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# Regions-based illustrative visualization of multimodal datasets

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## ABSTRACT

We present as novel method for the exploration of multiple overlapping volumes that provides flexibility to merge data in different ways in different regions. In each region, either one of the modalities is rendered alone or the fusion of two modalities is shown. In the regions where data is fused, the relative weights of each modality are defined with a 2D transfer function depending on the voxel's pair of property values. The regions can be defined interactively by painting on the volume. Alternatively, when one of the modalities has been pre-classified, a graph representation of the dataset is constructed, and regions can be defined as sets of voxels fulfilling a specific combination of classification criteria. In both cases, a different fusion and shading function can be defined for each region. In this way, illustrative images of the dataset can be easily generated applying effects of cutting away, ghosting and modality enhancement.

## 1. Introduction

Many biomedical applications require the analysis of complementary and supplementary imaging modalities to enhance structures, outline similarities, differences and contextualize one modality with the other. Various visualization systems support multimodal imaging. They allow the relative weight of each modality in the visualization to be defined. However, in general, they do not provide a means of performing different types of data fusion in distinct regions of the model. This functionality would provide better means of comparing and analyzing multimodal data. For instance, to better understand the extent of a brain vascular lesion using a multimodal dataset composed of images from Magnetic Resonance Angiography (MRA), Magnetic Resonance (MR) and Positron Emission Tomographies (PET), it is advisable to isolate in the rendered image the damaged portion of a vessel, but to surround it with the shape of the brain with the activity mapped on top of it.

In this paper we describe a GPU-based visualization approach that allows the relationships between different volume datasets to be explored. We provide means of defining different ways of shading and merging data in different regions of the model. The regions are defined either interactively by editing the volume, or after a classification process. In the latter case, a hierarchical graph structure of the multiple interrelated characteristics of each dataset is computed and rendered to allow users to interactively select the different regions to be fused.

The main contributions of the techniques described in this work are:

- the flexibility in assigning different fusion modes to different regions of the multimodal dataset,
- the use of the semantic structure of volumes to drive the exploration of the relationships between modalities,
- the exploitation of the hierarchical nature of the volume structure to achieve illustrative effects,
- the interactive edition of regions that gives users the sensation to be able to paint modalities one on top of the other,
- an architecture able to support any number and types of modalities.

## 2. Related work

### 2.1. Registration and scene structuring

Several problems come up when managing simultaneously image datasets from different sources. First, when the modalities are not captured simultaneously, the images must be registered in a common reference frame [1]. Then, data can be resampled into one volume in a preprocessing stage [2]. However, the resulting volume may be very large and with resampling inaccuracies. To overcome these drawbacks, the geometrical transformations can be applied during rendering [3]. In this paper, we use the latter approach.

When a large number of datasets only partially overlapping must be managed, it is necessary to define specific scene

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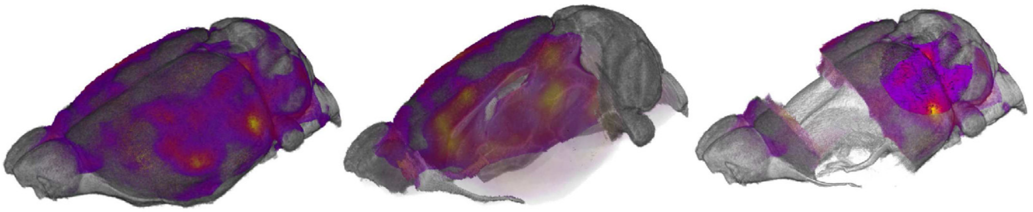

**Fig. 1.** The three fusion options on the *Rat* dataset (see characteristics in Table 1). Left: same fusion everywhere *(global fusion)*; Middle: a different fusion in specific pre-segmented anatomical regions (*segmented regions-based fusion*); (c) right: a different shading and fusion in interactively defined regions (*interactively edited regions-based fusion*).

representations schemes [4–6] in order to reduce data loading and avoid unnecessary sampling. Moreover, these models can allow the inclusion of translucent polygonal meshes in multi-volume scenes [7,3]. Our system does not use a particular scene structuring scheme, because we use datasets with a high overlap. However, the strategies that we propose are compatible with these techniques.

### 2.2. Rendering method

A major issue of multi-volume rendering is how to fuse data at the same spatial location. A common strategy is to merge data in 2D slices, and use 3D rendering of one modality only to interactively define the slices orientation [8]. However, this approach does not give any clues on the spatial relationships between modalities. Another approach, frequent in neuroimaging, is to render one modality contextualized with only one surface of interest of the other modality. For instance, SPECT values can be mapped onto a MR brain surface [9], or a translucent polygonal model of the brain can be rendered surrounding a rendering of PET [10]. In order to avoid partial occlusion of hidden activation areas, the surface can be replaced by a sparser representation of lines [11] or silhouette edges [12], or SPECT can be displayed with glyphs [13]. A third approach consists of applying Direct Volume Rendering (DVR) to the different modalities and blending them according to a user defined weight [14] at different stages of the rendering pipeline [15,16]. The main advantage of this strategy is that it allows the simultaneous exploration of all the features of the different modalities. However, its major drawback is that it is difficult to set shading and fusion parameters suitable for all the data [17]. In our system, we apply DVR to all the modalities, and we define different styles of shading and fusion in different regions in order to obtain the desired visual effects.

### 2.3. Regions-based exploration

The underlying idea of restricting blending to one isosurface is that the type of fusion should depend on the structures where it is applied. For instance, for the visualization of a mouse aorta with PET and CT images, Ropinski et al. [18] show PET data only in front of the aorta lumen. Rieder et al. [19] apply DVR to anatomical and functional data but use different illustrative styles to focus on one modality and use the other as context. In the pre-operative planning system designed by Beyer et al. [20], each voxel stores an identifier used to blend and render different modalities. Jainek et al. [12] segment the activation data into regions, and let users interactively select them in order to outline them. However, none of these systems offer a general mechanism to interactively apply different types of fusion in different pre-segmented or interactively defined regions.

Abstract representations of the volume structure for single-volume visualization have been explored in previously published work. Some authors [21–24] have designed exploratory tools inspired by data analysis and visualization techniques [25]. The underlying principle is to compute a conceptual model of the inner structures in order to allow the selection of regions and the specification of local rendering parameters. Chan et al. [26] focus on the exploration of the spatial relationships between features. Balabanian et al. represent relationships of geometrical inclusion [23,24], and Abellán et al. [22] represent the inclusion relationship between different classification criteria. We build on this latter approach and extend it to the exploration of multimodal datasets.

## 3. Overview

A complete multimodal study is composed of various volume models separately. The volumes are loaded into the GPU memory as 3D textures. Each volume is associated to its own coordinate system in a common reference frame. Each volume has its own shading transfer functions, i.e., its own mapping of property values to optical properties, mainly color and opacity.

Three fusion modes have been designed: *global*, *segmented regions-based* and *interactively edited regions-based* (see Fig. 1). In the three cases, the volumes are rendered in the GPU [27] using the highest resolution of the models as the sampling rate. In the *global fusion* mode, data are merged applying the same fusion function in all the overlapping region. In the *segmented regions-based fusion* and the *interactively edited regions-based fusion*, a different type of fusion can be applied in each region of the volume. The *segmented regions-based fusion* uses the classification of one of the volumes to construct a graph-based representation of the dataset structure which is used to select regions. In the *interactively edited regions-based fusion*, the regions are defined interactively by using editing tools on the rendered model. Finally, the *segmented regions-based fusion* and *interactively edited regions-based fusion* can be combined.

The system can deal with any number of modalities, but only two of them are merged at a time at a sample location, because blending more than two modalities leads to over-saturated images in which it is difficult to distinguish relevant features. In addition, specifying a *n*-dimensional fusion function would be very complex. Therefore, in each region, either a single modality is shown or two modalities are fused. In the next sections, for clarity, we describe the different modes on the basis of the fusion of two modalities, and in Section 7, we show how these modes are generalized for more modalities.

## 4. Global fusion

In the *global fusion*, the same type of fusion is applied to all the models. If a sample falls only into one of the two volumes, only this volume is rendered.

Fusion consists of mixing the two modalities according to a weight that depends on the combination of property values. This fusion is defined through a 2D function *FTF* (Fusion Transfer Function) that assigns a weight to each pair of voxel values. Given $\mathcal{V}_1$