A Survey on Immersive Analytics

Carla M.D.S. Freitas[1], Luciana Nedel[1], Anderson Maciel[1] and Regis Kopper[2]

[1]Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
[2]Duke University, Durham, NC, USA

Abstract

Immersive applications have been developed for many years to provide ways for interacting with virtual scenarios usually representing real world situations. Moreover, several applications have used 3D visual representations for conveying information about different datasets. The huge amount of data produced by different sources has been studied using visual data analysis techniques (or visual analytics) for which 3D representations are often part of the solution. Depending on the application domain, the use of immersive scenarios in visual data analysis techniques provides a strong support for users in tasks involving data comprehension. This report aims at providing an overview of the use of immersive techniques in data analysis applications.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; I.3.8Applications

1. Introduction

Most of the first computer graphics applications in the early 1980's were developed for representing data about objects and natural phenomena, being the seed for the scientific visualization area. Interaction techniques in some of those applications showed that virtual reality (VR) could play a major role in facilitating the understanding of the underlying data (see [BL92], for example). VR concepts started to be used in information visualization applications in an attempt at representing data using natural metaphors that would make easy both manipulation and navigation in large information spaces [RMC91] [APW96].

Along the last 20 years we have been facing a steady growth in the volume and complexity of data sets in all areas of human activity, and this imposes the search for solutions for representing and interacting with such data, in tight connection with the typical analytic procedures of each domain. Visual analytics, "the science of analytical reasoning facilitated by interactive visual interface" [TC05], has filled a gap with techniques that are now used in several areas [SWSM12] [WSL*14]. However, visual analytics techniques are most often based on "traditional" information (or data) visualization solutions, i.e., data analysis coupled with some interactive visualization technique. By "traditional", we mean standard desktop 2D user interfaces.

Nowadays, we face a scenario where technology improves at a rapid pace, and new ways of displaying and interacting with virtual worlds are likely to empower data visualization and visual analytics applications if adequately employed. The use of these new technologies for tasks involving discovery and interpretation of large and complex data sets has been called "Immersive Analytics". As stated by Chandler et al. [CCC*15], "Immersive Analytics is an emerging research thrust investigating how new interaction and display technologies can be used to support analytical reasoning and decision making'.

Immersion means the degree to which the display (in any human sense, including vision, haptics, olfaction, etc.) matches the perception of an equivalent stimulus in the real world. The concept of immersion is related to that of *presence*, which is the feeling of being *in* the synthetic virtual world as opposed to feeling as a spectator [Sla03].

The use of virtual reality, augmented reality (AR) and multimodal interfaces for data visualization and analysis presents several challenges that have been discussed for a while in the VR/AR community [MAB*06] [MGHK15a]. At the same time, there is a large body of research on information visualization using 3D graphics techniques (see, for example, the whole set of works published at the Vis conferences), which in many cases has been deemed as less efficient than 2D visualizations. However, currently available high-quality and low-cost displays and interaction technology, as well as related techniques seem now to be mature enough to be attractive to the visual analytics community as a viable choice. We will frame this work on the new opportunities for immersive analytics provided by these techniques.

This STAR aims at reviewing the use of immersive techniques in data analysis applications from different perspectives. We will address the application domains currently adopting such solutions as well as the possible future scenario that is likely to be supported by the plethora of display technology and forthcoming interaction techniques.

2. Relevance for the Vis Community

Throughout the years, there has been several initiatives for evaluating visualization techniques in order to assess usability and utility of data visualization techniques. See, for example, the BELIV workshop series, from 2006 [BPS06] to 2014 [LIIS14], that has been providing a forum to the discussions about research on evaluation of information visualization techniques. The increasing difficulty of tasks that deal with large and complex data sets imposes the need of adopting new ways of supporting users, whether they are experts on a specific domain such as, for example, biomechanics [BKV*10] or the general public accessing large sets from open data sources such as the US Data.gov site.

The theme is relevant for the Visualization community due to the impact of such technologies in possibly increasing user ability of reasoning about daily-presented data either as part of a job or simply as part of regular daily life. User experience is the central human-computer interaction concept in immersive analytics, and it is directly related to the ways data is presented to users and how they interact with it.

3. Planned STAR Structure

We have devised our report to address specific aspects of immersive analytics, including the uses already described in the literature and techniques we foresee as the solution for currently open problems. After presenting some initial concepts and a big picture of the field, we will structure the manuscript according to the following items. Comparative tables or illustrated taxonomy schematics will allow the analysis of the multiple dimensions.

Visualization and analysis. We plan to introduce visualization and data analysis concepts to create a common ground for the discussion about immersive analytics. We do not intend to address all the techniques already described in the literature but we will address the visualization techniques (and the corresponding data types and primary users' goals) as well as the data analysis methods we find appropriate for immersive applications.

Display: devices and techniques. Systems such as the HIVE (Highly Immersive Visualization Environment) consist of a very large screen, both in dimension and resolution, often combined with 3D glasses (shutter or polarized). However, the HIVE's [AEYN11] level of immersion is lower when compared with a CAVE [CNSD*92] or a Head-Mounted Display (HMD). In this part of our report we will discuss the adoption and implications of different display technologies for immersive analytics applications.

Interaction: devices and techniques. We will review interaction techniques designed for highly immersive visualization environments. Interaction in such environments requires specific techniques for data selection and manipulation that cannot compromise accuracy and performance [DNM12]. As for HMD, the sense of immersion imposes different requirements since the user is only able to interact with objects in the scenario. In all cases usability must be high, using natural metaphors [CKS14] for rapid understanding and ergonomic constructions to avoid fatigue.

Applications and uses of immersive analytics. In this section we will address different applications from molecular structures [RKN*13, KKL*15] to augmented reality ambient intelligence [BRM10, MBP13]. In this review, we will also cover the different research groups currently working on immersive analytics and the tools they employ in their developments, for example, the toolkit for hybrid reality environments (HREs) [FNM*14], used for collaborative tasks. An important point to notice is that VR or AR applications that simulate real environments are included only if their main purpose is to support the analysis of data about the environment, i.e., when the data *is* the main "object" in the environment.

Current and future challenges. We will conclude the report commenting on issues that are essential to be addressed to go further in facilitating the use of immersive analytics techniques in different contexts. This covers problems that have been reported in human-centered data visualization [YCKF15] literature. For example, what are the issues in providing people with smart and efficient ways to deal with the analysis of data about their own life [HTA*15].

4. Mais referencias

Labs: https://www.evl.uic.edu http://marvl.infotech.monash.edu.au

» 2014: Termo: Immersive Analytics. Primeira vez: Monash Immersive Analytics project.

Nos papers do google scholar, termo usado pela primeira vez em [Mar14].

[MAB*06] in the draft. Visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces. It has grown out of and is strongly related to information visualization. Visual analytic tools assist analysts in detecting the expected and discovering the unexpected from complex, noisy, incomplete, heterogeneous, and sometimes deliberately deceptive data. VR/AR research has claimed for years to provide the potential for more effective environments to understand and explore information spaces. This would seem to make VR technology a natural for application to visual analytics. However, visual analytics is focused on the analytical process not the tools and technology. As such, any new methods, techniques, and technologies need to show benefit to analysts working on real problems. Additionally, the majority of visual analytics research funding is not focused on disruptive physical interface technologies. Generally speaking, new technologies and techniques for visual analytics need to function within the current analytical environment. The purpose of this panel is to introduce the domain of visual analytics to the audience and explore how and where VR/AR research can be adapted for use in visual analytics. The panelists have been selected based on topic areas of research that have potential for near term insertion or impact on visual analytics. This panel will focus on the hard issues of defining what it will take to get VR technology introduced into the visual analytics research funding stream.

[DSAM06] In this paper we present a new tool for semantic analytics through 3D visualization called ?Semantic Analytics Visualization? (SAV). It has the capability for visualizing ontologies and meta-data including annotated web-documents, images, and digital media such as audio and video clips in a synthetic three-dimensional semi-immersive environment. More importantly, SAV supports visual semantic analytics, whereby an analyst can interactively investigate complex relationships between heterogeneous information. The tool is built using Virtual Reality technology which makes SAV a highly interactive system. The backend of SAV consists of a Semantic Analytics system that supports query processing and semantic association discovery. Using a virtual laser pointer, the user can select nodes in the scene and either play digital media, display images, or load annotated web documents. SAV can also display the ranking of web documents as well as the ranking of paths (sequences of links). SAV supports dynamic specification of sub-queries of a given graph and displays the results based on ranking information, which enables the users to find, analyze and comprehend the information presented quickly and accurately.

[BRM10] in the draft. Energy and resource management is an important and growing research area at the intersection of conservation, sustainable design, alternative energy production, and social behavior. Energy consumption can be significantly reduced by simply changing how occupants inhabit and use buildings, with little or no additional costs. Reflecting this fact, an emerging measure of grid energy capacity is the negawatt: a unit of power saved by increasing efficiency or reducing consumption.Visualization clearly has an important role in enabling residents to understand and manage their energy use. This role is tied to providing real-time feedback of energy use, which encourages people to conserve energy.The challenge is to understand not only what kinds of visualizations are most effective but also where and how they fit into a larger information system to help residents make informed decisions. In this article, we also examine the effective display of home energy-use data using a net-zero solar-powered home (North House) and the Adaptive Living Interface System (ALIS), North House's information backbone.

[JLJ*10] The Scalable Adaptive Graphics Environment (SAGE) is high-performance graphics middleware that enables ultrascale collaborative visualization using a display-rich global cyberinfrastructure. Distributed ultraresolution displays and high-performance-computing resources connect over high-speed networks to form this cyberinfrastructure. Over 40 sites worldwide, comprising universities, research institutions, and companies, have adopted SAGE to drive their ultraresolution displays.

Visualization of Large-Scale Distributed Data, 2012. citeleigh2012. The primary goal of visualization is insight. An effective visualization is best achieved through the creation of a proper representation of data and the interactive manipulation and querying of the visualization. Large-scale data visualization is particularly challenging because the size of the data is several orders of magnitude larger than what can be managed on an average desktop computer. Data sizes range from terabytes to petabytes (and soon exabytes) rather than a few megabytes to gigabytes. Large-scale data can also be of much greater dimensionality, and there is often a need to correlate it with other types of similarly large and complex data. Furthermore the need to query data at the level of individual data samples is superseded by the need to search for larger trends in the data. Lastly, while interactive manipulation of a derived visualization is important, it is much more difficult to achieve because each new visualization requires either re-traversing the entire dataset, or compromising by only viewing a small subset of the whole. Large-scale data visualization therefore requires the use of distributed computing. The individual components of a data visualization pipeline can be abstracted as: Data Retrieval -> Filter / Mine -> Render -> Display The degree to which these individual components are distributed or collocated has historically been driven by the cost to deploy and maintain infrastructure and services. Early in the history of scientific computing, networking bandwidth was expensive and therefore scarce. Consequently early visualization pipelines tended to minimize the movement of data over networks in favor of collocating data storage with data processing. However, as the amount and variety of data continued to grow at an exponential pace, it became too costly to maintain full replicas of the data for each individual that needed to use it. Instead, by leveraging the widespread expansion of the Internet and other national and international high-speed network infrastructure such as the National LambdaRail, Internet-2, and the Global Lambda Integrated Facility, data and service providers began to migrate toward a model of widespread distribution of resources. In this chapter we will first introduce the various instantiations of the visualization pipeline and the historic motivation for their creation. We will then examine individual components of the pipeline in detail to understand the technical challenges that must be solved in order to ensure continued scalability. We will discuss distributed data management issues that are specifically relevant to large-scale visualization. We will also introduce key data rendering techniques and explain through case studies approaches for scaling them by leveraging distributed computing. Lastly we will describe advanced display technologies that are now considered the ?lenses? for examining large-scale data.

[RKN*13] in the draft. Molecular Dynamics is becoming a principle methodology in the study of nanoscale systems, paving the way for innovations in battery design and alternative fuel applications. With the increasing availability of computational power and advances in modeling, atomistic simulations are rapidly growing in scale and complexity. Despite the plethora of molecular visualization techniques, visualizing and exploring large-scale atomistic simulations remain difficult. Existing molecular representations are not perceptually scalable and often adopt a rigid definition of surfaces, making them inappropriate for nanostructured materials where boundaries are inherently ill-defined. In this paper, we present an application for the interactive visualization and exploration of large-scale atomistic simulations in ultra-resolution immersive environments. We employ a hybrid representation which combines solid ball-and-stick glyphs with volumetric surfaces to visually convey the uncertainty in molecular boundaries at the nanoscale. We also describe a scalable, distributed GPU ray-casting implementation capable of rendering complex atomistic simulations with millions of atoms in real-time.

[FRDJ14] Parallel Processing and Immersive Visualization of Sonar Point Clouds. The investigation of underwater structures and natural features through Autonomous Underwater Vehicles (AUVs) is an expanding field with applications in archaeology, engineering, environmental sciences and astrobiology. Processing and analyzing the raw sonar data generated by automated surveys is challenging due to the presence of complex error sources like water chemistry, zero-depth variations, inertial navigation errors and multipath reflections. Furthermore, the complexity of the collected data makes it difficult to perform effective analysis on a standard display. Point clouds made up of hundreds of millions to billions of points are not uncommon. Highly interactive, immersive visualization is a desirable tool that researchers can use to improve the quality of a final sonar-based data product. In this paper we present a scalable toolkit for the processing and visualization of sonar point clouds on a cluster-based, large scale immersive visualization environment. The cluster is used simultaneously as a parallel processing platform that performs sonar beam-tracing of the source raw data, and as the rendering driver of the immersive display.

[FNM*14] in the draft. In the domain of large-scale visualization instruments, hybrid reality environments (HREs) are a recent innovation that combines the best-in-class capabilities of immersive environments, with the best-in-class capabilities of ultra-high-resolution display walls. HREs create a seamless 2D / 3D environment that supports both information-rich analysis as well as virtual reality simulation exploration at a resolution matching human visual acuity. Co-located research groups in HREs tend to work on a variety of tasks during a research session (sometimes in parallel), and these tasks require 2D data views, 3D views, linking between them and the ability to bring in (or hide) data quickly as needed. In this paper we present Omegalib, a software framework that facilitates application development on HREs. Omegalib is designed to support dynamic reconfigurability of the display environment, so that areas of the display can be interactively allocated to 2D or 3D work spaces as needed. Compared to existing frameworks and toolkits, Omegalib makes it possible to have multiple immersive applications running on a cluster-controlled display system, have different input sources dynamically routed to applications, and have rendering results optionally redirected to a distributed compositing manager. Omegalib supports pluggable front-ends, to simplify the integration of third-party libraries like OpenGL, OpenSceneGraph, and the Visualization Toolkit (VTK). We present examples of applications developed with Omegalib for the 74-megapixel, 72-tile CAVE2? system, and show how a Hybrid Reality Environment proved effective in supporting work for a co-located research group in the environmental sciences.

[CKNS15] Creative problem solving in digital space using visual analytics. This article presents a framework for understanding and explaining digital creativity within the growing area of interactive visual analytics. Through the study of extant literature, existing software products, and our own development experience, various aspects of digital creativity are explored in the context of interactive visual analytics and its application to decision-making and problem-solving. The proposed framework explores and fuses a number of models of individual, social, and domain creativity. It explains the challenges of the analyst navigating through rapidly growing and ubiquitous digital data with an objective to explore it, discover its meanings and associations, as well as solve problems and arrive at effective business decisions. As a creative process, interactive visual analytics differs from other forms of digital creativity, as it utilizes analytic models, relies on the analyst?s mental imagery and involves an iterative process of generation and evaluation of ideas in digital media, as well as planning, execution, and refinement of the associated actions. This process is also characterized as collaborative and social by nature as it comprises of analysts from data, problem, and visual domains, who share ideas and actions during analytic activities. We conclude by suggesting that interactive data visualization may provide opportunities for lay people to creatively engage with data analytics to explore the vast data resources that are freely available and in so doing, gain and communicate insights which may have the potential to impact their private lives and the world at large.

[CCC*15] in the draft. Immersive Analytics is an emerging research thrust investigating how new interaction and display technologies can be used to support analytical reasoning and decision making. The aim is to provide multisensory interfaces that support collaboration and allow users to immerse themselves in their data in a way that supports real-world analytics tasks. Immersive Analytics builds on technologies such as large touch surfaces, immersive virtual and augmented reality environments, sensor devices and other, rapidly evolving, natural user interface devices. While there is a great deal of past and current work on improving the display technologies themselves, our focus in this position paper is on bringing attention to the higher-level usability and design issues in creating effective user interfaces for data analytics in immersive environments.

[MGHK15b] [http://arxiv.org/abs/1506.08754] Improving Big Data Visual Analytics with Interactive Virtual Reality. Andrew Moran, Vijay Gadepally, Matthew Hubbell, Jeremy Kepner For decades, the growth and volume of digital data collection has made it challenging to digest large volumes of information and extract underlying structure. Coined ?Big Data?, massive amounts of information has quite often been gathered inconsistently (e.g from many sources, of various forms, at different rates, etc.). These factors impede the practices of not only processing data, but also analyzing and displaying it in an efficient manner to the user. Many efforts have been completed in the data mining and visual analytics community to create effective ways to further improve analysis and achieve the knowledge desired for better understanding. Our approach for improved big data visual analytics is two-fold, focusing on both visualization and interaction. Given geo-tagged information, we are exploring the benefits of visualizing datasets in the original geospatial domain by utilizing a virtual reality platform. After running proven analytics on the data, we intend to represent the information in a more realistic 3D setting, where analysts can achieve an enhanced situational awareness and rely on familiar perceptions to draw in-depth conclusions on the dataset. In addition, developing a human-computer interface that responds to natural user actions and inputs creates a more intuitive environment. Tasks can be performed to manipulate the dataset and allow users to dive deeper upon request, adhering to desired demands and intentions. Due to the volume and popularity of social media, we developed a 3D tool visualizing Twitter on MIT?s campus for analysis. Utilizing emerging technologies of today to create a fully immersive tool that promotes visualization and interaction can help ease the process of understanding and representing big data.

[PPKM15] The Reality Deck–an Immersive Gigapixel Display Papadopoulos, C. ; Stony Brook Univ., Stony Brook, NY, USA ; Petkov, K. ; Kaufman, A.E. ; Mueller, K. The Reality Deck is a visualization facility offering state-of-the-art aggregate resolution and immersion. Its a 1.5-Gpixel immersive tiled display with a full 360-degree horizontal field of view. Comprising 416 high-density LED-backlit LCD displays, it visualizes gigapixel-resolution data while providing 20/20 visual acuity for most of the visualization space.

[In Preparation, tem uma sinopse em pdf] Cybulski, Jacob, Morteza Namvar, Dilal Saundage, Susan Keller, Lasitha Dharmasena "Designing 2D and 3D VA for Interactivity and Collaboration: Visual Sensemaking."

5. Biographies

Carla Maria Dal Sasso Freitas is a full professor at the Institute of Informatics, UFRGS. She received a PhD degree in Computer Science from UFRGS in 1994, and currently leads the Visualization and Interaction Lab. She has already supervised more than 40 graduate students, and published more than hundred scientific papers. Her research interests are centered on novel interactive visualization techniques.

Luciana Nedel works at Federal University of Rio Grande do Sul (UFRGS), where she has an associate professor position since 2002. She received a PhD degree in Computer Science from Swiss Federal Institute of Technology (EPFL), Switzerland, in 1998. Her main interests include virtual reality, interactive visualization, and non-conventional interaction. In these fields, she published more than hundred scientific articles.

Anderson Maciel is an associate professor at UFRGS. He received his PhD degree from EPFL (Switzerland) in 2005, for a thesis on biomechanics-based models for virtual patients. He is co-author of papers in both graphics and medical related conferences and journals, being member of the CAVW and IJCARS editorial boards. His research interests include medical image analysis, virtual reality and human-computer interfaces, specially 3D and haptic interfaces.

Regis Kopper is an assistant research professor at Duke University and directs the Duke immersive Virtual Environment (DiVE). He received his Ph.D. in Computer Science from Virginia Tech, and has over 10 years experience in the design and evaluation of virtual reality systems. He is a recipient of the best paper award at IEEE 3DUI and of a 3DUI grand prize award, and his research has been funded by the DoD, NSF and NIH.

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