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Immersive WebXR Data Visualisation Tool

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Abstract

This paper presents a study of a WebXR data visualisation tool designed for the immersive exploration of complex datasets in a 3D environment. The application developed using AFrame, D3.js, and JavaScript enables an interactive, device-agnostic platform compatible with various devices and systems. A user study is proposed to assess the tool's usability, user experience, and mental workload using the NASA Task Load Index (NASA TLX). The evaluation is planned to employ questionnaires, task completion times, and open-ended questions to gather feedback and insights. The anticipated results aim to provide insights into the effectiveness of the application in supporting users in understanding and extracting insights from complex data while delivering an engaging and intuitive experience. Future work will refine and expand the tool's capabilities by exploring interaction guidance, visualisation layout optimisation, and long-term user experience assessment. This research contributes to the growing field of immersive data visualisation and informs future tool design.

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;*** • ***Applied computing*** → *Interactive learning environments;* ***Data visualisation;***

1. Introduction

The modern era has seen a proliferation of large-scale and complex datasets generated across various domains. Effective navigation, understanding, and interaction with these datasets call for advancements beyond the scope of traditional two-dimensional (2D) visualisations. Emerging from this need is the promising potential of immersive data visualisation leveraging (X)Reality technologies. Encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), these technologies facilitate an intuitive, interactive, and engaging exploration of data.

This paper introduces a novel WebXR data visualisation tool that sets a new precedent by offering users an immersive and interactive exploration of complex datasets in a 3D environment. The tool capitalises on the flexibility of WebXR standards, allowing it to function seamlessly across diverse devices and platforms. The tool's implementation utilises A-Frame, D3.js, and JavaScript, underscoring a harmonious blend of usability, user experience, and user interactivity.

A detailed user study has been proposed to evaluate the tool's effectiveness and provide a data-driven basis for future enhancements. This study aims to assess usability, user experience, and mental workload when users perform tasks on the system, using a combination of questionnaires, task completion timings, and open-ended questions to garner comprehensive user feedback and insights.

The distinctiveness of the tool lies not just in its current capabilities but also in its potential to support more intricate visualisations in the future, transcending the limitations of contemporary methods. It positions itself at the forefront of a paradigm shift towards more immersive and intuitive data interactions, contributing significantly to improved user engagement, refined statistical analyses, and efficient decision-making processes.

The remainder of the paper is organized as follows: Section 2 delves into a literature review on data visualisation techniques and WebXR technology, providing a backdrop against which the tool is developed. Section 3 details the tool's implementation, elucidating its unique features and design considerations. Section 4 proposes an evaluation strategy and speculates on potential insights gleaned from this assessment. Lastly, Section 5 concludes the paper, shedding light on future work and potential refinements to the tool, thereby charting the course for the next phase of this exciting journey.

1.1. Motivation

The primary motivation for this project lies in unlocking the latent potential of (X)Reality technologies and the emerging WebXR standards. The goal is to build intuitive, immersive data visualisation tools that enhance user understanding and decision-making significantly more engagingly than traditional methods. By align-

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ing with WebXR and OpenXR standards, the project aims to craft a solution characterised by its interoperability—accessible and functional across various devices and platforms. The tool's future extensions include the possibility of supporting more complex visualisations and promises to redefine the landscape of data interpretation and analysis across multiple domains.

2. Literature Review

This literature review probes the prospects and impediments of immersive data visualisation and analytics employing X-Reality technologies, namely virtual reality (VR), augmented reality (AR), and mixed reality (MR). A particular emphasis is placed on WebXR standards that have been instrumental in powering immersive data visualisation, enabling users to venture into complex datasets within three-dimensional (3D) environments [PNR20].

Previous studies endorse the merits of WebXR in immersive data visualisation, noting its enhanced interactivity, scalability, and accessibility irrespective of the device in use [BAB*18]. Nevertheless, a notable gap in the literature stems from the lack of standardisation in developing immersive data visualisation applications [WHXA18]. Researchers have underscored the pertinence of OpenXR standards in bridging this gap by offering a standard interface for XR hardware and software, simplifying development, and fostering interoperability [RTSB22]. OpenXR can bolster compatibility and accessibility, empowering developers to architect seamless applications across various devices and platforms [Fra22]. Despite the promising potential of (X)Reality technologies and WebXR standards, challenges and research gaps remain to be addressed.

The libraries selected for the development of our tool, namely A-Frame, D3.js, and JavaScript, were not chosen lightly. Each brings unique strengths to the table, ensuring the tool's robustness and functionality. A-Frame provides an easy-to-use and versatile framework for VR development, with strong support for WebXR standards. It promotes a simple, markup-based approach to VR development, making it more accessible to a wider range of developers [Fou21]. D3.js, on the other hand, is a well-established library for creating intricate data visualisations. It offers an extensive range of features and a high level of customizability, which makes it an ideal choice for creating the immersive visualisations desired in our tool [BOH11]. Lastly, JavaScript is the lingua franca of web development and enjoys widespread adoption. Its use ensures that our tool can be easily integrated and deployed across various web platforms [Fla06]. The selection of these libraries was motivated by a need to balance usability, functionality, and accessibility, thereby maximizing the tool's potential and reach.

Usability and user experience are crucial for the adoption and success of WebXR-based immersive data visualisation applications [BAGB19]. By delving into the design principles and interaction techniques tailored to immersive data visualisation, user engagement, performance, and cognition can be enhanced [Har20]. Moreover, the notion of collaborative immersive data visualisation warrants further research. The ability to improve teamwork and decision-making across various domains through collaborative features in WebXR-based applications is an area for exploration [Dea14; MAT18]. Scalability, a recurrent challenge for WebXR-based immersive data visualisation [AE18], calls for innovative techniques that can handle large datasets while maintaining interactivity and performance. Further research can also focus on supporting real-time data processing and visualisation within immersive environments [AE18]. Lastly, the seamless integration of WebXR-based immersive data visualisation applications with existing data management systems and tools remains crucial [Tre18], calling for the development of APIs and data exchange formats to ensure smooth integration and an enhanced user experience [Tre18].

The literature underscores the transformative potential of XR technologies and WebXR standards for immersive data visualisation and analytics [PNR20]. However, harnessing their full potential warrants further research and innovation, particularly in the areas identified as current challenges [JA22]. By concentrating efforts in these areas, developing and adopting effective immersive data visualisation tools using XR technologies and WebXR standards can chart a path for groundbreaking research, education, and industry solutions.

3. Tool Implementation Description

Our tool's architecture was meticulously crafted to offer a high degree of compatibility, targeting diverse devices and platforms. In addressing the feedback, we'll delve deeper into the specifics of the tool's architecture, detailing the underpinnings and the rationale behind our design decisions.

Architectural Blueprint: The modular design intentionally eliminated the need for platform-specific software, promoting user inclusivity. This is epitomised in the tool's user interface (UI), designed for intuitive navigation, interaction, and optimal user engagement, as illustrated in Figure 1.

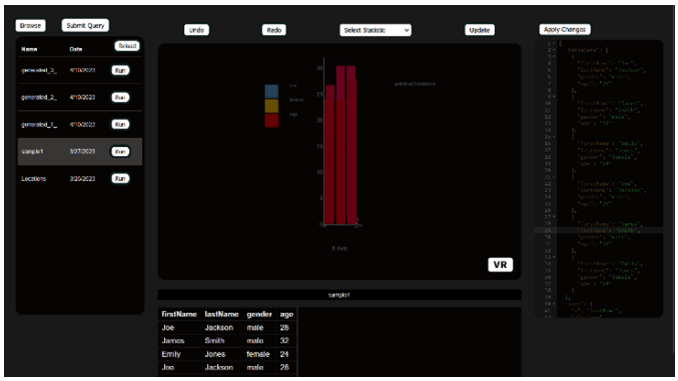

Figure 1: *The interface showcases meticulous attention to detail by exemplifying the user-centric design philosophy.*

Technological Synergy: Drawing from the literature, our selection of technologies, namely D3, React, and A-Frame, wasn't arbitrary but informed by their combined potential to enhance user performance and cognition in immersive environments. They harmonise to facilitate real-time data processing, enabling dynamic data set explorations.

The Document Object Model (DOM) model serves as the foundation, governing the interactions between components. The index.html is vital in laying out resources, including stylesheets, scripts, and dependencies. React's crafting interface prowess marries A-Frame's VR capabilities and D3's dynamic visualisation forte, culminating in the appD3V3.js. This file encapsulates the essence of our tool - bridging UI, VR, and data visualisation.

React components breathe life into A-Frame entities to elucidate further, setting the stage for 3D scenes. D3, on the other hand, dons the hat of a visual storyteller, translating raw data into compelling narratives. But it's not just about passive viewing; users are at the helm, navigating through data. Features like the 'cursor-listener' detect user interactions and evoke relevant responses.

Data Acquisition and Rendering: Our commitment to facilitating diverse data interactions led to the inception of `fetch_tables.js`, showcased in Figure 2. This module is entrusted with fetching and formatting data for visualisation.

Figure 2: *A closer look at the data-fetching mechanics in `fetch_tables.js`.*

A highlight worth noting is the multi-data point selection feature, depicted in Figure 3, which amplifies the tool's analytical depth.

For the Power Users: we've embedded a sandbox for enthusiasts to tinker around, and using the Ace code editor [SA15] allows real-time chart modifications. The integration of the Ace editor facilitates this, dynamically adjusting data based on code alterations.

Challenges and Triumphs: Melding React, A-Frame, and D3 was no mean feat. It demanded a carefully architected design and modular components. This methodology ensured a delineation between technologies without compromising coherence.

Data intricacies were addressed using D3's data-binding, ensuring a seamless data-to-visual transition. The tool's extensibility, facilitated by `fetch_tables.js`, empowers users with data manipulation tools like filtering and sorting, paving the way for deeper insights.

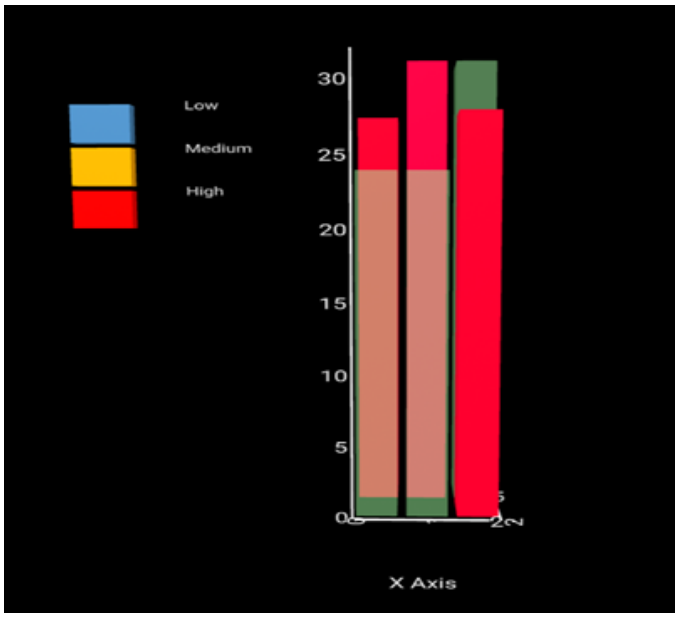

Figure 3: *Demonstrating simultaneous multiple data point selections.*

Lastly, our tool champions adaptability. It caters to both the tech-savvy and the novices, with configuration files offering rapid prototyping options. Its integration capabilities ensure it can weave into existing applications with minimal friction.

4. Evaluation Design and Expected Outcomes

This paper delineates a meticulous user study plan to ascertain the usability, user experience, and cognitive exertion associated with the immersive data visualisation tool. The bedrock of this evaluation, rooted in empirical methods, is the endeavour to optimise the tool and enrich the users' proficiency in distilling actionable insights from their visualisations.

4.1. Design of Evaluation Tests

The criteria for participant selection and the technological specifications remain unchanged. However, the rationale for the choice of tests and visualisations requires elucidation. The 3D bar chart was judiciously chosen not only for its universality but primarily to negate any confounding effects that unfamiliar visualisation methods might impose. By using bar charts, the focus remains steadfastly on tool interaction rather than the participant's interpretative capabilities.

For the user study, participants will interact with a dataset encapsulating the sales trajectories of a fictional enterprise. A circumscribed environment—a singular WebXR tool navigated via Oculus Rift HMD and Touch controllers—minimises variables, facilitating a more incisive analysis.

In practice, participants will be presented with four questions about the dataset, calibrated to assess their interpretative prowess within the VR environment. To equip participants with foundational navigational understanding, they'll undergo a brief orientation on Oculus Touch controller operations. Furthermore, the randomised sequence of tasks aims to mitigate any skew due to the learning curve or fatigue.

A dual-fold evaluation comprising the NASA TLX and the SUS survey will be administered post-engagement. The inclusion of these standardised scales is paramount. The NASA TLX is essential in gauging the cognitive demands of the tool, while the SUS serves as a barometer for its overall usability. Complementing these structured scales, open-ended queries will offer a granular insight into the subjective user experience.

4.2. Expected Outcomes and Potential Future Tests

Projected insights from the evaluation can be broadly categorised:

- **Cognitive Demands:** The NASA TLX will illuminate the cognitive landscape navigated by users, thereby pinpointing sections of the tool that may necessitate simplification or enhancement.
- **Usability Insights:** Drawing from the SUS scores, facets of the tool that resonate with user intuition and those that challenge it will be discerned. This quantitative measure, juxtaposed against qualitative feedback, will inform iterative design refinements.
- **Efficiency Metrics:** By clocking task completion, one can infer the tool's learning trajectory and potential bottlenecks that hinder swift navigation.
- **Data Interpretation:** The fidelity of participant responses will be an index of the tool's efficacy in facilitating data comprehension. Any disparities here could suggest the need for more intuitive visualisation techniques.
- **Qualitative Nuances:** Open-ended questions will serve as a repository of user sentiments, capturing the nuances of user engagement and areas of potential improvement.

In the continuum of this tool's evolution, future evaluations might delve into comparative studies, juxtaposing different visualisation techniques within the VR space. Such endeavours aim to discern the optimal visualisation strategy tailored to the VR environment.

This proposed evaluation serves as the linchpin between the current design and its potential evolutions, ensuring the tool remains congruent with user needs and contemporary VR capabilities. By meticulously interrogating its efficacy through the lens of rigorous empirical studies, we provide its readiness to meet the dynamic demands of immersive data visualisation.

5. Conclusion and Prospective Endeavours

The realm of immersive WebXR data visualisation beckons a revolution in our interaction with multifaceted datasets, and the tool delineated in this study seeks to pioneer this movement. Our proposed model is a testament to the synergistic potential of WebXR and data visualisation—crafting a digital theatre where data stories unfurl in an intuitive and engaging tableau. With the forthcoming user study, we intend to dissect its nuanced operations, mapping out its strengths and understanding the contours of its potential enhancements.

Our contribution, thus, is not just a novel tool but a stepping stone to more astute data interactions in virtual realms. This odyssey transcends traditional two-dimensional confines, plunging users into data landscapes, promising depth and clarity.

5.1. Future Endeavours

Our vision extends beyond the current design, aiming to sculpt a more holistic and versatile tool. The path ahead is charted with the following milestones:

- **Intuitive Interactions:** Recognising the heterogeneity of our user base, developing user-centric tutorials is paramount. The intent is to ease the Oculus Touch controller navigation, transforming the initiation phase into an immersive learning experience.
- **Ergonomic Visualisation Layouts:** The physicality of VR warrants a reconsideration of design ergonomics. Future versions will seek to minimise physical exertions, like excessive head movements, by reimagining the spatial organisation of data elements, possibly with adaptive layouts.
- **Visualisation Versatility:** The 3D bar charts are merely the vanguard of a plethora of visualisation techniques we seek to integrate. We aspire to weave a rich tapestry of visual stories tailored to specific data narratives by assimilating scatter plots, line charts, and intricate node-link diagrams.
- **Diverse User Group Evaluations:** Our commitment to inclusivity drives us to expand our evaluation horizons. We plan to engage with a broader spectrum of participants, focusing on varied expertise levels and demographic backgrounds, ensuring the tool resonates universally.
- **Longitudinal User Engagement Studies:** While initial interactions offer invaluable insights, the true grit of a tool is tested over time. Long-term studies will probe into user retention, evolving learning curves, and sustained engagement dynamics.

6. Concluding Remarks

As we stand at the cusp of a new era in data visualisation, the importance of our venture into immersive WebXR environments cannot be overstated. This project not only epitomises innovation but also serves as a beacon for future endeavours in VR data visualisation. Our commitment remains unwavering—to refine, reimagine, and revolutionise how we perceive and interact with data in the digital realm. Through continuous research and iterative design, we aspire to shape the future of immersive data storytelling.

7. Source Code

https://github.com/OgbondaGlory/Immersive-Data-Vis-VR.

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