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APPLYING GAMES DESIGN THINKING FOR SCIENTIFIC DATA VISUALIZATION IN VIRTUAL REALITY ENVIRONMENTS

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Resumo

Este trabalho propõe a aplicação do design de jogos no desenvolvimento de experiências de Realidade Virtual (VR) e Realidade Aumentada (AR) para visualização de dados científicos. Começamos introduzindo o desafio do design e como abordamos o design de experiências imersivas usando os princípios do design de jogos. Para isso, discutimos o caso do projeto e desenvolvimento da visualização de dados de órbitas e observações de terra em ambientes VR e AR. Limitações e resultados potenciais são discutidos e abordados em ambos os casos, incluindo as limitações das tecnologias propostas. Concluímos este artigo com recomendações para o uso do design de jogos aplicado neste contexto e como cientistas, artistas e designers podem colaborar em projetos futuros.

Palavras-chave: visualização de dados; design de jogos; experiências imersivas; realidade virtual; aplicações científicas

Abstract

This paper proposes the application of games design thinking in the development of Virtual Reality (VR) and Augmented Reality (AR) experiences for scientific data visualization. We start by introducing the design challenge and how we have approached the design of immersive experiences by using principles of games design. For that, we discuss the case of the design and development of visualization of orbits and earth observations data in both VR and AR environments. Limitations and potential outcomes are discussed and addressed in both cases, including the limitations of the technologies proposed. We conclude this paper with recommendations for the use of games design thinking applied in this context and how scientists, artists and designers could collaborate in future projects.

Keywords: data visualization; games design; immersive experiences; virtual reality; scientific applications

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1 Introduction

The world is in constant change with multiple connections between people, devices, objects, technology and the environment. There is an incredible generation of different types of datasets developed in a large scale. By 2025, it is expected that more than 150 zettabytes will require analysis (ROHIT, 2019). This means that super computers will have to deal with large amounts of data, opening new opportunities for the development of algorithms and data visualization techniques. For the scientific field, visualizing large amounts of data is crucial. On 10th April 2019, a ground-breaking publication (AKIYAMA et al., 2019) highlighting the first image of a black hole was shared online in multiple websites and social media. Newspapers such as *The Guardian* (DEVLIN, 2019) highlighted the importance of the relationship between "seeing" and "believing" and that an image like that not only represents a black hole, but it also confirms scientific principles. This shows that there are many different levels of visualization techniques for scientific data and it reinforces the value of visual cues.

Data visualization is a result of a combination of variables and visual elements and it can be integrated into many formats. That is, data visualization is the communication of data (KIRK, 2012). In fact, data visualization has the potential to persuade individuals because it "convinces" users on specific information since it is considered as evidence of a "fact" (PANDEY et al., 2014). However, with advances of immersive technologies, like Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) and more complex datasets, it becomes harder to handle different sets of data that could be not just in 2D but also in 3D. The implementation of VR, AR and MR technologies not only brings new challenges but also opportunities. Data visualization becomes, then, more than just passive visualization to more interactive data exploration. For example, instead of just looking at pre-established visual representations, scientists can interact, expand, choose and decide the best way to handle a dataset, looking for patterns and making decisions along the way. Although scientists could have some sense of control using interactive data visualization, what else can they do through the use this technology? What are the best practices to develop and design such experiences? The opportunities are huge and could transform the way scientists handle data from different domains. Thus, with interactive data exploration, there is an urge for a new paradigm. And with that, new forms of interaction, which borrows aspects from interactive media, such as games. Games are systems and have four main characteristics; they are guided by a goal, rules, feedback loops and they are voluntary activities (MCGONIGAL, 2011). This means that while playing games, players can get constant feedback from their actions. But, mostly, games are fun and the act of overcoming obstacles and achieving goals makes them pleasurable activities (LINDLEY; NACKE; SENNERSTEN, 2008). Games are also engaging and are strongly attached to a sense of control, feedback, social interaction, user's skills and challenges (OLIVEIRA; WANICK; DA MATTA, 2018). Thus, it is possible to ask: what would be the implications of merging games design and interactive data visualization? How can games design help designing compelling data explorations?

In this paper, we aim to answer the above questions. For that, we provide a review of the terms and main games design concepts that could be employed in data exploration contexts using VR technologies. This is followed by two illustrative case studies: orbital visualization and earth data visualization for scientific data. For each case, we discuss and show the application of games design concepts with VR technologies. In addition, in both cases we explain the main design challenges encountered and how emerging technologies influenced the design choices and vice-versa. The main contribution of this paper is the discussion of the application of VR for scientific data exploration (going beyond visualization) and the impact of games design principles in the interactive choices. We expect this paper might be of interest of designers, scientists and researchers who wish to understand and expand the knowledge of VR applications considering technological boundaries and design challenges.

2 Research Background

In this section, we introduce and discuss three domains: scientific data visualization and what has been currently used by scientists, interaction design in immersive environments (e.g. VR, AR) and games design concepts. The objective of this section is to identify the main components for development of scientific data exploration using VR.

2.1 Scientific data visualization

Scientific visualizations are difficult to compute and might require specific "visualizations", since they might be attached to the complexity of the dataset. There are indeed data visualization tools that can be used by scientists. For example, *ParaView*[4] is a tool that can work through multi-platforms analysing large datasets using 3D visualizations. Case studies using *ParaView* show cancer immunology visualization, CERN simulations, plane streamlines and visualizations used in science education. Similar products such as *Virtualitics*[5] also provide a similar service, mentioning the potential of integrating VR with intelligent agents to provide more efficient data analytics. VR/AR/MR technologies have boosted the opportunities to explore seamless relationships across different platforms. Much work has been done on the use of AR and VR in scientific visualization, derived largely from efforts driven by the need for flight simulation and training methods, such as Furness' (1988) early work on military flight simulators.

VR has found modern use in scientific applications where the data is high-dimensional, or too abstract to understand efficiently using traditional computer visualizations (ELSAYED *et al*., 2013). For example, Helbig *et al.* (2014) used VR to visualize atmospheric cloud data, to make more intuitive the 'correlations between variables like wind vectors, humidity and cloud coverage', to 'detect inconsistencies in the data', and to compare data from multiple models. Indeed, interviews conducted as part of the study rated the VR visualization as "highly supportive for analysing large heterogeneous datasets", and Helbig *et al.* (2014) cite that VR allows their 2D, 3D and 4D data to be visualized more readily, and that users are able to move through the data to allow 'flexible, task-specific analysis.' This is quite important since the task guides the way the visualizations are displayed. For instance, scientists may wish to "see" the relationship between a specific variable and another that can't be understood only by the means of the abstraction of numbers. Today, most of these interactions are undertaken via desktop computer screen (which is 2D) and the visualization

[4] https://www.paraview.org/
[5] https://www.virtualitics.com/

has limitations since it is not possible to "see" depth, unless the user rotates the visualization. This is why by using VR/AR/MR technologies could be helpful, adding this other layer of interaction and exploration to the data visualization. However, VR/AR/MR technologies do not replace desktop actions, but they complement each other (BACH *et al.*, 2018). This means that the task of using a computer to analyse data is not completely overridden by VR/AR/MR technologies.

2.2 Interactions in VR and AR environments

One of the biggest challenges about data visualization techniques is accessibility (KIRK, 2012). However, with VR/AR/MR scenarios, there is more to be considered. Not only users interact with the data, but there are 6 degrees of freedom (6DoF) to consider in such environments (FICTUM, 2016). This means that data could be represented everywhere and that the concept of spatial design is in the core of these applications.

Using space as part of visualizations is not new. For example, *AlloSphere*[6], a "spherical space" that could project many different types of scientific visualizations in a single immersive experience, expands the possibilities of data exploration (particularly for large datasets). This is similar to the *Light Sculpture Space* in Tokyo, created by the Japanese group *teamLab Borderless*[7] with animated projections of different natural environments in a room with mirrors and walls. These two examples are no exactly a result of VR/MR/AR technologies but it shows that visualizations and representations can make people feel more immersed. VR/MR/AR technologies make this "space" more accessible, since it is possible to create the same "space" in our homes or in the office. That is, we can design our own spherical space and project visual datasets anywhere we want. This is crucial for the development of VR applications since VR provides a sense of depth and spatial interaction.

During the 1990s, VR was a huge promise and it still is. The term "Virtual Reality" was first coined by Jaron Lanier[8] during late 1980's. It has taken at least 30 years for VR to see the boom of "possible" applications. Early VR systems were used as spatial ability training tools (DÜNSER; STEINBÜGL; KAUFMANN *et. al.*, 2006; SHUFELT, 2006), and were found to be a valid and effective method of training in the medical sector (VERDAASDONK *et. al*., 2008), reducing errors during certain surgeries by up to 66% (AHLBERG; ENOCHSSON; LARS, 2007). VR has its own characteristics; however, most of the hardware available follow the same features. VR hardware (e.g. *HTC Vive* and *Oculus Rift*) is composed by goggles with headphones, sensors and controllers. Software is similar and it follows guidelines, mostly supported by a User Interface (UI). This UI intermediates the interaction between humans and computers, usually through representations and commands (e.g. menus, windows, icons, pointers, buttons, etc.) (DIX *et al.*, 2004). In Virtual Reality (VR) environments the UI is inspired by natural interfaces that would eventually mimic some aspects of the real world and it is considered as 3D UI since it exists in a 3D environment. However, since the virtual world is *per se* virtual, then it is possible that it could not only borrow elements from the real world, but also from "fantasy" worlds. This is why we have looked at games as a possible venue for the integration of data visualization in VR environments.

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[6] AlloSphere - http://www.allosphere.ucsb.edu/
[7] teamLab Borderless https://borderless.teamlab.art/
[8] http://www.jaronlanier.com/general.html

2.3 Games design and data visualization

Games are interactive systems that convey problem solving (GEE, 2010). In games, players are presented to different challenges and should learn how to solve them. The difference from games and other “problems” is that in games there is a designed world that allows these problems to exist and to players to solve them. Data visualization provides ways to “solve” problems since it requires high-levels of cognitive functioning enhanced by pattern recognition (PATTERSON et al., 2014). Thus, there is a link between both. However, in games design, embodiment is key. For example, in games, players have to balance their own goals with the character’s goals in order to have an influence in the virtual world (GEE, 2008). This is consistent with the idea of the sense of control and that in a VR environment, users might understand actions better when they visualize their own hands instead of a cursor.

HUDs are key design elements in games, particularly in first-person shooting (FPS) games. There are at least two ways to display information in the game environment: diegetic and non-diegetic (PEACOCKE et al., 2015). This is also shown in Andrews (2010) spectrum graph (Figure 1). In other words, the diegetic HUD is part of the game fiction, whereas the non-diegetic format is not attached to the game world. To mention, the engine *Unity*[9] has also published in their page a summary of types of UI in VR environments: non-diegetic, spatial and diegetic, but that only spatial and diegetic UIs are available in VR. The spatial UI is similar to non-diegetic with the difference that the UI is positioned according to the world space, whereas the diegetic is attached to the world as part of a narrative. For example, in a game where the character can lose health in a battle, a diegetic way to show that the character is dying could be through a visualization of the character’s blood in the screen or the voice of character saying that he or she is not well. A non-diegetic way to show that the character is losing health is through health bars.

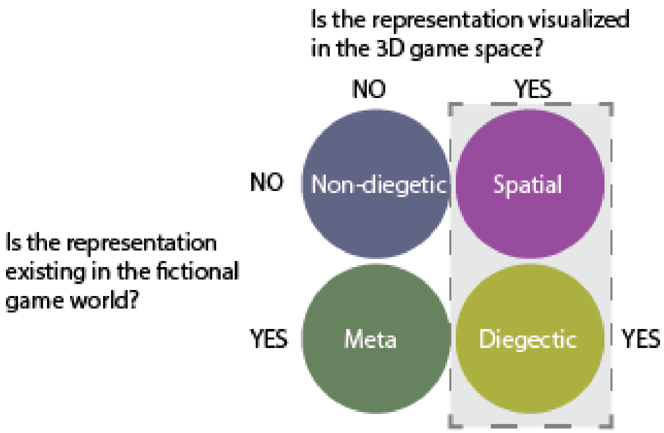

Figure 1: Spectrum of representations in the game world in the 3D space (adapted from ANDREWS, 2010); the dashed column shows the spectrum recommended for VR experiences

3 Development and applications

The methodology of this study shows the applications of this systematic thinking to two different scenarios: orbital visualization and earth visualization. In order to make the data visualization scenarios interactive and user friendly, we had to take account what was readily

[9] https://unity3d.com/learn/tutorials/topics/virtual-reality/user-interfaces-vr

available in the community and what we could develop further to fit the use cases of the project. We used mechanics such as tapping, scrolling, swiping and 'pinching' the screens on our mobiles everyday so with that in mind we tried to explore if VR/AR was capable of performing such functions as this would increase the device's accessibility to a wider audience. For each case study we also considered the hardware that could be utilised. These are: *HTC Vive*, *Oculus Rift* and *Hololens.* Both *HTC Vive* and *Oculus* are VR headsets, whereas the *Hololens* is an AR goggle hardware with its "own" software. For each scenario we describe the spatial UI element and a possible diegetic scenario.

3.1 Orbit visualization for Mission Design & Analysis

The visualization of the orbital motion of spacecraft in 3D space is one of the most natural applications of advanced visualization techniques of scientific data. For example, the website *Stuff in Space* provides real-time visualization of orbital data in which the user can interact with many points and orbits obtaining relevant information from a large dataset. This can be done by clicking on each orbit and rotating the Earth.

The difficulty with these types of visualizations is that while they look very appealing, they distort the scientific data underlying the visualization. Apart from the size of the objects being vastly exaggerated, the loss of depth perception greatly diminishes the ability to judge distances and hence the density of objects. This is particularly visible in the region just above the Earth surface, where orbits bend around to disappear behind the Earth. Thus, users need to rotate the Earth in order to have a full visualization of the orbit. In this scenario, the use of this visualization should function to aid researchers on gathering insights with more depth of perception. For example, researchers could walk around the Earth and see the orbit at once or just rotate the Earth on their hands (like a holographic image) (see Figure 2). Considering this, the main interactions we have identified for this scenario are zoom/expand, select the orbit, interact with the UI (use a slider to change the orbit's properties), rotate the (Point of View) PoV, speech input, change the PoV, "ride the orbit" and time-based navigation.

Figure 2: Scenario illustration (developed by the authors)

Zooming and expanding the orbit would allow users to interact with the content. For each device, this can be done differently. In the *Hololens*, it is necessary to use specific gestures that are recognised by the software. For the VR goggles it is necessary to use the controllers.

The same principle is applied in the other interactions and are similar to what can be done in a Desktop (except from the way the visualization is rotated). Different from a Desktop scenario, we have added a playful element that we called as “ride the orbit” (see Figure 3).

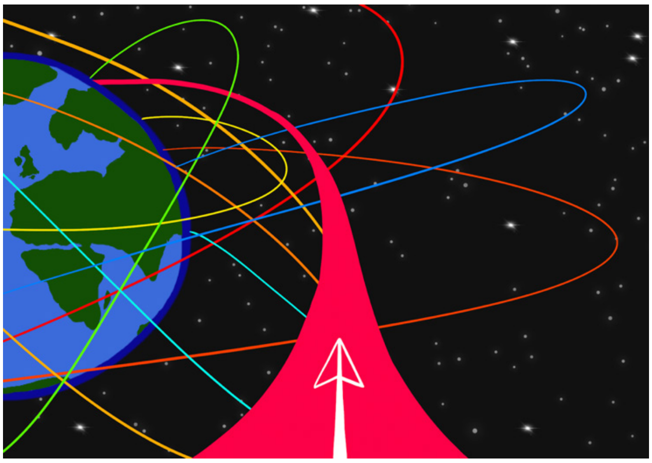

Figure 3: Ride the orbit scenario (developed by the authors)

While looking at the possible interactions with the orbits, riding the orbit was a playful approach given to the exploration of the orbital datasets. In this scenario, users can choose an orbit to ride and from that perspective they can choose to stop the orbit at any time to undertake specific analysis. The approach could be similar to a rollercoaster and it should function as a metaphor to “see” the data in a playful way (see Figure 4).

3.2 Earth Observation Data (“African Drought Monitor”)

This scenario focuses on the visualization of scientific data collected and derived from space based Earth observation. In particular, we focus on the application of the African Drought Monitoring project, which is an international collaboration between world leading universities and supported by the UN. The challenge in this field is to distil usable and actionable information out of the vast quantities of data produced by modern Earth observations missions and through data fusion with other ground-based data sources. This process is greatly helped by good visualizations of the varying geo-tagged indicators. Data is collected over a grid of points on the ground and traditionally a single scalar value is then visualized on a 2D map using a colour bar. The addition of a third dimension in VR/AR could allow more than one of these indicators to be displayed and analysed at the same time. This would be particularly useful for the analysis of cause and effect, as well as in determining how certain synthetic indicators computed by synthesizing observation data from different sources relate to actual observations. Considering this, the main interactions we have identified are for this scenario are the selection of specific datasets (through click and through gestures), zoom in/out, rotation, stacking datasets.

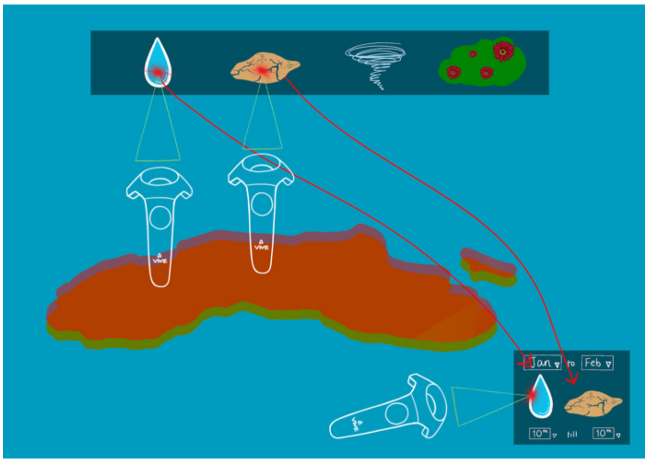

Figure 4: Selection of symbolic visualization of specific datasets (developed by the authors)

Figure 4 shows the section of specific datasets and the stacking of each data in the middle of the screen. Compared to the orbital scenario, this selection of datasets is a spatial representation of the data. Users can also select and combine datasets in the box in the bottom of the image (see combination of draught data and rain, represented by the raindrop).

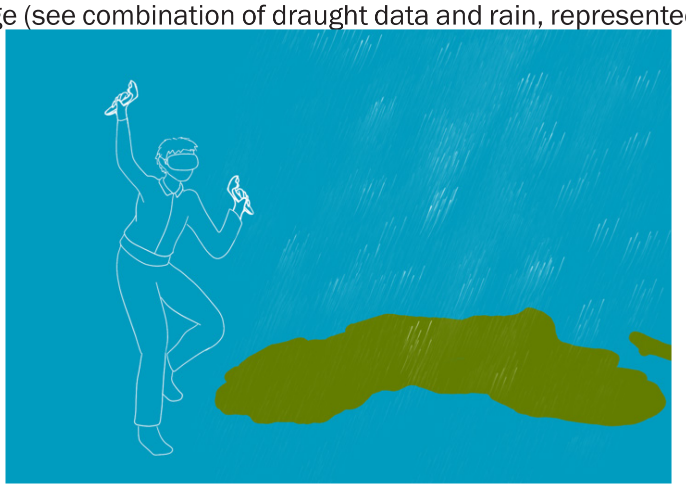

Figure 5: "Dancing" the rain dataset (developed by the authors)

Figure 5 shows the user interacting with the dataset, making body movements to "dance" the rain. Dancing the rain is a playful way to interact with the dataset and it could help users to "embody" the data. This is a diegetic way to interact with the data visualization in this scenario. Since the interactions are expected to occur in a VR environment, users could feel the simulated raindrops in their goggles and listen the rain whilst selecting it. This also adds a multi-sensorial layer to the data exploration.

4 Discussion

The idea of visualizing data in VR, AR and MR environments is that scientists could add another layer to the data visualization, aiding them to reduce cognitive overload and gain insights. Since games are interactive systems that can make players immersed into a specific content and "solve" problems, it was suggested that data visualization techniques could learn from games design in order to make this exploration more immersive. Despite usability and control issues, it is expected that immersion can benefit from "invisible" controls (BROWN;

CAIRNS, 2004). Thus, looking at the way the User Interface (UI) is designed in games has given insights to implement data exploration for scientific data. In games, there are four ways to integrate the UI with the game world (ANDREWS, 2010), but only two can be applicable to VR environments; these are spatial and diegetic UIs. Based on that, two case studies (orbital data and draught monitor data) were designed in order to illustrate possibilities of these UIs applied for scientific datasets in 3D environments. In both scenarios it was possible to integrate a diegetic element with the dataset visualization.

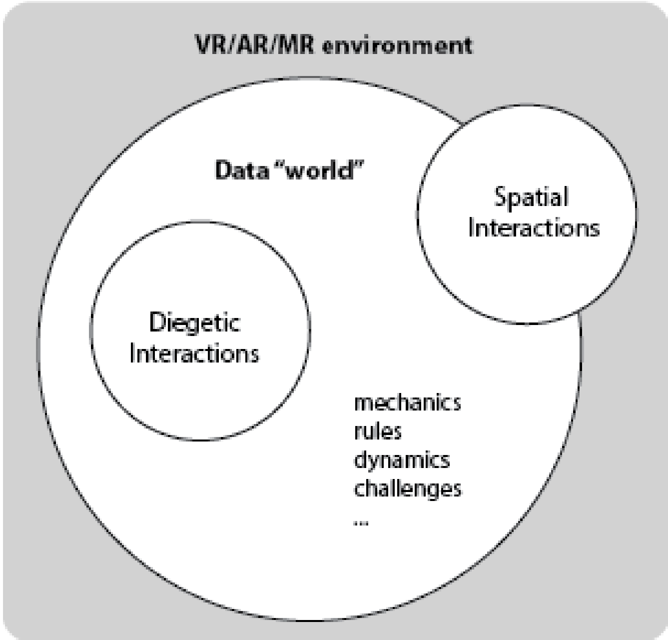

Figure 6: Integration of diegetic and spatial interactions in the data world represented in VR/AR/MR environments (developed by the authors)

Figure 6 shows the process undertaken to build the two scenarios mentioned in this paper. Thus, it is possible to say that scientific data "exploration" can benefit from games design as a discipline to provide visualizations that embed the data "world". However, it is possible that in the future each interaction with the dataset might have a different use. For example, scientists might not wish to "dance" the rain or ride the orbit while they are analysing datasets. This can function as a tool for outreach, bringing science to the general public. Thus, in the next stage of this project we expect to test the variations of the interactions with both scientists and the general public.

5 Final remarks

The current paper had the objective to introduce and explore the possibilities to integrate games design principles in data visualization techniques for scientific data exploration. In this paper, it was highlighted the possibility to visualize data in immersive environments such as VR, AR and MR. Due to the interactive nature of games and by looking at the main interactions and visual characteristics of the data visualization, diegetic elements (design features that are part of the game world) were combined with the data "world". That is, during the process, it was necessary to define the world in which the data was taking place. With this, the present paper showed the application of games design thinking for data visualization in immersive contexts. This was illustrated by two case studies and the discussion of the integration of both the “game” and the “data” worlds. We expect this paper might be of interest of designers, scientists and educators willing to explore the boundaries of VR/AR/MR as a new form of visualizing data and the integration of games design as a possible venue for designing these new interactions.

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