Improving 3D Visualizations: Exploring Spatial Interaction with Mobile Devices

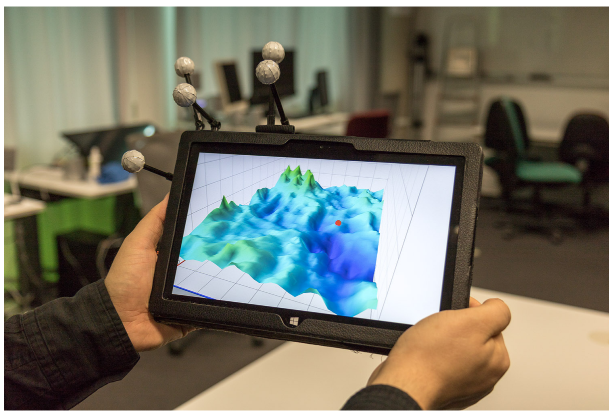

Figure 1: One of our prototypes, showing a 3D height map fixed in space and explored by spatial interaction.

Wolfgang Büschel
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany
bueschel@acm.org

Patrick Reipschläger
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany
preipschlager@acm.org

Raimund Dachselt
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany
dachselt@acm.org

ISS 2016, November 6–9, 2016, Niagara Falls, ON, Canada.
ACM ISBN 978-1-4503-4530-9/16/11.
http://dx.doi.org/10.1145/3009939.3009949

Abstract
3D data visualizations, while offering a lot of potential, have also well-known issues regarding occlusion and readability. Immersive technologies might help overcoming these issues by addressing the perceptional problems and increasing the tangibility of the data. In this work, we explore the potential of spatial interaction with mobile devices. Building on the related work and our own experiences, we report on visualizations that are fixed in space or fixed on the device, as well as combining them with head-coupled perspective. A number of prototypes we developed, helped us to gain practical insights in the possibilities and limitations of these techniques.

Author Keywords
Spatial Interaction; 3D Visualization; Head-coupled Perspective; Information Visualization; Tangible Displays

ACM Classification Keywords
H.5.2 [User Interfaces]: Input devices and strategies (e. g., mouse, touchscreen)

Introduction
Immersive technologies such as mixed reality glasses and location-aware mobile devices enable the visualization of data in the wild, unconstrained by traditional workplaces.

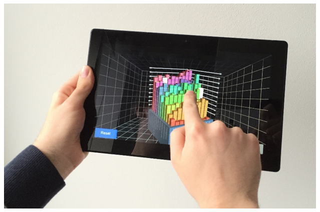

Figure 2: Bar chart fixed on the mobile device.

Figure 3: Bar chart fixed in space with spatial interaction.

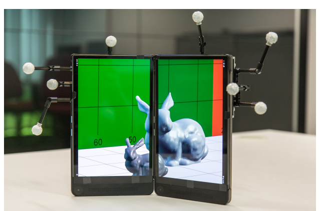

Figure 4: Two connected devices with a scene fixed in space and head-coupled perspective. The picture is taken from the tracked user's point of view.

This, as well as work on data physicalization, sparks a renewed interest in 3D visualization even outside of specific application cases. Many datasets are inherently three-dimensional and thus, 3D has long been used in scientific visualization for, e.g., medical, geographical or physical visualizations. However, there are limitations and issues of 3D visualizations such as occlusion, misleading perspective, and poor readability.

We envision that smart interaction and presentation techniques that make use of the new paradigms of immersive and mobile visualization can lead to a fruitful combination of the tangible nature of data physicalization and the dynamic, interactive nature of spatial interaction, thus addressing these issues. Specifically, we believe that making 3D visualizations more tangible by partly leveraging the advantages of physical visualizations can help users to explore and understand complex datasets more intuitively and efficiently.

In our research, we are interested both in visualizations fixed in space, where the movement of the mobile device is mapped to the virtual camera, as well as in visualizations fixed to a device, where mostly device gestures are used. We also investigate the potential of head-coupled perspective (HCP), where the device acts like a window into the scene and the perspective of the view changes according to the movement of the user's head. To explore the potential and limitations of these techniques, we developed a framework for spatial interaction in 3D environments as well as prototypes (see Figure 1) for each technique and their combinations. Further, we report on a preliminary study investigating HCP with visualizations fixed on the device.

Background

Our research builds on prior work on the topics of (3D) visualization, spatial interaction and head-coupled perspective.

There is a trend to bring visualizations to diverse devices and applying natural interaction techniques such as multi-touch to them [11, 12]. This push towards more natural, immersive, and tangible visualization is also evident in the recent work on data physicalization [10].

Spatial interaction is one promising approach towards combining the tangibility of such physical visualizations with the advantages of dynamic, virtual data representations. The concept of using spatially-tracked mobile devices has been introduced by Fitzmaurice [6] and has since been used for, e.g., 2D information visualization [15] and detail views into virtual 3D environments [3]. For different use cases, studies show advantages of such spatial interaction compared to traditional input techniques (e.g., [2, 14]).

Head-coupled perspective has already been proposed in the 1980s [5]. It has been used on mobile devices [7] and also in combination with tabletops [13]. The concept of Fishtank VR, a combination of stereo rendering and head-coupled perspective, has been presented by Ware et al. [16]. For a world-fixed display, Arthur et al. [1] found that users preferred HCP without stereo rendering to both fixed perspective rendering and stereo rendering that was not head-coupled. It is an interesting question if these findings also hold for mobile devices. In [17], the authors tested the error rate of a path tracing task in graphs for head-coupled and fixed perspective, both with and without stereo rendering. While the combination of both HCP and stereo rendering performed best, head coupling alone was more effective than stereo rendering with a fixed perspective.

Hürst & Helder [9] defined three different visualization concepts: standard visualizations, fixed world, and shoebox visualizations. They also proposed that an exaggerated mapping of rotation could be used for specific information visualizations. Later, Hürst et al. [8] differentiated be-

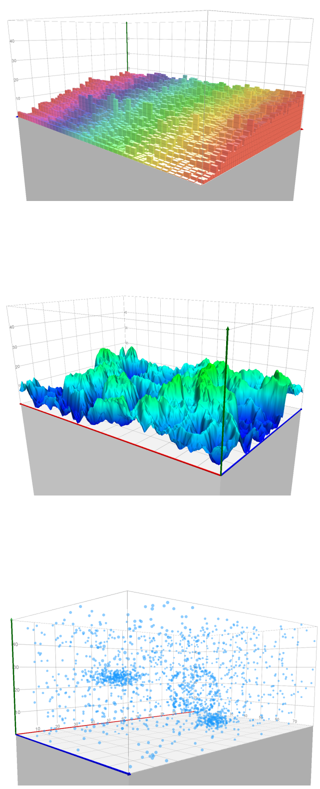

Figure 5: Some of the different visualizations currently supported by our prototypes: 3D bar charts, 3D height maps, and 3D scatterplots (top to bottom).

tween Standard VR, Shoebox VR, and Fishtank VR (without stereoscopic rendering like in [16]), the difference between the latter two being that Shoebox VR does not use the user's head position but only device tilting.

Practical Experiences

To explore the possibilities as well as the limitations of spatial interaction with mobile devices, we created several prototypes, which we continuously refined according to our observations. As the foundation for our prototypes, we developed a software framework for spatial interaction in 3D environments based on the *MonoGame*[1] 3D engine and written in C#. This framework enables us to quickly iterate over new ideas for visualizations and interaction techniques. Besides providing the basic elements for our 3D environments, it also includes a dedicated tracking server to monitor the position and orientation of devices and users. We use an infrared, marker-based tracking system consisting of 12 cameras. In our setup, we use both Windows (10.6", 1920 x 1080 resolution) and Android (8.4", 2560 x 1600 resolution) tablets as mobile devices.

Each particular prototype focuses on particular aspects of our envisioned techniques. We started by exploring the possible advantages of head-coupled perspective over conventional systems in our first prototype. It employs a small 3D bar chart in a fishtank visualization that is fixed on the device (see Figure 2).

We build on this foundation with our next prototype, which addresses 3D visualizations that are fixed in space (see Figure 3). For this, we implemented three common visualization types: A 3D bar chart, a 3D heightmap and a 3D scatterplot (see Figure 5). They can be explored by physically moving the mobile device around a table (1.2m x 0.8m x 0.7m), on which the visualizations is situated. The visualizations are considerably larger than in our first prototype in order to make use of the available space and to encourage users to move around. In addition to spatial interaction, we also implemented two touch camera models. We specifically wanted to explore if spatial input has advantages over touch regarding interaction speed and precision.

[1] https://monogame.org

In our recent prototype we revisited HCP and applied it to our concepts for spatial interaction for fixed in space visualizations. Furthermore, we expanded our concepts through the use of multiple mobile devices enabling dynamic multi user interaction. While our current implementation specifically uses two connected devices as a foldable display [4], independent devices are also possible (see Figure 4). For the future, this will enable us to practically investigate multi-user and collaborative scenarios.

Locality of Visualizations

When researching immersive techniques for data visualization, the locality of the data is a key aspect. In our approach, we use spatial interaction with mobile devices for 3D visualization. This offers two possibilities that were already generally described in [8] and that we examine specifically for 3D visualization. The first is to position the data in relation to a real world physical location and use the mobile device as a peephole into this virtual data space. The second approach is to virtually attach the data to the mobile device, using spatial interaction as a means to manipulate the view. In this case, the position of the tablet or phone is of subsidiary importance. In the following, we want to explore these two aspects of our research in detail.

Fixed in Space

This technique immerses a user within the visualization by using physical navigation. Exploring the three-dimensional data is achieved by directly mapping the movement of a mobile device to the location and orientation of a virtual camera. The user holds the mobile device in hand and walks around freely. Our studies show that this offers an intuitive way of manipulating the camera, which is understood almost immediately. With this technique, the dynamics of digital visualizations are combined with an increased tangibility of the data, which we believe may lead to higher user performance and satisfaction. So far, our findings suggest that at least simple navigation tasks benefit from spatial interaction, with less advantages for more complex tasks. To further increase the presence of the data, visualizations can be fitted onto real world objects like, e.g., tables. Our experiences show that this provides a point of reference (landmark) to the users that they can use to orientate themselves in the scene to easily memorize the physical position of interesting points within the visualization.

Another important aspect of using spatial interaction to manipulate the camera is that touch input on the mobile device is free to be used for other interaction tasks, like manipulating the visualization itself through suitable tools, e.g., clipping planes. We see a need for such tools, tailored to the specifics of different tasks and visualizations. A possible disadvantage of spatial interaction and physical navigation is the increased physical demand for users because they have to hold a (possibly heavy) mobile device the whole time, as well as continuously move around the room to explore the data. We believe that one solution for this might be to use spatial interaction for the initial exploration of an previously unknown dataset. After the user has gained a suitable understanding of the data and identified interesting points, these can then be explored by other means, like fixing the data to the device.

Fixed on Device

Having the data fixed on the device allows for a smaller scale, more personal use. This is more suitable for environments where it is not appropriate or feasible to explore visualizations using physical navigation. Examples are constrained office spaces, mobile use on-the-go, and phases of individual use during longer, collaborative work sessions. Spatial interaction is mostly limited to device gestures. Other modalities, such as touch, are needed even for simple tasks such as selection or zooming. On one hand, spatial interaction may be used for a shoebox VR [8] effect, where rotating the device controls an off-axis perspective projection for an improved 3D impression. On the other hand, it can also be implemented in the form of discrete gestures, e.g., flicking the device in a direction to rotate the view by 90°, enabling the user to rapidly explore the visualization from its main points of view. With spatial interaction limited to a set of more constrained gestures, we believe that physical demand is generally lower than with the data being fixed in space. Importantly, seated use is also possible.

Combination

As mentioned above, we propose the combination of the two techniques to help overcoming their particular disadvantages and building on their strengths. We envision that data is visualized in a defined space that is either used for its affordances, e.g., a landmark such as a table, or because it has an inherent connection to the data, e.g., a machine in a factory and its production data. Users explore the visualization using a combination of physical navigation to travel between parts of the dataset and small-scale spatial interaction to examine details. When they find an interesting subset of the data and would like to analyze it in-depth, they switch to the fixed-to-device mode. This allows them to take the visualization with them and, e.g., continue work while seated. A mode switch or some form of clutching mechanism would be used to change between the two visualization principles.

Head-coupled Perspective

Besides using spatial interaction, another promising way to increase immersion in 3D visualization is through head-coupled perspective (HCP). One expected advantage of HCP is the improved impression of depth, which may help users to better learn the spatial relations of individual data points in a visualization. Another possibility is that the natural and effortless perspective change by simply moving the head may lead to faster scene exploration and understanding. This could result in an intuitive solution to typical problems of 3D visualizations, like occlusion and determining the distance of an virtual object.

Withing our work, HCP could be combined with spatial interaction if the visualization is fixed in space as well as when its fixed on the device. To assess the usefulness of HCP, we ran a preliminary study comparing task performance for basic visualization tasks in 3D bar charts with and without HCP. We were interested if we would see the same advantages that have been shown by prior work (e.g., [1]) in our setup. However, in this initial investigations we could show neither faster completion times nor lower error rates for tasks such like comparing bars, ordering them, or finding the lowest and highest value. We believe that the visual instability introduced by permanent head tracking, including both tracking jitter and movements by the user, outweighs the advantage of an additional depth cue for the type of visualization that we examined (10 x 10 bar chart, fixed to device). In the future, it will be interesting to run similar tests with other, more complex visualizations, e.g., 3D graphs.

Conclusion

Making visualizations more tangible by using spatial input may help to address issues of perception and interaction. We believe that this potential to support the analysis of data in diverse use cases is as of yet untapped. In this work we gave an overview of our ongoing research on spatial interaction and head-coupled perspective for 3D data visualization. We presented insights into spatial 3D visualizations attached to devices and fixed in space, with and without HCP, that we gained from different prototypic implementations. Going forward, we will expand on this work and investigate basic aspects, such as collaborative work and the effects of different display technologies, as well as specific tools and interaction techniques for individual visualizations.

Acknowledgements

This work was in part funded by grant no. 03ZZ0514C of the German Federal Ministry of Education and Research (measure Twenty20 – Partnership for Innovation, project Fast) and the Excellence Initiative by the German Government (measure “Support the best”).

REFERENCES

1. Kevin W. Arthur, Kellogg S. Booth, and Colin Ware. 1993. Evaluating 3D Task Performance for Fish Tank Virtual Worlds. *ACM Trans. Inf. Syst.* 11, 3 (July 1993), 239–265. DOI: http://dx.doi.org/10.1145/159161.155359

2. Mattias Arvola and Anna Holm. 2014. Device-Orientation Is More Engaging Than Drag (at Least in Mobile Computing). In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI ’14)*. ACM, New York, NY, USA, 939–942. DOI: http://dx.doi.org/10.1145/2639189.2670245

3. Louis-Pierre Bergé, Marcos Serrano, Gary Perelman, and Emmanuel Dubois. 2014. Exploring Smartphone-Based Interaction with Overview+Detail Interfaces on 3D Public Displays. In *Proceedings of the 16th International Conference on Human-Computer Interaction with Mobile Devices & Services (MobileHCI '14)*. ACM, New York, NY, USA, 125–134. DOI: http://dx.doi.org/10.1145/2628363.2628374

4. Wolfgang Büschel, Patrick Reipschläger, and Raimund Dachselt. 2016. Foldable3D: Interacting with 3D Content Using Dual-Display Devices. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces*. ACM, New York, NY, USA, 6.

5. Scott Fisher. 1983. Viewpoint Dependent Imaging: An Interactive Stereoscopic Display. In *Proc. SPIE*, Vol. 0367. 41–45. DOI: http://dx.doi.org/10.1117/12.934299

6. George W. Fitzmaurice. 1993. Situated Information Spaces and Spatially Aware Palmtop Computers. *Commun. ACM* 36, 7 (July 1993), 39–49. DOI: http://dx.doi.org/10.1145/159544.159566

7. Jérémie Francone and Laurence Nigay. 2011. Using the User's Point of View for Interaction on Mobile Devices. In *23rd French Speaking Conference on Human-Computer Interaction (IHM '11)*. ACM, New York, NY, USA, 4:1–4:8. DOI: http://dx.doi.org/10.1145/2044354.2044360

8. Wolfgang Hürst, Jannes Beurskens, and Marco van Laar. 2013. An Experimentation Environment for Mobile 3D and Virtual Reality. In *Proceedings of the 15th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '13)*. ACM, New York, NY, USA, 444–447. DOI:http://dx.doi.org/10.1145/2493190.2494659

9. Wolfgang Hürst and Matthias Helder. 2011. Mobile 3D Graphics and Virtual Reality Interaction. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology (ACE '11)*. ACM, New York, NY, USA, 28:1–28:8. DOI: http://dx.doi.org/10.1145/2071423.2071458

10. Yvonne Jansen, Pierre Dragicevic, and Jean-Daniel Fekete. 2013. Evaluating the Efficiency of Physical Visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2593–2602. DOI: http://dx.doi.org/10.1145/2470654.2481359

11. B. Lee, P. Isenberg, N. H. Riche, and S. Carpendale. 2012. Beyond Mouse and Keyboard: Expanding Design Considerations for Information Visualization Interactions. *IEEE Transactions on Visualization and Computer Graphics* 18, 12 (Dec. 2012), 2689–2698. DOI:http://dx.doi.org/10.1109/TVCG.2012.204

12. Jonathan C. Roberts, Panagiotis D. Ritsos, Sriram K. Badam, Dominique Brodbeck, Jessie Kennedy, and Niklas Elmqvist. 2014. Visualization beyond the Desktop–the Next Big Thing. *IEEE Computer Graphics and Applications* 34, 6 (Nov. 2014), 26–34. DOI: http://dx.doi.org/10.1109/MCG.2014.82

13. Martin Spindler, Wolfgang Büschel, and Raimund Dachselt. 2012. Use Your Head: Tangible Windows for 3D Information Spaces in a Tabletop Environment. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces (ITS '12)*. ACM, New York, NY, USA, 245–254. DOI: http://dx.doi.org/10.1145/2396636.2396674

14. Martin Spindler, Martin Schuessler, Marcel Martsch, and Raimund Dachselt. 2014. Pinch-Drag-Flick vs. Spatial Input: Rethinking Zoom & Pan on Mobile Displays. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 1113–1122. DOI: http://dx.doi.org/10.1145/2556288.2557028

15. Martin Spindler, Christian Tominski, Heidrun Schumann, and Raimund Dachselt. 2010. Tangible Views for Information Visualization. In *ACM International Conference on Interactive Tabletops and Surfaces (ITS '10)*. ACM, New York, NY, USA, 157–166. DOI: http://dx.doi.org/10.1145/1936652.1936684

16. Colin Ware, Kevin Arthur, and Kellogg S. Booth. 1993. Fish Tank Virtual Reality. In *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems (CHI '93)*. ACM, New York, NY, USA, 37–42. DOI: http://dx.doi.org/10.1145/169059.169066

17. Colin Ware and Glenn Franck. 1996. Evaluating Stereo and Motion Cues for Visualizing Information Nets in Three Dimensions. *ACM Trans. Graph.* 15, 2 (April 1996), 121–140. DOI: http://dx.doi.org/10.1145/234972.234975