

Interactive Definition of Discrete Color Maps for Volume Rendered Data in Immersive Virtual Environments

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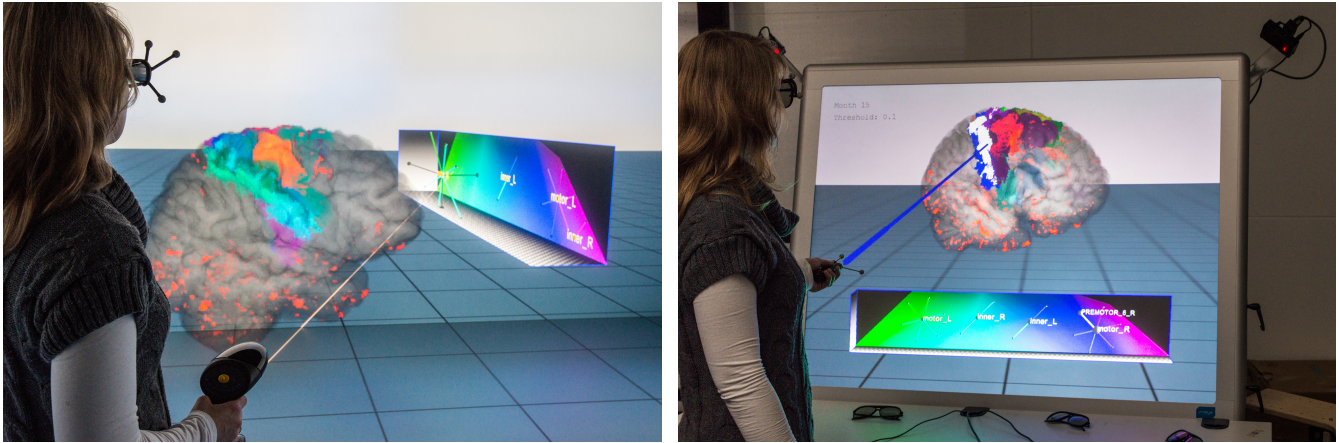


Figure 1: Visualization of the brain of a patient with a degenerative brain disease. Degenerated regions are marked in colors ranging from red to yellow, the remaining hues are used to highlight different brain areas. To obtain a color mapping that allows for a quick and correct distinction of areas and groups of related areas, the user can interactively modify the colors in a 3D widget as shown in a CAVE environment (left), and by direct interaction with the brain areas as illustrated on a semi-immersive VR display (right).

ABSTRACT

The visual discrimination of different structures in one or multiple combined volume data sets is generally done with individual transfer functions that can usually be adapted interactively. Immersive virtual environments support the depth perception and thus the spatial orientation in these volume visualizations. However, complex 2D menus for elaborate transfer function design cannot be easily integrated. We therefore present an approach for changing the color mapping during volume exploration with direct volume interaction and an additional 3D widget. In this way we incorporate the modification of a color mapping for a large number of discretely labeled brain areas in an intuitive way into the virtual environment. We use our approach for the analysis of a patient's data with a brain tissue degenerating disease to allow for an interactive analysis of affected regions.

Index Terms: H.5.2 [Computer Graphics]: User Interfaces—Interaction styles; I.3.7 [Computing Methodologies]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture; Virtual reality; I.3.8 [Computing Methodologies]: Applications—

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1 INTRODUCTION

When displaying data using direct volume rendering (DVR), transfer functions are applied to visually distinguish different structures. These functions can be, for example, data-driven, image-driven or based on spatial features, single- or multi-dimensional (cf. [5]), and pre-defined or created interactively.

In some application scenarios there are restrictions for the color range that can be used for transfer function definition. In cases where many different structures have to be distinguished, the process is complicated further.

We visualize data from a patient suffering from the corticobasal syndrome, a degenerative brain disease. These data include three different modalities: the brain anatomy, volumetric information on tissue degeneration, and a variety of cortical areas. The assignment of colors is constrained by domain specific, established color mappings: gray for anatomy, and red through yellow for increasingly degenerated tissue. Thus, the color mapping for cortical areas is restricted to hues from green to magenta to avoid ambiguity. Furthermore, the color saturation factor cannot be utilized completely, as the composition of colors from areas, degeneration and anatomy in the DVR already results in colors with varying saturation.

The patient's data were acquired with magnet resonance tomography five times over a period of 26 months. The first measurement is used as anatomical reference volume, and for the further data points deformation-based mapping with a non-linear registration was applied to determine the voxel-wise distortion of the brain tissue over time [8]. For a more fluent visualization between these time steps, additional volumes were interpolated to a total of 27 time steps. Furthermore, cortical areas registered to the patient's brain are available that are based on probabilistic maps of post-

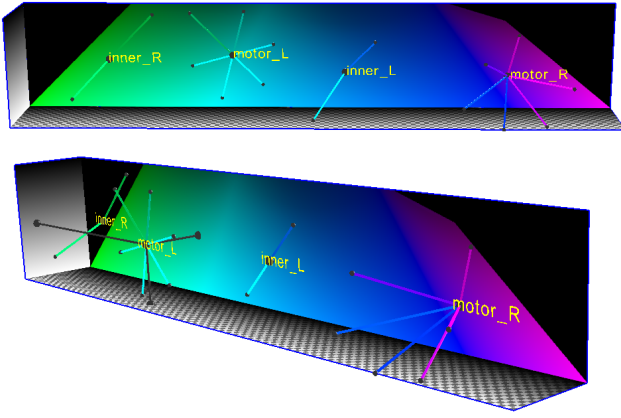


Figure 2: The ColorBox widget can be used to modify the color mapping to different brain areas. Each area is represented by a small sphere whose 3D position determines the area’s color and opacity. The spheres are grouped by connecting them to a larger group representative sphere that can be moved within this widget. While moving, the projections of the group sphere’s position on the different planes are displayed (bottom) and can be used for precise changes.

mortem brains. For further information on this data we refer to [3].

The cortical areas are included into the visualization to support the spatial understanding of the brain tissue degeneration when observing affected regions in order to draw conclusions to symptoms of this disease. In addition to the distinct degeneration in the premotor cortex, tissue decay occurs throughout the whole brain such that multiple areas are relevant for a detailed analysis. For demonstration purposes, a subset of 16 discretely labeled areas was selected and pre-arranged in 4 groups following anatomical relationships.

For an interactive examination of the patient’s data, it is important that the visibility of single areas or groups of areas can be toggled, and that they can be made semi-transparent to give a free line of sight onto degenerated regions or areas occluded by others. Furthermore, different area groups as well as areas within a group should be distinguishable, while keeping the group membership of areas easily recognizable. This is complicated by the limited availability of colors that can be used for the visualization, as well as by differences in inter-individual color perception. Existing tools for an intricate, interactive adjustment of transfer functions of volume data, such as presented by [9] and [10] rely on a rather complex 2D graphical user interface. This also applies to general color palette tools like [7], or specialized tools for creating harmonious color schemes as shown in [4]. However, for the enhancement of the inter- and intra-data perception and depth estimation between anatomy, degeneration, and cortical areas, we decided to visualize the data in a virtual environment (cf. [6]), such that the approaches stated above are not directly applicable.

In this work, we present an intuitive approach for the interactive modification and optimization of a discrete color mapping for brain areas in an immersive virtual environment with respect to the requirements and limitations stated above. In our approach, a 3D widget visualizes area group memberships and modifiable color and opacity characteristics (cf. Figure 1, left). The 3D representation of these properties exploits the depth perception provided by the immersive virtual environment, allowing for an easily graspable overview over the variable parameters. Additionally, direct interaction within the volume visualization is possible in order to toggle the visibility of individual areas and adapt their coloring (cf. Figure 1, right). The user can select visible areas with a 6DOF pointing device. Furthermore, a virtual stick can be inserted into the brain along which visible and invisible areas can be modified afterwards.



Figure 3: The color map texture containing all fully saturated colors with hues between green and magenta and brightness values over 30%. This texture is generated by a transformation of these colors from the CIELAB space onto a 2D plane, such that equal distances locally correspond to approximately equal changes in perceived color.

2 VISUALIZATION

Our visualization approach includes a DVR of the patient’s brain that combines anatomy, time-varying data of the brain degeneration and pre-defined cortical areas. The anatomy is displayed with low opacity to provide a view onto internal brain structures and degenerative changes, whereas the degeneration has high opacity to be easily graspable. While the colors for the anatomy (gray) and degeneration (red through yellow) are domain specific and fixed, the color scheme for the different areas can be changed to facilitate differentiation. Assigning a different, distinct color to each area supports fast discrimination of areas, and area boundaries in degenerated regions.

The active color scheme is visualized in the 3D *ColorBox widget* (cf. Figure 2). Each area is represented by a small sphere whose three-dimensional position within the widget defines the color and opacity values assigned to that area. The color value is determined by the orthogonal projection of the sphere onto the colored back side, while the opacity depends on the distance from that plane—full opacity when touching the color plane, fully transparent at the front side of the widget. Each group of areas is represented by a larger sphere that is connected to its members by a thin beam, each colored like the corresponding area. These beams illustrate the group membership, but also facilitate identifying the area colors more clearly. Moreover, the large sphere is labeled with the name of the group. The area representatives are ordered regularly around this large sphere, which typically results in similar colors within each group—to distinguish between different groups—but nonetheless produces distinct different colors for each area.

For a meaningful and well-distributed 2D color mapping of a large number of areas, it is important that distances between representatives are expressive. Thus, a given distance should be direction-independent and correspond to the same (perceived) change in color anywhere on the map. This property cannot be achieved in the common RGB or HSV/HSL color space. Simply using, for example, the transition of available hues from green to magenta on one axis and the color lightness on the other axis of the ColorBox widget does not yield a color distribution with the desired properties.

Therefore, in our approach, the color map texture is based on the CIELAB space, which is approximately perceptually uniform [2], and created as follows. Fully saturated colors in the HSV space form a bent, two-dimensional surface in the CIELAB space. For each distinct hue, the colors with brightness values over 30% are well approximated by a line segment. Note, however, that the brightness values in HSV are not distributed perceptually uniformly, such that they do not change with a constant rate along this line, and behave differently for different hues. To map this part of the CIELAB space onto a flat, two-dimensional surface, we arrange these line segments for all hues between 120° (green) and 300° (magenta) on a plane, maintaining the CIELAB distances between start and end points of neighboring segments, as well as the distance between both ends of each individual line. In the resulting

texture, local distances between colors approximately correspond to their distances in the CIELAB space, and therefore to perceptual differences (cf. Figure 3). In order to facilitate handling and comprehension of the color map texture, it is cut off to form a five-sided convex polygon as shown in Figure 2.

3 INTERACTION

In order to adapt the visibility of individual brain areas or to change their color mapping, the user can interact with the ColorBox widget or directly with the volume rendered brain. Both visualizations and their interactions are linked so that changes in either of the two can be followed in the other. Thus, the user can, for example, point at an area in the brain volume and see its name and which group it belongs to through its sphere representative. In the following, we describe which further interactions are possible with the ColorBox widget and the DVR visualization.

3.1 ColorBox Widget

The user can interact with the ColorBox widget using a 6DOF tracked pointing device, in our case an A.R.T. Flystick or a presenter (cf. Figure 1). When pointing at a small sphere, a label with the corresponding area's name is shown, while the area is highlighted in the volume visualization by coloring it white. Furthermore, the large spheres (group representatives) can be selected using InterSelect [1] and moved with a button press to change the colors and overall opacity used for that group. With respect to the color plane, all area representatives maintain their relative position to the group sphere, to preserve the relative color differences. When the group representative is moved, the opacity of all corresponding areas is set to the value determined by the selected position. This can be used to quickly hide or show a whole area group, or set a suitable opacity value for a view onto structures behind it without having to interact with each area individually. Moreover, keeping the opacity of visible areas of the same group equal emphasizes the perception of group membership, as their color change due to transparency and the color composition in the DVR is similar.

While a group representative is moved, its orthogonal projections on the three ColorBox widget planes are displayed as spheres which are connected to the representative with a thin beam (cf. Figure 2, bottom). These projected spheres can also be selected in the same manner and moved constrained to the two color dimensions (color plane), the height dimension (left plane) or the opacity dimension (opacity plane), respectively, to facilitate a more precise interaction through less degrees of freedom. During all movements, all group and area representatives are constrained to the polygon encompassing the color map texture with respect to the color plane by projecting them to the closest point on that polygon, if necessary.

3.2 Brain Volume

We propose two ways to interact with the brain volume in order to fine tune the color value of individual areas and toggle their visibility. The first method (*direct interaction*) allows the user to select brain areas to disable them or interactively adapt their color to better distinguish them from their neighbors. The second interaction method (*stick selection*) can be used to restrict further interaction to areas along a line to facilitate area selection and manipulation, especially for occluded areas or cluttered regions.

Direct interaction A virtual pointing beam is attached to the pointing device, which consists of two parts—a handle and a thinner elongation—that can be used to select areas in the brain visualization. An area is selected when the tip of the handle touches it. Otherwise, the first visible area encountered using raycasting in pointing direction is selected. This raycasting metaphor allows to select non-occluded areas simply by pointing at them. The shorter beam handle can be used to select areas located behind other areas by directly touching them with its tip, which can be useful as parts



Figure 4: By pointing into the volume, the user can create a stick that restricts the subsequent selection to the intersecting brain areas.

or the whole of the volume rendering can be semi-transparent, and occluded regions can therefore remain partly visible.

To obtain a good visual contrast, the selected area is highlighted in white. Moreover, the spheres in the ColorBox widget corresponding to this area and its group representative are temporarily enlarged as feedback, and a label with the area's name is displayed next to it (cf. Figure 1, right). Upon button press, the selected area is made invisible by setting its opacity to zero. This change is also visualized in the linked view of the ColorBox widget, where the sphere representative of that area is moved accordingly along the opacity dimension. As invisible areas are not selected by pointing, the user can use this interaction to quickly access hidden or occluded areas or disable those that are irrelevant to her current concern.

The color of a selected area can be adapted by pressing and holding the button while moving or rotating the input device to the left or right side. This interaction results in the corresponding area representative sphere being moved towards, or further away from its group representative. As each area representative of a group has a distinct angle in relation to the group sphere's projection on the color map texture, a certain distance to the other area representatives within the same group is maintained while changing its color. When a small area sphere reaches an edge of the five-sided polygonal color map texture, it moves alongside it, making larger color offsets possible where needed.

This interaction allows a user to easily and quickly modify the color of an area when she perceives it as too similar to the color of neighboring areas, without losing the basic similarity to the other colors in its group. Furthermore, it is not required that the user explicitly chooses a color for this area. This can become difficult, as it requires to keep the colors of all group members in mind while selecting a color that can be easily distinguished from nearby areas, but is nevertheless similar enough to indicate group membership. Instead, the user just drags until the color appears different enough from neighboring areas. The direction of movement of the input device can be very imprecise—as long as it is not orthogonal to the left/right direction—causing a gradual and comprehensible change in color. Note that this interaction cannot simply be replaced by an optimized color pre-selection, as color perception differs between users, and may even depend on the current view angle or task.

Stick interaction A further interaction concept provides a way of selecting areas in 3D along a relevant direction. By pressing a second button on the pointing device, the user can create a stick in pointing direction that intersects with the brain volume as shown in Figure 4. The interaction with brain areas as described above is

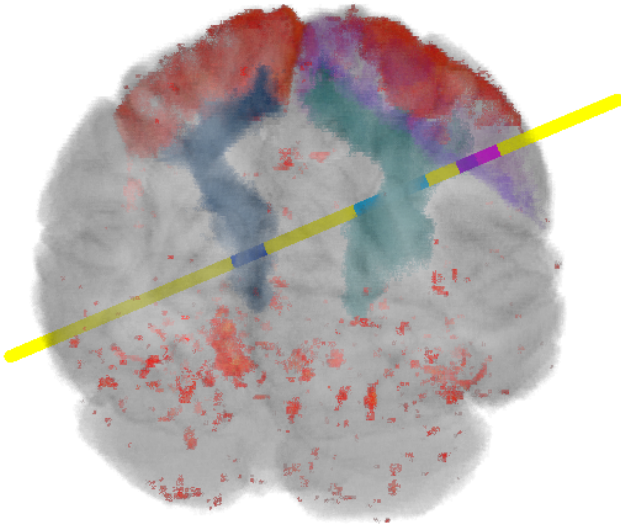


Figure 5: When the interaction is limited to areas along the stick, formerly invisible areas are displayed with low opacity, as can be seen for the magenta and violet area. Furthermore, the colors of the intersecting areas are mapped onto the stick.

now subsequently restricted to the areas that intersect with that line. In this mode, the selection of invisible (i.e., fully transparent) areas is also possible. To provide appropriate user feedback and spatial context, intersecting areas with very low or zero opacity are displayed with a certain minimum opacity. Furthermore, the intervals on the stick that intersect with an area are colored like that area (cf. Figure 5). All other, non-intersecting areas are hidden in this mode. Upon button press, the opacity of a selected area is toggled: If it is visible, its opacity is set to zero, otherwise it is reset to its group representative’s opacity, or 100% if the group is invisible. The user can remove the stick and return to the default mode by pressing the second button again.

We identify two main profits of this stick metaphor as additional interaction possibility. First, it allows in general to toggle the opacity of hidden brain areas directly from within the volume visualization. Second, as the tissue degeneration is expected to evolve from the brain surface into inner structures, the user can selectively examine particular directions. This possibility of restricting the selection from many areas to only those along the stick facilitates interaction with them, and mitigates occlusion problems of the often complex and sometimes intertwined area structures.

4 CONCLUSION

In this paper, we have presented an intuitive tool for interactive color map adjustments of volume data. In our case, we use a discrete color mapping, but the interaction principle of the ColorBox widget is not explicitly limited to this scenario. Instead, the selected colors could, for example, be used as the basis for an interpolated color mapping. The presented prototype is targeted for use in an immersive virtual environment, and therefore comes with clear and simple interactions. The ColorBox widget gives an overview over the areas and their color mapping and shows additional information with its sphere grouping and name labels. The direct interaction with the volume rendered brain aims to avoid disturbing the user’s focus on the brain itself. Here, opacity and color of individual brain areas can be modified, optionally with the help of a stick metaphor that enables to limit the selection to intersecting visible and invisible areas.

As this is a prototypical implementation, we see possibilities for several improvements and optimizations of this approach. First, to create the color map texture, we used a simple conversion from the sRGB to the CIELAB space. To obtain a color mapping that is actually perceptually uniform, the transformation should be calibrated to the display device. Furthermore, it should be examined whether the addition of certain not fully saturated colors into the color map, or the usage of a more advanced space such as CIECAM02 [2] holds any benefit.

In our prototype, area colors are changed in the volume interaction only by varying the distance between area and group representative. Different metrics to do this that use other color transitions, but keep the interaction similarly simple, should be examined. Another helpful aspect would be the option to save and load individualized color mappings or adapt to general user preferences.

In addition, a user study has to be performed to evaluate the users’ acceptance, the practicability, and the effectiveness of the approach, and to compare it to established techniques, such as 2D color map editors or predefined transfer functions. Furthermore, we are looking for more application scenarios for the ColorBox widget to explore its full capacities.

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