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BIG DATA VISUALISATION IN IMMERSIVE VIRTUAL REALITY ENVIRONMENTS: EMBODIED PHENOMENOLOGICAL PERSPECTIVES TO INTERACTION

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Abstract

Ever-increasing human-computer interactions with various tracking technologies are creating unprecedented amounts of data. The amount and complexity of this 'big data' creates various challenges for its storage, analysis and presentation, but at the same time, big data is suggested to open up opportunities for those who can leverage it. This paper will discuss using immersive virtual reality environments for visualising, interacting and making sense of big data. It reveals that many of the developed applications do not justify their approaches to presentation or interaction. A phenomenological perspective of embodied perception and interaction is discussed to ground future developments.

Keywords:

Human-Computer Interaction, Software Development, Visualisation, Big Data, Immersive Virtual Environment, Phenomenology, Embodiment

1. INTRODUCTION

Several authors have proclaimed that the time of big data is upon us. More ubiquitous mobile devices and applications, social networks, faster Internet speeds, and increasing and free cloud storage generate a digital ecosystem that allow users to generate unprecedented amounts of data [13]. Various forms of sensors and other tracking technologies contribute to the data flux, creating a complex Internet of Things [2]. Everything from mouse clicks, uploaded images, written messages to geographical data are stored in ever-growing databases and waiting to be explored further.

Big data is suggested to provide better insights of human behaviour and the world in general, and to lead to better segmenting of users and decision-making in various sectors of life from business to education. Murdoch and Detsky (2013) proclaimed in the area of healthcare that information is one of the primary inputs of modern industries. Because of this, the application of big data is inevitable, and it has the power to change and improve an industry. In the education sector, data mining and student cognitive modelling has been proposed to predict students' undesired behaviour and performance, assist in better grouping, and in giving automated feedback to both students and instructors [27]. Big data has been argued to give a better overall picture of company's supply chain, and lead to better understanding of customers, new innovations [32], and supply chain optimisation [19]. Dumbill (2012) argued that big data and its potential analytical insights are transferring information systems from the periphery of organisational development to the fore of it. Contemporary organizations are an informational loop where customer interactions with products and services can be analysed and inform further development. Organisations that effectively employ big data managing and analysis methods are suggested to gain a competitive advantage.

Meanwhile, big data poses also practical challenges. How to store, manage, retrieve, analyse and present this fast, varied and ever-increasing amount of data [28]? How to do it faster when for example bandwidth or processing power might be limiting factors? Also the lack of experienced experts and well-established software creates a barrier for the efficient use. Questions in ethics and privacy have also been raised. Some fear big data might be misused to control people [7], or that the underlying assumptions of the usefulness of big data might actually be misleading [8]. Various human contexts have randomness in their interactions. Does it make sense to trust such seemingly imprecise environments? There is potential to draw wrong conclusions as much as right conclusions.

Also, what does it mean when product users become research objects, perhaps sometimes even against their own better judgment [26]? As customers' purchase and interact with various products and services, what are the ethical implications of selling and profiting from customer data? This raises a question of who has access to the data: researchers, private companies or even governments?

Some question the underlying assumptions and the promise of big data, including how it might reinforce existing inequalities in the world. Does its premise, "more is more", reduce the accepted definitions of what is knowledge and valuable research, and have unjustifiably big effect in decision-making? How are big data samples formed and analysed, based on what questions, and how to ensure the data really reflect a certain population? [15], [25].

Varying definitions leave open questions about what exactly is big data. Eg. Dumbill (2012) defined it as,

> …data that exceeds the processing capacity of conventional database systems. The data is too big, moves too fast, or doesn't fit the strictures of your database architectures. To gain value from this data, you must choose an alternative way to process it. [13].

Fosso Wamba et al. (2015) examined big data in the use of state emergency services in New South Wales Australia. From several earlier definitions, they proposed an integrated definition of big data as

> …a holistic approach to manage, process and analyse 5 Vs (i.e. volume, variety, velocity, veracity and value) in order to create actionable insights for sustained value

delivery, measuring performance and establishing competitive advantages [19].

Boyd and Crawford (2012) argued that big data might be a misleading term from the beginning as some current data, easily analysed with just desktop computers, could be considered much 'smaller' than for example past census data. It is not just the question of quantity that creates the phenomenon of big data, but how to "search, aggregate, and cross-reference large data sets" [8] to make it meaningful. As understanding of the impacts of big data is still in the making, it is important to make explicit the underlying assumptions that might govern judging it to one way or another.

Big data has landed also in the education sector in the form of learning analytics and educational data mining. Better analytics are proposed to reduce costs, advise performance assessments of staff and learning units, and to improve the delivery of education in general [15], [16]. The annual speculative Horizon Report Higher Education Edition [21] noted in 2014 that the time to adaptation of learning analytics in a wider scale in higher education is year or less. According to the authors, "sophisticated web-tracking tools are already being used by leading institutions to capture precise student behaviours in online courses, recording not only simple variables such as time spent on a topic, but also much more nuanced information that can provide evidence of critical thinking, synthesis, and the depth of retention of concepts over time" (p. 39). Learning analytics are predicted to capture in what contexts and how students interact with learning content and software to "improve student engagement and provide high-quality, personalized experience for learners" [21]. The benefits of this are suggested to be more personalized support, adapting to students' need and giving personalized assistance to learners based on their level. Fernández-Gallego, Lama, Vidal and Mucientes (2013) proposed new algorithms for educational data mining to assess student's learning in educational 3D virtual worlds. They argued that analyzing student system logs would expose their level of learning. Such monitoring could help the instructor to make relevant changes to the learning flow in real time. Serrano-Laguna, Torrente, Moreno-Ger and Fernández-Manjón (2014) reported an initial work in developing a learning analytics model for game-based learning. Their work indicated that the complexity of different videogame approaches forces to simplify the development of generally applicable analytics models. As also in other sectors, not only the complexity of data, but also the complexity of usage situations creates development challenges.

Eynon (2012) observed several important areas for further discussion of the role of big data in education. First is ethical. What are the indications for privacy, what sort of data should be used and analysed, for what should it be used, and how might it direct behaviour?

> What happens to students who are most likely to drop out? Do we tell them, support them (which has economic implications), or let them sign up and take their money, knowing they will probably fail? What happens to serendipity in a system where all educational choices are based on recommender systems? What kinds of learning can a student truly keep 'private'? [15].

Secondly, how the pre-determined data-driven shape might form the outcomes of the research inquiry? As Eynon (2012) points out, data that inform what actions people have taken is valuable, but does not give out the whole truth nor the meaning people might assign to their actions, behaviour and social connections. The author points out that although big data might appear impressive, various research approaches are needed to understand what constitute phenomena around us. The author also notes that practical issues such as data storing, managing and processing are similar challenges in education as in other sectors. Eynon (2012) calls for a balanced discussion around big data that will include both barriers of use as how it can assist various stakeholders in the field.

One of the challenges big data poses is how much data are enough and what of it to model? For example in an educational analytics environment, are data about the students' past enough? Given that the students' learning is a product of their interaction with content and peers in a specific context, how to model this messy real life that lead to the students' state of learning?

The objective of this paper is to acknowledge these big questions, but not to try to find answers to all of them. Instead, the aim is to examine the use of big data through a specific area where it is increasingly applied, namely visualising it in immersive virtual environment (IVE) or virtual reality (VR). Many of the developed applications do not clearly justify their choices of presenting data or user interaction possibilities with it. The connection of the types of data presented and modes of interaction is not often well defined. The paper will describe big data visualisation and interaction in these applications and aims to better ground them in known aspects of human perception and cognition through a phenomenological perspective. It will also critically examine and vision how understanding human perception and interaction as embodied might advise the development of big data VR visualising applications.

2. BIG DATA VISUALISATION APPLICATIONS

This section will present developments of using immersive virtual environments to make sense of big data. It will ground the discussion of big data visualisation in developed applications and prototypes.

Visualisation has been suggested to be a valuable tool to disseminate big data. As the basic premise goes, visualisation of big data could help people to spot meanings that machines are not able to notice, to detect hidden patterns and correlations [35], and to make numbers more understandable for both general audience and scientists [7], [24], [33].

Although the current status of big data might push the recent developments of visualisation applications, using virtual reality for visualisation and manipulation of data has been well in the development for over 25 years, and some of the old libraries are still in use [36]. Also the aims, technologies and arguments for potential use have existed before the big data trend came to fore. In 1993, Cruz-Neira et al. (1993) reported collaboration with scientists from various fields to use an immersive virtual reality CAVE system to visualise and interact with presented research data in various areas such as living spaces, the Universe and galaxies, and brain structure. Their system used real architectural data to model a part of Chicago in the VR system, and allowed users to walk or fly through the environment and observe and manipulate specific objects of interest. Also some of the technologies that are currently receiving lots of media visibility have long roots. For example Sutherland (1968) introduced the first head-mounted display design already in the 1960's, and Cox, Patterson and Thiebaux (2000) filed a patent claim in 1997 for voice and gesture manipulation of data in an immersive 3D environment. As an example for the aims of visualisation, Beck (2003) reported the use of virtual reality based geographical systems (VRGIS) in the visualisation of landscapes, cities and whole geographical areas. New application developments were proposed to result in faster rendering rates and possibility to stream even complex and highly realistic models over the Internet. Beck (2003) visioned that VRGIS applications could be used for real-time visualisation of weather conditions, and in the tourism sector to present local sites and services.

Childs, Geveci and Schroeder (2013) identified several challenges in the development of new visualisation for handling big data, namely "massive parallelization, processor architectures and programming models, application architecture and data management, data models, rendering, and interaction" (p. 35). They also discussed what might be the suitable role and use for VR visualisation applications. According to them, aims and methods of data analysis should determine what sort of interaction methods should be used to interact with data. If visualisation is to be used to confirm hypotheses, quick simulations might not need complex interaction. On the other hand, if the aim is to use various parameters to view and explore results through simulations, interaction might be very important. The authors note that although new and cheaper input-output and tracking technologies from Microsoft Kinect to various mobile devices might make VR visualisation techniques more readily available and more acceptable in the eyes of the users, the wider acceptance for scientific data analysis is still open for scrutiny.

Donalek et al. (2014) were more hopeful that the benefits of visualising big data in immersive virtual environments would drive a positive development for a wider application. According to the authors, discovery of hidden patterns through the data is the most promising aspect of developments in using big data. The authors argued that,

> Visualization is the main bridge between the quantitative content of the data and human intuition, and it can be argued that we cannot really understand or intuitively comprehend anything (including mathematical constructs) that we cannot visualize in some way. Humans have a remarkable pattern recognition system in our heads, and the ability for knowledge discovery in data-driven science depends critically on our ability to perform effective and flexible visual exploration. This may be one of the key methodological challenges for the data-rich science in the 21st century. (p. 609)

Instead of applying various algorithms based on existing assumption of what data might be important and how, the authors argued that our natural spatial way of understanding the world as three-dimensional should drive the development of visualisation methods. Finding connections, patterns and anomalies in the data might lead to interesting new outcomes. In contrast to large and immovable VR systems, Donalek et al. (2014) aimed to develop easy to use, affordable and portable visualisation applications that would employ state of the art commercially available VR input and output technologies and sensors. They have connected these devices with environments such as Second Life and Open Simulator to test the fit of the combination for scientific collaboration. Their preliminary tests are a beginning for using Unity 3D to develop a multiuser scientific data visualisation platform, called the iViz.

Arsiwalla et al. (2015) reported a prototype environment for visualising and interacting with brain data [1]. The authors asked a question, how can visualising the ever-increasing data from neurobiological databases support our understanding of the brain? Neuroscience regards the brain as a "complex dynamical network of neurons" [1]. It is important to see the different parts in action in the context of the whole to understand how they work together. This need initiated the development of BrainX3 environment, which aims to both visualisation and analysis of brain activity. The immersive virtual environment is projected 360 degrees in a specific room with various sensors supporting interaction. The authors suggest that the development of the environment is based on "a natural user interaction paradigm (including user immersion and gesture based inputs)" [1]. The immersive virtual environment allows the user to navigate through neural networks by walking. It also allows the use of hand gestures and body positioning for bookmark data and manipulate the brain by stimulating regions and performing virtual surgeries. The initial observations are that the chosen interaction approach resulted in better understanding of the data in question, and also lead to a more enjoyable user experience [5].

Possible applications for making sense of big data have also been explored by teams in the entertainment sector. For example recently Maddix (2015) reported an early VR prototype. As part of a VR and big data development challenge, the team had to innovate how to transfer a large data set of lifestyle and biological sample data for visualisation in a virtual environment developed with the Unreal engine. The team experimented with using gaze recognition and new input devices such as the Razor Hydra 3D mouse to allow the user to search, examine, filter and manipulate data accurately in 3D. The user is visioned to stand in the middle of revolving spheres that visualise data queries in the VR environment. They also trialled using heat maps to signify important sections in the data. In the future, the team also aims to experiment with voice recognition to make navigation and the overall user experience even faster.

As can be seen from this introduction, various VR visualisation applications that report users interacting with data in 3D environments rarely justify the selected modes of interaction. Some do not ground them at all, and some refer to concepts such as 'natural gestures' and 'embodied interaction' without discussing more in-depth what they might mean. The next section will explore this are through phenomenology and embodied interaction.

3. EMBODIED INTERACTION AND PERCEPTION

This section will introduce a phenomenological perspective to how we perceive and interact with the world, and try to lay a more theoretically sound basis to understand some of the introduced forms of presentation and user interaction in VR environments for big data visualisation. As not the focus of this paper, deeper philosophical aspects of phenomenology will not be discussed in-depth. The section will concentrate on the concept of embodiment and how it has been perceived in the context of information systems and human-computer interaction [11], [31]. For those who wish to explore further the philosophical underpinnings of phenomenology in connection to human-computer interaction, accounts by Svanæs (2014) and Gallagher (2014) provide a good starting point.

Boland (1986) argued that understanding information systems as communicative acts by conscious and intentional human actors would lead to better outcomes in design and development. For this, phenomenological approach holds a great promise. He based on this argument on the notion that, "data becomes information in the consciousness of a human subject" (p. 200). According to Boland (1986), "Organizational actors never just react to situations, but first enact them and then make sense of what they have enacted" (p. 198). Human organisations are constituted through language and dialogue. He observed that some developments in information systems might fail before they even begin because of underlying assumptions of what constitutes information, how information is structured [12], and how organisational decision-making takes place. The value of phenomenology begins from the rigorous and systematic process of setting aside one's taken for granted suppositions. This is never entirely possible, but even partially done it can open new venues for understanding and development. The proceeding process of rigorous phenomenological analysis tries to uncover the essence of things and what constitutes them. According to Boland (1986), this allows better access to the everyday life where intentional actors are constantly bombarded with information and trying to cope with various meanings and communication situations. Studying actors and language in context can support more effective design of information systems to better support various organisational processes.

In contrast to existing positivist models of developing human-computer interaction and information systems, Dourish (2001) proposed an alternative perspective to developing human-computer interaction. According to Dourish (2004), positivist view presupposes that complex human behaviour can in general be reduced into mathematical models to find and analyse underlying patterns. Relying only to this view might inhibit HCI development and research because of the wrong underlying assumptions of what is context.

> …the idea that context consists of a set of features of the environment surrounding generic activities, and that these features can be encoded and made available to a software system alongside an encoding of the activity itself, is a common assumption in many systems. It is inherent in the notion that our systems will "capture", "represent" or "model" context—the normal and appropriate concerns of positivist design. (p. 22)

He presented a phenomenological view where instead of being information, context is considered to be a relation between objects and activity. Instead of pre-defined context, contextual features are dynamically defined. Context is not stable, but relevant to specific settings, actions and users. Context and content cannot be separated, but context is produced through activity (see also [34]).

Dourish proposed an alternative base for human-computer interaction and information systems through the concept of embodied interaction. Context does not mean only physical location, objects or other features that can be detached and coded individually. It is "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" [11]. Instead of being independent from user interaction, context is enacted by users. It is to allow "users to negotiate and evolve systems of practice and meaning in the course of their interaction with information systems" [11]. Meaning in the world is found through interaction: "embodiment is a participative status" [12]. Action creates new understanding. Instead of inhibiting action, information systems should make everyday practical activities easier. Because of this, understanding interaction as embodied works as a valuable starting point for human-computer interaction and information systems development.

Svanæs (2013) discussed embodiment in interaction design as a bodily experience. To understand the ever-increasing presence and use of technology we need to "understand the physicality of its contexts of use, including physicality of its users" [31]. Svanæs (2013) focuses especially in the embodied nature of perception. For Svanæs, our perception is embodied in a way that making sense of our surroundings is bodily and intentional: what we observe in the world is based on our goals and intentions. We make sense and meaning through bodily interaction with the world. He uses an interactive painting as an illustrative example of a user situation and the embodied nature of perception. In the example, the canvas of a painting is white. There is a button, "Touch me" that calls for action and changes the state of the painting to black if touched by the user. Svanæs (2013) explains:

> Without action, we are left simply with the visual appearance of a white canvas, missing out on the intended user experience of this work of art, which emerges through interaction… Experiencing the interactive artwork requires not only visual perception, but also an arm and a hand. Arm, hand, and eye movements are integrated parts of the perceptual process that leads to perception of the artwork's behavior. The interactive experience is thus both created by and mediated through the body. (p. 14).

Svanæs (2013) points out that technology can extend our perception. This allows us to proceed with our intentions in a way that well-designed and familiarized mediating technology might become transparent to our experience. Using an e-book reader's touch screen to turn a page or gaze-control to scroll are examples of interactions where our intention is to read, and our concentration is not on the technology itself. It is invisible to us. This can also be observed in the context of playing video games:

> In more complex interactions, such as when an experienced computer user plays the game World-of-Warcraft, the perceiving body extends into the game. When the player tries out a new sword that she has acquired for her game character, she perceives its behavior through the mouse and the part of the software that allows her to control her character [31].

Such perspectives of phenomenology and embodiment can provide a rigorous basis for designing meaningful interactions with immersive technologies. It can build a cornerstone for more robust and usable VR visualisation applications and interaction situations, make more explicit what sort of understandings might be possible through the use of VR visualisation applications, and also establish new research opportunities.

4. DISCUSSION: BRINGING EMBODIED PERCEPTION AND INTERACTION TO VR

Dourish (2004) argued that the way information is structured and presented affects the meaning people assign to it. On the level of giving 'better' knowledge, big data raises questions how do we come to know things, and what kinds of understandings might big data visualisation support? According to Eisner (1997), data presentation is closely connected to the nature of knowledge and how presented information can be considered as valid. He noted that different presenting methods (movies, stories or graphs) appeal differently to people. A movie with a plot might affect us differently than an academically accepted form of a research report consisting primarily of text, graphs and numbers. For example homeless people might appear to us differently through a movie than a research report presenting census data. In both of these cases, the object of presentation, homelessness, is given from a certain perspective. How information is presented directs perception. In a particular VR visualisation environment, someone has always developed it in a certain way. In the moment of doing so, the first step of tampering with the source data have already been taken. The question then is, does placing big data in a visualisation environment inherently mean it is already analysed at least on some level? Is any given approach to visualisation always already a perspective to the data in itself?

The fact that data visualisation environments are not only a medium for representation but also for interaction opens several questions about applying them for research. Does interaction with data in a visualisation environment alter it similarly to using qualitative and quantitative data analysis software? With the acting subject in some cases quite literally embodied in the centre of data, does it propose a new interactive medium for data analysis, presentation (which is what the word 'visualisation' might indicate) or both? If VR visualisation is a tool for analysis, does it afford transforming one kind of data to another kind of understanding (quantitative to qualitative), and how? What are its methods of analysis? Will there be VR-specific analysis methods one day, e.g. the 'VR ANOVA', or is using VR visualisation for data analysis based on premises that some might call more subjective? Technology always affords something, but at the same time, something else is restricted or left out. Statistics software can be used for quantitative analysis, but their application for qualitative analysis is limited or non-existent. This is because they have been designed to represent quantitative data, and support specific quantitative analysis methods. The developed software always directs user behaviour with what is possible in interaction, and it is always a design solution of the developer, affected by views of knowledge, needs and the world.

At the same time, phenomenological perspective of understanding our being in the world as the basis for the embodied human-computer interaction invites several new research and development opportunities. Many of the existing applications aim to enable interaction in ways that phenomenology has long since identified as important in human sense making. We understand the world by being in it with our body. We observe objects from different angles with moving our eyes in distinctive ways, touching things, rolling them in our hands, and testing what might happen to objects when we interact with them. Our understanding of the world is also contextual, active, intentional and social. As Svanæs (2013) observed, our personal backgrounds, intentions and tasks at hand affect our perception of things. Study by Vogt and Magnussen (as described in [31]) showed that artists and laypeople looking at the same artwork basically see a different painting. How might such insights advise how different end-users interact with different data and what kinds of knowledge do they find? Useful studies in this region could combine rich phenomenological descriptions of user experience with eye tracking data – now that some of the VR headsets are making it more available by starting to track users' gaze. This could give more valuable knowledge on the use of visualised big data in VR environments, and how tasks, roles and user interfaces affect interaction and knowledge.

On a level of what can big data inform us about, the work by Dourish (2004) proposes an important question, can everyday interactions and its meanings be captured and modelled? He argues that captured and re-presented data cannot give an authentic view to a context. Could visualisation and development of interactive situations based on big data add a new viewpoint to this comment or strengthen it? As a hypothetical example, let us presume big data in the form of opinions about a specific group of people is available. This opinion data would be fed to VR visualisation software, which then regenerated those attitudes to virtual agents who acted them. In the immersive virtual environment the user could engage in social interaction with the virtual agents who reacted based on the user avatar acting as a member of this studied group. How could this affect the user's understanding or feelings about this specific group? Some studies indicate that virtual experiences can affect our sense of self, our body and our opinions about other people. For example Banakou, Groten and Slater (2013) suggested that acting through another kind of body in VR could convey a new perspective to surroundings, and affect attitudes and behaviour. Also Fox, Bailenson and Tricase (2013) observed that wearing certain kinds of avatars affected real attitudes towards women.

Perhaps the connection of data visualisation and embodied interaction could be explored further in understanding our reactions and behaviour in everyday situations. A VR visualisation application could combine real traffic and map data to produce a computer-generated situational simulation where the user could sit in a car, in a traffic jam. The situation could be varied in multiple ways to determine how different conditions affected users' experience, and what decisions to get from A to B. Such experiments could guide the design of new applications to make a person's trip more enjoyable or safe. As it is done in an environment that allows various ways of data recording, mixed research with user experience accounts could advise the development of real world solutions.

When designing presentations and interactions with visualisations, we should make transparent what do we mean by referring to modes such as 'natural interaction'. If we consider interaction from a phenomenological perspective, natural means our everyday being in the world, and how things are given to us in our interaction with the world. We experience with our body as we are in the world. As such, this might not be directly transferrable for navigating virtual brains and galaxies, as they are not our natural environments. We cannot perceive them 'naturally' as they are not part of our natural experience. As a spatial experience, they are not familiar to us to make sense of (although outer space is of course to astronauts). This is not to say that visualisation where data is presented through more abstract forms is meaningless. Our understanding of grouping, velocity, symmetry and others laws of perception are still operational and might be useful. But the relationship between data visualisation and interaction with it should be made explicit to for more robust development.

5. CONCLUSION

The meaning of big data is still in the making, and its promise, peril or forms of accommodation to existing information systems processes and technologies are still open for further research and practical applications. Immersive virtual reality visualisation applications are developed in order to make sense of big data. Such applications allow varied modes of presentation and interaction, but their design approaches are not always explicit. The project of this paper has been to ground the development of big data visualisation in immersive virtual reality environments to existing understandings of human perception and interaction through a phenomenological lens and the concepts of embodied interaction and perception. Examining applications from this perspective has raised open questions about what modes of big data visualisation and interaction might be useful for building knowledge. Application development through the principles of embodied interaction and perception has been discussed in this preliminary work on the topic. Using embodiment as the basis for understanding how we come to know and what is the role of interaction in it has revealed new avenues for research and development in big data VR visualisation applications.

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