more than two dimensions of variables due to their structured approach. Tablets provide a different set of affordances compared to desktops, and might allow us to interact with data in new ways. We might use multitouch gestures and the physical "in your hands" nature of the device to create new, playful interaction techniques that help users to explore more dimensions and make deeper analyses. Further, discourse on ludic design suggests that the experiential nature of "learning by doing", or playing with systems with open experimentation can promote discovery, learning, and engagement [5,7].

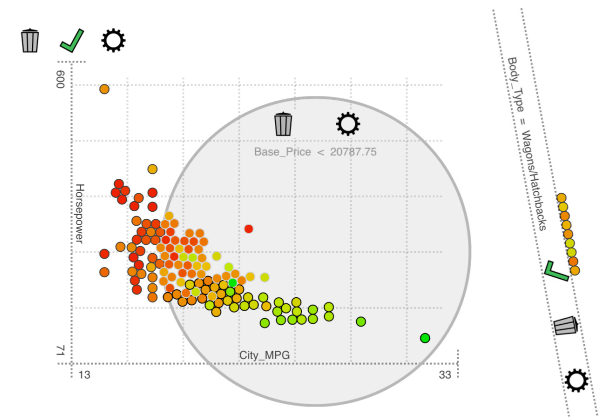

Figure 1: In this multivariate dataset each point is a car model. Points are first plotted by mileage and power. Wagons are separated with a wall. Finally, a lens filters by price.

In this paper we contribute TouchViz, a software system for visualizing multivariate data that harnesses the physical, embodied nature of tablet computers and physical models such as gravity and force to allow users to *explore* data rather than *see* data. Data are represented as actual physical objects that can be manipulated through user touches, tilts, and finger gestures. TouchViz provides an open sandbox for user interaction, supplying an array of force-based tools for structuring and manipulating data made physical. These tools promote curiosity, play, and exploration, leading users to trends and actionable findings encoded in data. By closely mimicking real-world force, gravity, and momentum, TouchViz allows users to explore many dimensions at once through multitouch interactions.

Related Work

TouchViz was inspired by the work of Yi et al. on Dust & Magnet, a system that used a magnet metaphor to visualize multivariate data [10]. Users could place magnets corresponding to different variables in the data, and as they wiggled the magnets, a cloud of datapoints would be attracted if they had high values in that dimension. We build on their idea of physically grounded data visualization and address new opportunities such as going beyond the desktop computer and mouse paradigm and moving beyond the limits of the magnet metaphor (such as the non-reversibility of interactions). As Klemmer, Hartmann, and Takayama suggest, the tangibility of an artifact, or how "natural" the mapping of action to physical reality can be highly influences the performance of a system. If people are "learning by doing" or playing, then the system should more closely model the physical [5]. Tablets offer a unique opportunity, as they are inside to the user's physical space. Tilt-able, tap-able objects make them open to more powerful interactions [7].

The way that people can organize their information and encode meaning also influences their performance. The open nature of Dust & Magnet allows users to place their own meanings in the way they move magnets and attract points. This "epistemic" interaction can improve user performance [5]. The desktop visualization system BumpTop demonstrates a similar sort of "epistemic" interaction, allowing users to toss and organize their files into meaningful piles and structures [1]. BumpTop's references to physical models make it easy to use and render its actions meaningful. However, as in Dust & Magnet, BumpTop is hampered by its dependence on desktop abstractions such as mice for interaction. The "epistemicity" of interfaces became a TouchViz design goal.

TouchViz builds upon a larger body of work that concerns visualizing multivariate data. One such early example uses fields of stars to visualize movies [2]. Dynamic queries allow users to sort through large groups of data by visualizing the results of their filtering while they filter [3,8]. Such a holistic view provides immediate feedback and helps users understand the consequences of their interactions. TouchViz enables similar functionality, but instead of dragging sliders to filter points, physical tools such as magnetic attraction, permeable walls, and overlapping lenses are used to drag, sift, and filter. Since points never disappear and their motion is always evident, the actions of filtering result provide immediate feedback through physical consequences. Another seminal example of multivariate visualization is parallel coordinates, which visualizes data on parallel axes to show multiple dimensions at once [4]. This type of visualization has been extended in Parallel Sets for categorical data [6]. TouchViz can use aggregated forces to approximate this technique. Since points can be pulled in multiple directions, different dimensions can pull a point in parallel, creating meaningful clusters of data. In summary, despite its different interaction methods, TouchViz can simulate existing multivariate visualization techniques, and goes beyond them.

Design and Implementation

The initial prototype for TouchViz operated using magnets as well as gravity by device tilt. Using an Apple iPad 2, we developed an application that loaded each point of data in a dataset into a sandbox as circles. Using the MIT licensed Chipmunk Physics

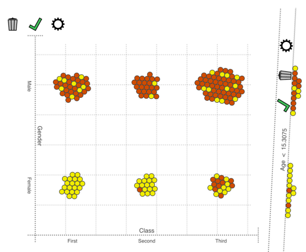

Figure 2: Identifying trends in a dataset of Titanic passengers. Here this user first charted passengers by their gender and cabin class. They changed the color of points to show survival. This demonstrated that more men (top) than women (bottom) died in the incident, and that there were more third class (rightmost groups) deaths. Finally, the user used a razor sieve to filter out passengers under 16. Since the points are still attracted to the chart, one can see that children were not excluded from the survival trend for adults.

engine, we made the points collide with each other and experience physically accurate gravity. We made a touch generate an attraction much like Dust & Magnet, pulling points that had high values in one dimension. We noticed that this prototype was already evocative as the points separated into meaningful clusters if we balanced gravity and attraction by tilting the tablet.

This led us to a process in which we loaded several datasets into the program and began to explore. When we felt a desire to interact with the points in a manner not yet supported, we developed a new tool that enabled that interaction. When a tool went unused or superseded, we removed it. If an interaction did not feel natural or fun, we iterated on it. Over many successive passes, we designed two types of tools in TouchViz: manipulative tools and interrogative tools. The manipulative tools exerted forces on points, changing their physical locations. The interrogative tools did not change the physics environment, but layered information on top of it. In concert these tools allow for the exploration of several dimensions at once.

When a user enters TouchViz, they select the data they want to explore, which can be loaded from a desktop computer or over the Internet. TouchViz then presents the user with a blank, white playing field that is immediately populated with small circles, each corresponding to one point of data (row in a spreadsheet). The user can choose tools and configure them using a palette (Figure 2) to interact with the data. All manipulative tools have on/off switches so that they can be temporarily disabled, as well as configuration panels. Any persistent tools (e.g., walls, lenses) placed on the screen can be deleted. A key point is that all tools in TouchViz are additive: they add forces to the underlying physics model, which integrates them to determine the resulting spatial locations and movements of the data points. This means that many tools can be combined in a consistent interaction model, and new tools can be easily added without requiring any changes to existing tools.

Our first three tools, gravity, attraction and color, represent interaction primitives. Users can tilt the pad to shift points. The attraction tool can be used for finding outliers in dimensions. The user simply puts their finger on the field and points begin to converge towards it. Points that are exceptionally high or low in values feel a stronger force, making them separate quickly. These points can then be isolated or interrogated. To better see these differences, users can use the colorize tool to change the colors of the points based on their values in one dimension. Numeric dimensions give points red-green heatmap colorations based on normalized value, while nominative dimensions give category colors. A legend is drawn to show value ranges and color mappings.

We adapted TouchViz's physics to support two traditional graphics tools: histograms and scatterplots. Users can use two fingers to place either a histogram or a scatterplot onto the field. These let users see data in a formal way as a part of their exploration process. This is instantiated by pulling points towards their respective location on the chart, meaning that multiple charts can be combined. The forces aggregate, so points are pulled towards the average of all of the forces combined. This lets users specify multiple balanced criteria or do a sort that takes into account multiple variables

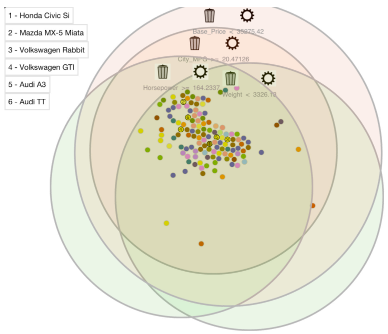

Figure 3: Using multiple lenses in a layer to find points that meet multiple criteria. The points that meet all of the filtering criteria are identified on the left and highlighted.

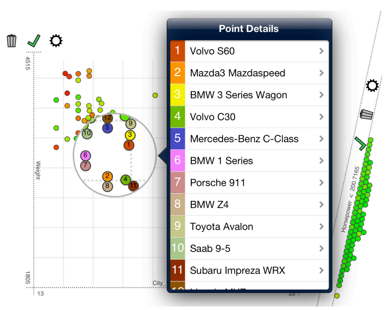

Figure 4: Exploring points in detail using a magnifying glass. In this case the user was trying to choose a car that fit several different criteria in a scenario.

Users may also want to filter points. We provide two means of filtering through manipulation. The first invokes the metaphor of drawing a razor blade across the screen. As the user puts two fingers down, a virtual razor blade is drawn between their fingers, and points encountering the razor get pushed as the user moves their fingers. The user can make the razor permeable, allowing points that match certain criteria to pass through. Tapping the razor turns it into a permanent wall that separates points (subject to the same permeability as specified for the razor).

Another way to filter points involves layering lenses. The user can place a colored lens on the field with certain criteria. Points that meet the lens' criteria are labeled and appear in a list. Points that do not meet the criteria are grayed out (Figure 4). Lens effects compound so they can be layered to make overlapping filters, for example to act as virtual Venn diagrams.

Users may also want to see details for several points or a single point. By double tapping, users can zoom in on a region and explore points in list form. We adopted a magnifying glass paradigm, as it is hard to tell from a finger press region which particular point the user found interesting. The magnifying glass keeps the general conformation of the points consistent, but clearly differentiates the details view from normal interaction. We number the points starting in the center in hopes that the center of the finger is close to what the user wanted to explore. By tapping on a point name in the menu a user can see the details of the point as well as its relative value compared to the other points.

User Study

To investigate whether TouchViz encouraged ludic behavior, and if people could use TouchViz to generate findings from a dataset, we conducted a user study. We recruited five participants of varying ages and experience levels with tablet computers. Because of the general lack of experience with tablets, we first gave them training for the software, spending roughly 3 minutes demonstrating each tool and one possible way of using it. We emphasized that the tools could be used in different ways beyond what we described. We then had the participants do a 10-minute opening task. Given a dataset of 200 random Titanic passengers, they had to identify as many patterns or trends in the data as they could. The dimensions included the class of the passengers, their age, their gender, and whether they survived. After this task, we gave them a dataset of car models. Given a set that had 4 different buying criteria across 4 dimensions for a pretend car buyer, we asked them to identify one or several good models in 15 minutes. Finally, we gave them a post-survey.

Our five participants all were able to identify at least one car and all found two or more trends in the Titanic dataset. Participants reported in 1-7 scale Likert survey questions that they would use TouchViz again (6.6) and found it fun (6.4), visually appealing (5.8), and generally easy to use after nominal training (5.63). One participant found the car task to be particularly engaging, exclaiming "Wow, 600hp. My god it's the Bat Mobile!?" when they found an outlier. Another mentioned that "…it illustrates the point," when doing the Titanic task, describing how they could estimate proportions just by glancing (as opposed to counting rows in Excel) (see Figure 2). One thought of their relatives' children, describing how they hated math and science, but that something "really cool" like TouchViz may enthuse them. Interestingly, the strategies iPad users and newcomers employed differed. The newcomers, still getting used to the iPad interface conventions, often repeatedly applied the same tool. They relied on many copies of a lens or many point details views rather than the mix of plots, walls, lenses, and attracting that more experienced iPad users employed. While they arrived at similar findings, their data organizations differed substantially (compare Figure 3 to Figure 4). After completing the tasks, users reported feeling a greater understanding of the dataset.

Conclusion

TouchViz represents a first step towards exploratory interactive tablet data visualization. By allowing users to explore and play in an open environment, TouchViz encourages ludic behaviors that reinforce learning and performance. However, this goal enforces some concrete limitations. TouchViz does not currently function for larger datasets as the field can become too crowded. Currently the program is limited to 200 datapoints, but features such as actual filtering could help reduce this overflow. Tools that allow users to combine points into semantic groups may also prove helpful. The tools are generalized to work across most kinds of data, but may be ill suited for certain domains or tasks. If a user has a concrete goal in mind, desktop visualization tools may be more effective.

TouchViz provides a new paradigm for data visualization supporting user understanding through physically grounded exploration. This paradigm could inform the development of new information interaction methods on larger surfaces and 3D environments. We hope that the approach we have described is a useful framework for future interactive data visualization research in multitouch and beyond.

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