Exploring hybrid reality environments for overview+detail tasks in immersive data visualisation

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Abstract

There have been a lot of advances in the field of Augmented Reality (AR), but there is limited research on the combined usage of AR and physical displays (known as Hybrid Reality Environments). We explore hybrid reality environments using a combination of Augmented Reality and high-density displays for large graph visualisation. We present the design of a system and early observation from a pilot study involving navigation in such a system.

Keywords

Hybrid Reality Environments, Augmented Reality, Immersive Analytics, Visaulisation

1. Introduction

There currently exists no ultimate display technology that has high-density, 3D stereoscopy, 360 degree field of view, and natural interaction. Conversely, the demands for visualising complex data accurately and in high-fidelity, as espoused by the emerging field of Immersive Analytics, is growing. In this work, we begin to explore a form of *hybrid reality environments* consisting of the combination of multiple display technologies, across conventional displays and Augmented Reality (AR), to support presenting large graph visualisations.

Traditional physical displays can provide a twodimensional (2D) view into the three-dimensional (3D) world. However, such projection loses stereoscopy and, as such, important information and cues may be lost in the resulting view. This is apparent in big data visualisation, where the high number of data points make the visualisation too dense to usefully interpret. Regular monitors have a small viewport which limits the information that can be displayed on them. To overcome this limitation, large displays like a CAVE system can be used to maximise information displayed. However, they are still limited to projecting information onto (or beyond) the display wall.

AR and Virtual Reality (VR) can be used to overcome some of these limitations as information is presented in stereoscopy and can appear directly in the user's sphere

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of interaction. This enables users to view a 3D visualisation from different perspectives by walking around it and fully utilising the spatial capabilities that VR/AR provides [1]. Using a 3D display such as the Hololens, for example, can improve the information presented by disambiguating the clutter found in 2D displays [2]. This makes the information presented more readable. The drawback with these types of displays are the limited resolution, field-of-view, and the low-performance power (in the case of AR). While most Immersive Analytics research focuses on either head-mounted displays *or* CAVE style displays [1] separate, there is value in leveraging the affordances of both technologies to address the shortcomings of any single technology.

In this work, we are interested in using head-mounted AR devices and high-resolution displays to support Immersive Analytics of large graphs visualisations. Immersive Analytics is "the use of engaging, embodied analysis tools to support data understanding and decision making" [3]. We describe a system that visualises large graph data using an array of large 4K displays in a CAVE-like arrangement to provide a detail of the graph, and a 3D overview of the graph provided by a Microsoft Hololens. We then present some early pilot observations that will guide future development.

2. Background

Data generated by technologies have grown progressively throughout the years. This has resulted in a huge amount of digital structured and unstructured data which is also known as "Big Data". It is difficult to make sense of these large set of data without any medium of conveying information. *Data visualization* plays a key role in making humans understand the complexity and the links between the data by externalising it through computer visualisation and human-computer interactions [4].

Information Visualisation (InfoVis) is a specific area

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of data visualisation concerned with the visualisation of abstract data. Such abstract data can include graphs or network data (such as social network [5]) which compose of a significant proportion of big data. Graph visualisation involves projecting network data, often as nodes and links between nodes, using a particular layout [6]. It is recognised in InfoVis that users benefit from an overview of the data to orientate themselves and identify points of interest. *Overview + Detail* is a set of InfoVis techniques that use multiple views, where one view shows an overview and another shows a detail view linked through interaction and visual cues [7].

2.1. Immersive visualisation

Throughout the last three decades, InfoVis has explored concepts of 3D visualisation on 2D displays [7], including 3D graph visualisation [8]. However, more recent research has been exploring the affordances of modern Virtual Reality (VR) and Augmented Reality (AR) technology for InfoVis tasks. Immersive Analytics is this area of research exploring the use of immersive technologies such VR and AR to support data understanding and decision making [9, 10]. The aim of Immersive Analytics is to solve the problem of interpreting big data visualisation with the use of natural (or embodied) interaction techniques. ImAxes [11] is such an Immersive Analytics tool for VR that demonstrates this characteristic of directly manipulating data by grabbing and moving it.

Graph visualisation has been explored in Immersive Analytics. Drogemuller et al. [12] developed a system for visualising large network data using VR. They subsequently evaluated techniques for navigating these networks [5]. One of the key techniques explored by the authors was a form of Overview+Context known as Worldsin-Miniature (WIM) [13], where an miniature version of the world (or in that particular case, a miniature graph) is presented to provide context to the user.

2.2. Hybrid reality environments

Febretti et al. [14] define hybrid reality environments as having the following characteristics: C1) a large highresolution display "approaching the sphere of influence and perception of a human", C2) stereoscopic support to visualise 3D data, C3) natural interactions, C4) space to support collocated collaboration, and C5) a software architecture to integrate the displays and interaction. Febretti et al. presented the CAVE2 system as addressing these characteristics. CAVE2 is a Cave Automatic Virtual Environment (CAVE) with stereoscopic high-density displays and tracked head and wand interaction. With the CAVE2 System, information was able to be presented more effectively to improve spatial understanding.



Figure 1: An array of large high-density 4K displays arranged in an arc. We refer to this setup as the CAVE display.

It is worth noting that while the CAVE2 demonstrates Febretti et al.'s hybrid reality characteristics using a single display technology, the definition does no preclude the use of *multiple* display technologies to address the characteristics. SecondSight [15] demonstrates a mobile phone coupled with an AR HMD to visualise data, in what the authors refer to as a hybrid *interface*. However, it should be noted that SecondSight does not meet characteristic C1 (a display approaching the sphere of percetion of a human) of Febretti et al.'s definition of hybrid reality.

One study [16] found that the interaction techniques between the devices in a hybrid reality environment can be inconsistent and discussed having to implement different interaction methods for the different devices in the environment. They built a framework for unified interaction scheme for the different displays in the Hybrid reality environment which is widely used for CAVE2 systems.

3. Hybrid reality visualisation system

It can be recognised that various display modalities (such as traditional displays or the Microsoft Hololens) have different benefits and shortcomings suited to particular tasks. We sought to overcome the limitation of a single modality by coupling the 2D environment of physical displays and the 3D environment of HoloLens to take advantage of the capabilities of both the systems while overcoming their singular limitations. This encourages collaborative use of the system and reduces the potential difficulty in analysing and interpreting the big data visualisation.

We developed a hybrid reality system for visualising large graph data (see Figure 1). This system was comprised of two display modalities: 1) four high-resolution 4K displays arranged in an arc (referred to as the CAVE for brevity's sake) and, 2) a Microsoft Hololens worn by the user. This combination of display technologies addresses C1–C4 of Febretti et al.'s hybrid reality. Our integrated system is shown in Figure 2.

The last characteristic (C5) of a hybrid reality system requires that the displays and interaction are part of a single synchronised environment, and the displays project aspects of that shared environment. From an implementation perspective, this requires a networking solution to synchronise the displays and design considerations as to aspects of the environment should appear in each display modality.

In the rest of this section, we describe the design of this system, first describing the general architectural design of the system to support hybrid reality followed by the specific design of the graph visualisation.

3.1. System Architecture

Our system is developed in Unity 2019. The system architecture is composed of a positional tracking layer, networking layer, a display configuration layer, and an interaction layer. For the **positional tracking**, we use the Optitrack Flex motion camera system. All displays within the environment are tracked, including the CAVE displays and the Hololens, using the the Optitrack.

For the **networking** and **display configuration**, we used the High-End Visualisation System (HEVS), a Unity framework developed by the University of New South Wales' EPICentre for running synchronous applications [17]. HEVS is a high-performance networking solution designed as framework for synchronising 3D environments with traditional displays. HEVS uses a JSON configuration file to define the position and relative orientation of the displays.

To enable hybrid reality environments, we expanded the HEVS framework to support the HoloLens. As the Hololens is a moving display, this required adapting the static display configuration of HEVS to support moving frames of reference. This modification forms the founda-



Figure 2: A view of our hybrid reality system visualising a spherical graph layout. A **detailed** graph is visualised on a array of large high-density 4K displays, while a 3D **overview** is provided in the Hololens.

tion of our **interaction** layer. The Hololens intergration affords two key aspects of interaction:

- 1. The system is able to track the user and their viewing direction in the physical environment, projecting the CAVE display from their point of view.
- 2. The natural hand interaction present in the Hololens can be used to interact with the virtual environment, including the CAVE displays.

This architecture enables a hybrid reality environment composed of multiple display modalities. A user is able to use the Hololens to visualise low-resolution but 3D information, while the CAVE can visualise high-density information but in 2D projection, all in a synchronised and shared virtual environment. Manipulating objects in the shared virtual environment is reflected across all display modalities.

Selective displays: One of our key insights when developing this system was that, while the displays should be in a shared synchronised environment to be considered hybrid reality, *the display do not need to, nor should they, project all aspects of the environment.* The displays should project aspects of the environment that they are most effective at displaying. For example, the Hololens has a relatively low-resolution with a small field-of-view but can do stereoscopic projection; as such, it is better suited to showing small 3D aspects of the environment. To enable this, we added support to tag objects within the virtual environment to appear in displays with specific capabilities.

3.2. Graph visualisation in hybrid reality

To explore our hybrid reality system, we applied it to the visual analytics task of graph visualisation. We created a virtual environment with a spherical graph layout with the user placed in the centre of the sphere. The CAVE displays sit in an arc within the sphere, thus projecting some of the graph layout onto the CAVE displays. An overview visualisation, in the form of a worlds-inminiature (WIM), sits in the centre of the environment. Graph nodes were presented in high-detail with textual labels in the CAVE display due to its high pixel-density, while only an abstract overview was presented in the WIM.

We chose a spherical graph layout as they have previously been demonstrated to be more efficient than 2D layouts for certain tasks in immersive environments [18]. To create the layout, we first apply a 3D force directed layout [19] to the graph. Then, for each node n in the layout, we project its position onto surface of a sphere:

$$pos(n) = \lambda \frac{n_{xyz} - C_{xyz}}{|n_{x,y,z} - C_{xyz}|}$$
(1)

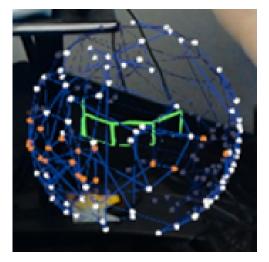


Figure 3: The graph overview hologram. The CAVE display is represented by the green outline. Nodes in orange are visible on the CAVE display.

Where C_{xyz} is the centre of the force directed graph layout and λ is the radius of the spherical projection. We set to 4 m which places the circumference of the sphere projection outside the arc of our CAVE displays.

Overview (Worlds in Miniature) design: To provide an overview visualisation, we include a Worlds-in-Miniature (WIM) in the centre of the environment. This WIM is projected into the Hololens display to leverage the Hololen's affordances of direct hand interaction and stereoscopic 3D visualisation. Users could rotate the WIM by pinching and dragging it with their fingers.

We used an iterative design process to develop the graph visualisation and WIM. An initial issue we came across was the user not knowing which nodes of the WIM could be seen in the CAVE display. Initially, we solved this by drawing the relative location of the CAVE displays as a green outline inside the sphere of the WIM. We further highlight nodes orange when they were visible on the cave display, as shown in Figure 3.

4. Pilot study

We ran a pilot study with three participants to gain some early observations of how hybrid reality environments could be used to navigate a complex graph visualisation. View navigation (in this case, rotating the spherical graph to locate particular nodes) is a fundamental task in visualisation and a good task to examine for hybrid display modalities. During the pilot, participants performed two related navigation tasks:

· Minimal task: Participants were asked to orientate

the graph so that the minimum number of nodes possible were present on the high-resolution displays.

• Maximal task: Participants were asked to orientate the graph so that the maximum number of nodes were present on the high-resolution displays.

The graphs were comprised of 60 nodes, with some nodes labelled with a letter. While orienting the graph, participants had to ensure that nodes labelled with the letters A to H were present in the CAVE display. This ensured that participants had to use both display modalities and leverages the affordance of the high-density displays to depict text. Participants were given a two-minute time limit for each task, displayed to the participant in the centre of the CAVE display. We measured task **time** and **error**, with error calculated as:

$$error = |O - A| \tag{2}$$

Where O was the optimal number of the nodes that should be present in the CAVE display, and A was the actual number of nodes the participants had in the CAVE display.

4.1. Conditions

The pilot had two display modalities as conditions to compare our hybrid reality environment to conventional displays:

- HoloLens: A 3D overview was presented in the centre of the room using the HoloLens.
- Laptop display: A 3D overview was presented in the centre of the room on a 2D laptop display.

To keep the conditions controlled, both tasks use HoloLens' gesture recognition for input; otherwise this input would not be suitably controlled [20].

4.2. Subjective questionnaire

At the end of the study, participants were asked to fill in a questionnaire composed of a series of Likert questions:

- Q1 I am proficient in using the HoloLens (1-7)
- Q2 I found the HoloLens controls easy to use (1–7)
- **Q3** The rotation input was easy to use with the HoloLens display (1–7)
- **Q4** The rotation input was easy to use with the Laptop display (1–7)
- Q5 The graph was easy to visually analyze in the HoloLens (1-7)

Condition	Task	Average Time	Average Error
HoloLens	Minimal	$45.76\mathrm{s}$	8.8
Laptop	Minimal	$39.37\mathrm{s}$	7.8
HoloLens	Maximal	$32.09\mathrm{s}$	12
Laptop	Maximal	$25.25\mathrm{s}$	8.8

Table 1

Pilot study summary results

- **Q6** The graph was easy to visually analyze in the Laptop display (1–7)
- Q7 Which device do you prefer more to view the graph?
- Q8 Which device do you think you were more accurate?
- Q9 Which device do you think you were faster with?
- Q10 Overall the HoloLens task was (SMEQ 0-150)
- Q11 Overall the Laptop task was (SMEQ 0-150)
- **Q12** Do you have any comments about the methods, or anything related to the tasks?

Questions Q1–Q2 were used to gauge an understanding of how proficient the user is with the HoloLens. Difficulty handling the controls may have an effect on the results. Q10 and Q11 of the questionnaire asked the user to answer how difficult the task was using a Subjective Mental Effort questionnaire [21], or SMEQ. The SMEQ asks the user to give a value from 0 to 150 to indicate how hard a task was to do. SMEQ was chosen over a simple Likert scale because it has been shown to be easy to use by users and reliable [21].

4.3. Design and procedure

Participants experienced 2 (display modalities) \times 6 (graphs). To ensure robustness when performing the study, we adhered to a script. In the script, we go through and explain the purpose of the study and how to use the interaction technique. We also go through some training where we explain how to use the drag gesture to rotate the sphere. There is also a training task for each condition/task pair (4 in total) before the actual began. Following the study, participants were provided the subjective survey to fill.

4.4. Observations

It is important to acknowledge that with such a small participant size, conclusive findings are hard to draw, however, we believe it is still useful to draw qualitative observations from the pilot to inform further design. **Performance:** On average across Minimal and Maximal tasks, the HoloLens was slower and had more error than the Laptop (see Table 1). There were only three users, so these results do not have much weight; however, it is still worth exploring why this may be. In the post-study questionnaire, one participant said that the "small field of view of the HoloLens made it less useful than the Laptop's physical display". Given the nature of the task, this is a big issue. When a user looks at the cave display, the sphere may be out of the view of the HoloLens, while they may still see it in their peripheral on the Laptop.

When looking at each user individually, the results are not as consistent as with the summary. When looking at the average error, two out of three users had less error using the HoloLens for the Minimal Task. It is also worth noting that one user was faster with the HoloLens for the Minimal Task and another was faster with the HoloLens for the Maximal Task.

Participant movement: Movement around the sphere and WIM was encouraged, however all three users showed an insignificant amount of movement. One user moved around the sphere for a single task, but the other users did not move during the HoloLens task at all.

Subjective feedback: There were not enough users in the pilot study to find any patterns from the questionnaire. Even so, there was no consensus for the subjective answers for Q7, Q8 and Q9. Howver, every participant did think that the graph was easier to visually analyse using the HoloLens (Q5 and Q6). The SMEQ value for each user was equal or higher for the HoloLens compared to the Laptop. This would imply having a 3D sphere over a flat view of the sphere involves more mental effort, something found in other studies [22].

5. Conclusions and future work

Hybrid reality environments show promise for specific Immersive Analytics tasks. Through our design, we recognised the value of a single shared environment across the displays, however, *those displays should only show aspects of the environment appropriate for the affordances of that particular display technology*. For example, Hololens may be suited to visualise a WIM in the environments to accomodate its limited field of view.

During the pilot study, we noticed that the users did not move very often from there starting location; it may be worth exploring techniques to encourage them to move around the space and leverage the density of the displays further. In the future, we plan to address these short comings and run a full study to understand the benefits of such environments.

References

- G. Cliquet, M. Perreira, F. Picarougne, Y. Prié, T. Vigier, Towards hmd-based immersive analytics, in: Immersive analytics Workshop, IEEE VIS 2017, 2017.
- [2] C. Ware, P. Mitchell, Visualizing graphs in three dimensions, ACM Transactions on Applied Perception (TAP) 5 (2008) 1–15.
- [3] T. Dwyer, K. Marriott, T. Isenberg, K. Klein, N. Riche, F. Schreiber, W. Stuerzlinger, B. H. Thomas, Immersive analytics: An introduction, in: Immersive analytics, Springer, 2018, pp. 1–23.
- [4] J. Moorthy, R. Lahiri, N. Biswas, D. Sanyal, J. Ranjan, K. Nanath, P. Ghosh, Big data: prospects and challenges, Vikalpa 40 (2015) 74–96.
- [5] A. Drogemuller, A. Cunningham, J. Walsh, M. Cordeil, W. Ross, B. Thomas, Evaluating navigation techniques for 3d graph visualizations in virtual reality, in: 2018 International Symposium on Big Data Visual and Immersive Analytics (BDVA), IEEE, 2018, pp. 1–10.
- [6] J. Díaz, J. Petit, M. Serna, A survey of graph layout problems, ACM Computing Surveys (CSUR) 34 (2002) 313–356.
- [7] M. Card, Readings in information visualization: using vision to think, Morgan Kaufmann, 1999.
- [8] A. Cunningham, K. Xu, B. Thomas, Seeing more than the graph: evaluation of multivariate graph visualization methods, in: Proceedings of the International Conference on Advanced Visual Interfaces, 2010, pp. 429–429.
- [9] K. Marriott, F. Schreiber, T. Dwyer, K. Klein, N. H. Riche, T. Itoh, W. Stuerzlinger, B. H. Thomas, Immersive analytics, volume 11190, Springer, 2018.
- [10] U. Engelke, M. Cordeil, A. Cunningham, B. Ens, Immersive analytics, in: SIGGRAPH Asia 2019 Courses, 2019, pp. 1–156.
- [11] M. Cordeil, A. Cunningham, T. Dwyer, B. H. Thomas, K. Marriott, Imaxes: Immersive axes as embodied affordances for interactive multivariate data visualisation, in: Proceedings of the 30th annual ACM symposium on user interface software and technology, 2017, pp. 71–83.
- [12] A. Drogemuller, A. Cunningham, J. Walsh, W. Ross, B. H. Thomas, Vrige: Exploring social network interactions in immersive virtual environments, ????
- [13] R. Stoakley, M. J. Conway, R. Pausch, Virtual reality on a wim: interactive worlds in miniature, in: Proceedings of the SIGCHI conference on Human factors in computing systems, 1995, pp. 265–272.
- [14] A. Febretti, A. Nishimoto, T. Thigpen, J. Talandis, L. Long, J. Pirtle, T. Peterka, A. Verlo, M. Brown, D. Plepys, et al., Cave2: a hybrid reality environment for immersive simulation and information

analysis, in: The Engineering Reality of Virtual Reality 2013, volume 8649, SPIE, 2013, pp. 9–20.

- [15] C. Reichherzer, J. Fraser, D. C. Rompapas, M. Billinghurst, Secondsight: A framework for cross-device augmented reality interfaces, in: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, 2021, pp. 1–6.
- [16] A. Febretti, A. Nishimoto, V. Mateevitsi, L. Renambot, A. Johnson, J. Leigh, Omegalib: A multi-view application framework for hybrid reality display environments, in: 2014 IEEE Virtual Reality (VR), IEEE, 2014, pp. 9–14.
- [17] T. Bednarz, Visualisation, simulations & expanded perception, 2019. URL: http://torch.unsw.edu.au/sites/default/files/ 48_Visualisation%2C%20Simulations%20%26% 20Expanded%20Perception_EN.pdf.
- [18] O.-H. Kwon, C. Muelder, K. Lee, K.-L. Ma, A study of layout, rendering, and interaction methods for immersive graph visualization, IEEE transactions on visualization and computer graphics 22 (2016) 1802–1815.
- [19] T. M. Fruchterman, E. M. Reingold, Graph drawing by force-directed placement, Software: Practice and experience 21 (1991) 1129–1164.
- [20] G. Ellis, A. Dix, An explorative analysis of user evaluation studies in information visualisation, in: Proceedings of the 2006 AVI workshop on BEyond time and errors: novel evaluation methods for information visualization, 2006, pp. 1–7.
- [21] J. Sauro, J. S. Dumas, Comparison of three onequestion, post-task usability questionnaires, in: Proceedings of the SIGCHI conference on human factors in computing systems, 2009, pp. 1599–1608.
- [22] J. Baumeister, S. Y. Ssin, N. A. ElSayed, J. Dorrian, D. P. Webb, J. A. Walsh, T. M. Simon, A. Irlitti, R. T. Smith, M. Kohler, et al., Cognitive cost of using augmented reality displays, IEEE transactions on visualization and computer graphics 23 (2017) 2378– 2388.