Evaluating 3D User Interaction Techniques on Spatial Working Memory for 3D Scatter Plot Exploration in Immersive Analytics

ISMAR 2023 (Conference Track)

Dongyun Han[1] and Isaac Cho[1] ([1]Utah State Univ.)

Jiwon Choi (2023713254)

Dept. of Computer Science and Engineering, SKKU

Table of Contents

Introduction

- Some visualization could be **more effective in immersive environments** (IE) than 2D desktop [2, 8, 9, 13, 16]

- Understanding **spatial working memory support** of interaction techniques is **critical in visual analytics** [4, 10, 11]

- However, it is unclear **how 3D user interaction** methods impact users' **spatial working memory** for immersive analytics.

Contribution

- **Evaluating the effectiveness of 3D user interaction techniques in Immersive Analytics**
  - (Walking, Teleportation, Grab) * (AR, VR) w. Corsi block-tapping test
- **Result**
  - Walking > Grab > Teleportation(VR)
  - Accuracy: AR is better than VR
  - Time: VR is better (shorter time) than AR

Related Work

- **Immersive Analytics**
  - Removes barriers between analysts and data to explore and analyze data-driven problems in the immersive settings of VR and AR.
  - Distance estimation [8], cluster identification [2, 9, 13], and outlier detection [16] were 3D > 2D
  - However, only a few studies have looked **at 3D user interaction techniques to support users' active immersive analytics tasks** in IEs.

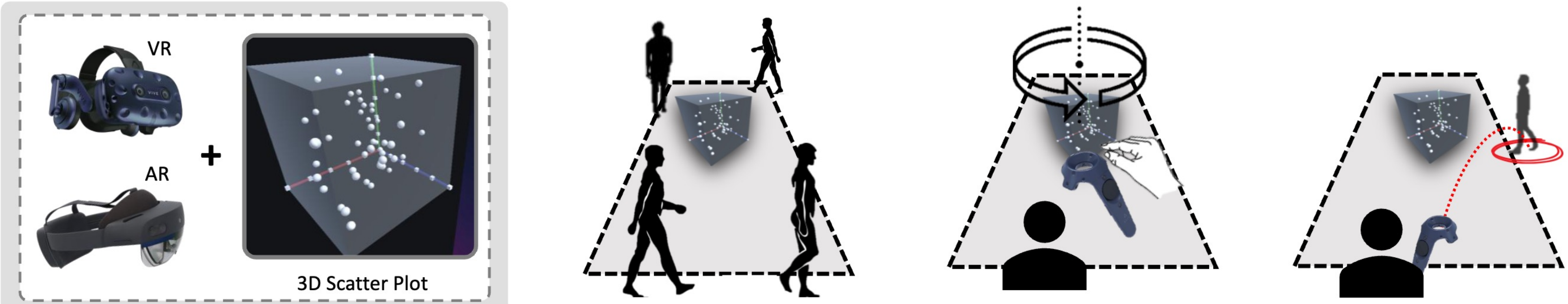
Related Work

- **Interaction Techniques for Immersive Analytics**
  - Natural and intuitive user interactions are essential for users to do effective immersive analytics [3, 12, 15].
  - However, still unclear how effectively 3D user interaction techniques support users' low-level tasks such as **memorizing** and **recalling** individual data for 3D data exploration.

Related Work

- **Interaction Techniques for Immersive Analytics**
  - Walking
    - Users can physically walk within IEs to navigate a 3D plot
  - Teleportation (only VR)
    - If the user points to a floor position by using an input device and activates Teleportation, the user will instantly move to that location [5]
  - Grab
    - Grab a 3D plot by operating one controller or hand and changing its orientation to see the plot from a different perspective

Related Work

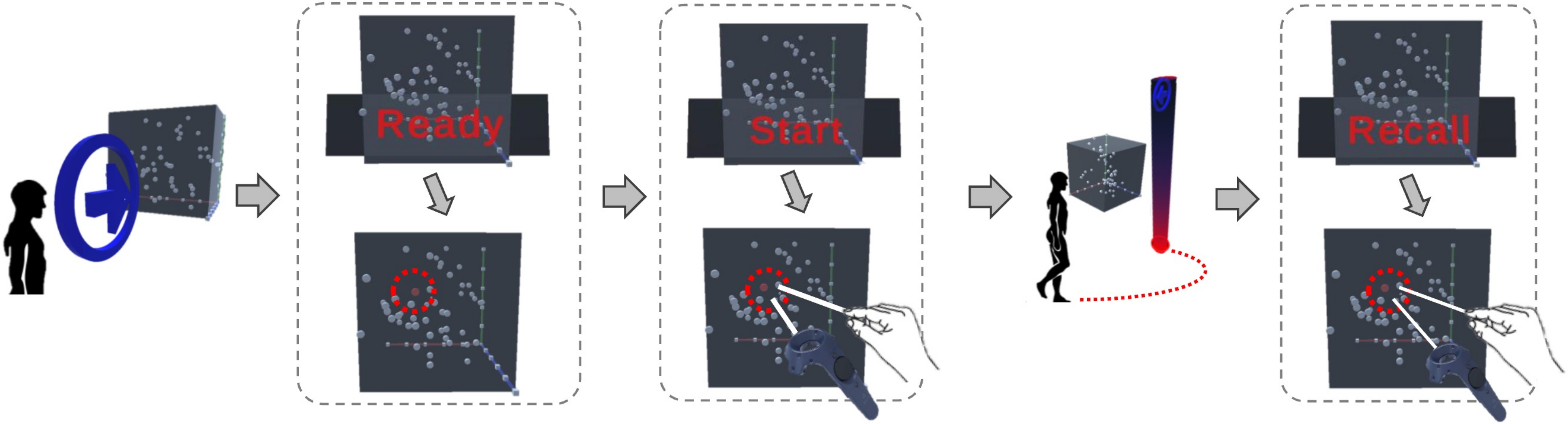


(a) Immersive Analytics (b) Walking (c) Grab (d) Teleportation

Method

- **Visuo-spatial Working Memory**
  - Capacity to maintain visuo-spatial information for a short term [14].
- **Corsi block-tapping task**
  - Psychological test for assessing the visuo-spatial working memory
  - Nine block, highlight by sequence, imitate the highlighting sequence (5~6 by AVG)
- **Ours**
  - 3D Scatterplot (with 30 data points), Length 3 Corsi Span

Method



(a) Start New Trial (b) Memorizing Stage (c) First Tapping Task Stage (d) Interaction Stage (e) Second Tapping Task Stage

Hypothesizes and Results (VR)

H1: (Accuracy) Walking and Grab > Teleportation

H2: (Interaction Time) Teleportation is Best

H3: (Sickness) Teleportation is Worst (High VR Sickness)

H4: Primacy Effect [6, 7]

Distance errors will increase with tapping order

Supported, Partial Supported, Rejected

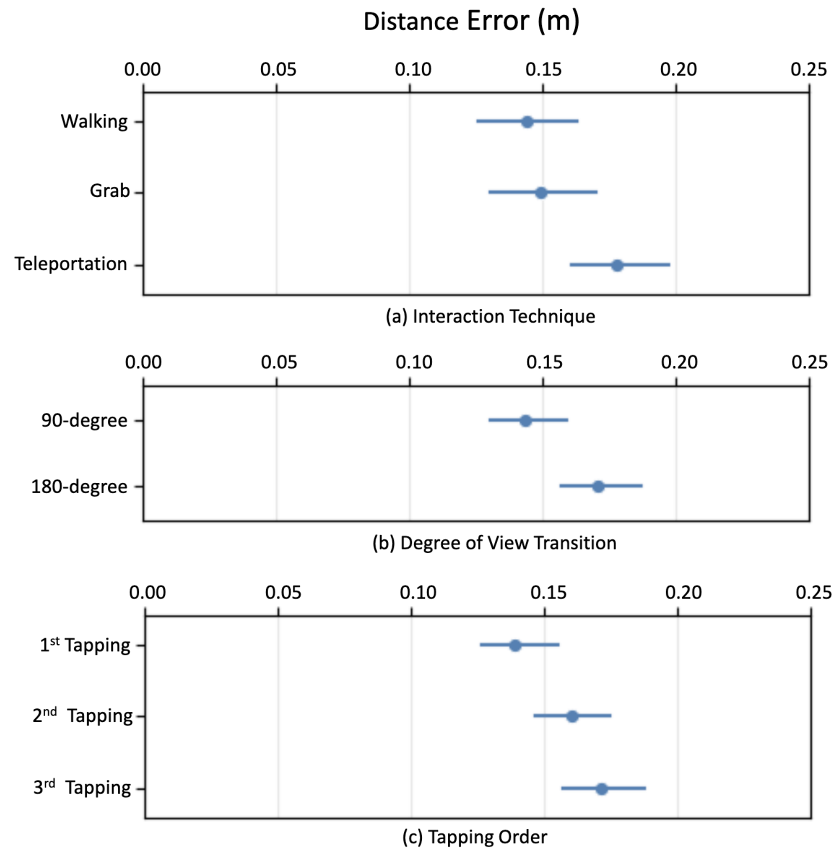


Figure 4: Distance Error Results with 95% CI in VR.

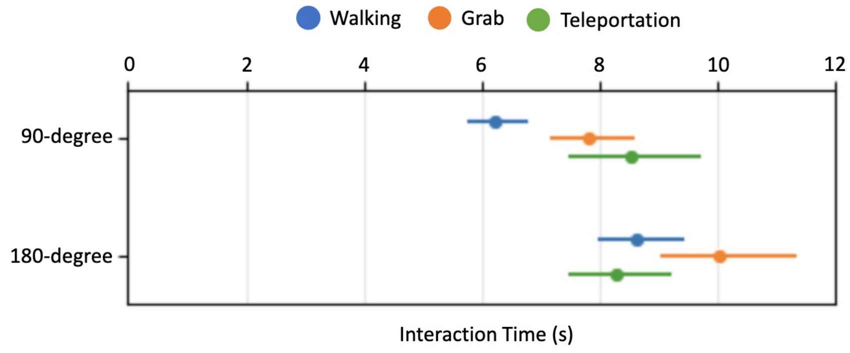


Figure 5: Interaction Time Results with 95% CI in VR.

Hypothesizes and Results (VR)

Table 1: **Results on Distance Error at Second Tapping Task in VR**

Factor	*DOF*	*F*	*p*	$\eta_p{}^2$
Technique × View Transition Angle	2, 178	.171	.843	.002
Technique × Tapping Order	4, 356	1.09	.358	.012
View Transition Angle × Tapping Order	2, 178	1.53	.218	.017
Technique	2, 178	5.17	.007	.055
View Transition Angle	1, 89	6.68	.011	.070
Tapping Order	2, 178	7.29	$<.001$	.076

Hypothesizes and Results (AR)

H5. (Accuracy) Walking and Grab are similar

H6. (Interaction Time) Walking is better than Grab

H7. (Sickness) Walking and Grab are similar

H8: Primacy Effect [6, 7]

Distance errors will increase with tapping order

Supported, Partial Supported, Rejected

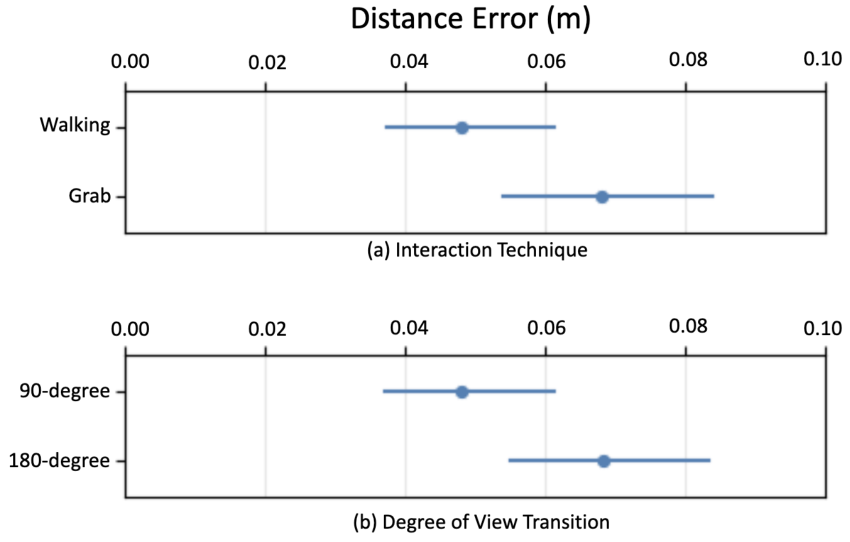


Figure 7: Distance Error Results with 95% CI in AR.

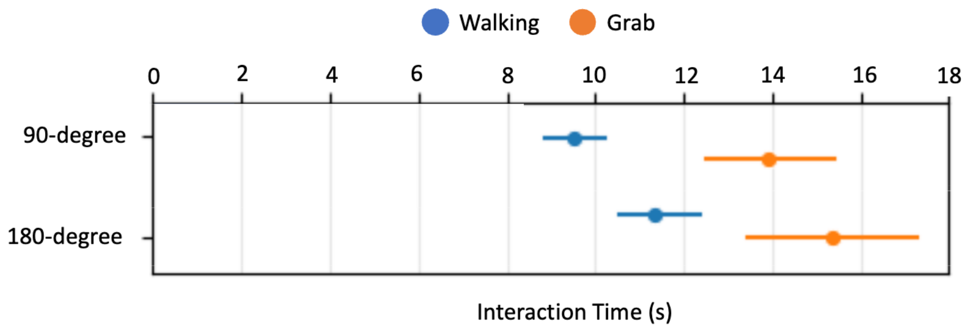


Figure 8: Interaction Time Results with 95% CI in AR.

Hypothesizes and Results (AR)

Table 2: **Results on Distance Error at Second Tapping Task in AR**

Factor	*DOF*	*F*	*p*	$\eta_p{}^2$
Technique × View Transition Angle	1, 49	.406	.527	.008
Technique × Tapping Order	2, 98	.920	.402	.018
View Transition Angle × Tapping Order	2, 98	.331	.719	.007
Technique	1, 49	6.09	.017	.111
View Transition Angle	1, 49	5.11	.028	.094
Tapping Order	2, 98	1.37	.257	.027

Hypothesizes and Results (VR vs AR)

H9. (Accuracy) VR is better than AR

H10. (Interaction Time) VR and AR walking are similar

H11. (Interaction Time) VR and AR grab are different

Supported, Partial Supported, Rejected

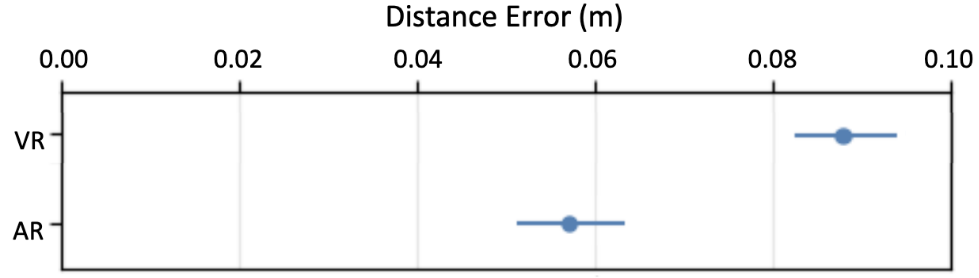


Figure 9: Distance Error Results with 95% CI in VR and AR. The VR results are normalized by multiplying the errors by 0.6.

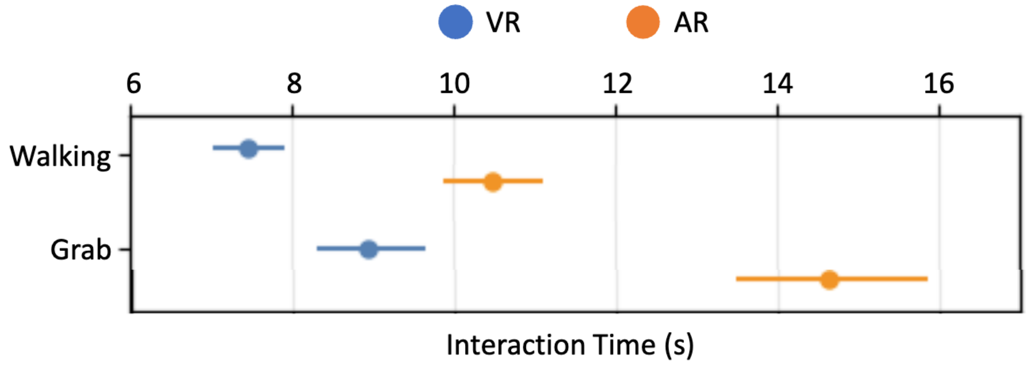


Figure 10: Interaction Time Results with 95% CI for Walking and Grab in VR and AR.

Discussion

- **Walking is best in both VR and AR**
- **AR is better than VR in terms of Working memory**
  - Environments work as anchor not distractors
- **Larger transition movements impair spatial memory performance**
- **3D user interaction techniques have comparable motion sickness**
- **Highlighting/annotation techniques would help users in low-level data exploration in IEs.**

Review

- **Analysis**
  - Critical research for immersive analytics.
  - The fact that study was limited to 3D Scatterplot is big limitation
  - Poorly addressing many low-level tasks [1] in information visualization.

- **My Future Direction**
  - Interaction techniques of immersive analytics for collaborative analysis
  - Investigate effectiveness 3D interactions by different low-level task [1]

References

[1] R. Amar, J. Eagan, and J. Stasko. Low-level components of analytic activity in information visualization. In IEEE Symposium on Information Visualization, 2005. INFOVIS 2005., pp. 111–117. IEEE, 2005.

[2] L. Arns, D. Cook, and C. Cruz-Neira. The benefits of statistical visualization in an immersive environment. In Proceedings IEEE Virtual Reality (Cat. No. 99CB36316), pp. 88–95. IEEE, 1999.

[3] D. Belcher, M. Billinghurst, S. Hayes, and R. Stiles. Using augmented reality for visualizing complex graphs in three dimensions. In The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings., pp. 84–93. IEEE, 2003.

[4] D. Belcher, M. Billinghurst, S. Hayes, and R. Stiles. Using augmented reality for visualizing complex graphs in three dimensions. In The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings., pp. 84–93. IEEE, 2003.

[5] D. A. Bowman, D. Koller, and L. F. Hodges. Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality, pp. 45–52. IEEE, 1997.

[6] J. Deese and R. A. Kaufman. Serial effects in recall of unorganized and sequentially organized verbal material. Journal of experimental psychology, 54(3):180, 1957.

[7] B. B. Murdock Jr. The serial position effect of free recall. Journal of experimental psychology, 64(5):482, 1962.

[8] R. Etemadpour, E. Monson, and L. Linsen. The effect of stereoscopic immersive environments on projection-based multi-dimensional data visualization. In 2013 17th International Conference on Information Visualisation, pp. 389–397. IEEE, 2013.

[9] M. Kraus, N. Weiler, D. Oelke, J. Kehrer, D. A. Keim, and J. Fuchs. The impact of immersion on cluster identification tasks. IEEE Transactions on Visualization and Computer Graphics, 26(1):525–535, 2019.

[10] J. H. Larkin and H. A. Simon. Why a diagram is (sometimes) worth ten thousand words. Cognitive science, 11(1):65–100, 1987.

[11] G. L. Lohse. The role of working memory on graphical information processing. Behaviour & Information Technology, 16(6):297–308, 1997.

[12] W. E. Marsh, J. W. Kelly, V. J. Dark, and J. H. Oliver. Cognitive demands of semi-natural virtual locomotion. Presence: Teleoperators and Virtual Environments, 22(3):216–234, 2013.

[13] L. Nelson, D. Cook, and C. Cruz-Neira. Xgobi vs the c2: Results of an experiment comparing data visualization in a 3-d immersive virtual reality environment with a 2-d workstation display. Computational Statistics, 14(1):39–51, 1999.

[14] M. Rizzo and S. Vecera. Psychoanatomical substrates of balint's syndrome. Journal of Neurology, Neurosurgery & Psychiatry, 72(2):162– 178, 2002.

[15] H. Slay, M. Phillips, R. Vernik, and B. H. Thomas. Interaction modes for augmented reality visualization. In InVis. au, pp. 71–75, 2001.

[16] J. A. Wagner Filho, M. F. Rey, C. M. Freitas, and L. Nedel. Immersive visualization of abstract information: An evaluation on dimensionally-reduced data scatterplots. In 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 483–490. IEEE, 2018