Identifying the Benefits of Immersion in Virtual Reality for Volume Data Visualization

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***Abstract*—Researchers have traditionally used desktop display systems for visualizing and analyzing volume data. This is partially due to the lack of empirical results showing benefits of immersion for analysis of volume data, and also due to the cost of highly immersive virtual reality (VR) platforms. Researchers exploring the benefits of immersion tend to compare entire display systems rather than evaluating the benefits of individual components of immersion. The VR community needs controlled experimentation to gather empirical data on the benefits of individual components of immersion. In order to generalize the results to a variety of domains, a taxonomy that classifies tasks performed with volume data into general categories is also needed. In our work, we have developed a preliminary task taxonomy and are performing studies to identify the effects of various components of immersion on volume data analysis tasks.**

Keywords-Task taxonomy, benefits of immersion, volume visualization, controlled experiments, virtual reality, virtual environments, immersive visualization.

I. VOLUME VISUALIZATION AND THE USE OF VR

Visually analyzing and exploring data in volumetric format is a common task for researchers from various domains. Volume visualization is used in medicine (e.g., functional MRI data from brain scans, CT scans of the heart or lungs), in cell biology (e.g., data from confocal microscopy), in geology (e.g., rock strata), in paleontology (e.g., fossil scans), and in many other disciplines [1].

Traditionally, scientists and researchers in these various domains have used desktop computer systems for visualizing and analyzing volume data. These systems have monoscopic rendering, a small field of regard (FOR) and field of view (FOV), and a small display size, and lack head-tracked rendering.

Many people have suggested using virtual reality (VR) systems with higher levels of *immersion* (the objective level of sensory fidelity provided by a system [2]) for scientific visualization, including the analysis of volume data, since immersive VR is designed to display spatially complex structures in a manner easier to understand and explore [3]. But there is little empirical evidence validating these claims.

II. HOW MUCH IMMERSION IS ENOUGH?

To validate the claims of the benefits of immersion, we can run empirical experiments comparing the effectiveness of different levels of immersion for analyzing visualizations of volume data. Researchers exploring benefits of immersion have traditionally compared specific systems in a wholesale fashion (e.g., desktop vs. CAVE vs. fishtank VR [4]).

These experiments are of great value to the VR research community. They demonstrate the benefits of immersion beyond the impressive visual appeal of VR. But the results of these experiments are limited in two important ways.

A. Limitation 1: Lack of generalizability of results to other VR systems

When entire VR systems are compared to one another, several components of immersion (e.g., FOR, FOV, stereoscopy, head-tracked rendering) vary simultaneously between conditions. If such a study identifies a benefit of immersion, we cannot know which component(s) or combination of components of immersion resulted in those benefits. As a result of this confound, we cannot generalize the results to VR systems beyond the specific systems that were studied. We do not know whether VR systems with an intermediate level of immersion might have delivered the same benefits as a highly immersive system. The importance of these finer differentiations stems from the costliness of highly immersive VR hardware such as CAVEs or head-mounted displays (HMDs). Also, given the availability of cheaper commodity VR hardware offering moderate levels of some components of immersion, we need finer-grained empirical results to determine whether such systems might have a more favorable cost-benefit ratio.

B. Limitation 2: Lack of generalizability of results to other domains

The second limitation arises due to the fact that experiments must evaluate the benefits of immersion using datasets and tasks from specific domains. Thus, it is difficult to apply the results to other domains and tasks. For example, a study showing that immersive VR is beneficial for analyzing volumetric brain scan data is of little import to the geologist. To realize the benefits of immersive virtual reality for volumetric data analysis for a broader audience, we need to establish the benefits of immersion in a manner generalizable across various disciplines, but it is impractical to do this by evaluating all possible datasets, tasks, and domains. We need a deeper understanding of the tasks involved in visual analysis of volume datasets if we are to make more general claims about the benefits of immersion.

III. NEED FOR CONTROLLED EXPERIMENTATION: ADDRESSING THE FIRST LIMITATION

In our work, we interpret immersion as a multi-dimensional continuum, having individual components that can be evaluated independently [5]. Controlled experimentation seeks to vary particular components of immersion and to evaluate all combinations of their levels, while holding all other components constant. This requires that a single high-end VR system, such as a CAVE or HMD, be used to implement all conditions. For example, in our recent study [6], we varied FOR (high and low levels), stereoscopy (on or off), and head-tracked rendering (on or off) in a four-screen CAVE while users performed tasks with two visualizations of volume datasets.

The results of such controlled experiments not only serve to identify the effects of individual components, but also interactions effect involving two or more components. For example, our study found evidence of better task performance and higher perceived usability in a condition with both head tracking and a high FOR, as compared to the other three combinations of those components [6].

IV. NEED FOR A TASK TAXONOMY: ADDRESSING THE SECOND LIMITATION

Researchers from various domains work with volume datasets from their own domain, but we believe there are many similar tasks across domains. A paleontologist counting the number of intracellular bodies in a volumetric scan of a fossil might be performing the same kind of task as a cell biologist looking for the number of soft floating tissues in the limb of a mouse. Tracing the path of blood vessels through a beetle's body may have the same characteristics as following a crack through a tectonic plate of the Earth. Estimating the separation between two blood vessels requires similar judgments as estimating the separation between two plumes emerging from the Earth's mantle.

In our work, we seek to analyze and categorize the tasks that researchers perform with volume datasets from different disciplines, in order to develop a high-level *task taxonomy* with various abstract categories of tasks. Each of the task categories may further encompass various sub-categories capturing the granular yet general tasks in that category. Based on interviews with a number of domain scientists, we have developed a preliminary set of task categories, including search and counting tasks, relative 3D position/orientation judgments, shape or density estimation, path-following, pattern identification, and shape description. This taxonomy will enable researchers to make more generalizable claims from experiment results.

V. CONTROLLED EXPERIMENTATION WITH A TASK TAXONOMY

The task taxonomy is designed such that when VR researchers establish the benefits of some components of immersion for a task in any category, the results can be generalized across all domains of volume data where tasks in that category are performed. For example, if we find the benefit of higher FOR for carrying out a specific type of search task in one domain, then similar search tasks performed in any discipline could hope to benefit from higher FOR.

The VR community will benefit the most from this approach if we are able to systematically develop a many-many mapping between the task taxonomy and the set of components of immersion, through controlled experimentation.

VI. CONCLUSION

Immersive VR platforms present untapped potential for exploring visualizations of volumetric datasets. The VR community needs empirical results to validate the claims of benefits of immersion for analyzing volume data. However, traditional experiments lack generality because of confounds involving multiple components of immersion and because of a lack of understanding of how tasks in one domain map to those in other domains. We have argued that these limitations can be addressed by controlled experimentation and a task taxonomy. Controlled experiments will reveal the benefits of individual components of immersion, as well as interactions among the components. A generic and high-level task taxonomy will allow us to generalize the empirical results showing benefits of immersion for a particular task to any domain using tasks from its category. The various components of immersion may also have differential effects on the different abstract task types performed with volume data from different domains, which will remain largely unexplored if we do not carry out controlled experimentation with a generic task taxonomy.

Our current and future research uses this approach, but it is unlikely that a single researcher or group can investigate all components of immersion and their effects on all task categories. We invite others in the immersive visualization community to validate and add to this important set of results.

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