# Some Thoughts on Augmenting Human-VE Symbiosis to Improve Knowledge Discovery from Volume Rendering

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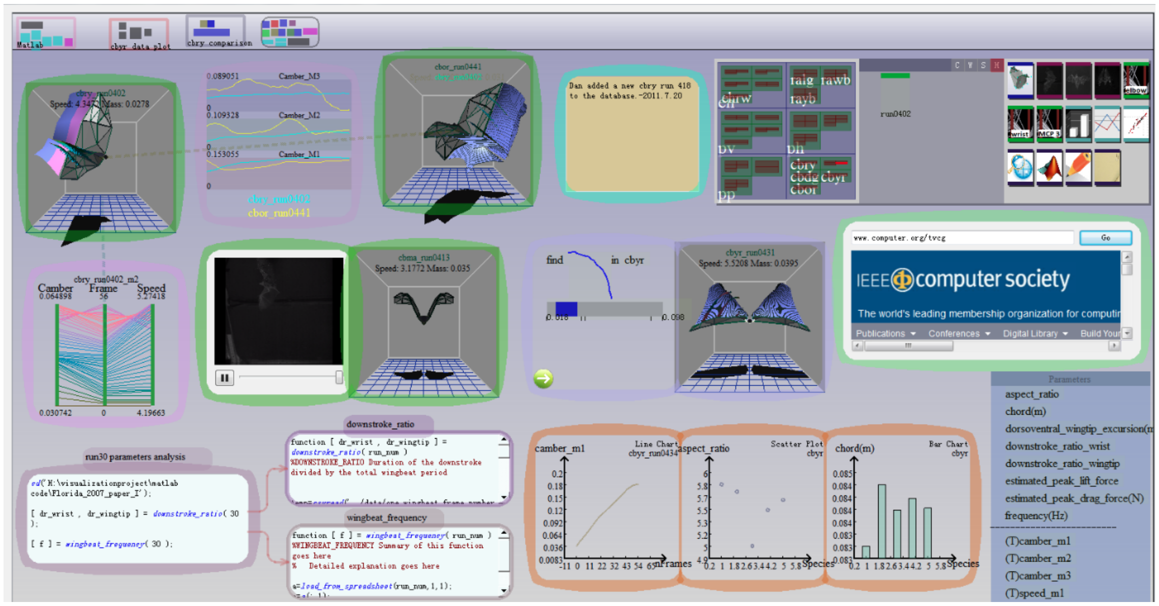


Figure 1: A mind-mapping environment in a 2D setting: my collaborators are interested in expanding this metaphorical interface of bubbles to immersive settings for multi-faceted volume rendering for knowledge discovery in medical domain. We have envisioned 3D bubbles will be created to become a mind-mapping tool.

## Abstract

The goal of this position paper is to consider how memory augmentation is evolving in designing immersive virtual environment (VE) interfaces to support visual sensemaking, especially for medical data where large volume renderings are useful. Pursuit of some of the memory augmentation in virtual environments (VEs) has led to brilliant successes. The cornerstone is to address issues with limited human working memory: how does the representation of the VEs affect our understanding of information? We draw on our past experiences working in immersive displays settings to propose some thoughts on improving human memory in VEs, exemplified using time-varying datasets. The effect of contexts, new evaluation metrics, and novel interface paradigms is also considered, so that we can not only track our own progress, but also help create a community of researchers who share common research standards.

## 1 Introduction

### 1.1 An Introductory Example

Licklider in his famous article on human-computer symbiosis emphasizes the coupling of the human brain to its machine equivalent, where human brains and computing machines will be working together seamlessly [5]. A way of interpreting this and expanding it to immersive virtual environments (VEs) is to enable better communication between human and VEs in which each extends and augments the other.

To understand what is possible with the system at present, let us consider a brain scientists studies in VEs of the improvement in human brain function over time.

*Lucy, the doctor, can set up clipping planes, can look inside, and can sculpt away peripheral fibers, in diffusion magnetic resonance imaging or DMRI [7], where the fiber tracts are overlaid on MRI images. Lucy can also easily select the fiber bundles of interest related to the diseased portion of the brain. To compare the same scan from two years ago, Lucy will have to reload a new image.... after a series of menu and interaction and checking back even further, Lucy has already forgotten the current pathological conditions, not to mention numerous physiological items in the patient history. In her office instead, doctors like her can present numerous images on the wall to compare and observe patient conditions - without needing to hold that information entirely in his or her brain - the limited working memory.*

Now what if Lucy can instead do the following?

*When Lucy does the same thing to query a series of images captured at different time, a new bubble view pops up into the scene where she could do a side-by-side comparison (Fig. 1); she can then bring up another bubble to show a series of images. The bubbles floating in space can be enlarged so she can make this focused*

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*view large enough as if immersed in a VE. When she interacts with the rendering of the view, the queries, instead of disappearing, appear along the periphery, giving her a context to make decisive conclusions about next queries...*

*Next, Lucy groups this newly queried data with the images captured two months ago: when grouped, the images automatically show the same view using the same cutting plane (Fig. 2). Since the screen resolution is high enough for her to read text, she brings up another view displaying the patient treatment history; she writes a few notes in a view bubble to prescribe some medicine and ask the patient to come back in two months for another DMRI. Every action, including the doctors queries and the current results, is saved in a XML. Two months later, when the patients new brain image is captured, Lucy reloads the XML and puts the new brain imaging into a bubble. simply grouping the view with a previous image. She then moves the bubbles around in the VE to enlarge some critical instances in the diagnosis. Lucy finds the BubblesVE very easy to remember so that she need not hold information in her head in making the diagnosis; the VE has almost become a mind-mapping of her thinking process.*

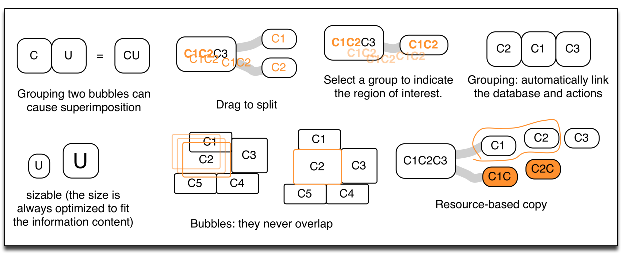


Figure 2: Some Composition Approaches between Views Expanded upon Javed and Elmqvist [2].

The two use scenarios reflect the differences between the classical volume rendering of VEs and the memory-enhanced one that could be used by brain scientists like Lucy. The new design supports brain scientists thought flow through novel space management. Volume rendering of medical data becomes an increasingly crucial source of information for diagnosis, treatment, and design in personalized medicine. VE is a great tool to serve the goal of dynamic data examination. Data captured from brain changes at various treatment stages (e.g., Alzheimers patients) become more time- and space-varying. Data also become more heterogeneous and multi-faceted (e.g., integration of gene markers, functional MRI, PET scans, CT, MRI, DMRI brain simulation, human physiological simulation) [3]. Our collaborators have been asking for user interfaces to help them examine all these image modality together. Current VEs are designed mostly to support use of single datasets and have limited support of dynamic discovery workflow, imposing greater cognitive loads in practical use for sensemaking.

### 1.2 Addressing Cognitive Limitations is the Key to Large Datasets Analysis

Our cognitive limitations are legion as having been recognized in Thomas and Cook [6]. Many of the things we wish to learn require far too much time and effort. We cannot listen to and understand more than one conversation at a time. We cannot remember most of the things that happen to us. Often, we fail to recollect information when needed even though we may recall it at some other time. In addition, for scientists knowledge discovery processes, humans have the limited working memory of 7 items or chunks and even more restricted visual memories of 5 items or chunks. Humans grasp the world through continuous visual scanning and through memorization to create understanding. The science and technology developed to build memory prostheses compensating for memory limitations will be a benefit to us all.

Currently, three-dimensional user interfaces are designed to promote usability with little regard for their impact on users subsequent cognitive representations and sustained decision-making process. Although focusing on usability and user studies has improved the efficiency of the interface, the emphasis on improving user interfaces has led to designs that make it unnecessarily difficult for users to understand, locate, and remember the very information that the systems are meant to deliver. Three-dimensional environments, with its unlimited space in depth, could provide room for more effective human thinking for information retrieval. Here we discuss a revolutionary re-conceptualization of immersive interaction as a way to augment human cognition, especially for medical data visualizations.

Our position statement is that we can circumvent fundamental human limitations by augmenting and optimizing uses of space that will make it easier for people to access, process, and retrieve the information presented within them, so that no information need be held in users' heads and all memory capacity can be used for more critical sensemaking tasks. These environments will support the context-sensitivity that is the hallmark of human memory. Think about how our memories are triggered by our natural surroundings. The unanticipated sight of a friend spontaneously brings memories about how his or her life relates to our own. We remember material in relation to the context in which it was encountered. By embedding information in distinctive, imageable, multi-sensory contexts, virtual environment (VE) tools can provide the sorts of memory hooks that naturally engage the human mind; VEs can prompt a new kind of presence through such human engagement rather than purely from those factors offered by the input and output devices.

There is a big idea here. We have been developing ideas and thinking about VEs merely to expand our motor and visual behavior, and memory assistance via some landmark uses. We have just begun to realize that interface techniques in immersive settings can be designed so that scientists immersed in VEs can become more creative and have more memorable experiences. Just as glancing a whiteboard or enjoying discussions with a friend can remind us of something we wish to know, technologies can intercede on our behalf and trigger our memories in the relevant context through immersive interfaces. Augmenting memory in this way will extend our ability to learn, discover, and create by providing memory assistance where and when we need it.

## 2 Interface that Extends our Memory to Help People Work and Remember

If we are to design a volume rendering in VE to augment our memories, we need an understanding of how our memory works and how VEs have been designed to utilize human memory. Work has been done on tell stories about volume data and exploiting muscle memory (e.g., in menu design). Few, however, attempt to compensate for our limited working memory for large scientific data uses (beyond those navigation aids).

The benefit of memory augmentation can be pervasive. We envision the following:

- Presenting scientists with many 3D volumes as if they are many 3D small multiples of yellow notes on a whiteboard in a manner that optimizes their memorability. Different from yellow notes, these views can be resized and linked by the user as if telling a story about data and the process of discovery. No information disappears in context, and scientists can access and display as many views as they want.

- Optimizing metaphorical interface design by expanding our current 'bubbles' design to form 3D environments in which memories are triggered through optimized interaction. 3D

Bubbles are not like floating views because they never overlap; they carry behaviors; they can be grouped; when grouped, the view of the data is synchronized.

- Assisted-decision-making environments in which scientists can take more active control over their data in a digital-memory VE that saves every use and provides an effective means for information retrieval.

Currently, VEs present a ubiquitous sameness within and across tasks. This provides few contextual hooks upon which users can attach their memories. When we are searching our own memories, we rely heavily upon remembered contexts or schemas in our mind to form newer ones, thus acquiring new knowledge [1, 8]. This research broadens the goals of 3D interface design to include maximizing the use of the space in VEs as memory aids. Since human memory storage and retrieval are indexed to context, context will vary with important changes in information content.

This new visual design adds new dimensions of measuring VE effectiveness. In addition to evaluating an interface by metrics like task completion time and error rate, measuring how much of the information presented by that interface can be recalled later could help us learn us how an interface can best support scientists decision-making workflow. Through the interface breaks the reality, we believe it can increase the level of the sense of presence because humans will become more engaged.

## 3 Some Design Considerations

**Local Context and Global Context.** The scenario of use in Section 1.1 shows how preserving context in multiple compositional views can improve recall, therefore is relevant to contextual settings in the global views; we call this condition global context. Another type of context belongs to the local context related to voxels in each view. Our collaborators also suggest that instead of removing the parts clipped, keep them in context, so they could quickly bring them back or learn better what are being cut. This is important when they perform exploratory data analysis. There are numerous focus plus context volume visualization techniques that have addressed this concerns and our collaborators especially like the method by Li et al. [4].

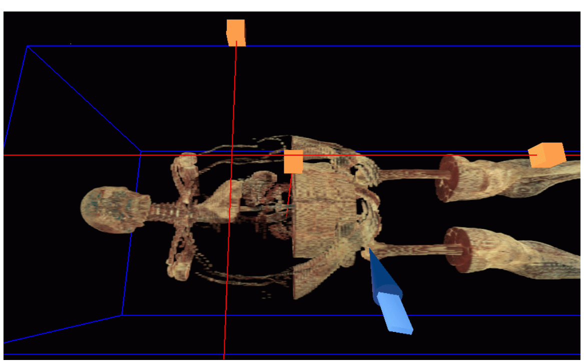

Figure 3: Our collaborators in medical field suggested that interaction with data should never loose context: the data that are removed should remain in place, unlike the one in this picture.

**Metaphorical Interface for Information Decomposition.** Design scalable interfaces to let users select and focus their attention on the right view at the right time. When information grows, the first challenges is to display data to allow easy access. We approach the problem of large data visualization by determining a general scalable UI design for large dataset visualization in VRs. As the goal is to amplify human cognitive capabilities, we seek to simplify the interface design so as to improve performance on repetitive tasks without requiring extensive interactivity while immersed. People working in 3D to solve problems approach their tasks with different perspectives, different spatial viewpoints, different hierarchical objects, and different roles. In order to coordinate multiple datasets, they need a common set of goals and a shared language for discussing them.

**Focus on Under-Utilized Sensory Modalities**. Current user interfaces for volume rendering in immersive VEs rely almost exclusively on the visual and haptic channel. Recent advances in technology and processing power are beginning to make it possible to convey information productively to users via auditory, haptic, and even olfactory channels. We believe that especially for improving information recall, the use of non-visual stimuli will be extremely important, especially when multiple modalities are used in concert.

**Using Context to Improve Recall.** People use context to cue retrieval of memories. Anecdotally, people encode information in relation to their spatial surroundings with little or no effort. Our design expands this observation to 3D space and defines interface behaviors for information search. The context can then later be used as a retrieval cue. Some interesting research questions we could address might include:

- How large can the effect be of using the external memory displays? The effect of context on memory has been observed over in psychological literature. The engineering approach ? to see how much memory can be improved when contextual variables are combined for maximal effect ? has not yet been taken.

- How much does context selection matter? Memory is facilitated whether or not the context is related to the content, but it is not clear how much making the content relate to the context improves the magnitude of this effect.

- How important is it to have the context present at the time of recall? The literature suggests not only that it helps to have a rich context to associate with a memory, but also that having that context present during retrieval is beneficial.

**Evaluation Mechanisms.** Empirical metrics of how well people can remember information they accessed earlier and how well the externalization can assist discovery *process*. A typical evaluation will entail building a prototype to a fixed set of display and information presentation parameters, having users perform a number of tasks with that configuration, and then waiting between one and seven days and testing the ability to recall information accessed with the system. On some occasions, we will make clear to the users that they will later be tested on memory recall, but on other occasions they will believe that their goal is to perform a given task and will not know that they will be tested later. We do this because we do not want to measure how well the users can remember when focusing on recall, but instead how much the systems improve memory with no active effort by the users. We can establish benchmarks for information displays regarding improving memory from a workflow perspective, for example how people solve problems and build a taxonomy of tasks and conditions. We could compare the following settings:

- A “single view,” which utilizes a standard volume rendering on which contextual techniques are introduced to the degree afforded by this visualization. Initially, we will seek to create distinctive surroundings that are associated with the brain datasets. Context in single-portal displays can also be introduced by splitting the views and by presenting in-place views.

- A “single view in immersive use,” which combines the depth and large workspace of large immersive VEs and a large set of vertical or tilted screens that create an unlimited contextual space around the user.

- A “VolumeBubbles” which is a fully immersive environment that lets users sense a distinctive “place” to improve presence and recall. This interface could be implemented not only on desktop but also large displays or immersive VEs.

## 4 Conclusion

This article presents some design speculations for novel immersive volume rendering interfaces. Though speculation can be exciting in provoking new ideas, it is not sufficient for verifying and evaluating the methods. Some rigorous principles for testing and validating our design will be much needed. Also, the opinion here is only one viewpoint. Occlusion, non-photorealistic renderings, and other perceptual and cognitive issues remain challenges for volume rendering in VEs. More research is needed to examine how new ideas can be reconciled and exploited in our exciting VE community.


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