Rejuvenated Medical Visualization

Large-scale, whole-body visualization, visualizing physiology, non-standard imaging and simulations, and cohort studies

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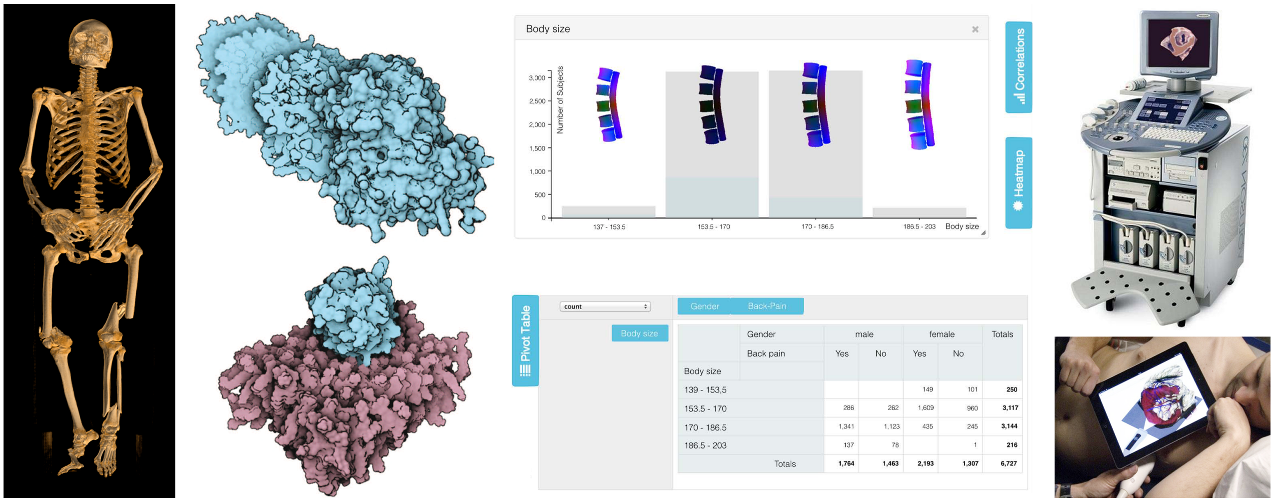

Abstract

Medicine is one of the primary drivers of visualization research and medical visualization (MedViz) is a vibrant and successful field with a tradition of dozens of years. Traditionally, a lot of MedViz research has been focused on the visualization of a single, unimodal patient dataset, being usually defined on a regular grid in 3D and capturing a selected part of the human anatomy. As a prominent example, volume rendering has been extensively studied, together with advanced lighting simulation, etc. In recent years, however, the most pressing challenges in MedViz have broadened, not at the least paralleling new developments in image acquisition, and being associated with a growing data complexity, and advances in medical diagnosis and patient treatment. It is now becoming increasingly common, that several datasets are acquired, also at different points in time, and that in-vivo information, related to physiology, is complementing the more traditional anatomical information. Different imaging modalities are applied and whole-body scans facilitate the screening for disease and amplify the opportunities of forensic pathology. Data may also be measured or computed in a numerical simulation over complex grids, e.g., in ultrasound imaging or in the simulation of blood flow in cerebral and aortic aneurysms. All this data needs to be integrated with the anatomical scans. While traditional MedViz usually focuses on data of a single patient, the large data pools that are acquired in longitudinal cohort studies, for example, in epidemiology, involving hundreds to thousands of individuals (the cohort) pose tremendous new challenges. These include the combined visualization of image and non-image data as well as the integrated visualization of heterogeneous data. The effective and efficient interactive exploration of large medical data requires innovative technology and dedicated interaction techniques such as table-top user interfaces and gesture-based interaction.

In this tutorial, we discuss the above-mentioned modern challenges in MedViz, followed by examples of and strategies for the development of new solutions to cope with these challenges with respect to specific (clinical) problems. We explore a variety of advanced MedViz topics. In particular, we discuss the interactive visualization of whole-body medical volume data, visualization techniques addressing the readability problem of Ultrasound by enriching the data with other types of medical data, the visualization of more abstract physiological data in its anatomical context, and the interactive visual analysis of heterogeneous image-centric cohort study data. Sufficient room for discussion is also planned as part of this tutorial.

1 Why is this Tutorial Worthwhile?

A review of all IEEE VIS publications in 2013 and 2014 indicated that medical visualization (MedViz) spans the realms of scientific visualization, visual analytics, and information visualization. In IEEE SciVis alone, one third of the publications was either targeted at a specific clinical problem or applied medical data for illustration purposes. While some publications were still dedicated to subfields with a longer tradition, such as optimized lighting in volume rendering and the visualization of vasculature, new subfields received increased attention. For instance, computational fluid dynamic simulations of blood flow were investigated, longitudinal data of large cohorts in epidemiology were analyzed, the visual readability of Ultrasound data was improved, and the display of anatomical data was enriched by physiological information. This tutorials is meant to acknowledge these new trends in MedViz and expose them to the interested visualization community. We show that MedViz rejuvenates by new opportunities and according visualization challenges and that there is a strong need for new research in MedViz, not at the least because of the outstanding relevance of modern MedViz. The tutorial is presented by leading researchers with excellent communication skills and long-lasting experiences from teaching. The talks will be stimulating by also discussing open problems. All tutorial speakers, as well as their topics, do not only aim at describing the current academic progress but also describe the contribution to modern medical diagnosis and patient treatment.

Tutorial History MedViz tutorials have been held in different versions at IEEE Visualization from 2003 to 2008, evolving from a half-day tutorial, covering the basics of MedViz, to a full-day tutorial addressing also advanced MedViz topics. Every year, the tutorial topics were updated (and some of them were replaced by new topics). The tutorial notes of the years 2006–2008 (including extended reference lists, videos, etc.) are available at: `http://www.vismd.de/doku.php?id=teaching_tutorials:start`. Our own experience and the tutorial feedback which we received in 2006 and 2007 led us to the conclusion that we should focus on advanced topics. Most of the basic topics seem to be sufficiently known, but questions on how to derive visual solutions for specific clinical problems were still of interest. Hence, we offered a half-day tutorial in 2008, focusing on advanced topics, e.g., the visualization of cerebral multi-modal volume data, the visual analysis of perfusion data, and diffusion tensor imaging of the brain and the heart muscle. With the new tutorial (this one), we aim to acknowledge a number of interesting changes in MedViz and therefore focus on challenging new trends. Accordingly, the entire tutorial is prepared around new topics. All parts are described in more detail in the syllabus section.

Level of Difficulty/Prerequisites *Intermediate/Advanced.* We assume a solid understanding of 3D graphics and the basic principles of visualization and medical imaging. Although we focus on recent research, we are not addressing experts in particular.

Intended Audience Tutorial attendees are researchers and practitioners in MedViz, who are interested in modern MedViz and the related applications. The tutorial should be both inspiring for young colleagues, who explore new opportunities in MedViz research, as well as for practitioners, who are interested in catching up with new trends.

2 Tutorial Syllabus

The tutorial is designed as a textbook-like presentation. Besides the presentation of exploration, visualization, and interaction techniques, it also includes an introduction into the recent trends in MedViz and is completed by a discussion with the tutorial attendees. The proposed tutorial schedule is as follows:

- I Introduction, *Oeltze-Jafra* (20min)
- II Interactive Visualization of Whole-Body Medical Volume Data, *Ynnerman* (40min)
- III From Static to Dynamic – Visualization of Real-Time Imaging Data, *Bruckner* (40min)
- — Break (20min)
- IV From Anatomy to Physiology, *Hauser* (35min)
- V From Single-Patient to Cohort Study Data, *Oeltze-Jafra* (35min)
- VI Discussion and Closing Words, *All Presenters* (30min)

Part II This part of the tutorial takes its starting point in the latest medical scanning modalities with a focus on computed tomography (CT). It is today possible in routine medical diagnostic work to capture a whole body with high resolution in two seconds generating 20,000 slices of high resolution image data. The tutorial will provide an overview of the CT technology that makes this possible and also extrapolate into the future of CT and the exciting development of 4D scanning and multispectral detectors. The tutorial will then address strategies for interactive visualization of whole-body scans and the data reduction and compression schemes enabling interactive visualization on large touch surfaces such as the medical visualization table [8] which is used in the diagnostic workflow, presurgical planning and in medical education. Increasingly advanced volumetric illumination methods are also being used in the high quality full body rendering pipeline [3] and the tutorial will show methods and results from some of the latest global illumination approaches applied to whole-body scans. The tutorial will also show how advanced illumination can be used to convey multi-field data such as contextualized fMRI or CT-PET data [9].

Part III Ultrasonography has become a standard tool in obstetrics, cardiology, gastroenterology, and many other medical fields and the range of applications is constantly growing. The technology has progressed rapidly from initial 1D signals over standard 2D sonography to 3D volumetric ultrasound. Recently, the rapid increases in processing power coupled with advances in digital beamforming have enabled the real-time capture of high-resolution 3D volumes hence making ultrasound a true 4D imaging modality which paves the way for a number of new important clinical applications such as the in-vivo assessment of heart defects [2] or the prenatal diagnosis of neurological problems [7]. However, despite its advantages, the visualization of ultrasound data is plagued by several challenges. Compared to other common tomographic imaging modalities such as CT or MRI, ultrasound has a much poorer signal-to-noise ratio and suffers from various acoustic artifacts such as attenuation focusing and interference [11]. This part of the tutorial will give an overview of latest advances in ultrasound technology, their applications, and the associated visualization challenges as well as recent approaches for overcoming them.

Part IV Generally, medical visualization assists the diagnosis of diseases as well as the treatment of patients. Capturing the patients anatomy, which to a large degree is in the focus of traditional MedViz, certainly is one important key to the success of medical visualization. At least equally important, if not even more, is the consideration of physiology, entailing the complex of function (or malfunction) of the patient. Modern imaging modalities extend beyond the simple depiction of static anatomical snapshots to capturing temporal processes as well as to covering multiple scales of physiology eventually linking molecular biology to medicine [6]. The visualization of human physiology complements other techniques, for example lab tests for quantifying certain physiological functions. We deem ourselves at the beginning of an interesting extension of MedViz research to increasingly capture physiology in addition to anatomy [1].

Part V Large-scale longitudinal epidemiological studies such as the Study of Health in Pomerania (SHIP) [10] investigate groups of people with common characteristics or experiences (a cohort) including socio-demographic and biological factors. Their goal is the characterization of health by identifying risk factors and their relations to diseases and the indication of a per subject risk of developing a disease. Carried out in waves over many years, they comprise thousands of individuals and ten thousands of variables. Unique for SHIP is the inclusion of medical image data acquired via an extensive full-body MRI protocol. Current SHIP-research projects are the characterization and differentiation of age-dependent and pathologic variance in spinal curvature and the investigation of relations between the parenchyma tissue proportion in the female breast and the risk of getting breast cancer. A major goal is the visual analysis of inter- and intra-subject group statistical variance in curvature and parenchyma tissue proportion. In this tutorial, we present an interactive visual analysis approach that fits into the epidemiological workflow and facilitates hypotheses validation and generation [4, 5]. The approach supports a bi-directional analysis of the non-image and the image data.

3 Presenters' Contact Data and Biographies

Steffen Oeltze-Jafra (Organizer)
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Steffen Oeltze-Jafra received the diploma (M.Sc.) degree in computational visualistics from the University of Magdeburg (UoM), Germany in 2004. In 2010, he received his Ph.D. in computer science from the the same university. Since April 2010, Steffen is is a postdoctoral fellow at the Computer Science Department at the UoM. His research interests are in medical visualization, in particular the visual analysis of simulated blood flow and 4D-perfusion data, in biological data visualization, and in the visual analysis of epidemiological cohort study data. In 2004 and 2008, Steffen received the "Karl-Heinz-Höhne" award (2nd and 1st place) for his scientific work on the visualization of vasculature with convolution surfaces and the interactive visual analysis of perfusion data, respectively. He won the 2005 and 2008 annual research awards of the computer science faculty at the UoM for his work on vessel visualization and his scientific overall achievement, respectively. Steffen organized the IEEE Vis tutorials Interactive Visual Analysis of Scientific Data (2012 and 2013), "Visual Medicine: Techniques, Applications and Software" (2006) and "Advanced Visual Medicine: Techniques, Applications and Software" (2007).

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Anders Ynnerman received a Ph.D. 1992 in physics from Gothenburg University. During the early 90s he was doing research at Oxford University, UK, and Vanderbilt University, USA. In 1996 he started the Swedish National Graduate School in Scientific Computing, which he directed until 1999. From 1997 to 2002 he directed the Swedish National Supercomputer Centre and from 2002 to 2006 he directed the Swedish National Infrastructure for Computing (SNIC). Since 1999, he is holding a chair in scientific visualization at Linköping University and he is the director of the Norrköping Visualization Center - C, which currently constitutes one of the main focal points for research and education in computer graphics and visualization in the Nordic region. The center also hosts a public arena with large scale visualization facilities. He is also one of the co-founders of the Center for Medical Image Science and Visualization (CMIV) and he is serving as the chair of the scientific council for CMIV.

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Stefan Bruckner 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. Stefan currently serves on the editorial board of Computers & Graphics.

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Helwig Hauser graduated in 1995 from Vienna University of Technology (TU Wien), Austria. In 1998, he finished his PhD project on the visualization of dynamical systems. In 2003, he finished his Habilitation at TU Wien entitled "Generalizing Focus+Context Visualization" – in 2006 this work was awarded with the prestigious Heinz-Zemanek Preis. In 2013, H. Hauser received the Dirk Bartz Prize for Visual Computing in Medicine from Eurographics. One of his main activities, more recently, is to chair visualization conferences, including EuroVis 2011, PacificVis 2012, and IEEE InfoVis 2013. H. Hauser is member of the EuroVis Steering Committee, the TopoInVis Steering Committee, and has served / is serving on the Editorial Boards of Computers & Graphics, Computer Graphics Forum, and IEEE Transactions on Visualization and Computer Graphics. After first working for TU Wien as assistant (since 1994) and later as assistant professor, he changed to the new VRVis Research Center in 2000. There, he led the basic research group on interactive visualization (until 2003) before he became the scientific director of VRVis (until 2007). Since then, 2007, he is a full professor in visualization at the University of Bergen in Norway.

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