“Large Volume Data Visualization”

PROJECT REPORT

FOR THE

SUMMER RESEARCH INTERNSHIP PROGRAMME 2017

BY

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CANDIDATES' DECLARATION

We hereby declare that the work presented in this project report entitled "**Large Volume Data Visualization**", submitted towards fulfilment of Summer Research Internship at Indian Institute of Information Technology, Allahabad, is an authenticated record of our original work carried out from May 15, 2017 to July 10, 2016 under the guidance of **Prof. Anupam Agrawa**l. Due acknowledgements has been made in the text to all other material used. The project was done in full compliance with the requirements and constraints of the prescribed curriculum.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: 10 July 2017
Place: Allahabad

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ABSTRACT

A novel approach for GPU-based 3D volume rendering in high quality of large out-of-core volume data has been implemented. Our prime focus was on the storage of large volume data in a hierarchical data structure (i.e. octree) which stores the data in form of bricks, in addition every brick is further divided into macro-cells for easier traversal of data during run-time.

The approach performs accelerating structure traversal out of GPU ray casting loop in an intensive manner and introduce an efficient & reliable empty-space culling methodology by rasterizing the proxy geometry of a view-dependent portion of the octree nodes. Octree traversal is now performed on CPU while rasterization and visualization processes are performed on the GPU. Rasterization pass is able to capture all of the bricks that the ray penetrates in a per-pixel list. Moreover, as the per-pixel list is captured in a front-to-back order, our ray-casting pass requires only to cast rays inside the tighter ray segments. During the phase of evaluation and testing, this approach achieved 2 to 4 time faster rendering speed than the current state-of-the-art algorithm (which performs traversal of data structure on GPU) across a variety of data sets. As branch-intensive operations are operated in CPU at a better rate than on a GPU while floating point computations are better performed on GPU.

Moreover, efforts have been made to build the whole system more user-friendly & interactive. By enabling both keyboard as well as mouse functionalities, extensively working over the UI part, the final product is more user-oriented.

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1. Introduction

Our project focuses on 3D visualization of human medical data which is large-scale and has to be interactive, hence we are motivated to use GPU techniques.

1.1 Motivation

With the improving technology, medical diagnosis and increasing population the size of medical data (MRI, CT Scan etc.) is increasing day by day. Thus, the problem of visualization of large data arises which is very prominent in this era. However, so as to deal with the ever-increasing resolution and size of today's volume data, it is really crucial to use highly scalable visualization algorithms, data structures, and efficient architectures in order to circumvent the restrictions imposed by the constrained amount of on-board GPU memory. Volume visualization deals with methods to explore, analyse and visualize volumetric data acquired in medicine, computational physics and various other scientific disciplines. In other words, it is a method of extracting meaningful information from volumetric data using interactive graphics and imaging and it is considered with data representation, modelling, manipulation and rendering. Interactivity in resolution is making both the computational and the visualization effort proportionally equivalent to the amount of data that is actually visible on screen (output-sensitive algorithms and system designs).

GPU-based large volume data visualization techniques based on the notions of actual output-sensitive resolution visibility and the current working set of volume, bricks the current subset of dataset that is minimally required to produce an output image of the desired display resolution.

2. Problem definition

To visualize large volume medical human data on GPU efficiently. It can be used to view human body in different resolutions and perspectives based on the requirements of the user, hence interactive. This requires effective handling of large data in a structured way, keeping in mind the memory constraints.

2.1 Objective

To build a robust system which could be used to visualize data independent of its size on any inexpensive hardware having minimum specifications.

- Modelling the data using multi resolution model like octree.
- Selective rendering of data as required by the user, hence output-specific and Interactive.

3. Literature Survey

Table 1. Literature Survey Table

S. No.	Title	Year	Journal/ Conference	Objective	Method	Dataset Used & Size	Advantage	Disadvant- ages	Challen ges Dealt	Future Scope
1	A single-pass GPU ray casting framework for interactive out-of-core rendering of massive volumetric datasets [3]	2008	Journal Visual Comput 2008	To present an adaptive out-of-core technique for rendering large scalar data volumes employing single-pass GPU ray casting	Volumetric dataset is decomposed into small cubical bricks, which are then organized into an octree structure maintained out-of-core and during run time loading the working set on the GPU	Multi-gigavoxel CT dataset	Octree is used for data representation maintained out-of-core. At runtime, an adaptive loader, which executes on the CPU, updates the view and transfers the function-dependent working set of bricks maintained on GPU memory by asynchronously fetching data from the out-of-core octree traversal. Out-of-core data management is beneficial for filtering out as much data in an efficient way that is not contributing to a particular image	The rendering working set will not efficiently update as the integration of level-of-details available and the visibility culling techniques are not used which is required	To handle vast data efficiently	To exploit the capability of this system to perform a full- volume ray tracing so as to produce higher quality images that incorporate in them more advanced shading effects
2	A Survey of GPU-Based Large-Scale Volume Visualization [2]	2014	Conference Eurographics Conference on Visualization (EuroVis) (2014)	To give an overview of the current state of the art in GPU techniques for interactive large data volume visualization		Large Volumetric Data	Octree is use as the data structure in volume rendering which enables adaptive level of details Along with empty space Skipping. Using Output Sensitives Algorithm Was making their running time	For large-scale Rendering of data, all the stages in this pipeline have to be scalable (i.e., in our context: output-sensitive), or they will become the bottleneck		

							dependent on the size of the output generated rather than the size of the input given. Focus on Ray-guided and visualization-driven architectures.	for the entire application otherwise the visualization will not be done perfectly and accurately.		
3	Octree Rasterization: Accelerating High-Quality Out-of-Core GPU Volume Rendering [1]	2013	Journal IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS	The prime target is to make high-quality visualization more practically available in the clinic by the use of a consumer-level GPU	Store volumes of data in an octree (of bricks) Each having further split Into regular Macrocells. Using accelerating structure traversal in an efficient manner out of the GPU raycasting loop and by rasterizing the proxy Geometry of a view dependent portion of the octree Nodes. This Rasterization pass captures majority of the bricks that the ray penetrates in a per-Pixel list.	Large out-of-Core 3D volume Data.	It prime focus is to make high-quality visualization to be more practical by the use of a consumer level GPU. It introduces a new out-of-core GPU 3D volume Rendering way, which combines object-order and image-order advantages and acts as a general acceleration approach, which makes complex visualizations possible, while maintaining interactivity at the same time. The algorithm proposed can achieve 2-4 times faster rendering speed than the current state-of-the-art algorithm for large out-of-core data sets, while also producing high-quality rendering using tricubic Interpolation.	The efficiency of the hierarchical octree scheme involving bricks often suffers from per-pixel traversal of the acceleration structure, which is a branch-intensive operation and may not perform well on some modern GPU architectures, which have a heavy performance penalty for divergent Branching.	Maintaining octree on GPU limits the data Size. Raycasting by passing each brick, hence increasing the overhead	This methodology can be used in various visualization systems, such as in multiple user activities, comparative and multiple volume studies, or on time-varying data visualization in future work

4	GPU-based Volume Rendering for Medical Image Visualization [4]	2005	Conference Engineering in Medicine And Biology 27th Annual Conference	To facilitate the usage of some well-developed hardware resource, a graphics processing unit (GPU)-based 3D volume ray-casting algorithm is proposed		CT scan of the Stanford terracotta bunny (512*512*360) Real clinical human abdomen CT data, (400*400*344) MRI head scans (190*217*190) MRI head scans (256*256*109)	The work that it involved is the storage of volume data in texture, resampling and interpolating them using hardware instead of the software. This paper presented a novel 3D volume-rendering algorithm for medical data visualization using NV40 GPU. Based on the flexible programming model of FV40 pixel shader.	It does not use any data pipeline to implement the 3D ray-casting operation completely in GPU so, the large-scale data cannot be visualized using this Algorithm.	The algorithm employed a native pre-classification method to classify the voxels before interpolation, since this must be done in CPU, it costs much time	Transferring classification operation into the GPU to get even quicker interactive speed
5	A Framework for Rendering Large Time-Varying Data Using Wavelet-Based Time-Space Partitioning (WTSP) Tree [5]	2004	Conference VG'05 Proceedings of the Fourth Euro graphics / IEEE VGTC conference on Volume Graphics	To present a new methodology to manage and render large scale time-varying data using the wavelet-based time-space partitioning (WTSP) tree	The design goal of the WTSP tree is to support the interactive browsing of data at some arbitrary spatio-temporal scales using Haar wavelets, we can build a binary time tree associated with each of the spatial nodes with a method similar to the error	Large scale time-varying data	We present a new approach to manage and render large scale time varying data using the wavelet-based time-space Partitioning (WTSP) tree. We utilize the hierarchical WTSP tree data structure to capture the spatio-temporal locality and coherence of the underlying time-varying dataset and exploit the wavelet transform to convert the data into a multiresolution	The Primary goals of our work is to decorrelate the time-varying dataset into some range of spatio-temporal level of details, and to develop an efficient data management Scheme to Enable rapid dynamic run-time data retrieval and Reconstruction.	The formidable challenge for interactive volume rendering is the huge amount of data	Studying different approaches to combine the WTSP tree data structure with other data compression schemes. For instance, to incorporate the Laplacian pyramid structure into the WTSP tree and trade space for reconstruction and rendering time

					tree algorithm		spatio-temporal Representation. During rendering, the wavelet-compressed data stream is decompressed on-the-fly and rendered using 3D hardware Texture mapping. WTSP tree allows random access of data at arbitrary spatial and temporal resolutions at runtime.	So basically it focused on the space and time management of rendering and visualization rather than the image quality and the results accuracy.		
6	Interactive Iso-surface Ray Tracing of Large Octree Volumes [6]	2006	Conference Interactive Ray Tracing 2006, IEEE Symposium	To present a technique for ray tracing iso surfaces of large compressed structured volumes of data	Implementation is based on the following theoretical concepts: octree data structure, point location and nearest neighbour finding, and the octree traversal	UNC DATA: Blunt Fin (40x32x32) Protein (64x64x64) Enzyme (97x97x116) Dolphin (320x320x40) NMR Brain (256x256x109) CT Head (256x256x113)	It present a technique for ray tracing isosurfaces of large compressed structured volumes. By embedding the accelerated octree and scalar data in a single structure and employing optimized octree hash schemes, we achieve the competitive frame rates on some common multicore architectures, and are able to render large time-variant data that could not otherwise be accommodated. It involves Compressing the large-scale volumes into an octree structure, and employing that for ray traversal.	Adaptive isosurfaces extraction techniques are fast, but depend on effective processing and streaming of large data to the CPU. They render a piecewise linear mesh that may be topologically different from the true isosurfaces as defined by the source data.	Interactive Rendering of large volumes is a difficult problem in visualization. With direct volume rendering, GPU memory Is able to impose an absolute constraint on the volume size, and the video bus restricts real time 3D rendering of time-variant datasets.	Exploiting the multi resolution nature of the octree to generate a dynamic, view-adaptive levels of detailed scheme. Such a system would be able to reduce the complexity and variance of the overall scene

7	Interactive GPU-based Volume Rendering for Medical Image [7]	2009	Conference Conference on Biomedical Engineering and Informatics	This method makes use of the tri-linear interpolation to Accelerate the speed of rendering. Besides the usage of volume ray-casting in back-to-frond order when the voxel's opacity is accumulated to a threshold then after calculation will be discarded.	The proposed algorithmic approach implements ray casting operation completely in GPU. It performs re-sampling 3D volume data, represented as a stack of 3D texture, onto a sampling surface. The 3D volumetric ray-casting algorithm performs in fragment shaders	Skull CT scan data set (256x256x256) Human head MRI data set (256x256x256) Pet data set for chest (512x512x256) Head CT scan data (256x256x84)	To facilitate the use of well-developed hardware resource, GPU-based 3D volume ray-casting algorithm is proposed which implements the volumetric ray casting operation completely in the GPU. The algorithm resamples 3D volume data, represented as a stack of 3D texture onto a sampling surface. It is processed on an interactive rate even for direct volumetric rendering while keeping the high image quality.	Due to the Very Large number of trilinear interpolations that have to be processed so as to produce image results of high quality, the availability of direct 3D volume rendering has yet been restricted to high-end workstations and special purpose graphics hardware.	The visualization of such data in an interactive manner is a challenge, since the frame rate is heavily dependent on the amount of data that have to be visualized	
8	Mapping High-Fidelity Volume Rendering for Medical Imaging to CPU, GPU and Many-Core Architectures [8]	2009	Journal IEEE Transactions on Visualization and Computer Graphics	To learn and analyze new volumetric rendering algorithms that are suited to modern parallel processing architectures	It uses the Thread and data parallel implement-ation of ray-casting that makes it suitable to key architectural trends of three major commodity parallel architectures: multi-core, GPUs, and an upcoming many-core Intel R architecture code-named Larrabee	Three sets of human CT data (16-bit) Large medical human dataset (750x750x1000)	This paper describe a thread and data parallel implementation of volumetric ray-casting that makes it suitable to key architectural trends of three modern commodity parallel architectures: multi-core, GPUs, and an upcoming many-core Intel R architecture code-named Larrabee. Overall implementation of ray-casting in parallel manner delivers close to 5.8x speed-up on quad-core Nehalem over an optimized scalar version running on a single core.	The advantage is the challenge for providing improvised health care efficiently, which is complicated by the scale & size of the data. Despite the availability of various general purpose and specialized rendering engines, the medical community has not yet widely adopted the volumetric visualization except in	The challenge is to provide improved health care efficiently, which is complicated by the magnitude of the data. Despite the Availability of several general purpose and specialized rendering engines, volume visualization has not been widely adopted by the medical community except in certain specific cases	

								Certain specific cases. In ray-casting, as the ray traverses through the volume, they access voxels with a non-constant stride.		
9	Large Scale Volume visualization on GPU A Just-in-Time Compiled Sparse GPU Volume Data Structure [9]	2015	Journal IEEE Transactions on Visualization and Computer Graphics	To reduce the memory bandwidth (bottleneck in GPU) for sparse volume data structures that pose a trade-off between efficient memory usage and access performance	Present a new sparse volume hybrid data representation (JiTTree) that makes it possible to combine the various elemental data structures resulting in lower memory usage while enabling high runtime performance. No memory Fetches & swaps are required for the kd-tree traversal. The encoding of splitting axis order is directly done in the conditionals Moreover, the splitting plane positions are generally inserted as literals.	Stag beetle dataset (brick size-32*32*32) Kingsnake dataset (brick size-128*128*128)	This paper presents JiTTree, a novel & new sparse hybrid volume data structure that uses just-in-time compilation to overcome the representation problems. In this paper we present JiTTree, a new type of sparse volume data representation that enables efficiency in accessing memory storage and high speed data access. The JiTTree is the just-in-time compilation phase that transforms data into efficient access functions. Thereby it enables the use of several kinds of data structures for representing data volume, without introducing a significant traversal overhead. By	The basic principle of the data structure is to adapt to the local sparsity of a specific data set. Other volume representation often make the distinction between dense and empty (or homogenous) regions and treat these regions differently.	The JIT approach transforms memory-bound programs into instruction-bound programs. Although data structure is not designed for dense data, it outperforms other representations, such as a dense bricking, for most cases. However, for a better analysis of the data structure we used data sets with varying scarcity.	just-in-time compilation of the root level to improve performance ; to add dynamic write capabilities in addition to the read-only access; improve the JIT compilation approach for other memory access patterns like ray traversal

							Combining multiple sparse data structures and reducing traversal overhead we leverage their individual advantages. JiTTree reduces the traversal overhead of the resulting optimal data structure			
10	A Survey of Octree Volume Rendering Methods [10]	2006		Survey and comparison of existing works employing octrees for volume rendering		Large Volume Data	This paper perform surveys and compares the existing works which employ octrees for 3D volume rendering. It's Main focus is specifically on extracting out direct volume rendering, and iso-surface ray tracing. It surveys the varieties of octree available and the efficient hashing schemes for their traversal.	It only examines Octrees that are of considerable interest in Field of volume Rendering only, we are not able to compare its usefulness towards any particular purpose.		Future applications of volume rendering using octrees could attempt to combine the pure octree approach with GPU rendering approaches , using out-of-core methods
11	Cell Octrees: A New Data Structure for Volume Modelling and Visualization [11]	2001	Conference, Proceedings of the Vision Modelling and Visualization	An Improvisation in the bono approach which uses an incomplete octree structure with a relatively smaller memory		Large Volume Data	A new indexing method was proposed which uses an incomplete octree structure and requires less storage memory. It present an improvement of BONO (Branch On Need Octree) approach which uses an incomplete Octree structure with a smaller memory. The methodology indexes various set of cells as a block when their property value is nearly uniform. In this method, the prune condition is totally independent of threshold and the point of view. The tree branches that do not index cells containing the isosurface are not processed, so the building time of iso-surfaces is reduced.	When the number of cells of any dimension in the volumetric data is not a power of two, or is not equal to the number of cells of another dimension of it, then nodes will not have all eight children. In such cases, octree will be having a larger spread in the lower levels i.e. closer to the leaf nodes, and a smaller spread in the levels close to the root node. Consequently, having smaller storage requirements.	An improvement of bono, noted as octree with cells, has been accomplished	Values of properties may be stored in the octree, so grid storage is not necessary and there may be further reductions in the storage constraints.

12	Multi Resolution volume visualization with a texture - based octree [12]	2001	Journal The Visual Computer 2001	Reduction in the amount of texture memory that is required for rendering a 3D volume data, and thus reducing the texture loading overhead of the rendering engine.	Texture-based octree	MRI brain (32 MB) MRI Brain (4 MB) CT jaw (32 MB) CT Jaw (11 MB) CT Vertebra (64 MB) CT Vertebra (42 MB)	The prime focus of this paper is to speed up the texture based rendering of volumetric datasets. The paper do propose a new texture memory representation & some management policy that was able to substitute the classical one- texel per voxel concept for a hierarchical approach. This method benefits nearly homogeneous regions and regions of somewhat lower interest. The proposed algorithm is totally based on a simple traversal of the octree representation of large-scale Volumetric data Driven by a user-defined image quality, defined as a combination of data homogeneity and prime importance, a set of octree nodes are selected to be rendered on the fly. The degree of accuracy that is applied to represent each one of the nodes of the cut in the texture memory is basically set independently as per the user-defined parameters.	The algorithm that is proposed does not consider view-dependent criteria (which are based on the perspective distortion and the shrinkage of farthest of data sections) as, in 3D volume rendering, the differences in the ratio of projections are very limited. This paper is basically focused on The speedup of the 3D volume Visualization in so the other attributes (i.e. image quality) are considered as a secondary choice		"Future work" is Addressed So to analyze The various approaches for selecting the interest Function which is able to better Satisfies user-Defined Constraints viz, Problem of the Combination of surface and the Volume Information
13	Enabling the interactive display of large medical volume datasets by multiresolution bricking	2009	Journal Springer Science	To implement a bricked, hierarchical, out-of-core partition-based strategy to balance the usage of main (CPU) memory and external (GPU) memory	Retrieving data present in a discrete multi-resolution model, along with a bricking technique combined with it.	Visible Human Male (Size-3.15 GB) (1760 x 1024 x 1878) Visible Human Female (Size-12.03 GB) (2048 x 1216 x 5186)	The purpose of research was to find out a significant faster approach to 3d visualize large datasets using multiresolution bricking & hierarchical data structures like octree	Approach was not able to compress datasets in presence of noise		Further can be extended for exploiting the use of multithreading in the GPUs to speed up the pre-processing. Also possible to further compress the pre-processed bricked layout data

4. Methodology

The visible Human male dataset is used for experimentation. It is of 3.15 GB RAW file. The data is made up of a stack of images of resolution 1760 X 1024. The stack consists of 1878 slices. Each slice represents the body cut horizontally. The paper [1] & [13] are our base research paper as they introduces a novel method to process the large volume data efficiently.

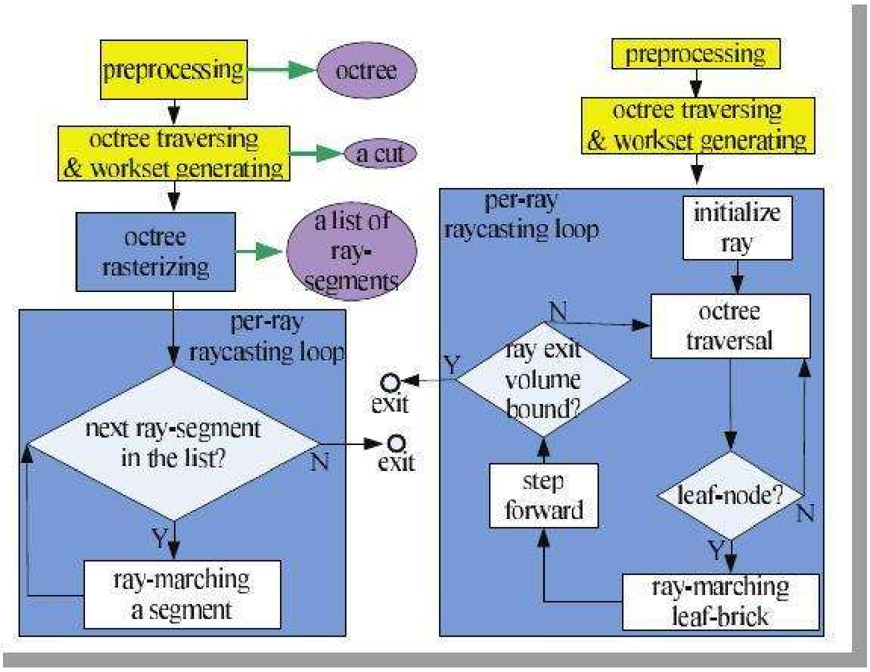


Figure 1: ***Flowcharts of our approach (left) and the previous out-of-core GPU 3D volume rendering approach (right).***
Yellow boxes are executed on the CPU, all other boxes on the GPU. Control flow is indicated by the black arrows & the output of intermediate data is indicated using green arrows.

The flow of method in Figure 1 is explained as follows [1]:

4.1. Pre-processing

A large volume dataset is first pre-processed using blocking techniques (division of large dataset in blocks of data) and storing it in Octree (a 3-D data structure is represented in the form of recursively sub-dividing into eight octants). An **octree of bricks** is constructed where the actual resolution data is stored in leaf nodes. At each level or node a brick of same dimension B_{res} is made. The length of the tree is kept shallow which results in courser bricks. Inner bricks are built using down sampling of the lower level nodes like averaging filter, in this way the whole dataset can be represented as a multi-resolution hierarchy maintained on the CPU. Each node of the octree points to a particular brick having a constant resolution that resembles the part of the volume corresponding to that particular node.

Pre-processing steps comprises of 3 main steps:

1. Sampling
2. Bricking
3. Compression

Bricks store extra overlapping voxels, which helps in accessing the neighbouring voxels at runtime using the tri-cubic interpolation and gradient computations. Since the octree don't use any transfer function for empty space culling it uses macro-cells for storing the min-max scalar values for each of the corresponding bricks, for efficient brick culling. The dimension for macro-cell is M_{res}

4.1.1. Octree Creation and Visualization of View-Dependent Working Set :

1878 slices were first constructed into a single 3D-Volume. Dimensions of each image slice is 1760 * 1024. Brick size of every node in octree is taken as 220*128*235.Single large Volume is splitted into 512 bricks of resolution 220*128*235. These bricks are then averaged by a factor of 8 to construct 64 bricks of same resolution which are further averaged by a factor of 8 to construct 8 bricks which are then combined to form a single root. These bricks are then saved as nodes of an octree where root acts as parent having 8 children which are individually divided into 8 more children. Structure of the octree node is as follows –

```
struct node{
        ifstream fp;
        struct node *child[NO_CHILDREN];
        struct node *parent;
        int level;
        int a[3];
        int no_children;
        int is_leaf;
        string name;
};
```

Table 2: Structure of octree

4.2. Generation of a View-Dependent Working Data-Set

For viewing different frames a cut is decided out of the octree according to the required frame. The cut includes different resolution nodes as per needed dependent on the viewing angle. This cut-portion is used for updating the GPU pool of bricks for rendering. If we zoom the image the children of the current node has to be loaded and if we zoom out then multiple nodes has to be fused together. For deciding the cut breadth first order octree traversal is used starting from the root node and is continued till the required node is found.

Work-set Generation Algorithm

```
Initialize queue with root tag = 2

while(stack_not_empty)
  { cur = queue.front()
  queue.pop()

  split cur in 8
  octants if possible
  for (i = 0; i < 8; i++) { if
    ROI lies in octant[i]
      if ROI lies completely in octant[i]
        tag = 1
        push in
      brick_pool else
        tag = 2
        push in queue
    else
      tag = 0
  }

}
copy brickpool to cudaMemory
```

Table 3: Workset Generation Algorithm

4.2.1. View-Dependent Brick Sorting

The nodes in the cut-portion are rasterized as before. Hence we sort the nodes and store them in front to back fashion using a pointer list which is stored for further use. Pointers to the traversed cut-nodes are stored in a STL list. A node that is traversed is always replaced by its children to front-back order during depth-first search, this is done till a node labelled as node cut-portion is found. It is implemented using an 8 * 8 table for lookup purpose. Each row of the look up table is able to encode a possible order of all the 8 octants according to the viewpoint in the octree space.

4.2.2. Memory Management of the Working Dataset

The cut-portion represents the brick data and macro-cell data of the nodes. This data is then transferred to GPU asynchronously. The working set is loaded into 2 memory pools:

✓ **Brick Pool**

It is organized ad a 3D texture of specific size and dimension. Each of the cell of this pool corresponds to a particular brick, and the cell stores the corresponding brick Id B_{ID}.

✓ **Macro-cell Pool**

The 3D macro-cell pool is packed with the corresponding brick's macro-cell at particular brick id B_{ID}.

4.3. Proxy-Geometry Rasterization

The comparison between 2 pass and normal rasterization is shown in Fig 3. The explained process of two pass rasterization could be seen in Fig 4. In the first pass, rasterization of the proxy geometries of the whole working set of bricks is performed and all bricks are captured that a ray penetrates into a per-pixel list. In second pass, we are rasterizing all the non-empty macro cells (of all the bricks) and refine the per-pixel list in which each element will be containing a ray-segment corresponding to that particular brick which the ray penetrates. This results in the skipping of empty spaces of macro cell. Fig 4. Gives detailed process for the 2nd pass i.e. traversing the macrocells.

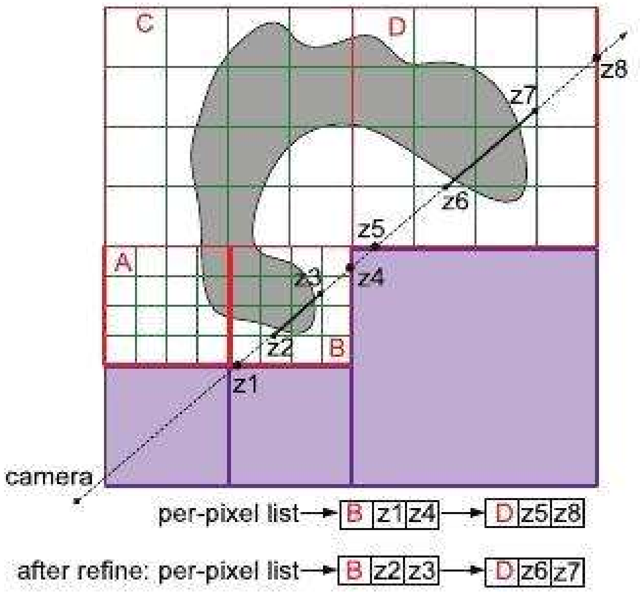
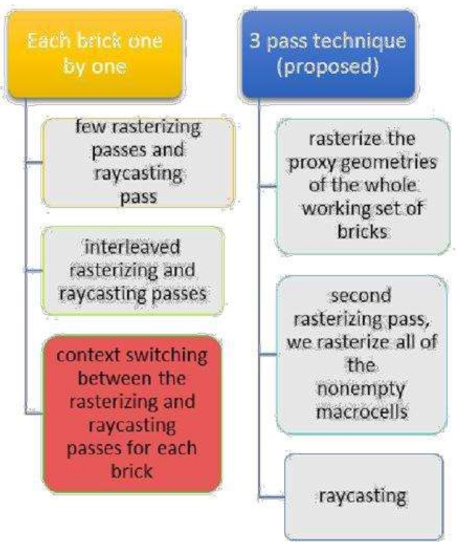


Figure 2: ***Philosophy of Approach: The cut-portion is composed of all of the active bricks (red—A, B, C, and D) at different ROIs depending on the current view. Each active brick is subdivided into macrocells which are green coloured. Empty bricks of purple colour are never added to the octree-cut. We are firstly rasterizing active blocks so that the active blocks can be captured by the fragment shaders that the ray penetrates (B and D) into a list in front-to-back order. Then we are rasterizing the nonempty macrocells and refining the z-values in the list in order to get a tighter ray segment (shown as the solid black line) for each brick at the accuracy of the macro cell level.***

4.4. Raycasting

For each desired image pixel, a ray is generated. Using a simple camera model, the ray originates at the centre of projection of the camera and traverses through the image pixel on the imaginary image plane floating in between the camera and the volume to be rendered. In the raycasting pass, depth interval is defined by the two extreme end points of the ray-segment that performs the GPU raycasting for that corresponding brick.



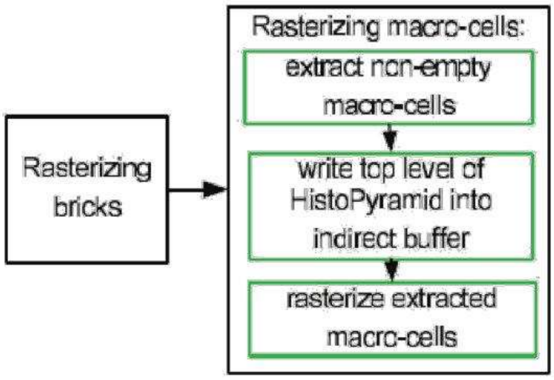


Figure 4: Flowchart of rasterization

Figure 3: Comparison between 2 pass rasterization Process and normal method

4.5. Interactive Visualization

Once we are ready with the pre-processed data organised in the form of multibricks in octrees, we need to interactively visualize it. Keyboard as well as Mouse both functionalities are incorporated to enhance UI features.

4.5.1. Keyboard Approach

In this method, various keystrokes are devised to interactively visualize the datasets. Initially the root file of pre-processed data organised in octree is loaded, which is of lowest resolution. Now, from this we can visualize any portion of body using these keystrokes:

Key ‘0’: Upper Right Front
Key ‘1’: Upper Left Front
Key ‘2’: Upper Right Back
Key ‘3’: Upper Left Back
Key ‘4’: Lower Right Front
Key ‘5’: Lower Left Front
Key ‘6’: Lower Right Back
Key ‘7’: Lower Left Back

Key 'b': Back Key to come back to parent node
Key 'h': Reset Key to come back to root node
Key 'q': Exit

4.5.2. Mouse Approach

In this, we are using ROI (Region of Interest) selection using mouse, a rectangular box is used to select the same. Once the rectangle is positioned appropriately, we can render the selected portion in higher resolution by selecting the appropriate child node of the current node using octree traversal.

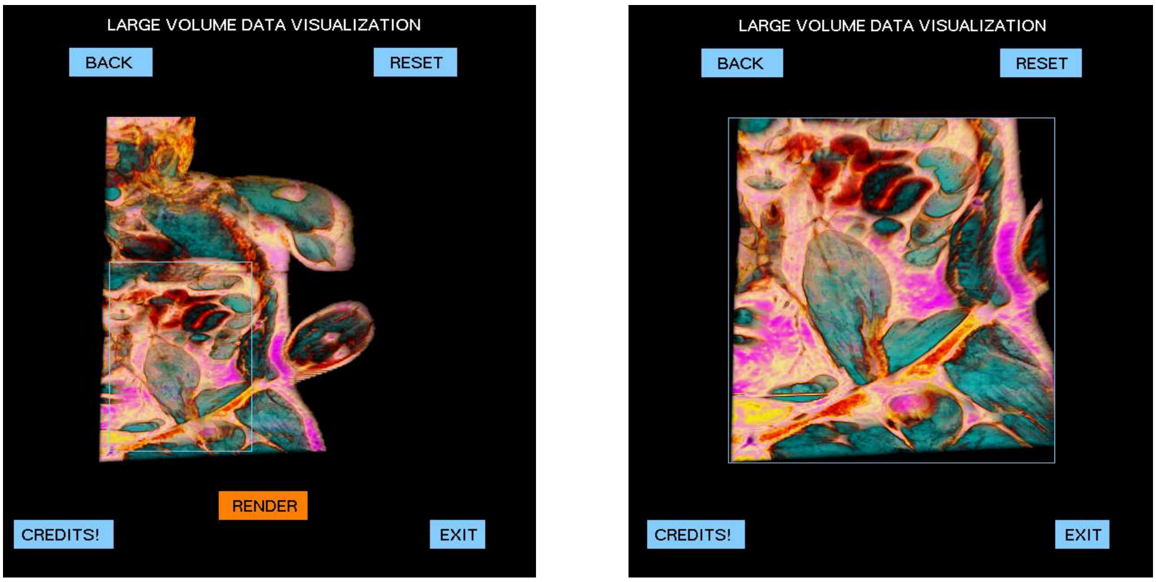
Moreover, Left Mouse click is used to rotate the body throughout the screen & Right Mouse click is reserved for zoom In & Out purpose.
ROI Selection is done using Mouse Scroller Click/ Mid Mouse click.

Algorithm applied for selection of appropriate file to be rendered on the fly:

Step 1: Identification of Body Orientation using viewRotation matrix
Note: Currently 4 Orientation are supported Front, Back, Right Side, and Left Side

Step 2: Identification of Quadrant in a particular orientation
Using extreme coordinates of ROI selection rectangle viz (X_{r1}, Y_{r1}), and (X_{r2}, Y_{r2}) and comparing with the mid points of the cubical box viz (X_m, Y_m).

Step 3: Using the selected orientation and the quadrant, appropriate brick is selected from the CPU and copied to the GPU for rendering purpose.



(a) **(b)**

Figure 5(a): ROI Selection and (b): Rendered Output of ROI in Higher Resolution

5. Hardware and Software requirements

5.1 Software Requirements

- CUDA enabled system i.e. nvcc Compiler
- OpenGL
- Windows: Visual Studio (8+)
- Linux: gcc compiler
- National Library of Medicine Visible Human Body (Male) 3.15 GB Dataset

5.2 Hardware Requirements

SPECIFICATIONS	
GPU processor	Tesla C1060
CUDA Cores	240
Shader clock	1296 MHz
Memory	5888 MB
Total available graphics memory	4096 MB
Bus	PCI Express x16

6. Activity Time Chart

Work done (Phase 1)					Work done (Phase 2)		
Week 1: 15th May - 22nd May	**Week 2: 22nd May – 29th May**	**Week 3: 29th May – 5th June**	**Week 4: 5th June – 12th June**	**Week 5: 12th June – 19th June**	**Week 6: 19th June – 26th June**	**Week 7: 26th June – 3rd July**	**Week 8: 3rd July – 10th July**
Literature Survey	Environment Setup: OpenGL and Cuda C	Learning OpenGL and Cuda C	Data Collection & Code Walkthrough of the previous version	Fixing Initial Bugs in the previous version & pre-processing of data	Adding Keyboard functionality and Interactive visualization using octree traversal	Adding UI Support & Mouse Functions.	Extensive Bug-Fixing and Testing

7. Experimental Setup and Results

Experimental Setup was as follows:

1. Linux Operating System
2. OpenGL Api
3. Cuda C Enabled
4. gcc compiler to run native C code
5. nvcc compiler to run Cuda C code

Following are the screenshots of the product for interactive visualization of the medical dataset that we have done so far:-

(a) (b)

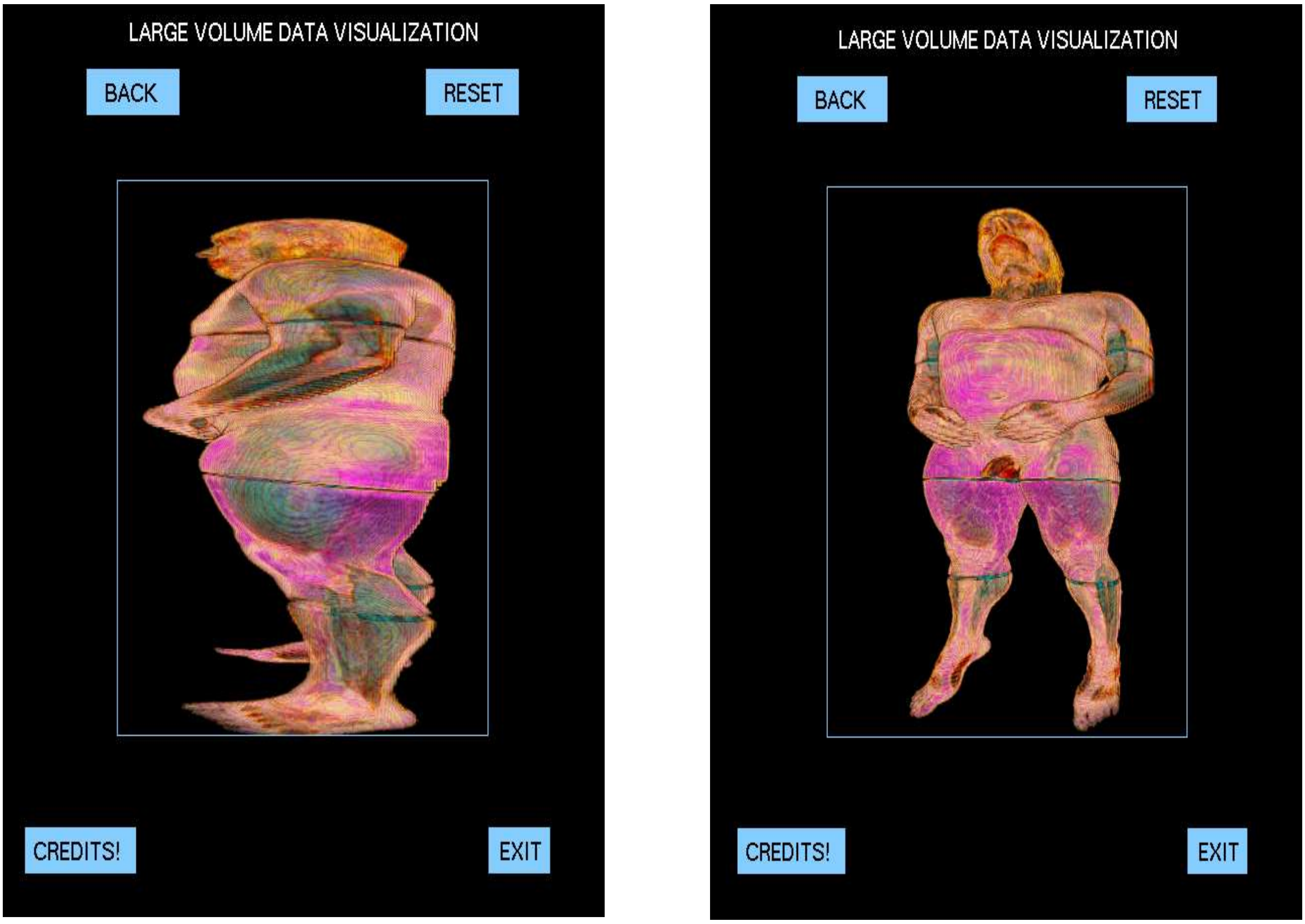


Figure 6: (a) and (b) are 2 different orientation of root node

(a) (b)

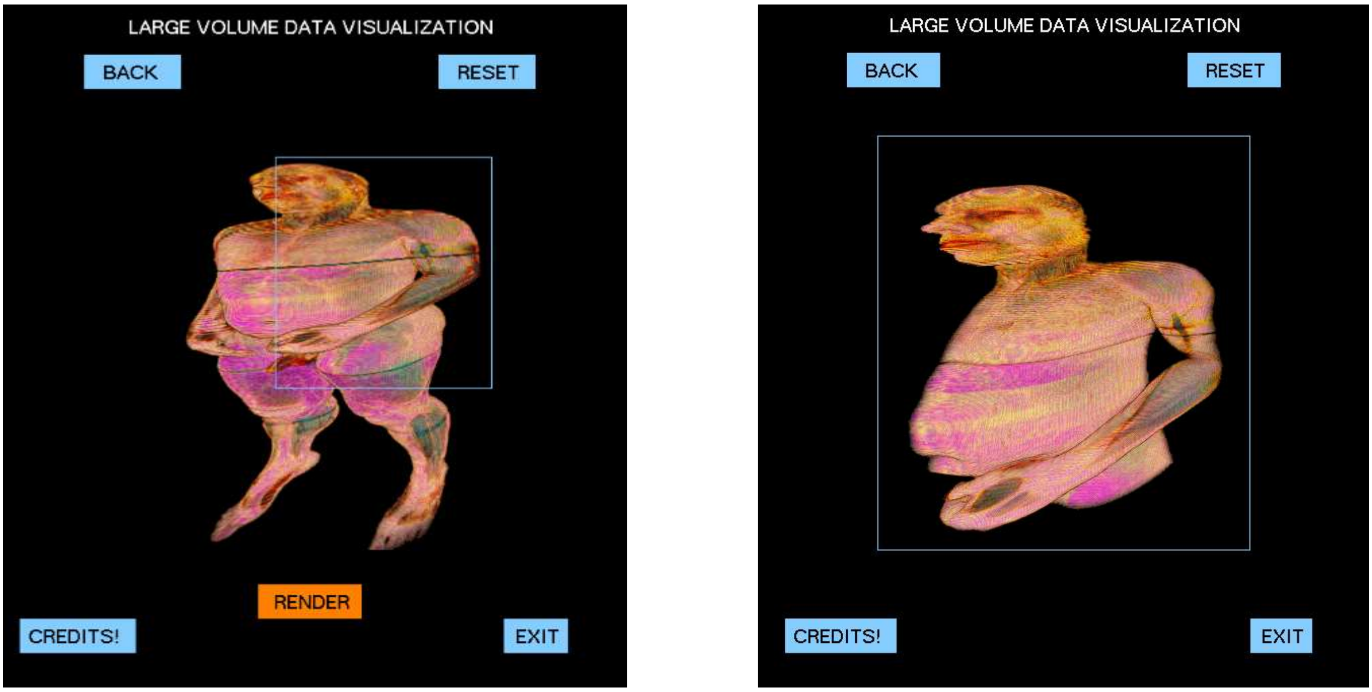


Figure 7: (a) Original Portion of root level and (b) Interactively Visualized Portion

(a) (b)

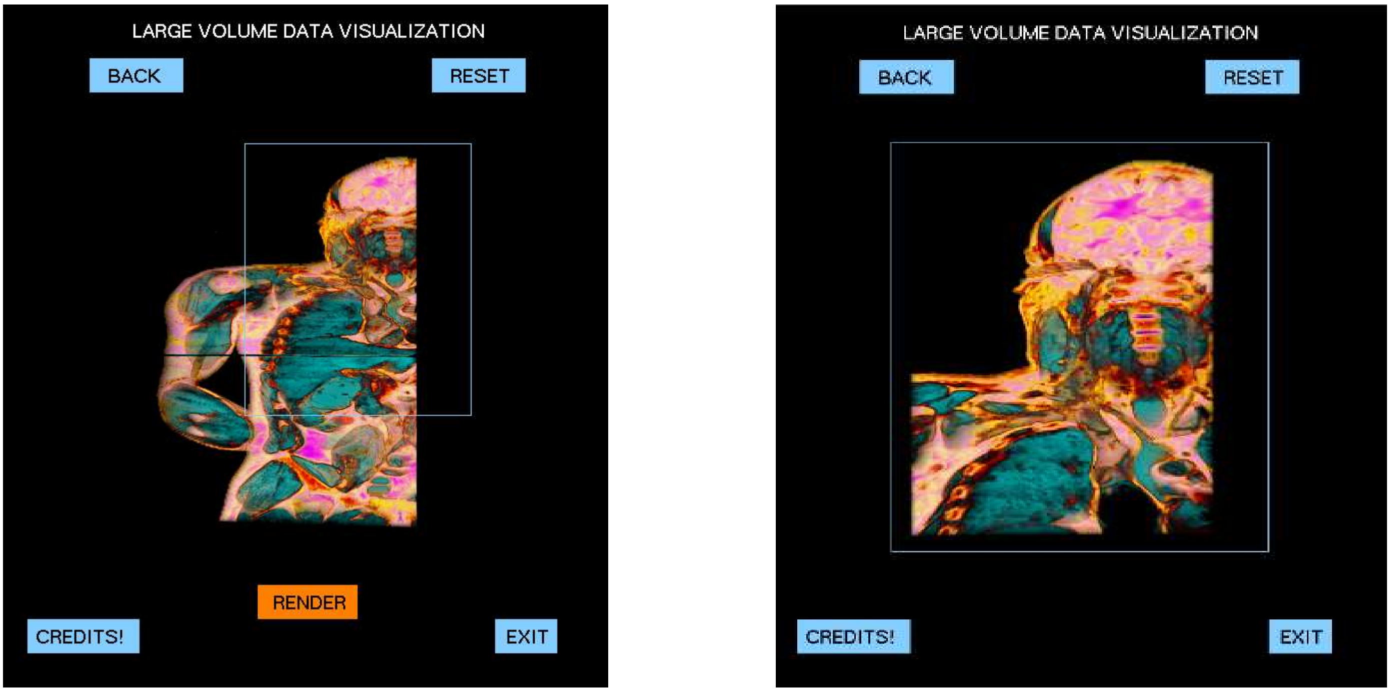


Figure 8: (a) Original Portion (b) Interactively Visualized Portion

8. Performance Comparison

Performance comparison on the basis of rendering quality, when we performed visualization using the source codes of different algorithms which are available as open source and on our technique, the results obtained have smoother image quality from the technique using GPU octree rasterization methods (i.e. the proposed methodology).

Performance comparison on the basis of rendering speed with a Traversing Algorithms using GPU Octree. Octree creation method takes 5-10 minutes on any type of datasets. After which octree traversal, rasterization, per-pixel list generation and rendering are done in matter of minutes as they are performed on GPU using maximum number of cores which can be utilized. As octree creation for a dataset is only performed once and stored in hard disk, the rendering speed is 2-4 times greater than what was performed by previous algorithms which performed octree traversal on GPU.

Table 4: Comparison between CPU and GPU time

S. No.	Processor	Time Require from 8 to 1 brick construction	Time Require from 64 to 1 Brick construction
1.	**Quad Core**	~20 mins	~2 hrs
2.	**Intel i3**	~12 mins	~45 mins
3.	**Intel i5**	~5 mins	~25 mins
4.	**GPU**	~micro secs	~secs

9. Future Scope and Conclusion

In our method which we have implemented is a fast, GPU based out-of-core 3D volume ray-casting, which moves the branch-intensive octree traversal out of the GPU ray-casting loop and after the traversing completes, execute it on the GPU. By introduction of the tighter depth range for the GPU ray-casting it exercised the greater control over the rendering process by using the hardware rasterization unit performance. This method also offers somewhat more sophisticated & efficient empty space skipping, and also makes possible the use of advanced features like cubic interpolation in an interactive manner for the large out-of-core data sets. Since the presented method provides a general accelerating scheme by rasterizing an octree to generate tight ray segments, and the approach can also be used to improvise the performance of the other visualization & rendering systems, such as in multiple user activities, comparative and multiple volumetric studies, or as a future work apart from these we can also use it for time-varying data visualization. Improvements like a more generalized method to deal with the size of brick irrespective of the size of data and optimum number of levels will help to enhance the performance.

A viable future scope of this approach is to be able to visualize multiple bricks that are falling in the Reason of Interest (ROI).These multiple bricks may be present at any level of the octree.

10. References

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