[DC] Scan2Twin: Virtual Reality for Enhanced Anatomical Investigation

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Abstract

Interpreting 3D information from 2D slices of data points is a notoriously difficult process, especially in the medical field with its use of scan imaging. This dissertation aims to apply and assess the advantages of virtual reality (VR) for exploring volumetric visualization of medical images and enable efficient generation of explicit, unambiguous surface models. I will evaluate the effects of stereoscopic viewing on different methods of volumetric data visualizations, experiment with tool development to increase 3D modeling accessibility, and an expert review of the overall system design we refer to as Scan2Twin.

Index Terms: Human-centered computing—Visualization—Visualization systems and tools; Computing methodologies—Computer graphics—Graphics systems and interfaces—Perception

1 Introduction

Diagnosis and treatment of cancer often require analysis of 3D human anatomy using 2D imaging techniques such as magnetic resonance images (MRI). However, the ability to read MRI has a steep learning curve [5], and, even for experts, is a taxing process because it requires the viewer to make 3D conclusions from 2D image slices through the body. Additionally, each person on the treatment team must individually construct their own 3D mental model, which results in diverging interpretations and misunderstandings that can negatively impact patient outcomes [3].

One method to combat this problem is to generate concrete 3D models from images for explicit visualization of the anatomy (e.g., 3D Slicer). However, the process can take several days due to manual segmentation of individual images and requires a software technician to operate the complex software [1]. Alternatively, automation via machine learning (ML) algorithms can assist 3D model generation but current solutions lack robustness to handle abnormal pathology and are susceptible to critical errors in over-processing data noise or small anatomical features. By contrast, the focus of our work keeps the expert radiologist in control to correct misinterpretation of anatomic detail and to prevent misunderstanding by the recipients by explicitly representing organ and tissue surfaces.

In this doctoral thesis, I will combine aspects of cognitive psychology, data visualization, and surface modeling to construct a software system tailored to the radiological challenges of MRI interpretation and conversion to an unambiguous 3D model. This system will comprise of a traditional 2D scan interface for defining volumes and structures of interest and a VR exploratory environment for data exploration and model creation.

In conjunction with developing this system, I will study how VR display and interaction capabilities can benefit stereoscopic viewing of volumetric medical data in comparison with traditionally accepted methods. The research will also include experimentation with tools to increase accessibility of 3D model curation and annotation for medical experts to refine 3D models automatically generated from 2D scan data.

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2 Scan2Twin System

In this research we are developing Scan2Twin, the multi-interface application depicted in Fig. 1. The goal of the system is to enable the explicit construction of 3D representations of a patient's MRI that is accessible to members of cancer treatment teams. The construction can then be used for concrete visualization, exploratory analysis, and clarifying team communications. The development of this research is motivated by challenges distilled from annual oncology review reports, physician anecdotes, and an analysis of available tools' success regarding adoption in practice and frequency of use.

By eliciting feedback from our medical collaborator, we have performed several cycles of an iterative design loop to address these domain challenges, settling on the following system design solution characterized by two major components: a familiar 2D scan interface using desktop peripherals (the leftmost image in Fig. 1) and a VR exploratory environment (shown in the 2nd and 3rd images from the left in Fig. 1).

2.1 Familiar Data Selection Interface

To construct the 3D visualization there needs to be a data selection process for which components of the MRI to voxelize into a volumetric form. One of the most prominent challenges this system faces is inherent apprehension from the medical field to adopt new technologies. To address this concern, the system starts with a familiar interface and interactions typically expected of working with MRI data. The system allows for the definition of structures of interest within a selected volume through a visual interface that displays the MRI in the traditional style for easy browsing and value selection. These interactions require fine motor navigation and lack any of the benefits afforded by the use of VR, and as such are accomplished with the use of a monitor, mouse, and keyboard.

2.2 Natural Volumetric Data Exploration with VR

In addition to supporting the selection and voxelization of relevant anatomical structures, the system supports an immersive VR environment that enables the user to navigate within the constructed data visualization.

Dan and Reiner [2] informs us that viewing 3D data naturally decreases cognitive load when compared to viewing the same data flattened into 2D representations. Laha et al. [4] supports the use of VR headsets for viewing 3D data by improving spatial understanding via stereoscopic depth cues and native navigation such as head-tracking. However, this literature fails to explore the implications of these benefits on the impact of different data visualization encodings and the ability to distinguish between true noise and ill-defined details.

As the system is meant to provide 3D modeling at an accessible level to medical practitioners, a major focus of the iterative design loop has been to construct a set of tools that enables detailed data curation and augmentation of structural appearances. The resulting set of tools currently available in the VR mode of the system include erasing, splitting, meshing, tracing, and data verification by overlaying the scans in 3D space.

3 Evaluation

Multiple evaluations will assess the Scan2Twin system and contribute new empirical knowledge of 3D visualization.

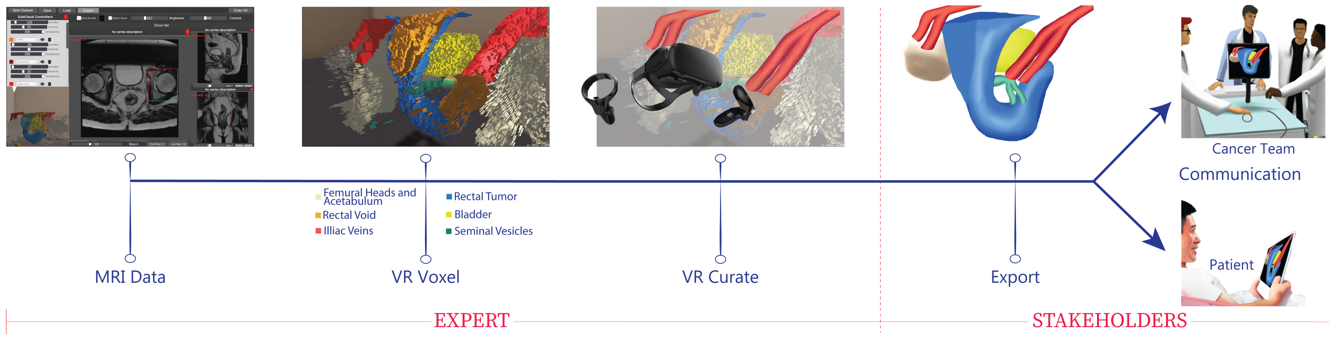

Figure 1: A visualization of the proposed pipeline for the software: familiar scan interface, initial voxelization of the structures, viewing and interacting in VR environment, exportation of results, use/benefit of output.

3.1 Study 1: Display Type and Rendering Technique

Initial investigations of available volume rendering techniques, when used in VR, revealed a lack of alteration to the techniques to account for the nuances of VR viewing, missing a true volumetric structure that allows for complete spatial exploration. To ensure effective interactive visualizations of volumetric data, I will test the effects of viewing modality on the appropriateness of different rendering styles for volumetric data exploration: volumetric rendering, surface transparencies, and voxel stippling.

This will be a controlled experiment with first and second-year medical students. The study will compare the three styles given domain-specific tasks such as orienting to a described viewpoint and determination of structural intersections using either a desktop setup (the control group) or the VR environment (the experimental group) to investigate the volumetric data. The study will measure the time to complete the task, the number of movements required to complete it, and a post-interview asking about the participant's perceived ability to understand the dimensionality of the visualization and retention of contextual details. The resulting best technique will be implemented in the system design for the final evaluation.

3.2 Study 2: VR Mesh Modification

Because the project is based on the need to have radiologists review and curate ML-suggested 3D model fitting, I will validate the efficacy of interactive 3D model editing by users lacking experience with 3D graphics or modeling. I will perform a within-subject experiment to evaluate the mesh editing capability between a traditional modeling interface (e.g., Blender) and our streamlined VR environment. Participants will be presented with the raw 3D data in the form of a voxel cloud and a preliminary surface model fitted to the data constructed by a shrink-wrapping algorithm. While the particular data visualized will be different for the traditional and VR environments, the number, distribution, and degree of alterations to the mesh needed to properly fit the data will be equivalent. Study measures will include the number of actions required to fit the provided mesh to the available data, time taken to complete the task, frequency of altering viewpoint, and accuracy of the final model.

3.3 Study 3: Expert Review

I will evaluate the system with feedback from medical experts. By the time of this consortium, I will have conducted a formative evaluation through a semi-structured interview with five expert users focusing on comfort with the interfaces, perceived scenarios of use, appropriateness of the available tool-set, and individual levels of trust of the visualizations produced. A future evaluation will incorporate the findings from the described studies and be conducted using domain expert subjects using an updated semi-structured interview following a set of tasks to be completed in the environment to simulate plausible use cases.

4 Conclusion

Scan2Twin has high potential to advance our understanding of how different viewing modalities can affect the data encodings we choose, adding to the guidelines which already account for the type of data being visualized. These results will further motivate new design considerations for interacting with data visualization in VR, and provide answers to challenges proposed by the medical field. This research will also lay the groundwork for future exploration into the impact of egocentric exploration of data on the accuracy of memory recall and clarity of communication. I would like to discuss the following at the doctoral consortium to improve the research design:

> [noitemsep]Recommendations for maintaining external validity using non-expert subjects and non-domain-specific tasks for experiments of the generalized methods. Appropriate task complexity for the modeling experiment (Study 2) to sufficiently restrict actions to necessary operations while maintaining fairness for comparisons with a comprehensive modeling tool like Blender. Recommendations for the scoping of the user tasks in our evaluations to better balance participation by both expert and non-expert participants.

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