Position Paper: Touch Interaction in Scientific Visualization

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ABSTRACT

Direct-touch interaction is receiving an increasing amount of attention in the HCI domain and has recently been applied to some problems in information visualization. However, the field of scientific visualization has not seen much work on how direct-touch interaction could benefit the interactive visualization process. One reason may be that scientific visualization typically deals with datasets that are defined in 3D space, while touch input is two-dimensional. Therefore, to control scientific datasets in interactive visualizations one has to define intuitive mappings from 2D input to 3D manipulations for a variety of data types and exploration techniques. In this position paper we discuss some of the challenges of using direct-touch interaction in the field of scientific visualization that arise from the specific constraints of scientific visualization and argue for the development of integrated techniques to overcome these problems.

Keywords: Direct-touch interaction, scientific visualization.

INTRODUCTION

Scientific visualization is the science of creating graphical representations of scientific data that is the basis of research in virtually all domains of science. Scientific visualization (as opposed to information visualization) deals predominantly with data that is spatially explicit in 3D, i. e., for each data point a precise 3D location is known. Such data includes CT/MRI scans in medicine; particle simulations in physics, astronomy, or swarm behavior; molecular models in genetics, biology, chemistry, or material sciences, or shapes of functions or sets in mathematics, to name but a few examples.

It is a recognized fact that a good visualization needs to support user activities beyond viewing the data [35]. Scientists need to be able to drill down and find details about what seems important, relate information on many levels of granularity, and gain an encompassing picture about relationships and correlations present in their data to form hypotheses and plan next step actions. To support interactivity in scientific visualization two main aspects require dedicated research attention: (a) ***interaction models for control and exploration*** of the visualization to support problem solving and (b) ***interactive rendering speeds*** to achieve real-time refresh rates for minimal disruption of higher-level tasks. Many new techniques have been and are being developed based on GPU processing which address the second challenge successfully. The challenge of providing novel solutions for interactive exploration, navigation, and problem solving with three-dimensional scientific visualizations [21] is one that has received less attention in the field of scientific visualization to date. We therefore argue in this paper that we need to embrace emerging interactive display technology and investigate its use for creating engaging and intuitive interactive next-generation scientific visualization work environments.

DIRECT-TOUCH INTERACTION

In particular, touch-sensitive displays have numerous important but unexplored benefits for scientific visualization: they provide *enough area and resolution* to explore visualizations, they facilitate *awareness* in *collaborative settings* [17], and they offer *natural direct-touch interaction* which provides *somesthetic information and feedback* beneficial for effective interaction both in real and virtual environments [28], and the direct-manipulation metaphor of touch interaction allows people feel *in control of their data* [19] and has shown to *outperform mouse input* for specific tasks [22]. Despite these advantages, however, to date there is little support for interactive scientific visualization on these large displays. While touch interaction has previously been explored in a general visualization context (e. g., [9, 10, 18, 26]) much remains to be learned about ***employing direct-touch input specifically for three-dimensional scientific visualization***.

CONSTRAINTS OF SCIENTIFIC VISUALIZATION

Traditionally, PC-based environments or dedicated hardware setups [2] such as virtual reality environments (e. g., the Responsive Workbench [23] or the CAVE [3]) have often been employed for scientific visualization. While such settings have numerous advantages for creating and viewing visualizations, both have disadvantages for the interaction with 3D data. In PC settings, for instance, one typically interacts indirectly though a mouse. In VR environments one can interact directly by means of tracked objects in physical space (e. g., wands) but this type of control often leaves viewers with the feeling of interaction in "empty space" without adequate haptic feedback or rest positions. Touch interaction, in contrast, provides direct control (in 2D) with somesthetic feedback [28] which can alleviate this problem by allowing users to feel "in control of the data." Unlike manipulating 2D data, however, touch interaction with 3D data or within 3D environments is a challenging task [30] because it requires an under-constrained mapping from 2D input parameters (touch) to transformations in 3D space (mouse-based interaction faces the same problem). To address this issue of 2D-to-3D mapping, several interaction techniques have been described in the past [5, 6, 7, 8, 11, 13, 14, 15, 20, 24, 25, 27, 36, 37, 38] and from which we can take inspiration. Yet, scientific visualization has a number of unique characteristics which make dedicated research necessary.

Only few of the previously named approaches [5, 11, 38] deal with the specific ***needs and requirements of scientific visualization***: First, scientific visualization has broad applicability and developed techniques cannot be specific to one type of digital object or a specific geometric projection. Virtually all of the above referenced methods address the 3D touch interaction problem only for a specific type of object (e. g., medium sized closed shape, planar representation, or particle cloud) in a specific environment (e. g., top-down projected space with ground plane or object(s) freely floating in space). Our goal is to develop and encompassing interaction landscape for scientific visualization which supports multiple different interaction methodologies in an environment that can change depending on the type of data being visualized. For example, when interacting with a volumetric dataset it is often necessary to independently control one or more cutting planes (i. e., planar objects) that are used to reveal the inside of the dataset together with an interaction of particle layer data (i. e., many points too small to use their surface to constrain an interaction). Secondly, for scientific visualization it is essential that interaction can be controlled precisely in 3D for space-accurate exploration. Many existing techniques lack the necessary precise control (e. g., [37]) for scientific exploration and even the ones with good control are still subject to the inherent imprecision of direct-touch input. Lastly, scientific visualization interaction includes many dedicated actions beyond general 3D navigation and object manipulation. These additional interactions are essential to scientific data exploration and include selection, object and parameter manipulation, interaction with the time axis, etc.

FUTURE RESEARCH DIRECTIONS

As a consequence of these unique constraints, we suggest a number of research directions for facilitating the exploratory interaction with three-dimensional scientific datasets using touch-sensitive displays.

Integrated Direct-Touch Interaction Toolkit

First, we plan to develop a toolkit for three-dimensiona direct-touch interaction with scientific data. This toolkit needs to comprise a set of integrated techniques and methods to support two main visualization feedback loops: the *data manipulation loop* and the *exploration and navigation loop* [35]. The toolkit's purpose, therefore, is to make the 3D interaction techniques readily accessible for a variety of scientific visualization applications and also to outside researchers. The *data manipulation loop* for visualization application includes basic data interactions such as selection and positioning of objects in space. While these are basic operations, they are fundamental to many follow-up interactions in the navigation and exploration loop. For example, data representations need to be found, selected, and possibly positioned before they can be effectively compared or correlated. Interactions for the *navigation and exploration loop* are complex as they need to encompass theories of pathfinding, map use, spatial metaphors, awareness, and feedback [35].

The development of techniques dedicated to scientific visualization for both loops needs to start by developing data manipulation methods for general view changes (i. e., camera or projection manipulations) not only for the visualized data but also for dedicated data exploration elements such as cutting planes or drilling tools. Therefore, it is necessary to support a catalog of interaction needs for scientific visualization—abstracted across datasets and tasks. For this purpose it will be necessary to analyze several existing scientific visualization tools from various application domains and data types (e. g., brain visualization, astronomic particle visualization, fluid flow simulation) and identify their most fundamental and common interaction requirements. The resulting toolkit may not need to completely re-invent new 3D interaction techniques but may incorporate some of the previously developed approaches for direct-touch interaction with 3D objects [5, 6, 7, 8, 11, 13, 14, 15, 20, 24, 25, 27, 36, 37, 38]. However, care must be taken to make the different modes of manipulation compatible with each other.

In a second stage, it will be necessary to integrate methods for the exploration and navigation loop. For this purpose one first needs to add selection strategies that are compatible with the view selection techniques. The selection techniques also need to go beyond the common tap-to-select because scientific datasets can comprise a variety of different data types (e. g., volumetric data, particle data, line data, or surface data). Based on the ability to select data and/or subspaces, mechanisms for the manipulation of selected objects (relocate, reorient, or resize), for specification of parameters (e. g., transfer function manipulation, placing seed particles, etc.), for interaction with the scale of the displayed dataset (potentially across several magnitudes of scale), and many others need to be integrated. Moreover, domain-specific interaction-techniques need to be supported, e. g., specific ones for geological data [31, 32]. Similar to the constraint for the selection techniques, also the data manipulation techniques need to be compatible with the remaining techniques of the toolkit. One of the major challenges, therefore, will be to provide the set of interaction techniques in an integrated manner such that they do not negatively affect each other.

Precise Control Issues

An important additional challenge that arises when employing direct-touch interaction is that touch input is inherently imprecise due to the size of our fingers as interaction tools—while scientific visualization often comes with a requirement of precise location and control of 3D data. Here, two aspects of precise control play an important role. The first aspect is the translation of imprecise touch input into control of similar precision as the mouse. Here, we can learn from HCI research which in the past has developed several strategies to provide such precision (e. g., [1]). The second aspect of precise control arises from scientific visualization's need to single out specific parameters and to control them without affecting others. This aspect implies that, in addition to fully integrated interactions, we need to also support partial interactions. For example, instead of only the known pinching interaction (RST, [16, 27]), scientific visualization needs support for navigation along or rotation around a single axis. Therefore, an Interaction Toolkit needs to support techniques that allow users to single-out certain parameters.

Stereoscopic Displays

Additional challenges arise when one wants to retain the benefits of direct-touch control but, at the same time, wants to take advantage of the improved depth perception provided by traditional dedicated visualization environments with stereoscopic displays. Research has shown that touch interaction with stereoscopic displays is challenging because it is strongly affected by parallax between the images displayed for both eyes [33]. Only when a virtual object is within a small distance from the screen can people perceive their touches as affecting the virtual objects [34]. Moreover, when viewing an object displayed as reaching out of a display people often attempt to touch "in thin air." In contrast—if an object is displayed "below the surface"—people may not even perceive the display surface as being present and hit the (to them invisible) display in an attempt to touch the object behind it. While solutions such as transparent props [29], separating the touch surface from the stereoscopic display [12], or tilted setups in connection with shallow-depth data [4] can be be used to alleviate this problem somewhat, these solutions lack support for dynamic visualization elements or the diverse character of scientific data in general.

Large Displays and Multi-User Settings

The large size of traditional visualization displays prompts the question of multi-user visualization settings, in particular if interaction techniques based on multi-touch input are used. Not only do certain 3D touch interaction techniques not scale well to large settings (e. g., [38]) or are not compatible with vertical display setups (e. g., [37]), the possibility for several people using the same visualization environment simultaneously raises additional questions. For example, one could envision interactive discussions between colleagues, the use of touch-controlled visualization in group discussion, and the interactive touch-based presentation of visualizations to a larger audience. Yet, it is not simple to extend single-user interaction techniques to multi-user ones. For example, a single-user 3D exploration method being applied on a large wall display may not be suitable for a presentation setting since the interacting person is largely occluding the interaction and visualization space. In such situations it may be necessary to separate the interaction from the visualization space and to employ dedicated awareness techniques. An additional important challenge is that current multi-touch display technology does not support tracking of user identity. Without user identity one has to develop heuristics to determine which user issued a certain interface command and react to synchronous input accordingly. Multiple concurrent changes to an object require addressing computational challenges and, more importantly, how conflicts are handled.

CONCLUSION

We believe that—despite the discussed issues/challenges—touch interaction can have a tremendous impact on how visualization is being used by domain scientists (and beyond). Direct-touch interaction has the potential to facilitate the use of scientific visualization on a much larger variety of display and user settings, instead of being restricted to largely single-user, mouse/keyboard-based interaction in PC environments or specialized 3D visualization hardware. Thus, instead of only being the end product of a scientific exploration process, intuitive touch-based interactive visualization technology can be tightly integrated into the scientific exploration process, and could actively be used for gaining an understanding of the analyzed data. This means that scientists may be able to use 3D interaction techniques to not only discuss ideas but instead to collaboratively create and manipulate visuals that illustrate their data, resulting in fundamental insights and an easy way to communicate these to others.

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