RegHieVis: Region-based Hierarchical Visualization of Volume Data Ensembles

User Manual

1. First Steps

When starting the application, you will be asked to choose a dataset file. To generate a dataset, start the application using one of the following command line options:

```
RegHieVis.exe teardrop

RegHieVis.exe tangle

RegHieVis.exe spheres
```

This process may take a few minutes. Once finished, it is recommended to save the dataset using the **Save Ensemble** button on the top-left. Next time you start the application, simply choose the previously saved file instead of providing command line arguments.

1.1 Requirements

The software was tested on the following hardware configurations:

CPU: AMD Ryzen 5 5600x	**GPU:** GeForce RTX 2060
CPU: AMD Ryzen 5 3600	**GPU:** GeForce GTX 1060
CPU: AMD Ryzen 5 3600	**GPU:** GeForce GTX 1070

The software was tested on the following screen resolutions:

Full HD: 1920 x 1080 (16:9)

QHD: 2560 x 1440 (16:9) **(highly recommended)**

It is not guaranteed that the software works flawlessly on any other configurations.

1.2 Dataset Format

Compatible datasets must be binary files with the following format:

```
<volume>                                    // labels (not optional)
uint64( 0 )                                 // reserved
uint64( field_count )                       // number of fields
field_count times:
    <string>                                // name of field
    uint64( member_count )                  // number of members
    member_count times: <volume>            // members
```

<volume> has the following format:

```
<string>
int32( dim_x )                              // size in x
int32( dim_y )                              // size in y
int32( dim_z )                              // size in z
dim_x * dim_y * dim_z times: float32        // volume data
float32( domain_min )                       // domain minimum
float32( domain_max )                       // domain maximum
```

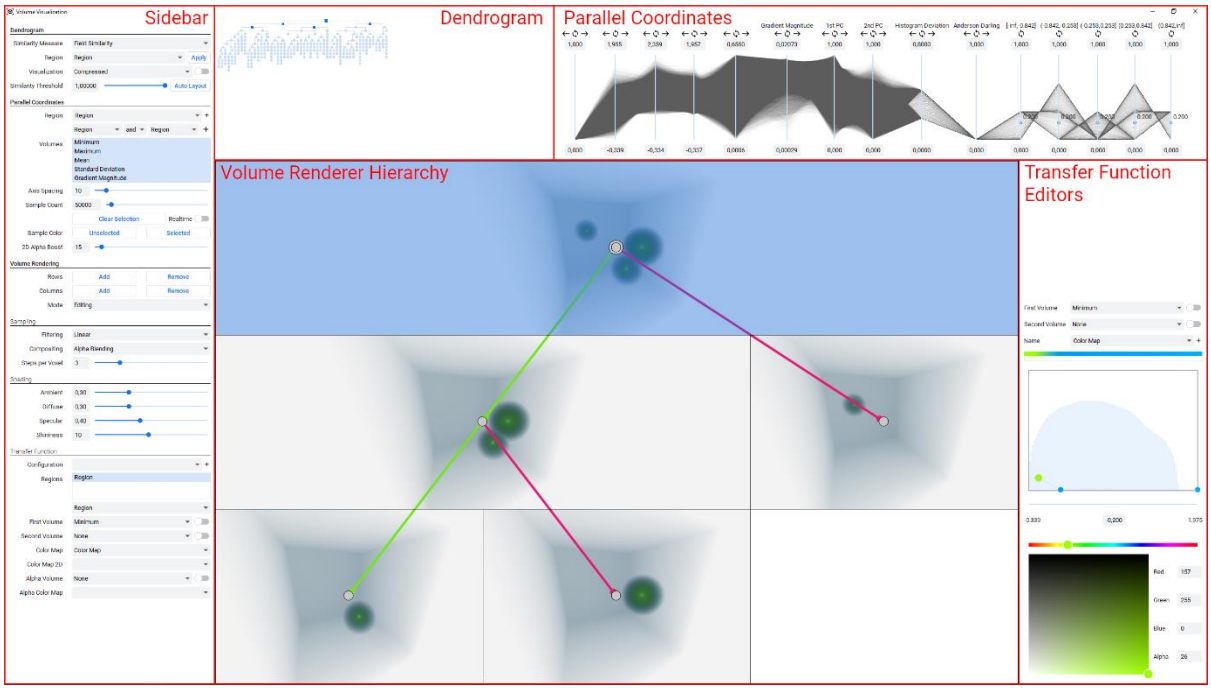
<string> has the following format:

```
uint64( length )                            // length without '\0'
length times: uint8                         // characters
```

After loading a dataset in this format for the first time, it is recommended to save it using the **Save Ensemble** button at the top-left to avoid performing the precomputations again.

2. Overview

The application is divided in five parts: the **sidebar** (left), the **dendrogram** (top left), the **parallel coordinates** (top right), the **transfer function editors** (right) and the **volume renderer hierarchy** (middle). Each part has their own chapter explaining it.



3. Sidebar

The sidebar is divided in four categories: **General**, **Dendrogram**, **Parallel Coordinates** and **Volume Rendering**. Each part will be explained individually.

3.1 General

Save Ensemble (Button): Save the current ensemble to a file.

3.2 Dendrogram

Similarity Measure: Choose the similarity measure that is used for the computation of the dendrogram.

Region: Choose the region that will be used as a mask for the computation of the similarity measure. Press **Apply** to recompute the dendrogram using the specified region.

Visualization: Choose the layout of the dendrogram. Use the checkbox to enable using the similarity for the node's vertical position.

Similarity Threshold: Use the number field or slider to define a similarity threshold. All nodes that have a higher similarity will be collapsed. Press **Auto Layout** to transfer the current dendrogram to a hierarchy of volume renderers (**NOTE:** be cautious not to use this when the tree is large).

3.2 Parallel Coordinates

Region: A drop-down list of all regions. Use it to select the currently active region, change the name of a region, copy the current region using **+**, or remove the current region using **-**. Choose two existing regions and a binary operator to create a new region by pressing **+**.

Volumes: A list of available derived volumes. Select a volume to hide/show its axis in the parallel coordinates. Scroll using the mouse wheel.

Axis Spacing: Choose the spacing (in pixels) between parallel coordinates axes.

Sample Count: Choose the number of samples (voxels) to be shown in the parallel coordinates and in the scatter plot of the 2D transfer function editor. Press **Clear Selection** to clear the selection of the current region. Use the **Realtime** checkbox to make brushing interactions apply in real-time.

Sample Color: Press **Unselected** to change the color of unselected samples using the HSV-Color-Picker on the bottom-right. Press **Selected** to change the color of selected samples. Press **Color Map** to use the currently active color map to color the parallel coordinate lines. Press it again to disable using the color map.

2D Alpha Boost: The scatter plot in the 2D transfer function editor uses the same colors for samples as the parallel coordinates. Since the visualization is sparser, a higher opacity can be used. Use the number field or slider to boost the opacity of points in the scatter plot.

3.3 Volume Rendering

Rows: Use **Add** and **Remove** to add or remove a row from the volume renderer grid.

Columns: Use **Add** and **Remove** to remove a column from the volume renderer grid.

Mode: Switch between **Viewing** and **Editing** modes. These modes change the interaction with the volume renderer hierarchy. Please refer to the respective section for more information.

3.3.1 Sampling

Filtering: Switch between **Linear** and **Nearest**(-Neighbor) filtering for the ray casting algorithm.

Compositing: Switch between **Alpha Blending** (front-to-back), **First Hit**, **Maximum Intensity** and **First Local Maximum** composition modes.

Steps per Voxel: Choose the steps per voxel used in the ray casting algorithm.

3.3.2 Shading

Ambient: Choose the ambient reflection constant used in Phong shading.

Diffuse: Choose the diffuse reflection constant used in Phong shading.

Specular: Choose the specular reflection constant used in Phong shading.

Shininess: Choose the shininess constant used in Phong shading.

3.3.3 Transfer Function

Configuration: A drop-down list of all configuration. Use it to select the currently active configuration, change the name of a configuration, copy the current configuration using **+**, or remove the current configuration using **-**. (**NOTE:** Each volume renderer is assigned to one configuration, which determines the regions and transfer functions that volume renderer will show)

Region: A list of available regions for the current configuration. Select a region to enable/disable it. Scroll using the mouse wheel. Rearrange regions by dragging them to change their priority (highest priority at the top). Use the drop-down menu to choose the currently active region from a list of enabled regions.

First Volume: Choose the first input volume type for the current region of the current configuration. Use the checkbox to enable difference volumes.

Second Volume: Choose the second input volume type for the current region of the current configuration, or **None**. Use the checkbox to enable difference volumes.

Color Map: Choose a 1D color map for the first input volume.

Color Map 2D: Choose a 2D color map for the two input volumes. (**NOTE:** This option is only available when two input volumes were selected)

Alpha Volume: Choose the input volume used for the separate alpha channel, or **None**. Use the checkbox to enable difference volumes.

Alpha Color Map: Choose a 1D color map for the alpha input volume.

4. Dendrogram

Nodes that correspond to a volume renderer are shown in dark blue. The node that corresponds to the currently selected root volume renderer is displayed larger. The nodes in the sub-tree of the currently selected root volume renderer are shown in light blue. Other nodes are shown in gray.

Hover over a node: Show the underlying similarity value and number of volumes/members in that sub-tree.

Click on a node: Select that node as the starting point for the currently selected root volume renderer. This will also select that sub-ensemble for usage in the parallel coordinates.

5. Parallel Coordinates

Arrow Left/Right: Move an axis to the left or right.

Circling Arrows: Invert the selection on this axis.

Number fields above/below axes: Change the displayed interval of values.

Hover over an axis: Show the value that is mapped to that location.

Click + Drag: Select an interval (brushing) to be added (**left-click)**, removed (**right-click**) or zoomed to (**middle-click**). This will affect the currently active region (**Sidebar → Parallel Coordinates → Region)**.

Mouse Wheel: Zoom (hold **Ctrl**) or shift (hold **Shift**) the displayed interval.

Alt + Mouse Wheel: Scroll horizontally.

6. Transfer Function Editors

First Volume: Choose the first input volume type. Use the checkbox to enable difference volumes.

Second Volume: Choose the second input volume type, or **None**. Use the checkbox to enable difference volumes.

Name: A drop-down list of all color maps using the specified input volumes. Use it to select the currently active color map, change the name of a color map, copy the current color map using **+**, or remove the current color map using **-**.

If you selected **None** as the second input volume, you will see the 1D transfer function editor. If you selected a second input volume, you will see the 2D transfer function editor.

HSV-Color-Picker: Use it to pick a color…

6.1 1D Transfer Function Editor

Preview of the current 1D color map. The top half shows the RGB values with full opacity; the bottom half uses opacity.

Node editor. A nodes vertical position corresponds to the opacity of its color. Its horizontal position corresponds to its value inside the domain.

> **Hover:** The hovered value is highlighted on the axis below the node editor. If a node is hovered, it will be displayed larger.
>
> **Left-click a node**: Select a node while hovering it. The color of the selected node can be adjusted using the HSV-Color-Picker below the transfer function editor.
>
> **Left-click in empty space:** Create a new node at that location. Its color will be interpolated from the closest nodes to the left and right.
>
> **Left-click and drag a node:** Move a node around, changing its value inside the domain and its opacity.
>
> **Right-click a node**: Delete a node. (**NOTE:** There must always be at least one node).
>
> **Middle-click a node:** Split (or un-split) a node. The two halves can be colored separately.
>
> **Key 'L':** Switch between using a linear and logarithmic scale for the 1D histogram.
>
> **Key 'R':** Reset the color map to the default.

Thresholding axis. Perform brushing interactions to threshold parts of the color map.

> **Click + Drag:** Select an interval to be added (**left-click)** or removed (**right-click**).

Number Field. Only visible when a node is selected. Use it to set the exact value (horizontal position) of a node.

6.2 2D Transfer Function Editor

Polygon editor. A scatter plot shows the distribution of voxels in the current sub-ensemble. Draw colored polygons to define a 2D color map.

> **Hover a polygon:** The hovered polygon will be displayed with a light-gray border.
>
> **Left-click a polygon:** Select the hovered polygon. The selected polygon will be displayed with a black border. Change the selected polygons color using the HSV-Color-Picker.
>
> **Left-click + Drag:** Draw a polygon using the current color of the HSV-Color-Picker. Hold **Shift** to add the selected voxels to the current region instead.
>
> **Right-click a polygon:** Delete the hovered polygon.
>
> **Hold Shift + Right-click + Drag:** Remove the selected voxels from the current region.

Domain (x): Change the domain of the 2D color map for the first input volume. Press **Fit** to fit the domain to the current scatter plot.

Domain (y): Change the domain of the 2D color map for the second input volume. Press **Fit** to fit the domain to the current scatter plot.

7. Volume Renderer Hierarchy

The volume render hierarchy has different interactions depending on its mode (**Sidebar → Volume Rendering → Mode**).

7.1 Editing Mode

In editing mode, the volume renderer grid is displayed. Its size can be adjusted using the sidebar (**Sidebar → Volume Rendering → Rows / Columns**). Note that you can only remove rows or columns if they are completely empty.

How to change the ensemble of a volume renderer? Only the ensemble of root volume renderers can be changed. The circle in the center of a root volume renderer will show two outlines in black (instead of one). To change the ensemble of a root volume renderer, select it by clicking on it. Then select a node inside the dendrogram (by left-clicking on it) to select the sub-ensemble. (**NOTE:** The root volume renderer will remain selected when switching modes)

How to add a volume renderer? To add a volume renderer, hover over an empty cell (you may need to increase the size of the volume renderer grid), press left-click and drag your mouse to draw a rectangle and release. The volume renderer will occupy all grid cells that intersect with the rectangle, these cells are highlighted in light blue. If the rectangle intersects with an existing volume renderer, that volume renderer is highlighted in red.

How to remove a volume renderer? Hover over it (not in the center) and press right-click. Note that all inbound and outbound edges are also removed.

How to add edges between volume renderers? Hover over the center of a volume renderer (the circle will be highlighted in light blue). Drag your mouse using left-click (for edge type **left child**), right-click (for edge type **right child**) or middle-click (for edge type **sibling**). Release your mouse on the center of another volume renderer (the circle will be highlighted in light blue).

How to remove edges between volume renderers? If you add an edge that already exists, it will be removed.

How to change the configuration of a volume renderer? Hover over it and use your mouse wheel.

7.2 Viewing Mode

In viewing mode, you can directly interact with individual volume renderers.

How do I change the camera position and viewing direction? Use left-click and drag to change the viewing direction of the camera. Use right-click and drag to change its position.

How do I perform region brushing in volume renderers? To show/hide the current region inside volume renderers, press '**R**' when any volume renderer has focus. Mouse interaction will now no longer change the camera, but can instead be used to perform region brushing. Drag your mouse using left-click (to restrict the region), right-click (to add to the region) or middle-click (to remove from the region). Release your mouse and the selected voxels will be handled accordingly.

How do I invert the current region? Press '**I**' while any volume renderer has focus and the region is currently being shown (by pressing '**R**')

How do I enable the slice viewer? To switch between the slice viewer and the 3D view, press '**S**' when any volume renderer has focus.

How do I change the view direction in the slice viewer? Use your mouse wheel to iterate through slices. Hold **Shift** while doing so to iterate through viewing directions.

8. Third-Party

- Qt 5.15.2 was used as a GUI framework for this project and is available under the GNU Lesser General Public License version 3. (https://www.qt.io/download-open-source)

- Eigen was used for principal component analysis and is available under the MPL2. (https://eigen.tuxfamily.org/index.php?title=Main_Page)

- Google Fonts icons were used for the GUI and available under the Apache license 2.0. (https://fonts.google.com/icons)

- The json.hpp header by Niels Lohmann was used to parse JSON files and is available under the MIT License. (https://github.com/nlohmann/json)

- RenderDoc was used extensively for graphics debugging and is available under the MIT License. (https://renderdoc.org/)