Towards Utilizing Novel Interactive Displays for Information Visualization

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ABSTRACT
Visualization research has yielded a number of useful techniques to generate visual representations and to allow users to explore data interactively on computer screens. Yet, the constantly growing complexity of today's data calls for new ways of visual and interactive data analysis. This is where new display and interaction technologies offer promising possibilities yet to be explored. In this work, we identify three gaps to be addressed by future research. (1) The *technology gap* is about the lack of a systematic mapping of common interaction tasks onto interaction modalities. (2) The *integration gap* concerns the integration of novel interaction techniques and technologies with existing information visualization approaches to create new powerful visualization solutions. (3) The *guidelines gap* criticizes the shortage of support for users to choose suitable solutions for the task at hand. We outline related challenges and ideas for future work by the example of our work on tangible views for information visualization.

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INTRODUCTION

The goal of visualization is to support people in forming mental models of otherwise difficult-to-grasp subjects, such as massive data, complex models, or dynamic systems [12]. The term *forming* implies that visual output is not the end product of visualization. It is rather the process of adapting the visual output and interacting with the data in order to gain insight.

For several decades, visualization researchers have developed a wealth of visualization and interaction concepts for many different types of data and tasks. What most of the existing techniques have in common is that they are targeted for regular desktop workplaces with a computer display, a keyboard, and a mouse. With the advent of new display technologies, such as large high-resolution displays or small hand-held displays, it became necessary to adapt existing visualization approaches or to devise new ones. Recently, modern interaction technologies, such as multi-touch interaction or tangible interaction have considerably broadened the spectrum of what's possible and created a need for rethinking existing visualization solutions with regard to interaction. The seamless integration of both display and interaction in a single touch-enabled device, such as interactive tabletops and tablets, makes direct manipulation [11] truly direct. By exploring information directly under your fingertips, the *forming* of mental models for interactive visualizations seems to be particularly well supported and promising.

In this paper, we aim to describe several issues concerning the future development of information visualization in the context of new interactive surfaces and interaction technologies. We identify gaps in the state of the art, illustrate them with our own previous work [3, 13] and motivate possible next steps for future research. Here, our main concern is related to the systematic investigation of the possibilities of the classic as well as the promising new technologies, on the one hand, and the well-justified application of these possibilities to solve visualization and interaction tasks, on the other hand.

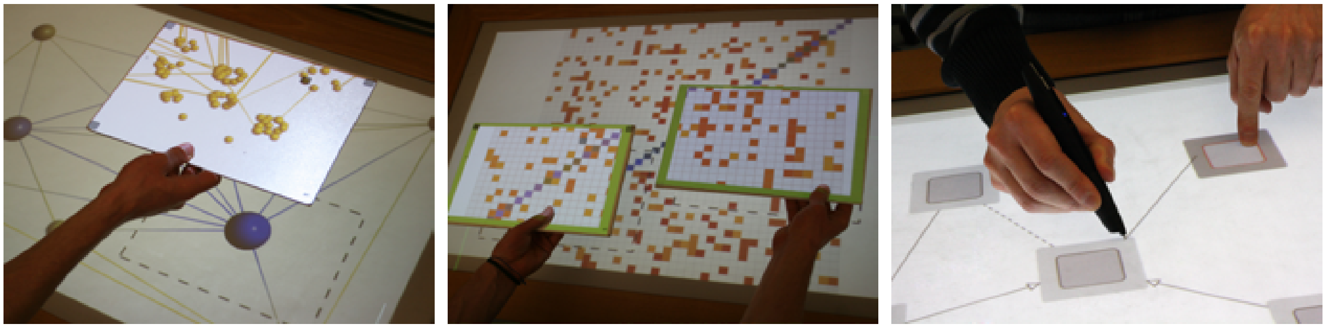
IDENTIFYING THE GAPS

In the following, we identify three research gaps worth being addressed by future research.

Technology Gap

Visualization research builds upon commonly accepted strategies for visualizing data. In his classic book, Bertin [1] introduces visual variables and defines how data is to be mapped onto them. Cleveland and McGill [2] investigate the effectiveness of visual encodings for data exploration. Thus, on a conceptual and on an experimental level, we have backed knowledge how to transform data D to visual representations V using the mapping $vis : D \to V$.

However, there is no such commonly accepted mapping in terms of interaction. So far, mouse and keyboard have been the basic and dominant devices for user interaction. Advances in technology have recently added new modalities to the interaction toolbox. Multi-touch interaction, gestural interfaces, pen-based interaction and tangible interaction are only a few examples. What still has to be developed is the mapping $interact : T \to M$ that defines how interaction tasks T are effectively and efficiently carried out with the different interaction modalities M available. Obviously, specifying appropriate sets T and M turns out to be a necessary and challenging condition for successfully developing novel interactive visualizations. Therefore, a repertoire of suitable interaction techniques has to be defined and described in a consistent way, which eventually allows for an



(a) Semantic zooming of node-link diagrams by lifting/lowering a tangible view [13]. (b) Tangible views applied to compare different parts of a matrix visualization [13]. (c) Manipulating node-link diagrams by using multi-touch and pen input [3].

Figure 1: Utilizing novel interactive displays for information visualization.

easy task mapping. Implementing the new techniques will also form the basis for future visualization applications.

Integration Gap

Closing the technology gap will result in a new repertoire of interaction techniques. However, by now users of interactive visualizations mostly apply techniques that are designed for classic desktop computers. Utilizing novel interactive displays for visualization purposes has not received much attention so far. So there is a gap in terms of promising new possibilities on the one hand, but only little integration of these possibilities into visualization research and applications on the other hand.

Yet, there are first approaches that specifically address the integration of visualization and interactive display technology. For instance, Isenberg et al. [5, 6] utilize interactive tabletop displays for collaborative visualization, Voida et al. [14] discuss design considerations for interacting with data on interactive surfaces, Spindler et al. [13] contribute the concept of tangible views for information visualization, Heilig et al. explore multitouch input for interacting with scatterplots [4], and Kosara [7] investigates multi-touch brushing for parallel coordinates. However, these first visualization approaches using novel interactive displays primarily address very specific problems. The broad range of possibilities of the new technology have by far not been explored sufficiently nor analyzed appropriately.

Closing this gap by systematically exploring the design space for combining modern visualization approaches with recent interaction technologies will lead to novel solutions for today's data exploration challenges.

Guidelines Gap

With the combination of different visualization techniques and interaction technologies, a vast body of possible solutions becomes available. This immense variety of existing and possible new approaches makes it difficult for users to decide which techniques to use. What is needed in the future are guidelines or rules for choosing effective approaches for the data, tasks, and device context at hand.

An excellent example of systematically choosing "good" visualizations is Mackinlay's [10] pioneering work on automating the design of visual representations. The beauty of this approach is that it enables automatic suggestion of visual variables based on a given data type (quantitative, ordinal, nominal). This is possible thanks to the well-defined sets of data types and visual variables, which abstract from the subtle details of real world problems. It is part of ongoing research how the details of today's often complex visualization application scenarios can be integrated.

Wouldn't it be great if we had a similar system to which we input our data D and our tasks T, and the system would tell us which visualization techniques V and interaction modalities M to use given a particular input and output setup? Obviously, the required mapping $guide : D \times T \rightarrow V \times M$ will be difficult to define. We consider solving this research question a formidable and rather long term task.

DISCUSSING THE GAPS

Narrowing and eventually closing the aforementioned gaps will require much research. It is beyond the scope of this article to comprehensively suggest directions for future work. We would rather like to use an example to illustrate possible avenues of investigation.

We chose the example of *tangible views for information visualization* [13] for the following reasons. Tangible views illustrate quite well the new possibilities of advanced technology with a set of different interactive visualizations (see Figures 1(a) and 1(b)). They also serve as a good illustration of what is still missing. Finally, since tangible views are our own previous work, it is easier to criticize and to envision research goals.

Conceptually, tangible views are spatially aware lightweight displays that serve two purposes simultaneously: visual output and direct input. Multiple of such tangible views are used together with an interactive tabletop display to build a multi-display multimodal visualization ensemble that supports both interacting *on* the views (by using touch and pen input) and interacting *with* the views (by moving them through the physical space above a tabletop and performing gestures). An interaction vocabulary (see Figure 2) has been compiled as the basis upon which manifold applications can be developed. Several example visualization cases illustrate how tangible views can be utilized to display and to interact with

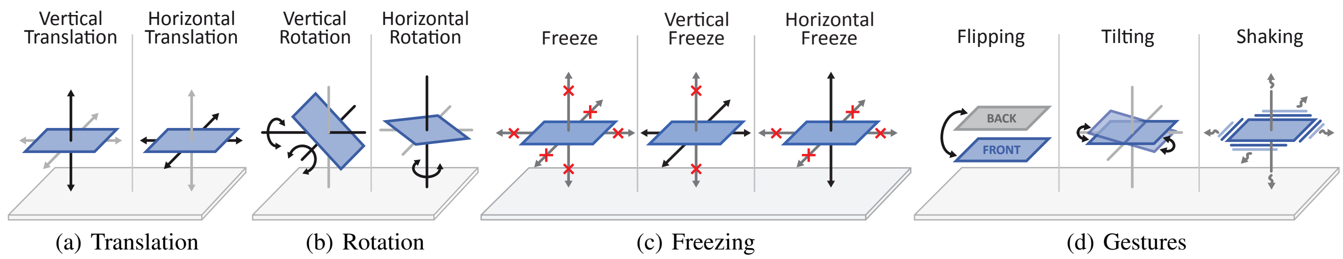


Figure 2: Extract of the interaction vocabulary provided by tangible views. The figures show *with*-the-view interactions only, *on*-the-view interactions, such as pen and touch input, can be found in [13].

data. These use cases include scatter plots and parallel coordinates plots of multivariate data, node-link representations and matrix representations of graph data, as well as map-based visualization of spatiotemporal data.

Addressing the Technology Gap

In order to arrive at a mapping $interact : T \rightarrow M$, we first need a specification of the set of interaction tasks T. There are approaches that provide first categorizations of interaction. Yi et al. [15] describe a list of general interaction intents in visualization. Besides these general descriptions, more specific categorizations exist. For instance, dedicated interaction tasks for exploring graphs are described by Lee et al. [9]. These are valuable starting points for defining a comprehensive set of interaction tasks. Most likely, this set will contain tasks of different complexity ranging from very basic selection to common brushing and linking to the more complex applications of logically combinable dynamic filtering.

Secondly, defining an interaction vocabulary as in [13] is a valid first step for closing the technology gap. Such a vocabulary serves as a container that holds technically possible solutions to be utilized for interaction tasks. The tangible views vocabulary focuses on interaction with spatially aware lightweight displays. However, it is not comprehensively addressing the different classes of interactive displays in general. So, future work has to systematically extend the interaction vocabulary with further interaction modalities M.

An example for a successful $interact$ mapping can be given for the task of exploring spatio-temporal data with tangible views. Such data can be mapped to the virtual volume above a tabletop, where the XY-dimensions encode spatial location and the Z-dimension represents time (i.e., space-time-cube [8]). In order to control which part of the geo-space and which time step are visible ($\in T$), the user can translate the tangible view horizontally and vertically ($\in M$), as shown in Figure 2(a).

Another example is the adjustment of a visualization parameter, e.g., the distortion factor of a fisheye lens ($\in T$), which can be mapped onto rotating the view horizontally ($\in M$) as shown in Figure 2(b).

Addressing the Integration Gap

Closing the integration gap, that is bringing together visualization research and new interactive displays, involves many different aspects. To name only a few, integration is necessary on a conceptual level (e.g., utilizing tangible views for focus+context visualization), on a software level (e.g., combining different visualization and interaction toolkits), as well as on a hardware level (e.g., integration of lightweight displays with touch and pen input and tabletop displays). Because we cannot detail all aspects here, we will resort to illustrating the integration of *exploration* and *manipulation* of node-link diagrams of graphs as an example.

Usually, exploration tasks and manipulation tasks are considered separately from each other. While exploration is largely addressed in the visualization community, manipulation tasks are more relevant in the realm of human-computer interaction. For instance, with tangible views we mainly support the exploration of node-link diagrams by utilizing the *with*-the-view interaction modalities (see Figure 1(a)). Other works address the authoring and manipulation of the underlying graph data, e.g., by using multi-touch and pen input for diagram editing as shown in Figure 1(c) [3]. Taking advantage of both worlds by integrating them into a single unified system would clearly be useful, not only because users could accomplish multiple tasks within the same familiar environment, but also because data exploration often involves data manipulation (at least temporary) for testing different "what if" scenarios.

However, such integration also implicates several challenges. On a conceptual level, distinctive features of different interaction modalities and visualization techniques need to be combined appropriately for different tasks. This could be achieved, for example, by utilizing *with*-the-view interaction for exploration aspects, while the more precise *on*-the-view interaction could be used for manipulation tasks. Seamless switching between these tasks could be accomplished by choosing different tools or even different interaction modalities, e.g., touch input for zooming/panning and pen input for graph editing. On a software level, different software worlds need to be consolidated into a single framework that addresses issues such as distributed rendering required for a multi-display setup, state synchronization between different devices, and most importantly the incorporation and adaption of visualization techniques that meet the requirements of such a setup.

Addressing the Guidelines Gap

The developed example cases of tangible views indicate that there is much potential in utilizing new technologies for information visualization. Although being interesting examples, it remains unclear why and how tangible views are used under which circumstances and when alternative solutions might be better suited (as one reviewer of [13] once pointed out). So, there are often questions like *Would you really carry out this task with tangible views?* or *Wouldn't this be easier to accomplish with basic mouse interaction?*

Even though the introduction of an interaction vocabulary is an important step, there are still no definite rules for its application. In order to make information visualization on modern interactive displays a viable approach, we should strive to provide concrete answers and guidelines much like in the spirit of Bertin, Cleveland and McGill, and Mackinlay.

However, developing approaches for guiding the user in choosing the "right tool" is ongoing research, which is challenging for the following reasons. First, it is usually more difficult to categorize the data, because today's data sets are increasingly complex and heterogeneous. Furthermore, one has to take the users' tasks and goals into account with regard to both: what the users want to see and how they would like to interact. In terms of the output, a step has to be made from simple visual variables to more complex visualization techniques, and possibly to combinations thereof. The aspect of interaction is entirely missing in classic works. Given some data and a suitable visualization, how can the user effectively interact to accomplish the tasks and to achieve the goals? And finally, it is no longer just a question of which visualization technique to use for which data and task, but rather one of which display and interaction technologies to use for which visualization techniques, data, and tasks.

CONCLUSION

For taking full advantage of novel display and interaction technologies for information visualization, several gaps have to be addressed as identified and illustrated in this paper. First, a categorization of interaction tasks and a repertoire of novel interaction techniques have to be described, which then allows for mapping specific tasks to particular techniques. Secondly, the design space of combining novel interaction concepts and existing visualization approaches has to be explored appropriately. Thirdly, guidelines have to be developed for choosing appropriate and effective approaches within a vast body of possible solutions. Filling these gaps step by step is a formidable task that can only be accomplished by a vivid research community bringing together visualization and interaction experts.

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