Challenges in Collaborative Immersive Visualization

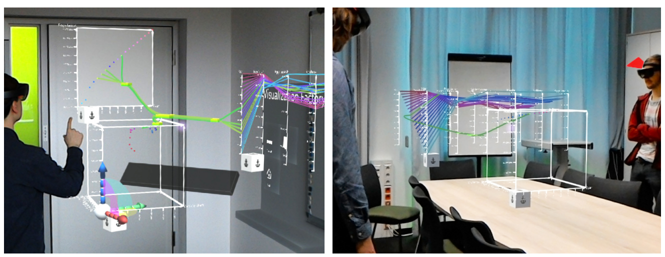

Figure 1: (Left) Example setup in *CollARVis*, our collaborative AR visualization toolkit. Our work on this toolkit helped us to gain insights into the challenges discussed in this paper.
(Right) Two users exploring data collaboratively. The red marker over the person on the right shows his viewing direction and indicates to the other user that hologram sharing is working.

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4th Workshop on Immersive Analytics:
Envisioning Future Productivity for Immersive Analytics, April 2020
ACM 978-1-4503-6819-3/20/04.
http://immersiveanalytics.io/

Abstract
In this paper we discuss challenges in collaborative mixed reality visualization. Despite recent advances in immersive technologies in general and, specifically, Immersive Analytics, systems rarely leave prototype status and are seldom found in real-world usage. Based on our ongoing research in Mixed Reality data visualization and experiences with our own toolkit for collaborative immersive visualization, *CollARVis*, we identify important challenges of such systems and examine possible approaches to address them. By doing so, we contribute to the ongoing discussion how future immersive applications can be made more practical for productive environments.

Author Keywords
Information Visualization; Immersive Analytics; Augmented Reality; Collaboration

CCS Concepts
•Human-centered computing → Information visualization; Mixed / augmented reality;

Introduction & Background
The last few years saw significant advances in the still-young research field of *Immersive Analytics* (IA) [9]. Commercial AR and VR hardware is available and Mixed Reality

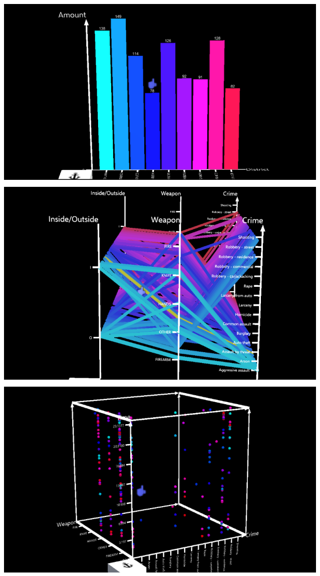

Figure 2: Some of the visualizations supported by *CollARVis*: histograms, parallel coordinate plots, and scatterplots.

visualization frameworks such as IATK [6] and DXR [12] have been developed, in many cases decreasing the barriers of entry into the field.

Accordingly, a number of works have been published in IA and the surrounding areas, including both research on systems/environments (e.g., [5]) and on specific aspects such as visual link routing ([11]), interaction (e.g., [7]), or investigations of individual visualization types (e.g., graphs [3]). At the same time, however, adoption for real-world use cases in professional settings seems to be lagging behind. There are first examples of evaluation in more realistic use cases (e.g., [1, 10]) but clearly, a variety of challenges still remain to make IA truly practical. Here, we specifically examine collaborative immersive visualization in Augmented Reality. We first describe our in-house AR visualization toolkit, *CollARVis*. Then, we discuss challenges that we identified during its design and while applying it to our research. We also point out how these challenges of collaborative AR visualization might be addressed in the future.

A Prototypic AR Visualization Toolkit

We built *CollARVis*, a prototypic AR visualization toolkit for the Microsoft HoloLens, using the Unity 3D engine. It is based on *VinkedViews* [8] and uses Microsoft's HoloToolkit[1]. *CollARVis* supports loading arbitrary data tables from CSV files and to visualize the data in a set of different 2D and 3D visualizations that can be placed freely in the environment (see Figure 1). Currently, our toolkit supports scatter plots, histograms, parallel coordinate plots, and line charts, each in 2D and 3D (see Figure 2). We specifically designed *CollARVis* to be multi-user capable with one device acting as the server that all other clients connect to. No additional server infrastructure is necessary, allowing for co-located collaborative exploration of data sets in different environments with minimal setup effort (see Figure 1).

[1]Microsoft HoloToolkit: https://github.com/microsoft/MixedRealityToolkit-Unity/tree/htk_development

In a typical workflow, the first user takes the server role and all additional users would then connect via a session browser. The users are presented with a workbench-like UI where they can load a dataset. After the data has been loaded, the workbench shows all variables in the dataset (see Figure 3). Users create new visualizations by picking a subset of variables and then choosing the desired type of visualization (see Figure 4). Only those visualizations that match the number and type of the selected variables are shown. All users can explore the data collaboratively, no distinction between user roles is made. Once placed, visualizations can be moved and rotated freely (see Figure 6). They can also be temporarily disabled or deleted completely. All changes to the visualizations are synchronized between users in real time.

During the development and use of our toolkit, both in our research projects and in students' projects, we noticed different challenges for actual, practical use. In addition, we also carried out more structured hands-on sessions with colleagues from the department to collect additional insights into these challenges. In the following, we discuss these insights and approaches to address them. For some of the challenges, we have initial measures in place in our prototype, others remain for future work.

Challenges

We roughly divide the challenges into three groups: Technical challenges related to the software architecture and low-level features, workflow challenges related to different usability aspects, and the challenge of how to evaluate collaborative immersive visualization prototypes.

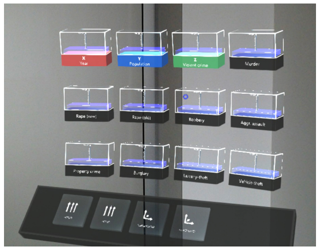

Figure 3: Configuration menu in our toolkit. Users can freely select variables and then choose between all matching visualizations. Here, three variables are selected and highlighted in red, blue, and green.

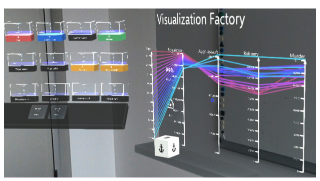

Figure 4: After choosing five variables (highlighted) and selecting 2D parallel coordinate plot as the type, the new visualization is spawned.

Technical Challenges
Even with the progress in hardware capabilities and tool support that we have seen in the recent past, technical challenges still remain.

Networking On a technical level, fast and reliable networking between the devices is one of the fundamental challenges inherent to collaborative systems. In principal, a multitude of solutions exist. However, when specifically looking for network libraries running both on the HoloLens and working within Unity, there are surprisingly few options, most of which are low-level in nature. As such, adding multi-user support to an existing solution is especially challenging. Ideally, this has to be considered already in the early design phase. In our experiences, even then, new functionality will regularly lead to additions to the net code.

Registration & Hologram sharing Providing the users with a stable, unified coordinate system is a particular challenge. The HoloLens supports the concept of serializing world anchors, i.e., descriptors of local spatial properties, to allow multiple devices to share one coordinate system. However, in our experience these world anchors lack precision and also quickly become unstable when multiple users dynamically occlude parts of the environment or the environment itself changes. All of these cases regularly manifested during demonstrations, both in-house and on conferences. To position content relative to specific real-world objects, we also used optical marker tracking (typically using Vuforia). Orientation precision, in particular, was often unsatisfactory. Thus, a more practical solution includes an additional manual alignment step. In [4], we used an infrared marker tracking system to track both a HoloLens and a phone and to bring them into a shared coordinate system. However, this approach is not suitable outside of instrumented research labs.

Framework extensibility & performance To increase general flexibility or to address specific use cases, any practical framework will support some form of extensibility. On the other hand, performance optimizations are often necessary when developing for the HoloLens. A resulting problem, which we observed in current solutions, is that shaders are used to draw data objects, e.g., the glyphs in a scatter plot. While this can lead to significant performance advantages, it also means that any changes to, e.g., selection or highlighting become non-trivial, as shader code needs to be rewritten.

Workflow Challenges
In addition to technical obstacles, there are also workflow issues regarding collaboration in immersive visualization.

Interaction Interaction for Immersive Analytics has been researched for quite some time, and rightly so, as natural interaction is one of the potential advantages compared to traditional setups [2]. Despite this, current mid-air gestural interfaces as used by the HoloLens (both the original and, although more sophisticated, its successor) are cumbersome and, for many users, quite hard to grasp. A practical solution needs to support both the quick setup of visualizations including their general configuration, filtering, etc. and fast navigation & selection techniques. Using additional input devices may address this. To this end, we proposed combined spatial/touch input with mobile phones for panning and zooming in 3D data spaces [4]. We believe that relying on well-known, available devices for input would be beneficial for productive use. In addition, these devices could function as additional personal screens during group work. One particular use case is the configuration of visualizations. In light of the strenuous deployment process for the HoloLens, users need to be able to select, spawn, and reconfigure visualizations at runtime. In addition to

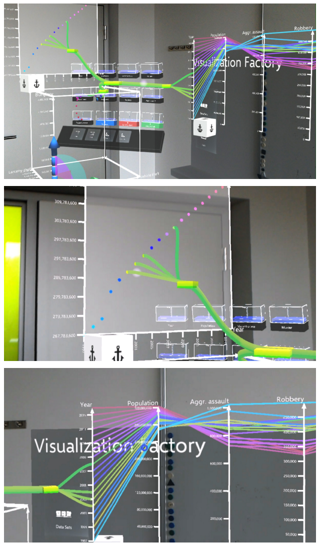

Figure 5: Visual links between data objects help to locate views and emphasize logical connections among them.

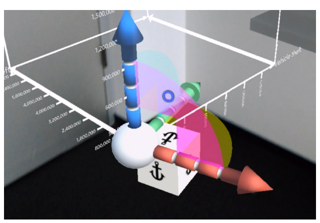

Figure 6: Translation widget on a visualization. Visualizations can be arranged freely in physical space. Using world anchors and persistent configurations, a setup can be restored in place at a later time.

the immersive workbench approach pointed out above, we also tested mobile phones as configuration interfaces in *CollARVis*. Offloading this part of the interface to a phone frees up space for the actual visualizations and reduces occlusion for the collaborators. It is also less cumbersome for this type of GUI-centric interaction than mid-air gestures.

Awareness One advantage of an Augmented Reality system, compared to Virtual Reality, is better awareness of the surroundings and, for collaborative systems, the other users. However, awareness is still limited. The eyes are covered by HMDs, spatially distributed content may lead to collaborators not facing each other at all times, and individual data views may erode the concept of a shared context. Thus, we believe that supporting awareness of the other users' actions is an important challenge. In our toolkit we currently support this in two ways. We use visual links between selected data objects in different visualizations. This helps users by pointing out relations of the individual views and serves as a spatial cue to visualizations outside their field of view (see Figure 5). We also highlight users by drawing a marker over their head (see Figure 1). While this may seem trivial at first, it shows whether a user is connected to the system or merely wearing their HoloLens. It also serves as a real-time indicator of tracking/registration quality and could be extended to show labels or color-coded status information.

Persistence & Transitions An aspect that is typically out of scope for research prototypes is to enable smooth transitions between collaborative work and phases of more traditional, individual work. This includes the persistence of workspace configurations needed to come back to the system later on. During the work with *CollARVis*, we found that the configuration of the workspace, i.e., loading data, spawning visualizations, etc. requires some effort, even if considerable thought is put into designing the UI. We address this by allowing users to save and load workspace configurations. In our current implementation, workspaces are always loaded in addition to the current scene, allowing users to combine pre-configured views at will.

Evaluation Challenges
Finally, we see the evaluation of current and future systems as one of the principal challenges of collaborative immersive visualization. The evaluation of any multi-user system already poses challenges such as acquiring enough participants (especially domain experts), complex multi-device setups, fusion of log files, etc. For Augmented Reality systems, this is exacerbated by the difficulty to visualize and analyze 3D spatial interaction in environments containing both physical and virtual objects. However, if we want to examine the use of physical space, awareness of the collaborators' actions & system state, or user roles, we need tools that support such use cases while preserving the often important relations between the physical environment and the virtual content. Toolkits such as MRAT [10] are a first step in this direction.

Conclusion
In this paper we examined typical challenges in the development of collaborative immersive visualizations in Augmented Reality. Building on the experiences with our AR visualization toolkit, *CollARVis*, we identified technological challenges, challenges for typical workflows, and the challenge of evaluating such systems. We also briefly discuss first steps to address some of these challenges. We hope that these insights can help to nurture the discussion on how we can bring Immersive Analytics into real-world use.

Acknowledgments

This work was funded by the German Research Foundation (DFG, Deutsche Forschungsgemeinschaft) under Germany's Excellence Strategy – EXC-2068 – 390729961 – Cluster of Excellence Physics of Life of TU Dresden, as part of TRR 248 (grant 389792660), and DFG grant CollabWall (DA 1319/11-1).

REFERENCES

[1] Andrea Batch, Andrew Cunningham, Maxime Cordeil, Niklas Elmqvist, Tim Dwyer, Bruce H. Thomas, and Kim Marriott. 2020. There Is No Spoon: Evaluating Performance, Space Use, and Presence with Expert Domain Users in Immersive Analytics. *IEEE Transactions on Visualization and Computer Graphics* 26, 1 (Jan 2020), 536–546. DOI: http://dx.doi.org/10.1109/TVCG.2019.2934803

[2] Wolfgang Büschel, Jian Chen, Raimund Dachselt, Steven Drucker, Tim Dwyer, Carsten Görg, Tobias Isenberg, Andreas Kerren, Chris North, and Wolfgang Stuerzlinger. 2018. *Interaction for Immersive Analytics*. Springer International Publishing, Cham, 95–138. DOI: http://dx.doi.org/10.1007/978-3-030-01388-2_4

[3] Wolfgang Büschel, Stefan Vogt, and Raimund Dachselt. 2019. Augmented Reality Graph Visualizations: Investigation of Visual Styles in 3D Node-Link Diagrams. *IEEE Computer Graphics and Applications* 39, 3 (2019), 29–40. DOI: http://dx.doi.org/10.1109/MCG.2019.2897927

[4] Wolfgang Büschel, Annett Mitschick, Thomas Meyer, and Raimund Dachselt. 2019. Investigating Smartphone-Based Pan and Zoom in 3D Data Spaces in Augmented Reality. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '19)*. Association for Computing Machinery, New York, NY, USA, Article Article 2, 13 pages. DOI: http://dx.doi.org/10.1145/3338286.3340113

[5] Marco Cavallo, Mishal Dolakia, Matous Havlena, Kenneth Ocheltree, and Mark Podlaseck. 2019. Immersive Insights: A Hybrid Analytics System ForCollaborative Exploratory Data Analysis. In *25th ACM Symposium on Virtual Reality Software and Technology (VRST '19)*. Association for Computing Machinery, New York, NY, USA, Article Article 9, 12 pages. DOI: http://dx.doi.org/10.1145/3359996.3364242

[6] Maxime Cordeil, Andrew Cunningham, Benjamin Bach, Christophe Hurter, Bruce H. Thomas, Kim Marriott, and Tim Dwyer. 2019. IATK: An Immersive Analytics Toolkit. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 200–209. DOI: http://dx.doi.org/10.1109/VR.2019.8797978

[7] Adam Drogemuller, Andrew Cunningham, James Walsh, Bruce H. Thomas, Maxime Cordeil, and William Ross. 2020. Examining virtual reality navigation techniques for 3D network visualisations. *Journal of Computer Languages* 56 (2020), 100937. DOI: http://dx.doi.org/https://doi.org/10.1016/j.cola.2019.100937

[8] Georg Eckert. 2019. *Vinked Views: An augmented reality app for immersive analytics*. limbusdev, Dresden, Germany. https://github.com/limbusdev/VinkedViewsMR Based on commit 26e4a05.

[9] Kim Marriott, Falk Schreiber, Tim Dwyer, Karsten Klein, Nathalie Henry Riche, Takayuki Itoh, Wolfgang Stuerzlinger, and Bruce H Thomas. 2018. *Immersive Analytics*. Vol. 11190. Springer. DOI: http://dx.doi.org/10.1007/978-3-030-01388-2

[10] Michael Nebeling, Maximilian Speicher, Xizi Wang, Shwetha Rajaram, Brian D. Hall, Zijian Xie, Alexander Raistrick, Michelle Aebersold, Edward G. Happ, Jiayin Wang, Yanan Sun, Lotus Zhang, Leah E. Ramsier, and Rhea Kulkarni. 2020. MRAT: The Mixed Reality Analytics Toolkit *(to appear at CHI 2020)*.

[11] Arnaud Prouzeau, Antoine Lhuillier, Barrett Ens, Daniel Weiskopf, and Tim Dwyer. 2019. Visual Link Routing in Immersive Visualisation. In *International Conference on Interactive Surfaces and Spaces 2019*. Daejon, South Korea. DOI: http://dx.doi.org/10.1145/3343055.3359709

[12] Ronell Sicat, Jiabao Li, Junyoung Choi, Maxime Cordeil, Won-Ki Jeong, Benjamin Bach, and Hanspeter Pfister. 2019. DXR: A Toolkit for Building Immersive Data Visualizations. *IEEE Transactions on Visualization and Computer Graphics* 25, 1 (Jan 2019), 715–725. DOI: http://dx.doi.org/10.1109/TVCG.2018.2865152