Vox-Insight: Web-Based Visualization Tool for Multimodal Image Analysis

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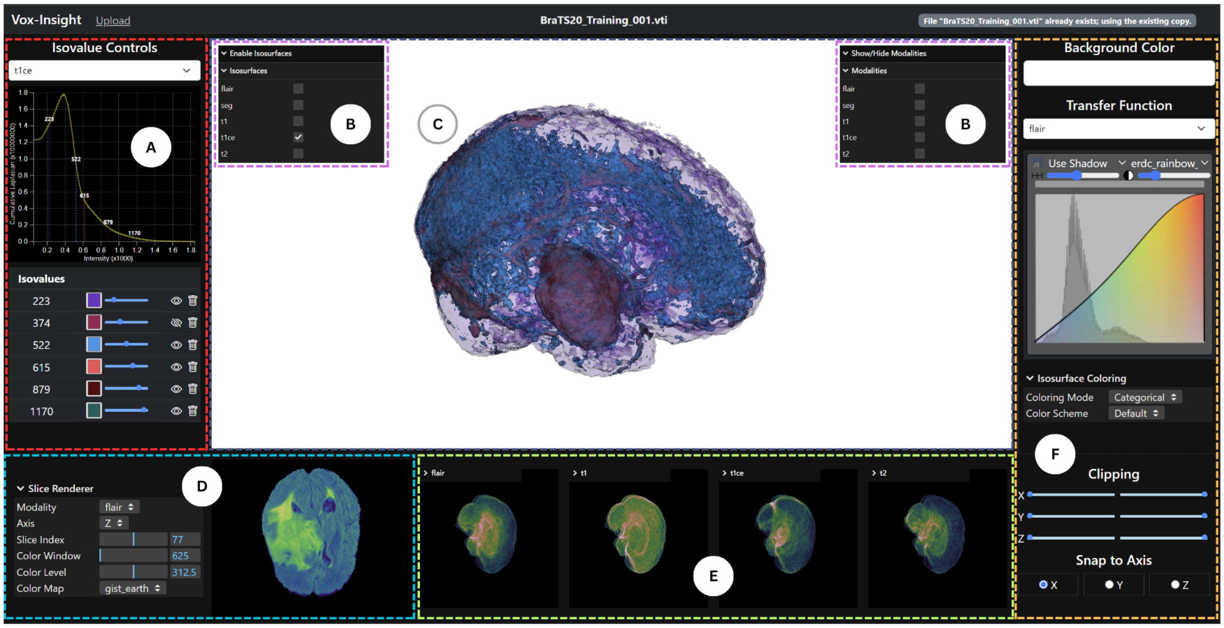

Figure 1: The *Vox-Insight* framework, shown here with a multimodal brain MRI from the BraTS20 dataset. **(C)** is the rendered 3D volumetric dataset, **(B)** controls which modalities are shown in the volume renderer, and **(F)** provides per-modality coloring and clipping controls; **(A)** cumulative Laplacian histogram, computed separately for every modality. Prominent peaks mark candidate isovalues; each can be toggled, re-colored, or re-weighted; the histogram also allows the selection of new isovalues. **(E)** for every modality the X-, Y- and Z-direction gradient magnitudes are collapsed to 2-D heat-maps, providing a quick visual summary of edge content; **(D)** 2-D renderer for axial, coronal, or sagittal slices of any modality with independent window/level and color map controls.

Abstract

Visualization of multimodal scans from MRI, CT, PET, and related sequences is central to diagnosis. Vox-Insight is a web-based framework that scales to multi-volumetric datasets and unifies their exploration through 2-D and 3-D views. The 3-D renderer supports simultaneous multi-channel volume and mesh rendering, while an adjacent slice viewer enables rapid analysis guided by the volumetric context. Gradient-aggregated maps expose high-contrast regions to guide channel selection, while automatic isosurface extraction and color assignment provide instant, informative renderings. This overview-and-detail workflow lets users quickly find and examine relevant structures across modalities.

Index Terms: Volume Rendering, Tumor Visualization, Isosurfaces, Multimodal Visualization, Scientific Visualization

1 Introduction

Non-invasive imaging techniques such as magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET) are central to medical analysis. Each imaging technique offers multiple modalities that highlight distinct tissue characteristics. For example, the T1, T2, and FLAIR sequences commonly used in brain MRI emphasize gray-white matter contrast, water content, and cerebrospinal fluid [4] respectively. Effective co-visualization of these modalities is crucial for understanding underlying structures and aiding the diagnostic process.

To address this need, we present *Vox-Insight*, a web-based interactive visualization tool of multimodal imaging data. The dashboard integrates mesh and volume rendering, a histogram-guided interface for automatic and manual iso-value selection and coloring, 2-D summaries of each modality, and slice-wise exploration.

2 Related Work

This section reviews previous works for multimodal medical visualization tools and their respective advantages and limitations. *Brain-Browser* by Sherif et al. [9] and *Papaya* by Lancaster et al. [6] are both web-based visualizers that support multimodal visualization of slices in axial, coronal, and sagittal planes but, unlike *Vox-Insight*, provide no support for 3-D volume rendering.

Paraview by Ahrens et al. [1], and *3D Slicer* by Kikinis et al. [5] are two powerful desktop-based visualization software with multimodal 2-D and 3-D support, but they both lack an intuitive interface for working with isosurfaces and their detection. *Vox-Insight*, on the other hand, offers a toolkit for multimodal image rendering that follows the "overview-and-detail" principle: it unifies rich 2-D and 3-D visualizations in a single view and streamlines analysis through automatic isosurface detection and coloring.

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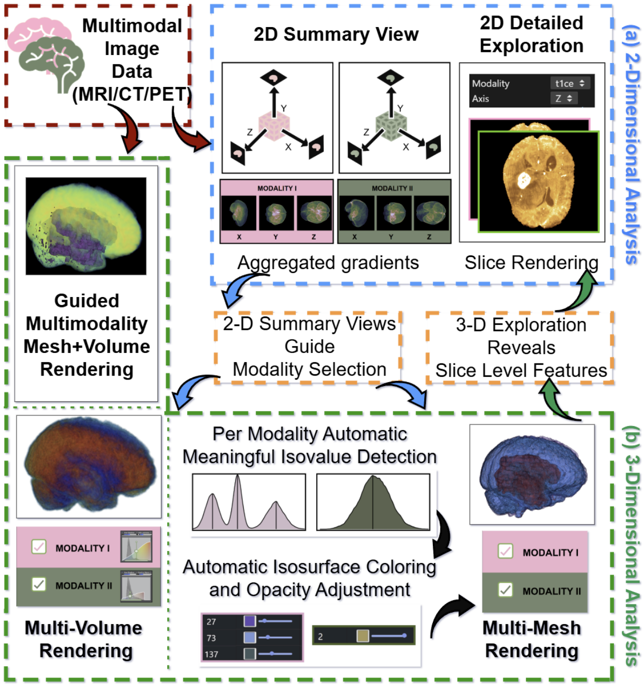

Figure 2: *Vox-Insight* Pipeline Overview. Any imaging dataset can be explored in two complementary ways together: **(a)** 2-D analysis and **(b)** 3-D analysis. Aggregated gradients in the 2-D view summarise the information in each modality, and help guide modality selection for the 3-D view, while inspection of the 3-D renderings can prompt the user to examine the corresponding 2-D slices in greater detail.

3 Methodology

For any given imaging dataset, *Vox-Insight* provides complementary 2-D and 3-D interaction and exploration capabilities, illustrated in Figure 2.

For multimodal datasets, users commonly require flexibility to enable or disable individual channels for composite volume rendering. However, as the number of modalities increases, selecting relevant modalities becomes harder due to cognitive overhead. To alleviate this, we introduce a "2-D summary view" displaying aggregated gradient magnitude images along each axis for each modality. Computing the gradient magnitude at each voxel highlights sharp intensity changes, and summing these magnitudes along a given axis produces a 2-D map of cumulative edge gradient magnitude for that modality. This allows quick visual comparison of modality-specific features, helping users make informed choices about modality selection. Additionally, the 2-D analysis panel also provides per-modality slice rendering along axial, coronal, and sagittal planes, as shown in Figure 2.

In the comprehensive 3-D viewer, *Vox-Insight* supports simultaneous rendering of multiple modalities and facilitates extraction of meaningful isosurfaces using the Marching Cubes algorithm. To guide users towards informative isovalues, we implement end-weighted Laplacian histograms as described by Pekar et al. [8], automatically detecting salient intensity boundaries. These histograms also serve as an interactive interface for manual selection and refinement of additional isovalues, since such values typically appear in high-curvature regions. While visualizing the extracted surfaces, *Vox-Insight* automatically assigns categorical user-modifiable colors and sets opacities linearly according to each surface's intensity, such that all surfaces are visible during a back-to-front alpha blending. The resulting renderings can reveal interesting features of a modality such as the tumor highlighted in Figure 1.

Finally, users can customize the 3-D visualization through modality-specific 1-D transfer functions, allowing fine-grained control over intensity to color and opacity mapping in the rendering. Clipping controls along the x, y, and z axes further allow users to isolate and focus on relevant structures within the volume.

4 Implementation

Vox-Insight is a fully web-based framework. The backend is implemented in Flask 3.1.1, while the frontend uses VTK.js for both the 2-D slice and 3-D volume renderers and D3.js to display the Laplacian histograms.

All visualizations in the paper were created using the BraTS 2020 dataset [7, 2, 3], which contains brain MRI scans in modalities including T1, T1 contrast-enhanced (T1CE), T2, and T2 Fluid-Attenuated Inversion Recovery (FLAIR).

5 Conclusion and Future Work

We presented *Vox-Insight*, an interactive tool for multimodal image visualization. By providing correlated 2-D and 3-D analyses within a single dashboard, *Vox-Insight* lets users explore each view with greater context. Automated isosurface detection and coloring deliver information-rich renderings from the outset. Additionally, *Vox-Insight*, provides more fine-grained control over per-modality coloring compared to similar web-based tools.

Computer-aided diagnosis (CAD) can benefit from visualization frameworks such as *Vox-Insight*; beyond visualizing CAD outputs, it can also serve as an annotation tool for imaging datasets. Future work includes enhancing automatic isosurface detection, more intuitive multimodality transfer function design and gathering expert feedback to refine usability.

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