An Interaction Continuum for Visualization

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Abstract—It is the year 2039, the desktop is not dead, and it does not look like this situation will change for a while. In any practical application domain in which data visualization is used, the desktop remains to be one of the most important tools for data exploration, analysis, and processing. Since the year 2014, non-desktop platforms for data exploration including large displays, immersive environments, tangible controls, and mobile devices have found their place for data visualization applications—but they have not and will not replace the desktop in many practically relevant tasks. Instead, researchers have finally begun to work toward an interactive visualization continuum that allows researchers and data analysts to transition between the different platforms and to use the tools for those tasks they support best: the desktop for in-depth, single-user analysis and novel platforms for group discussions, mobile data access, and/or good spatial perception.

Index Terms—Display environments for interactive data exploration and visualization.

1 The State of the Art—An Antithesis

It is the year 2014: The desktop is alive and thriving—at least for many forms of professional work with data and visualizations. Mobile touch-enabled devices such as tablets and smart phones may be in the process of replacing PCs for many tasks in personal computer usage including web browsing, e-mail, social media interactions, and second screen applications for media consumption. I would argue, however, that this is largely not the case for applications in which visualizations are explored in professional environments. In these application scenarios, the desktop environment has irrefutable advantages: high processing powers (on the PC itself or in client-server scenarios), high graphics capabilities, precise input, easy data exchange possibilities, robust input processing, and many more. In contrast, immersive environments are difficult to set up, calibrate, and maintain; large displays do not provide similarly precise input modalities; and mobile devices do not have the same computing/graphics powers and also suffer from imprecise input.

I also believe that this situation will not change in the foreseeable future because the mentioned advantages of desktops and disadvantages of novel devices will continue to exists. In my view, the desktop will continue to be a major (if not the most important) platform for visualization use. We can certainly try to address some of the issues in the novel platforms such as working on precise interaction mechanisms for touch input or investigating robust calibration for immersive displays. I believe, however, that it would be better to think about how to use the different platforms for what they support best, and to come up with better ways to transition between the different platforms.

In this position paper I focus, in particular, on 3D spatial data that plays an important role, for example, in medicine (e. g., CT or MRI scans, dwMRI-based fiber tracking, etc.), fluid mechanics (e. g., 3D fluid flow simulations), other domains in physics (e. g., many 3D simulations), astronomy (e. g., 3D particle datasets of mass distributions in the universe), biology (e. g., molecular structures), etc. Interactive visualizations [10] in these application domains are particularly interesting and challenging for novel interaction platforms because they not only require good graphics computation support but they also can benefit from stereoscopic 3D displays and/or tangible interactions due to the three-dimensional nature of the data, while at the same time requiring adequate interaction techniques.

These requirements have lead to dedicated display and input environments being developed—not only recently. For example, immersive environments [2] such as the Responsive Workbench [13] and the CAVE [4] have been created and haptic manipulation using force-feedback devices [15] have been explored. The reason that these innovative display environments seemingly have not seen a wide-spread adoption can be seen in the complex nature of their technical setup, the need for calibration and constant re-calibration, and continued need for maintenance. Visualization applications in these environments often need to be specially created and developed, and a transition to the more wide-spread tools on desktop platforms is typically difficult.

More recently, novel touch-based interaction paradigms have also been explored for 3D spatial datasets [6, 7, 11]. A particular challenge here is that the input is inherently two-dimensional, while the data and thus the manipulations have to happen in a three-dimensional space [11]. That means it is necessary to think about the nature of natural interaction [16] and, in particular, gestural interaction [8] that is often advocated to be beneficial in these environments. Precise input that is fundamental to effective and efficient data exploration still remains a challenge. When employed in connection with mobile devices, the processing and graphics power is often an issue in the context of the large datasets that need to be examined. Because many of these challenges remain unsolved to this date there are still only few solutions available and its seems that such platforms are rarely employed in practice.

Despite the mentioned challenges, however, the novel platforms do offer numerous advantages in how they support interaction with digital content including visualizations. For example, it is often mentioned that touch input can lead to faster target selection when compared to mouse interaction [12], that it can be beneficial in collaborative settings [5], and that it provides somesthetic feedback important for interaction in real and virtual environments [14]. Most importantly for the interaction with spatial data, however, is that touch input is inherently direct in the data manipulations and thus provides a high degree of *immersion through interaction*—people often report that they feel in control of the data [17]. Stereoscopic environments, in contrast, offer a high degree of *visual immersion* which is similar important for the exploration of spatial data. Tangible interfaces combine some of the advantages of touch input and stereoscopic displays: they provide tangible 3D elements to control the interactive exploration with data, albeit without the flexibility of changing the representation (of the tangible) that both touch input on flat screens and stereoscopic displays offer.

2 Vision: An Interaction Continuum for Visualization

My vision for the future, therefore, is not that the desktop is being replaced by any of the existing or future interactive platforms. My vision, instead, is that that we find a way to combine the different interactive data exploration environments to be able to profit from their respective advantages. I envision an environment that lets researchers transition from their desktop-based data analysis tools to large screens with touch input or tangible controls, to immersive rooms, to mobile devices, and maybe also to combinations of these. I would like this continuum to go beyond the simultaneous use of a few of the named data exploration paradigms as has been explored already (e. g., [3])—I would like to be able to transition from one environment to another one in a way that is as seamless as possible. This would enable researchers to make use of the different single (or combined) environments for what they support best. For example, touch-based large displays could support collaborations of small groups, complex spatial datasets could be analyzed in immersive rooms, special statistical data analyses and in-depth follow-up explorations could be conducted using the traditional desktop tools, and mobile touch-enabled devices could be used for data presentations in coincidental meetings or as a second screen to control large monoscopic or stereoscopic data displays. In all of these environments, one should be able to access the same data (potentially adjusted in its detail or resolution to the specific display and interaction), use the same or similar interaction paradigms, and be able to access matching data analysis tools adjusted to the respective input device. However, my interaction continuum for visualization needs to go far beyond a simple data transfer as it is being investigated in Ubicomp scenarios for multi-display environments. Instead, we need to understand how the different tasks in visualization [1] can be supported in the different environments, how we can capture and transfer insights gained in one environment to be used in another one, and which tasks are supported best in which environments.

This vision is, at this point, still a relatively vague hope for the future and many questions remain unanswered. For example, I am not sure if it is possible to create a set of interaction techniques that not only works in one environment but relates to those used in others and if such a set of interactions can be sufficiently general to be able to apply to all or at least many of the application domains in which 3D data is being analyzed (also see the discussions by Daniel F. Keefe and myself [11]). If not, can we at least create a set of fundamental interaction techniques that can be shared among different disciplines and interaction platforms? Moreover, in the context of novel interactive platforms people often describe the interaction to be "natural." I believe that this term is ill-defined and often badly understood. What does the notion of "natural interaction" really mean in this context is unclear since in data analysis applications we often talk about experts who can spend some time to learn a new tool or technique. A "natural interaction" for them would probably also include one that allows them to easily control a chosen parameter in a precise way, not only gestural control such as pinch-to-zoom which combines four degrees of freedom in a single, imprecise interaction. Of course, for being able to create an interaction continuum we also would need to create an underlying technical platform that supports the intended transitions. Would it be possible to create an API or a toolkit—maybe inspired by how TUIO [9] supports the processing of many different kinds of touch input and tag sensing for multiple hardware and software platforms?

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