Visibility Driven Focus+Context Visualization of Multimodal Volume Data

M.Tech Thesis
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Introduction

- The aim of this thesis is to study mechanisms to improve focus+context visualization of multimodal volumetric data, in particular use of visibility histograms is investigated.
- Visibility histograms provides intuitive cues to the user about the contribution of particular scalar values to the final image.
- Technique is demonstrated on multimodal data - CT and PET - to produce fused focus+context volume visualization, with focus on PET data, while the CT dataset provides clear contextual information.
- We use ray tracing approach, which is implemented on GPU shaders to enable interactive response.

Non Photorealistic Rendering

- By lifting the burden of realism, non-photorealistic rendering(NPR) can be used to illustrate subtle spatial relationships that might not be visible with more realistic rendering techniques.
- The integration of volume rendering with NPR is an intuitive and natural progression given the communicative and expressive capabilities of NPR.
- Volume NPR techniques can be used to create visualizations of volume data that are more effective at conveying the structure within the volume.

Focus+Context for Volume Visualization

- Visualization of CT, MRI or PET data allows physicians and radiologists to see internal structures and organs with much greater detail.
- In some cases there is too much data to be displayed at once on a computer display.
- A simple and widely used solution is to zoom into specific region, and get lost in the dataset, resulting in loss of context, because we are no longer able to visualize the entire dataset.
- Another approach to increase visibility of the specific region by making the occluding materials completely transparent.
- This brings focus to the region of interest, but, we could lose the context since the surrounding material or regions may become too transparent to provide meaningful information.

Related work

- Many techniques for multimodal visualization render the multi-volume by mixing the component volumes at a certain step of the volume rendering pipeline, such as, accumulation, illumination or at pixel levels[1]
- In another approach, one set of data and optical transformations are applied to the region of interest, and a different set of transformations to the remaining data.
- Few other techniques include interactive cuts [13], distorted views [22], opacity peelings [26] or ghosted views [11].
- The technique of importance-aware rendering [21] and importance aware compositing [7], can help visual hidden structure.
- But both these technique require prior definitions of context regions.

Objective

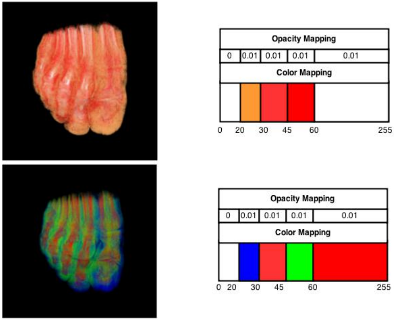
The objective of this thesis is to study techniques for viewing of volumetric data with the ability to support interactive and intuitive mechanisms for adjusting opacities of volume elements, such that it enhances visibility of structures or regions of interest to achieve “ focus+context ”.

Direct Volume Rendering using Raycasting

- Volume rendering is a set of techniques used to display a 2D projection of a 3D discretely sampled data set, typically a 3D scalar field
- Direct volume rendering involves generating visualizations without creating intermediate geometric structures, but simply by a direct mapping from volume data points to composited image elements.
- Classification is a term that refers to assignment of optical properties to data values. Classification is one the most important steps in the volume rendering pipeline, since it is these optical properties that will either emphasize an feature or de-emphasize it.
- The assignment of optical properties to data values is accomplished using a transfer function.

Transfer Function

- The role of the transfer function is to emphasize features in the data by mapping values and other data measures to optical properties.
- The simplest and most widely used transfer functions are one dimensional, and they map the range of data values to color and opacity.



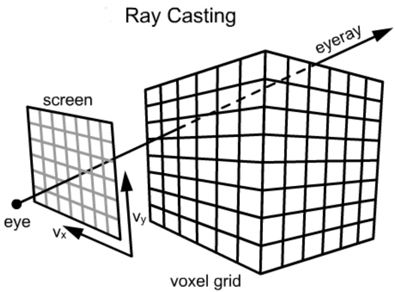
Region of Interest

A region of interest (often abbreviated ROI), is a selected subset of samples within a dataset identified for a particular purpose. A ROI can be any of the following:

- Volume of Interest, which is specified as a range of voxels within an 3D volume. For example, we could define a cubic, spherical or cylindrical ROI.
- A range of voxel intensities can also be a ROI.
- A range of voxel intensities of one modality can be defined as an ROI in a multi-modal setup.

Volume Ray Casting

- Raycasting is a technique to visualize volume data. It is method in which for every pixel in the image, a ray is cast through the volume.
- The ray intersects(or passes close to) a line of voxels. The color of the pixel is computed based on color and transparency of the voxels that are intersected by the ray.



Volume Ray Casting - Basic Algorithm

- Generally, the volume is enclosed within a bounding primitive, a simple geometric object usually a cuboid that is used to intersect the ray of sight and the volume.
- In general, the volume is not aligned with the ray of sight, and sampling points will usually be located in between voxels. Because of that, it is necessary to interpolate the values of the samples from its surrounding voxels.
- After all sampling points have been fetched, they are composited along the ray of sight, resulting in the final color value for the pixel that is currently being processed.

Volume Ray Casting - Two-pass Rendering

- To perform raycasting on a volume for an arbitrary view direction, we need to compute the points at which each ray enters and exits the cube corresponding to the volume.
- An efficient and convenient method for this is to render the front and back faces of the cube into separate images.

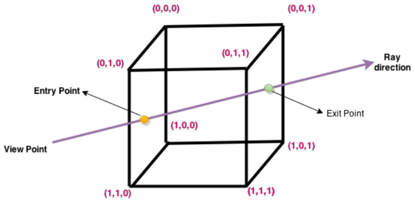


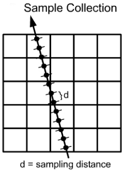
Figure : Assigning unique colors to all corners to the bounding box.

Pseudocode of Two-pass Volume ray casting

First pass: render the backface of the boundbox
Second pass: render the frontface of the boundbox
Lookup volume exit position from backface 2D texture
Entry position obtained at second pass
Compute ray of sight direction
While in volume
    Lookup data value at ray position
    Apply transfer function to data value
    Accumulate color and opacity
    Advance along ray

Sampling

- Along the ray of sight within the volume at equidistant locations samples are selected.
- Generally, the volume is not aligned with the ray of sight, and sampling points will usually be located in between voxel's.
- Because of that, it is necessary to interpolate the values of the samples from its surrounding voxels.



Compositing

Back-to-Front Compositing Equation

- In this technique, samples are sorted in back-to-front order, and the accumulated color and opacity are computed iteratively.

$$\hat{C}_i = C_i + (1 - A_i)\,\hat{C}_{i+1} \tag{1}$$

$$\hat{A}_i = A_i + (1 - A_i)\,\hat{A}_{i+1} \tag{2}$$

Front-to-Back Compositiong Equation

- In this technique, samples are sorted in front-to-back order.
- The composition is done towards the back and the current transparency is known at all times, the compositing can be stopped early when the opacity is above a threshold

$$\hat{C}_i = (1 - \hat{A}_{i-1})\,C_i + \hat{C}_{i-1} \tag{3}$$

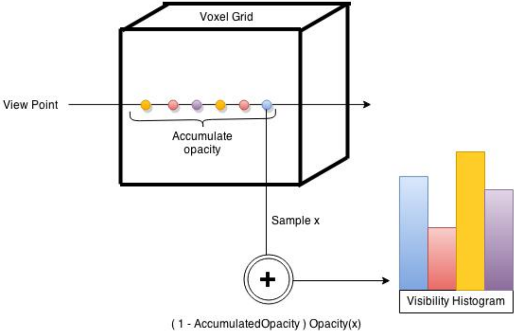
$$\hat{A}_i = (1 - \hat{A}_{i-1})\,A_i + \hat{A}_{i-1} \tag{4}$$

Visibility

- One of the limitations of contemporary visualization systems is the inability to quantify how visible a feature of interest is.
- To be more effective, along with traditional transfer function design, visualization systems must also incorporate a measure of visibility.
- Visibility metric, attemps to measure the impact of individual samples on the image generated by a volumetric object. It is measured as the contribution of a structure of interest to the final image.
- Here, visibility can be used to quantify the quality of transfer function and ease their design towards more meaningful and efficient visualization. Transfer functions generated with this approach are called as visibility driven tranfser functions.

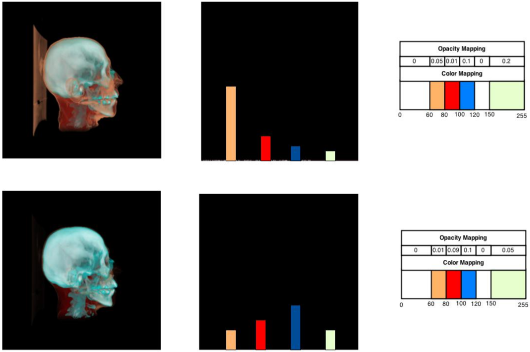
Visibility Histogram

- A visibility histogram is a representation of distribution of the visibility metric in relation to the domain values of the volume.
- Samples are weighted by visibility and added into bins that partition the range of values in the scalar field.



Visibility Histogram - Influence of the Transfer Function

- Visibility histograms are transfer function dependent.

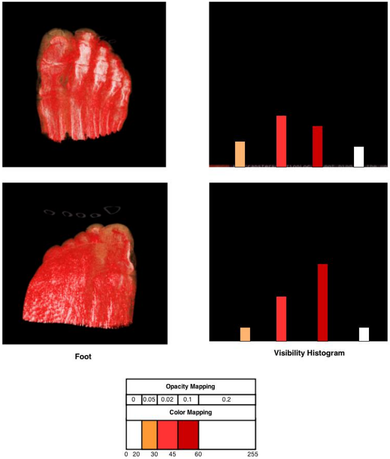


Volumetric head visualization

Visibility Histogram

Visibility Histogram - Influence of the Viewing Direction

- A visibility histogram for a particular dataset is dependent on the direction from which the dataset is looked at, i.e. the direction of the viewing rays which traverse the data set.

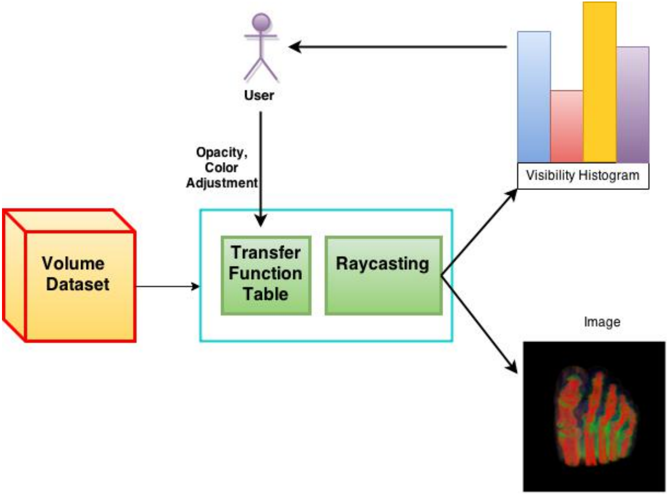


Role Of Raycasting In Computing Visibility Histogram

- Using the front-to-back compositing scheme

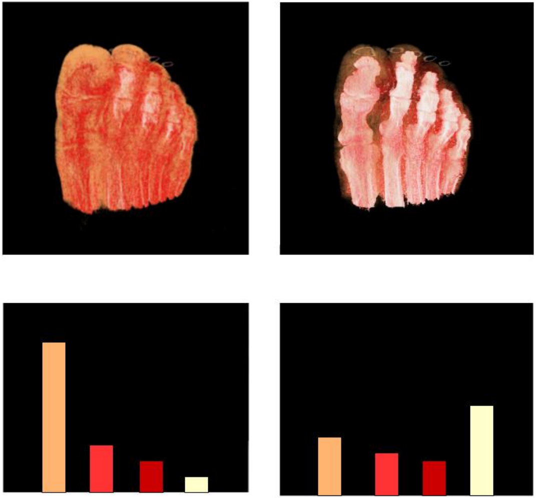
Transfer Function Design

Manually Generated Transfer Functions



Occulsion Signature

The Visibility histogram helps find occulsion patterns.



(a) Visibility Histogram

(b) Visibility Histogram

Focus+Context Using Visibility Histograms

- A region of interest can be a range of voxel intensities, and this segmentation is achieved using transfer function.
- Visibility histogram gives graphical cues on visibility of samples in making of the final image.
- Since range of voxel intensities define the ROI, visibility histogram can be used to find visibility of the ROI.
- Using the visual cues from the Visibility Histogram, the user can modulate opacities to set the focus on ROI.
- Tradeoff between visibility and spatial clarity can be handled, by adjusting opacities of regions surrounding the ROI untill it meets user requirement.

Context+Focus Visualization For Multimodal Volume

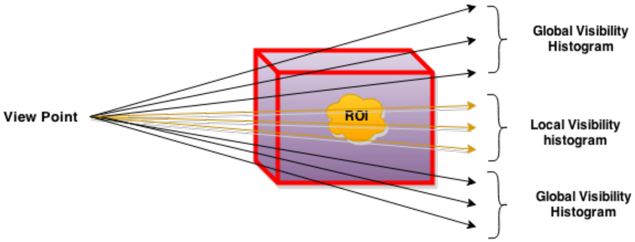
- The advantage of using additional modalities is that they provide complementary or Supplementary information.
- For example PET and CT dataset, PET data acts as the ROI we need to focus and CT data gives us the context.
- One technical challenge that lies in multimodal dataset visualization is in ROI definition.
- One way would be set up a ROI around the structure of interest manually by identifying some key boundary points.

Context+Focus Visualization For Multimodal Volume

- If the structure is complex, user needs to define a larger number of boundary points around the ROI, which is time-consuming and error-prone.
- One solution to this problem is to define a sphere or bounding box covering the ROI
- This solution is difficult to adopt, when the structure is complex, scattered or noisy.

Local Visibility Histogram

- For those rays hitting the ROI, local histograms is computed for each ray
- Rest of the rays cast into the volume are used to compute the global histogram.
- Using this, the user will now be able to manipulate the area of ROI, and control the visibility of this area.



Local Visibility Histogram

- Once visibility histogram is known, opacity of samples in the ROI are adjusted using the formula

$$A'(x) = A(x)\,(\,1 - VH(X)\,)^{e} \tag{5}$$

- where, A(x) and A$'$(x) are the old and new opacity mappings for intensity x.
- VH(x) is the visibility associated with that intensity in the visibility histogram.
- e is the exponent that defines the strength of such a mapping.
- When VH(x) is high(ie., it is more visible) it is likely to be made more transparent.
- When VH(x) is low, these samples do not occlude much and are retained to provide context.
- This helps in keeping context clear which increasing the focus.

Effects of visibility-weighted adjustment e.

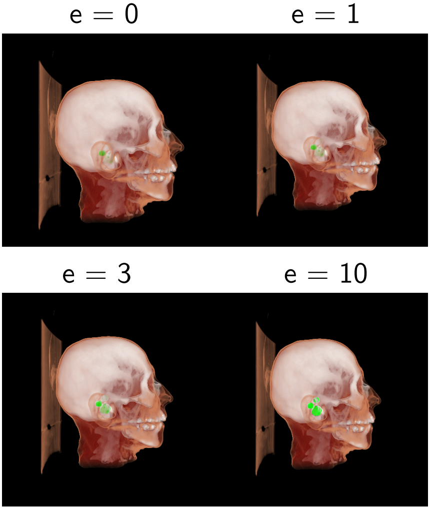


Figure : Effects of visibility-weighted adjustment e.

Volume ROI

A region of interest can also be a volume, which is set of voxels within an 3D volume.

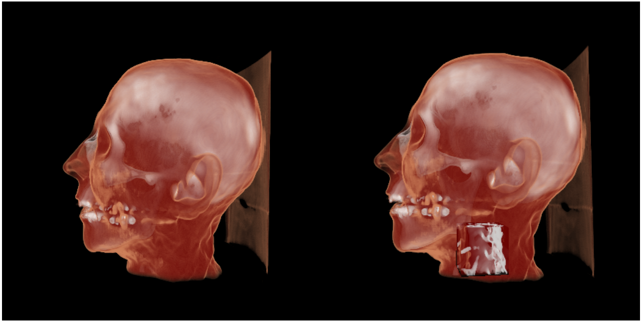


Figure : ROI bounded by a volume.

Implementation

- Two-pass Rendering & dataset used.

Future work

- We can incorporate lighting for better illustrative visualization.
- We can extend to two-dimensional transfer functions, for silhouette rendering in ROI and produce enhanced visualizations by incorporating NPR techniques.
- Volume raycasting and visibility driven transfer function techniques can also be used to visualize iso-surfaces of volumetric dataset.
- Another important future work will be to extent our work to enable visualization of non-uniform grids.
- We can also extend our approach to study effects of intergrating other NPR technique for multimodal visualization.
- We can work on the implementational aspects of the semi-automatic transfer function generation.

References

John Smith (2012)
Title of the publication
Journal Name 12(3), 45 – 678.

Thank You!