IEEE VIS 2015 Tutorial:
Direct Volume Interaction for Visual Data Analysis

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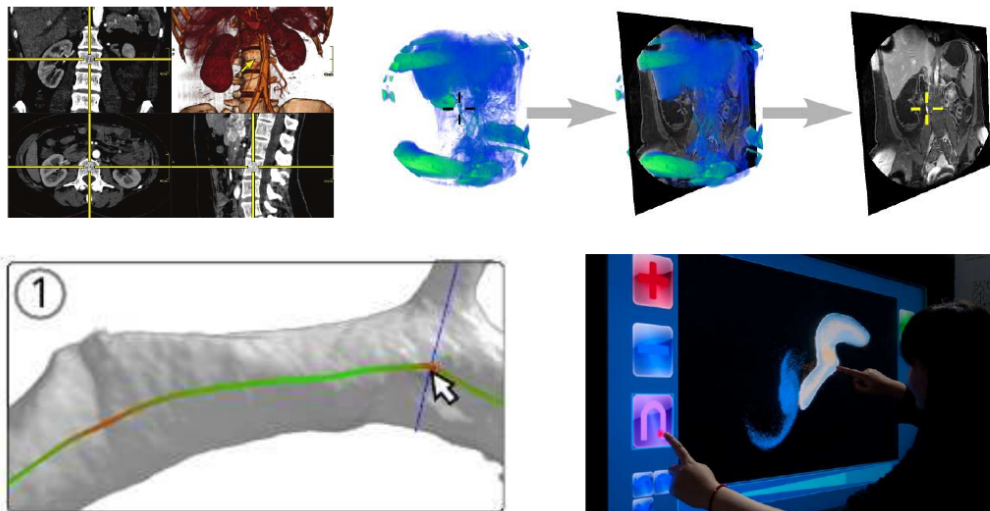
Fig. 1. Different types of direct volume interaction.

Abstract—Natural sciences, medicine and engineering are only a small selection of application domains where volumetric data, continuous as well as scattered, are close to ubiquitous. While the visualization of such data itself is not straightforward, interaction with and manipulation of volumetric data - essential aspects of effective data analysis - pose even further challenges. Due to the three-dimensional nature of the data, it is not straightforward how to select features, pick positions, segment regions or otherwise interact with the rendering or the data themselves in an intuitive manner. In this tutorial we will present state of the art approaches and methods for addressing these challenges with a special focus on the users' analysis and interaction tasks, as well as on the application of the methods in a large variety of application domains.

The tutorial will start by reviewing common classes of interaction tasks in volume visualization, motivating the need for direct interaction and manipulation, and describing the usually encountered difficulties. Interaction with visualization traditionally happens in PC-based environments with mouse and 2D displays. The second part of the tutorial discusses specific interaction methods that deal with the challenges in this context. Furthermore, an overview of the range of applications of these techniques is given to demonstrate their utility. The use of alternative paradigms for interaction with volumes is discussed in the third part. Such paradigms, e.g. in the context of touch interfaces or immersive environments, provide novel opportunities for volume exploration and manipulation, but also pose specific challenges themselves. The last part completes the tutorial's scope by a treatment of higher-level interaction techniques guiding users in navigation and exploration of the data using automatic or semi-automatic methods for identifying relevant parameter ranges. Such techniques employ additional, sometimes workflow-specific, information to assist in choosing effective volume visualization techniques and related attributes.

Index Terms—Interaction, interactive selection, sketching, manipulation, volume rendering, volume data, point clouds, volume picking, point picking, marking, volume pinpointing, novel interaction platforms, guided navigation, guided exploration.

✦

1 INTRODUCTION

- *Alexander Wiebel has been with Coburg University of Applied Sciences and Arts during preparation of the tutorial and is now with Worms University of Applied Sciences, Worms, Germany.*
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- *Tobias Isenberg is with INRIA-Saclay, Orsay, France.*
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- *Timo Ropinski is with Ulm University, Ulm, Germany.*
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A previous version of the proposed tutorial was held at Eurographics 2015 on May 4th 2015 as "Tools & Techniques for Direct Volume Interaction". Course materials of the previous tutorial are available at: http://tutorials.awmw.org/DirectVolumeInteraction. Course materials for the current tutorial for IEEE VIS 2015 will be made available at the same website. The tutorial notes will include the description of the tutorial, an overview of the material covered in each talk, a copy of each presenter's slides, and reprints of selected publications that describe some of particular techniques presented in our lectures.

As we expect an audience with a stronger interest regarding data analysis and in the direction of what users want to achieve when interacting with a volume, this tutorial for IEEE VIS 2015 will have a slightly shifted focus compared to the Eurographics 2015 tutorial. All parts of the tutorial are revised to place more emphasis on user tasks

and application domains related to the volume interaction.

2 TUTORIAL LEVEL AND INTENDED AUDIENCE

An **intermediate knowledge level** of interactive computer graphics and scientific visualization algorithms is required. Programming experience of interactive graphics and some awareness of issues regarding interaction with and perception of volume data visualization may be helpful. Not required: prior knowledge of or background in 3D user interfaces, perceptual psychology, or human- computer interaction.

The intended audience consists of computer graphics and visualization researchers, programmers, other users of volume visualization and all those interested in tools and techniques for direct interaction with volume data its challenges, common solutions and the latest advances.

3 INSTRUCTORS

Brief resume of the instructors indicating their background in the area the tutorial addresses (in alphabetical order).

Stefan Bruckner [WWW] is professor in visualization at the Department of Informatics of the University of Bergen, Norway. He received his master's degree in Computer Science from the Vienna University of Technology (VUT), Austria in 2004 and his Ph.D. in 2008 from the same university. He was awarded the habilitation (venia docendi) in Practical Computer Science in 2012. From 2008 to 2013, he was an assistant professor at the Institute of Computer Graphics and Algorithms at VUT. His research interests include interactive visualization techniques for biomedical data, illustrative visualization, volume rendering, and visual data exploration. His research has received publication awards at several international events including VCBM 2014 (best paper and honorable mention), SCCG 2013 (best paper), EuroVis 2010 (best paper), and Eurographics 2007 (3rd best paper). He won the Karl-Heinz-Höhne Award for Medical Visualization in 2006 and received the 2011 Eurographics Young Researcher Award. He is a member of the IEEE Computer Society, ACM SIGGRAPH, and Eurographics.

Tobias Isenberg [WWW] is senior research scientist (directeur de recherche) with the AVIZ project team at INRIA-Saclay, south of Paris in France. He received his Ph.D. degree from the University of Magdeburg, Germany. Previously he held positions as post-doctoral fellow at the University of Calgary, Canada, and as assistant professor at the University of Groningen, the Netherlands. His research interests comprise topics in scientific visualization, in illustrative and non-photorealistic rendering, and interactive visualization techniques. In particular, he is interested in how we can make use of touch-enabled displays to support intuitive and effective forms of interaction with scientific data. He is a member of the IEEE, IEEE CS, VGTC, ACM, ACM SIGGRAPH, and Eurographics.

Timo Ropinski [WWW] is professor in Visual Computing at Ulm University, Germany, where he is heading the Visual Computing Group. Before moving to Ulm he was Professor in Interactive Visualization at Linköping University, Sweden, where he was heading the Scientific Visualization group. He received his Ph.D. in 2004 from the University of Münster, where he was also awarded the habilitation (venia legendi) in 2009. Ropinski's research is focused on volume rendering, biomedical visualization and interactive visual decision making. He headed the winning team of the IEEE Visualization contest 2010, and he has held tutorials at Eurographics, ACM SIGGRAPH and IEEE Visualization. Furthermore, he is a member of the IEEE Computer Society, ACM, and Eurographics.

Alexander Wiebel [WWW] is professor of software development and digital media production at Worms University of Applied Sciences in Germany. He received his Dipl.-Inf. (MS in computer science) degree from the University of Kaiserslautern in 2004 and his Ph.D. degree from Universität Leipzig in 2008. For both degrees he performed research in the context of flow visualization. As a postdoctoral researcher at Max Planck Institute for Human Cognitive and Brain Sciences, and later at Zuse Institute Berlin (ZIB), he conducted research in interactive visualization of 3D MRI data with a focus on intuitive selection of structures in direct volume renderings. During this time, Alexander Wiebel lectured at Universität Leipzig and Freie Universität Berlin. Between 2013 and 2015 he was a professor of visual computing at Coburg University of Applied Sciences and Arts in Germany. His research received a nomination for the best paper award and an honorable mention at IEEE Visualization in 2007 and 2010 respectively.

4 TUTORIAL ORGANIZATION

This tutorial (2×100) minutes and is organized in four parts. See table 1.

4.1 Part 1: Visualization of volume data and the need for interaction (Ropinski)

Within this part, we lay the foundation for the rest of the tutorial. We review common classes of interaction tasks in volume visualization, whereby we delineate direct from indirect interaction paradigms. To bring previous work into a common context, we will analyze interaction techniques by considering them as the method for changing parameters of volume visualizations, whereby the domain, in which the interaction is applied, plays a central role. We will further discuss how different paradigms can be used to either modify spatial parameters or to alter global, non-spatial parameters. Based on these observations and classifications of general interaction tasks, we will derive interaction tasks in the context of volume visualization. We will show how these tasks can be investigated from a semantic point of view or a technical point of view, e.g., selection vs. picking. From a technical perspective, we will derive and discuss the common basic demands these tasks have, and address challenges related to 2D and 3D interaction. Furthermore, we will discuss discipline-related specifics of these tasks, as they occur in many areas exploiting interactive visualization.

Relevant Literature

1. M. Brehmer, T. Munzner. A Multi-Level Typology of Abstract Visualization Tasks. IEEE TVCG, 19(12):2376-2385, 2013. [PDF]
2. B. Shneiderman. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. IEEE Symposium on Visual Languages, p. 336-343, Washington, 1996. [PDF]
3. K.T. Nguyen, A. Ynnerman, T. Ropinski. Analyzing and Reducing DTI Tracking Uncertainty by Combining Deterministic and Stochastic Approaches. International Symposium on Visual Computing, pages 266-279, 2013. [PDF]
4. S. Diepenbrock, T. Ropinski. From Imprecise User Input to Precise Vessel Segmentations. EG Visual Computing for Biology and Medicine - 2012. [PDF]
5. S. Diepenbrock, T. Ropinski, K. Hinrichs. Context-Aware Volume Navigation. IEEE Pacific Visualization, 2011. [PDF]
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7. J. Mensmann, T. Ropinski, K. Hinrichs. Interactive Cutting Operations for Generating Anatomical Illustrations from Volumetric Data Sets. Journal of WSCG, 16(2): 89-96, 2008. [PDF]
8. T. Ropinski, J. Praßni, F. Steinicke, K. Hinrichs. Stroke-Based Transfer Function Design. IEEE/EG Volume and Point-Based Graphics, p. 41-48, 2008. [PDF]

4.2 Part 2: Direct Manipulation (Wiebel)

Interaction with and manipulation of volumetric renderings and volumetric data are naturally non-trivial tasks when carried out on common 2D displays with mouse and keyboard input. This part will concentrate on techniques which take the provided 2D input and translate it into application-specific direct 3D actions and manipulations regarding the volume. Input types we will discuss include points (picking), lines (sketching) or regions (marking). Depending on the user task at hand, semantics of the resulting 3D actions range from simple selection of positions, lines and surfaces in 3D, to segmentation, labeling,

14:00	-	14:05	Introduction (Ropinski)
14:05	-	14:45	Part 1: **Visualization of volume data and the need for interaction** (Ropinski)
14:45	-	14:50	Questions
14:50	-	15:30	Part 2: **Direct manipulation** (Wiebel)
15:30	-	15:40	Questions and discussion
15:40	-	16:15	Break
16:15	-	16:55	Part 3: **Interaction with non-standard input and output devices** (Isenberg)
16:55	-	17:00	Questions
17:00	-	17:40	Part 4: **Visual Exploration and Guided Navigation** (Bruckner)
17:40	-	17:50	Questions and discussion
17:50	-	17:55	Closing remarks (Wiebel)

Table 1. Tutorial schedule. Date: Sunday, 2015-10-25. Location: Monroe, Palmer House Hilton, Chicago, USA.

3D painting, and adaption of the transfer function or the data themselves. We will give a detailed description of the possibly needed additional or meta data for each technique. An overview of common applications of the mentioned techniques for imaging and simulation data from medicine and natural sciences will demonstrate the utility of the techniques.

Relevant Literature

1. A. Wiebel, F. M. Vos, D. Foerster, H.-C. Hege. WYSIWYP: What You See Is What You Pick. IEEE TVCG, 18(12):2236-2244, 2012. [PDF]
2. S. Owada, F. Nielsen, T. Igarashi. Volume catcher. In Proceedings of the 2005 Symposium on interactive 3D graphics and games, I3D '05, p. 111–116, New York, USA, 2005. [DOI]
3. L. Yu, K. Efstathiou, P. Isenberg, T. Isenberg. Efficient structure-aware selection techniques for 3D point cloud visualizations with 2DOF input. IEEE TVCG, 18(12):2245-2254, Dec. 2012. [WWW]
4. H. Peng, et al.. Virtual finger boosts three-dimensional imaging and microsurgery as well as terabyte volume image visualization and analysis. Nature Communications 5, Article number: 4342, 2014. [DOI]
5. S. Stoppel, H.-C. Hege, A. Wiebel. Visibility-Driven Depth Determination of Surface Patches in Direct Volume Rendering. EuroVis Short Papers 2014, p. 97-101, Eurographics Association, 2014. [DOI]
6. K. Bürger, J. Krüger, R. Westermann. Direct Volume Editing. IEEE TVCG, 14(6):1388-1395, 2008. [DOI]
7. H. Guo, N. Mao, X. Yuan. WYSIWYG (What You See is What You Get) Volume Visualization. IEEE TVCG, 17(12):2106-2114, 2011. [DOI]
8. P. Kohlmann, S. Bruckner, A. Kanitsar, M. E. Gröller. Contextual Picking of Volumetric Structures. In Proceedings of IEEE Pacific Visualization, p. 185–192, 2009. [WWW]
9. See part 1 reference 4: "From imprecise user input ..."

4.3 Part 3: Data Exploration on Novel Interaction Platforms (Isenberg)

In addition to traditional PC-based interactive platforms for the exploration of volumetric data, several others exist that place emphasis on spatial perception, direct manipulation, or mobility. For example, stereoscopic environments such as CAVEs provide an excellent visual immersion which is essential for the exploration of 3D spatial data such as volumes. More recently, touch-based interaction became available on large displays which provides immersion through direct manipulation. This part of the tutorial will explore the interaction challenges when using these environments to explore volumetric data. We will discuss the differences between immersive and projected display environments, direct vs. indirect input/interaction, and the role of tactile feedback for the interaction. To give specific examples for practically relevant interaction tasks, we will discuss examples of touch-based navigation and selection in both projected and immersive interaction settings, and mention other interaction tasks when manipulating 3D data on 2D touch surfaces.

Relevant Literature

1. S. Bryson. Virtual reality in scientific visualization. Communications of the ACM 39(5):62–71, 1996. [DOI]
2. D. Coffey, N. Malbraaten, T. Le, I. Borazjani, F. Sotiropoulos, A. G. Erdman, D. F. Keefe. Interactive slice WIM: Navigating and interrogating volume datasets using a multi-surface, multi-touch VR interface. IEEE TVCG 18(10):1614–1626, 2012. [DOI]
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9. See part 2 reference 3: "Efficient structure-aware selection ..."

4.4 Part 4: Visual Exploration and Guided Navigation (Bruckner)

In particular in the context of visualization applications targeted at users with a limited technical background, it can be beneficial to constrain the users' freedom and instead provide automated guidance and suggestions to simplify the interaction. This part of the tutorial will focus on guided navigation and visual exploration strategies which exploit additional information in order to fully or semi-automatically assist the user in specifying relevant visualization parameters for particular tasks. This includes common settings such as the viewpoint, clipping planes, transfer functions, but also extends to the choice of the visualization technique itself. Such approaches frequently rely on additional knowledge and we will discuss different strategies for obtaining the required information. Finally, we will review approaches for integrating such guidance into existing workflows with a particular focus on medical and biological applications.

Relevant Literature

1. P. Kohlmann, S. Bruckner, A. Kanitsar, M. E. Gröller. LiveSync: Deformed Viewing Spheres for Knowledge-Based Navigation. IEEE TVCG, 13(6): 1544–1551, 2007. [WWW]
2. See part 2 reference 8: "Contextual Picking ..."
3. G. Mistelbauer, H. Bouzari, R. Schernthaner, I. Baclija, A. Köchl, S. Bruckner, M. Srmek, M. E. Gröller. Smart Super Views - A Knowledge-Assisted Interface for Medical Visualization. In Proceedings of IEEE VAST, p. 163-172, 2012. [WWW]
4. U. D. Bordoloi and H.-W. Shen. View Selection for Volume Rendering. In Proceedings of IEEE Visualization, p. 487–494, 2005. [DOI]

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7. See part 2 reference 7: "WYSIWYG ..."