Studying Direct-Touch Interaction for 2D Flow Visualization

Tobias Isenberg, Uta Hinrichs, and Sheelagh Carpendale

Abstract—Traditionally, scientific visualization research concentrates on the development and improvement of interactive techniques to support expert data analysis. While many scientific visualization tools have been developed for desktop environments and individual use, scenarios that go beyond mouse and keyboard interaction have received considerably less attention. We present a study that investigates how large-display direct-touch interaction affects data exploration and insight generation among groups of non-experts exploring 2D vector data. In this study, pairs of participants used interaction techniques to customize and explore 2D vector visualizations and collaboratively discussed the process to develop their own understanding of the data sets.

Index Terms—Interactive scientific visualization, direct-touch interaction, wall displays, qualitative evaluations, 2D vector visualization.

1 Introduction

Research in scientific visualization has made enormous progress in recent years, allowing us to get a better understanding of complex datasets. With the exception of co-located VR applications and a number of distributed visualization environments (including VR ones), however, most research in scientific visualization has focused on developing and improving techniques that are aimed toward individual data exploration and analysis by expert users. Moreover, such analysis and exploration typically occurs in desktop environments using keyboard-and-mouse interaction. However, the advance of large, touch-sensitive display hardware has enabled us to explore other forms of interaction techniques within scientific visualization environments.

Most notably is direct-touch interaction on large displays which potentially has a number of advantages for scientific visualization. Large displays offer more space for high-resolution data and support co-located collaborative data analysis, adding the possibility to actively present, discuss, and explore hypotheses or findings about data in-place. Direct touch also enables direct interaction with visual elements as well as gestures or hand postures as alternatives to mouse-based interfaces. Such alternative interaction techniques may be more suitable in collaborative analysis tasks since direct-touch provides rich awareness cues. These cues are important during collaborative analysis and seamlessly integrate with group discussion. It has been found, e. g., that 'hands-on' interaction can enhance engagement and understanding, especially within learning environments [1], showing promise for scientific visualizations targeted toward non-expert audiences as well.

The idea of analyzing scientific visualizations on large displays using direct-touch interaction raises several research questions. For instance, how do scientific visualization techniques need to be designed to support large-display direct-touch interaction? And how does the use of large display hardware and direct-touch interaction influence the way how people approach the analysis of scientific datasets?

We present a qualitative study that explores the potential of an interactive 2D vector analysis visualization tool [8] as used by groups of non-experts. The study was conducted on a direct-touch enabled large-display. We asked non-expert pairs to analyze two different 2D vector field datasets. The results of this study further our understanding of how people made use of this interactive visualization tool and of the methods they used to explore the data individually and collaboratively.

We found that the ability to directly experiment with the data visualizations of previously unknown datasets helped participants to develop an understanding of the data's behavior and to detect local phenomena and causalities. All participant groups engaged in lively discussions and made varied use of the customization and interactivity offered in the tool. We observed frequent turn-taking, communicated through movement in front of the display and gesturing. Customizable glyphs, animation, and direct manipulation of visualization elements were used extensively to create personalized visualizations and supported various data analysis strategies including local and global data exploration. Participants did not follow a linear sequence of analysis strategies but fluidly went back and forth between different exploration activities. This lack of temporal sequencing in tasks parallels observations in a previous study on co-located collaborative work [7].

• *Tobias Isenberg is with the University of Groningen, E-mail: isenberg@cs.rug.nl. Uta Hinrichs and Sheelagh Carpendale are with the University of Calgary, E-mail: {uhinrich|sheelagh}@ucalgary.ca.*

2 Related Work

Most systems for scientific visualization are developed for single-user desktop systems, thus interaction with the data typically occurs using keyboard or mouse. With the advent of large, high-resolution displays some time ago, more specific virtual analysis environments such as the CAVE or the Responsive Workbench were developed that required new interaction metaphors for work with visualizations. The interaction design of these environments aimed at creating a natural mapping of physical input, for example from tracked gloves or wands, to convey a feeling of embodiment in the virtual world.

The progression of large touch-interactive screen technology offers new interactive environments for scientific data analysis that do not require people to wear special equipment such as glasses or gloves to perform interactions. Such direct interaction techniques can be more accessible because of their resemblance with real-world interaction, and lend themselves more easily to collaboration [15]. However, with large display direct-touch interaction, we face a number of challenges: we need to design adequate mappings between input and interaction to support scientific data exploration and learn how people can adapt to these mappings on large display surfaces in general. Some research has been done in this direction. For example, Forlines and Shen [4] visualize geospatial data and explore multi-user zoom-in-context interaction. They map the user input to data manipulations by providing dedicated elements, DTLenses, that represent the data manipulations. Our study is based on [8] where similar exploration objects and hand postures are used to visualize 2D vector field data. We build upon this work, looking specifically how groups of people make use of these features during their data exploration process.

The type of data used in our study, vector or flow data, is relevant to many application domains such as physics or meteorology. Several visualization techniques have been developed to help analyze 2D and 3D vector data. These techniques include direct visualization using, for instance, glyphs, texture-based approaches, geometric techniques, and feature extraction [10]. Even though many recent approaches address more complex issues in three-dimensional vector visualization, two-dimensional techniques still play an important role. This is particularly true for datasets that are presented to a non-expert audience, for example, in weather reports and forecasts or in educational environments such as geography classes. Closely related to the visualization techniques employed in our study are methods that allow interactive exploration of vector data such as selecting a specific view of the data or changing global attributes. Some techniques go beyond such straightforward interaction and explore interactive probing and annotation of

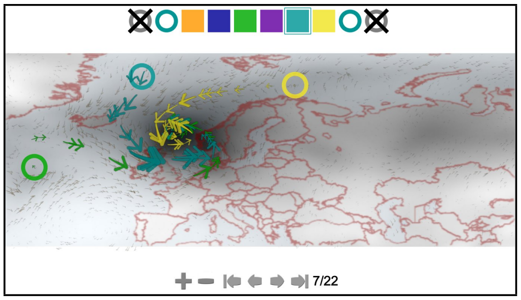

Fig. 1. Screenshot of the adapted interface for collaborative interactive 2D vector data exploration and visualization, with example visualization.

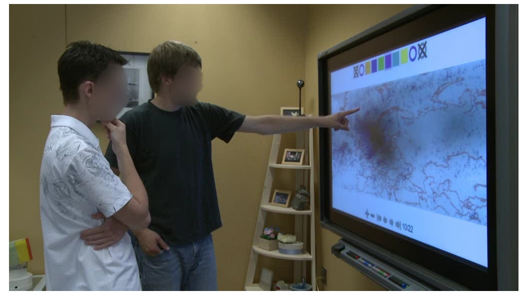

Fig. 2. Participants in front of the touch-sensitive wall display, collaboratively working with our data exploration and visualization tool.

flow fields with glyphs to show local properties [3] or use customized glyphs [9, 13, 17]. Also, techniques have been developed for interactive particle sources placement [11, 18]. The techniques we use in our study are related to these approaches in that all are based on visualization of 2D vector fields using particle sources while the tool used in our study [8] provides ways for direct-touch interaction with static and animated, customized glyphs as outlined in the next section.

3 Hand-Posture-based 2D Vector Visualization

Combining traditional 2D vector visualization techniques with direct touch display technology, Isenberg et al. [8] have previously developed a vector visualization technique that allows people to explore 2D vector data using several hand postures on a large interactive wall display. This approach is unique in three ways. First, it allows people to draw their own glyphs to represent the vector data. Second, the tool enables global exploration of data behavior by filling larger areas of the data display with glyphs. Alternatively, data can be explored locally by using ‘glyph sources’ that constantly emit animated glyphs. Third, the interface of the visualization tool is also based on hand postures. These postures rather than typical buttons and sliders are mapped to adding or removing glyphs to and from the data display.

These interactive visualization techniques can be used as follows. After a 2D vector dataset (e. g., wind data) is loaded, people can bring up a drawing canvas where they create (draw) the desired glyph to represent the data (e. g., an arrow or a straight line) using different hand postures to determine the stroke width. When the drawing canvas is closed, glyph instances can be added to the data display with the loaded 2D vector data using different hand postures (fist for adding several glyphs or finger for adding individual glyphs). The orientation and size of the glyphs reveal the character of the loaded data, namely the local direction and strength of the vector field. To explore the flow behavior of the data, glyph sources can be added to the data display. These sources can be moved around within the data display to explore different areas. Different shapes, line widths, and colors of glyphs can be used simultaneously to highlight certain aspects of the dataset.

For the study we added a number of features to the interactive visualization to account for the study tasks as well as to address some usability issues uncovered during pilot studies. Those features included controls to add or removes globally from the data display, and cycling through the different time steps of the data set (Fig. 1).

4 Exploratory Study

The goal of our study was to better understand how pairs of people work with customizable vector visualization on a large touch-interactive display. Specifically, we investigated the potential of hand-posture-driven interaction with vector data to ease the process of exploring and visualizing such datasets and how people approach 2D vector data analysis tasks using our visualization tool on a large wall display. Quantitative study methods that rely on controlled study scenarios and the collection and analysis of numerical data are less adequate for answering open-ended questions like these. We therefore conducted an exploratory laboratory study where pairs of participants were asked to complete a series of experimental tasks. The study was based on a mixed methods approach which allowed us to combine qualitative with quantitative data collection and analysis to shed light into people’s analysis processes while using our visualization tool.

Participants and Setting. Sixteen university students (seven females, nine males) participated in our study. They were asked to work together in groups of two as a strategy to increase verbal explanations and ‘thinking aloud,’ resulting from discussions with the partner. This helped us to gain insights into participants’ thought processes during the data analysis. Groups performed the study tasks on a 5’ $\times$ 3’ plasma wall display (1360 $\times$ 768 pixels) with direct-touch interaction enabled using a SMART DViT overlay. The experimental software ran on an Intel 2.4 GHz Windows XP PC. The display was large enough to comfortably accommodate both participants standing next to each other (Fig. 2). While participants had to interact with the display standing, they were able to sit down on a couch located in front of the display. Participants were free to move around the display while solving the experimental tasks. Due to technical reasons our visualization tool is a single-touch interface which forced participants to take turns with display interaction. While this condition led to some interferences between group members during the visualization analysis, it did not hamper collaboration as we will describe in the findings.

Experimental Data, Tasks, and Procedure. Participants were asked to use our visualization tool to analyze two different real-world 2D vector datasets: wind data from a storm that hit Europe in the spring of 2008 (22 time steps, enhanced with a map of Europe showing high and low air pressure zones in form of a gray-scale color scheme; Fig. 1), and a moving fluid simulation where an obstacle causes turbulences (22 time steps, enhanced with a line integral convolution visualization [2] of the vector data, showing flow direction; Fig. 3, left).

Participant groups were asked to work on five tasks in total—four tasks based on the wind dataset and one task involving the fluid dataset. After a short introduction to the tool and a practice task, each study task involved answering one or two open ended questions concerning relations within the data (e. g., relation of low/high air pressure and wind speed) as well as the assignment to illustrate certain particularities within the data using the visualization tool. The assignment for the second dataset (moving fluid) was a free-form exploration of data followed by a presentation of the general behavior of the data. Groups were given 10–15 minutes to solve each of these experimental tasks. A semi-structured interview concluded the study where we elicited subjective perceptions from participants regarding their general experiences with the visualization tool. We also followed up on certain analysis strategies we had observed which participants used to gain insights into how they approached the experimental tasks. Each study session took approximately 1.5 hours in total.

The purpose of this setup was to observe how the participant groups would approach the tasks in general, using the visualization tool. We were, in particular, interested in the different strategies that groups would apply to solve the tasks. We used the answers that groups provided for each question/task as an indicator how well they understood the dataset after this short time of exploration. Furthermore, we closely observed groups conducting the experimental tasks to be able to evaluate the interaction techniques the visualization tool provides.

Data Collection and Analysis. Two examiners oversaw each study session to minimize bias, with one of them being external to the project team. Each study session was videotaped and screen captures were taken every 10 seconds. Both experimenters took notes of their observations, highlighting particular events and participants' comments. These field notes informed the semi-structured interview to ask participants about their strategies or events that happened while participants were solving the tasks. To answer our research questions, the video data was analyzed in-depth regarding exploration strategies that participants applied for the experimental tasks and the use of particular features of the visualization tool, e. g., animations and customized glyphs. We also analyzed how participants interacted with and in front of the large touch-interactive display, individually and with the partner.

5 Findings

Our findings focus on the strategies that groups applied for exploring the provided datasets using large-display direct-touch interaction. We first provide a brief overview of how groups generally approached their analysis tasks before addressing the influence of the physical display characteristics on exploratory data analysis and collaboration.

5.1 Exploration Approaches

In general, all participant groups took a similar approach for exploring and visualizing the data which can be categorized into four activities: drawing, overview, local exploration, and temporal exploration:

Drawing. Our tasks and visual tool required groups to first draw a glyph in order to explore the data, hence this was the activity participants started with. Participants frequently experimented with different glyph shapes and hand postures when drawing glyphs, creating on average 2.75 ($\sigma = 1.581$) different glyphs for the illustration task and 1.594 ($\sigma = 0.946$) for all other tasks.

Overview. After a representative glyph was drawn, participants of all groups first tried to gain an overview of the dataset. To achieve this they equally distributed the drawn glyph on the display, generally using the '+' button (in 97.5% of all tasks) and, in addition to this, occasionally the fist posture (in 35.0% of all tasks) to adjust glyph density in some areas of the data display.

Local Exploration. All groups explored local features of the dataset, in particular by placing sources in various locations (in 82.5% of all tasks). Sources were dynamically moved to probe and explore local aspects of data. Occasionally, groups used the one finger posture for fine-grained continuous local exploration (in 22.5% of all tasks).

Temporal Exploration. Since our study tasks required exploration of temporal changes, all groups made heavy use of the time controls, frequently stepping back and forth in time. This temporal exploration sometimes required rearrangement of sources or adding glyphs.

These activities did not follow a linear sequence, paralleling previous work [7]. While participants would typically start by drawing a glyph and distributing it evenly across the data display for overview, local and temporal exploration happened without a visible sequence, with participants often switching back and forth between both activities. Also, participants sometimes decided in the middle of a task to go back to the drawing stage and to bring in a new glyph shape.

We also noticed that no group went through a pre-discussion on how to solve the task in general, what steps to take, or what an answer should look like, before actually approaching the task. Instead, discussion occurred in parallel to the data exploration and visualization activities and evolved naturally from the task. Participants would either just start an activity and discuss observations in the data display during or after the action took place. They sometimes had just a brief exchange about next exploration steps, for instance, when they wanted to draw a new glyph or move on to the next time step.

5.2 The Role of Large Display Direct-Touch Interaction

We observed close collaboration among participants of all groups and noticed a high engagement of participants (for all groups and tasks), visible in active discussions of ideas or hypotheses and lively interaction with the data display. This is apparent in the extent to which they discussed ideas concerning the glyph drawing, exploration strategies, and hypotheses about the data. In two groups, one participant was more dominant and took the lead in activities such as glyph drawing. In the remaining six groups, participants actively took turns with glyph drawing and data exploration. Typically, during non-active moments, a partner would participate in activities by providing verbal feedback to actions carried out by the other participant. Constraining participants to single-person interaction sometimes led to interferences with both participants trying to interact with the display at the same time and the system ignoring the second input. However, conflicts like this were usually resolved quickly and did not limit collaboration among group participants. In fact, we observed frequent turn taking among all groups and study tasks. A participant of a group would step back from the display, handing over the exploration to the partner. Meanwhile, he or she would actively follow the interactions of the partner and observe changes on the display, always prepared to jump in and take over if some new idea occurred (e. g., Fig. 3, left).

This contrasts previous studies involving collaborative tasks on large vertical displays where groups were found to usually elect a person 'in charge' of the interaction while other group members would stay rather passive [14]. We attribute this high engagement of both group participants to their similar level of expertise with the datasets, the exploration techniques we provided, and the physical study setting. The datasets were relatively unknown to participants, thus close collaboration and discussion was important for coming up with hypotheses and causalities. This was facilitated by the large display and rather broad interaction techniques, easily visible to both participants. The visualization tool did not force participants to linearly follow a predetermined sequence of exploration activities, but allowed participants to explore based on their interest. Consequently, participants repeatedly and without any effort switched between different exploration strategies discussed above, including the observation of the data visualization. Thoughts, ideas, and hypotheses were collaboratively discussed and explored, through interaction and discussion, ultimately leading to a basic understanding of the data, evident in the answers that participants provided for our experimental questions.

Fluid collaboration and maintaining awareness of the partner's exploration activities require the support of deictic communication means, such as gestures and body movement (e. g., [6, 16]). We found that the large display and the direct-touch interaction supported these communication mechanisms well, allowing participants to frequently switch back and forth between data exploration and gestures without having to worry about external input devices. All groups frequently used hand gestures, such as pointing with a finger, a hand, or both hands, to communicate and exemplify certain insights (e. g., Fig. 3). Participants expressed ideas and thought processes to their partner via gestures, directly speaking to each other, and accompanying an action with speech. Turn-taking often happened non-verbally, communicated by stepping toward the display or reaching out for it.

6 Discussion

Reflecting critically on our findings and interpreting the results, we consider our study to be a step toward understanding the use of direct-touch interfaces for data exploration and visualization and discuss in the following new research questions that arise from our findings.

We found that the **possibility to manipulate elements through direct touch** enabled participants to quickly test different hypotheses. Most interaction techniques had a direct local impact on the visualization elements. Moving the finger while touching a source, for example, would move the source to a different location or running the fist across the display would locally add glyphs. Participants had no problems understanding this direct mapping, evident in their fluid interaction with the visualization tool. Another advantage of direct touch in our large-display setting is that it enabled the temporarily non-active participant to visually track the activities carried out by their partner, contributing to the awareness during collaboration. When supporting direct-touch manipulations of elements, however, it is important to map interaction techniques in a consistent way. While our tool allowed to directly move sources within the data display, this was not possible for already created glyphs. This caused some confusion among participants who tried to move glyphs via direct-touch interaction.

With the exception of drawing a glyph as a first step which was required by the program, participants did not explore data following a

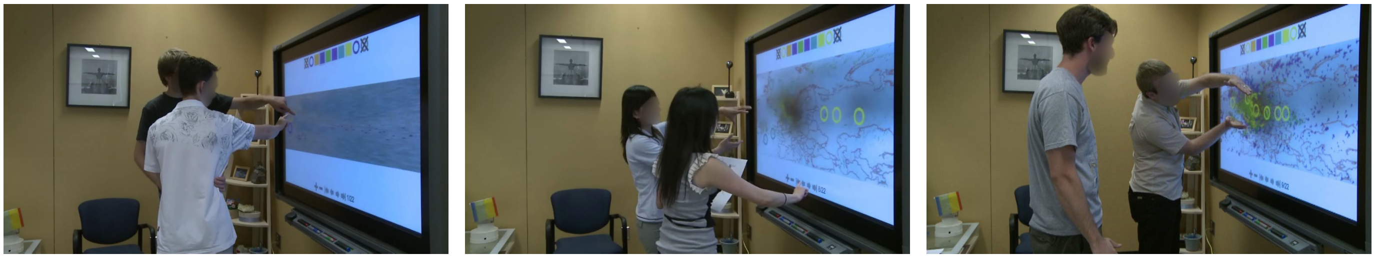

Fig. 3. Participants using various gestures to explain ideas or thoughts to each other, and/or to reference locations on the data display.

particular sequence of activities. Exploration strategies such as gaining an overview of the data, examine local regions or probing, creating additional glyph shapes, or exploring data along temporal dimensions were applied in various sequences. The tool did not enforce a certain sequential order in which exploration activities had to be applied (except for the initial drawing), but participants decided when to apply them. We believe that the support of this kind of **free-form data exploration** is important to enable interest-based exploratory data analysis. That is, visualization tools should provide certain basic functionalities that can be used by people as needed and which even can be 'appropriated.' Appropriation happened with our visualization tool, for instance, when some groups 'invented' continuous probing. While both the sources and the single-finger-posture were initially intended for other activities, participants appropriated them for their own purposes. While future work needs to explore how scientific visualization tools can support free-form data exploration in general, we hypothesize that it is, in particular, facilitated through large-display direct-touch interaction because this form of interaction is evocative of how people 'handle' and appropriate basic tools in real life.

It has been shown that collaborative data exploration can lead to better results and insights than analysis by individuals [12]. In our study, participants collaboratively discussed ideas and hypotheses while exploring the data at the same time and adjusting their analysis based on this discussion. We believe that this combination of discussion and exploration activities positively affected participant's understanding of the data and was enabled by the interactive large display technology we employed. However, further studies are needed to confirm this. The use of **large displays to support co-located collaboration for scientific visualization**, thus, needs to be explored further—in scientific, educational, and other domains. While our study setup did not support simultaneous multi-touch interaction, it would also be interesting to investigate exploration techniques that make use of this technology and its impact on collaboration strategies during scientific data analysis.

7 Conclusion and Future Directions

We discussed aspects of a study that investigated how pairs of people explore customizable vector visualizations on a large, touch-sensitive screen. Several factors in this visualization lead our participants to in-depth and insightful explorations of the data. This is a promising result since our participants were not experts in scientific visualization. Overall, we observed a high degree of engagement that was evident in the frequent turn-taking and exchange of ideas by participants. We attribute this high engagement of our non-expert participants and the quick understanding they were able to gain about the unknown datasets in part the direct-touch interface, as well as the possibilities to customize and personalize the data display. We believe that tools such as this one could be particularly useful in classroom settings, enhancing traditional teaching methods with 'hands-on' learning. Students exploring data using the tool would, similar to our participants, directly experience certain correlations such as the specific rotation directions of low and high pressure zones, which could foster learning.

The findings from our study point toward numerous interesting future research directions in the application of interactive and animated visualizations. In particular, the potential of large-display direct-touch interaction should be explored further with regard to different scientific datasets including three-dimensional ones. 3D direct-touch techniques using multi-handed interaction have been developed for large horizontal direct-touch displays [5, 19] and could be applied to various scientific visualization techniques, such as volume renderings or three-dimensional vector datasets. In addition, our study suggested the benefit of co-located collaboration for scientific data analysis. While most visualization and interaction techniques for scientific visualization concentrate on individual analysis scenarios or distributed collaboration, future research could consider co-located collaborative settings with several people discussing and interacting with scientific data together.

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