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An Improvement to Ray Casting: A Model Based Approach

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Abstract An optical model as well as an implementation model for ray casting is presented. Then it is demonstrated how this work's proposed rendering method relates to these models. The optical model expresses how a point with in a volume is affected by the light source and density. In the implementation model a viewing plane or in other words a 2D plane comprising of pixels casts a ray for each pixel along a particular viewing direction. In order to obtain a single color and opacity value for each pixel, voxels that are aligned with a ray perform interpolation (filtering) at a constant interval. The colors and opacities are then merged via composition in front to back or back to front order.

Keywords image segmentation · volume rendering model

Mathematics Subject Classification (2010) 97R60

1 Introduction

This work raises a substantial issue in the computer assisted visualization domain. It observes the current direct volume rendering techniques and specifically ray casting as insufficient means for fine visualization and proposes a union between image processing merit and computer graphics for an enhanced visualization effect. Ray casting is a direct volume rendering technique, suitable for volumetric visualization of sampled data [2]. However, it suffers from elementary classification process and inferior transfer function design. An image processing based approach could therefore be used to advance the ray casting's classification process and improve its transfer function based object distinction capabilities.

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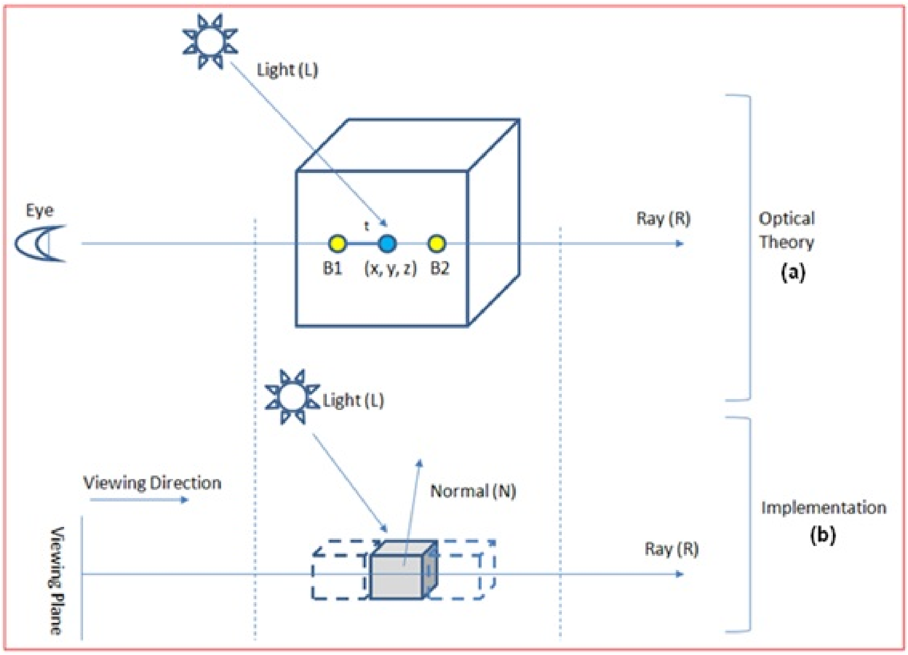

Fig. 1: (a) Optical model of ray casting (b) Implementation model of ray casting.

2 Ray casting optical model

In figure 1 part (a) we have an optical theory section that demonstrates a ray traversal through a volume. The intensity value of point (x, y, z) that travels along the ray(R) and reaches the eye depends upon three factors.
First, the illumination (I(x,y,z)) reaching the point (x, y, z) from the light source.
Second, a reflection function P.
Third, local density$(D(x, y, z))$ which refers to the fact that a few bright fragments scatter less light in the eye direction than a few dim fragments.
The density and illumination from the light source are given by equations (1) and (2) respectively.

$$D(x(t), y(t), z(t)) = D(t) \tag{1}$$

$$I(x(t), y(t), z(t)) = I(t) \tag{2}$$

The Intensity value of point (x, y, z) that travels along R from a point distance (t) is therefore given by:

$$I = I(t)D(t)Pcos(\phi) \tag{3}$$

Where ϕ is the angle between R and L (the light vector for the point (x, y, z)). The calculation of $I(t)$ is complex since one has to consider how radiation is attenuated in its journey from the light source through the volume until it reaches the point (x, y, z). This calculation is the same for the journey of reflected light from the point (x, y, z) along R until it reaches the eye. In most algorithms this calculation is ignored and is set to a uniform value. However, if we want to include this calculation in our optical model we can state it as:

$$exp(-T \int_{B_1}^{B_2} D(s)ds) \tag{4}$$

Where T is a constant that converts density to attenuation. Now, combining equation (3) with equation (4) we get an inclusive optical model expressed by equation (5).

$$A = \int_{B_1}^{B_2} (exp(-T \int_{B_1}^{t} D(s)ds))(I(t)D(t)P(\cos\phi))dt \tag{5}$$

The optical model provided above can not be implemented as it is. Algorithms that implement the general model of ray casting involve the simplification of integrals. The method by which this simplification is done is called additive re-projection.

3 Ray casting implementation model

As depicted by figure 1 part (b), in this model a viewing plane or in other words a 2D plane comprising of pixels casts a ray for each pixel along a particular viewing direction. In order to obtain a single color and opacity value for each pixel, voxels that are aligned with a ray perform interpolation (filtering) at a constant interval [1]. The colors and opacities are then merged via composition in front to back or back to front order. To be more specific we would like to demonstrate how ray casting is implemented by [3]. Visualization and classification are the two pipelines used by [3]. The outputs produced by these two pipelines are combined via compositing in order to produce the final image. In the visualization pipeline each voxel is given a shade via local gradient approximation. A normal is then calculated for each voxel based on its shade. Normals are then passed to a standard phong shading model in order to produce a three color component value for each voxel. In classification pipeline opacity is given to each voxel. Upon associating color and opacity with each voxel compositing is performed [4]. Equation (6) depicts the composition process.c is color, α is opacity, C_{in} is the incoming color / opacity to voxel x and C_{out} is the outgoing color / opacity from voxel x.

$$C_{out} = C_{in}(1 - \alpha(x_i)) + C(x_i)\alpha(x_i) \tag{6}$$

As far as modeling is concerned our proposed solution resembles both of the above discussed optical and implementation models except that in our case we do not carry out voxel filtering and composition all the way through the volume at once. Our proposed approach is rather tag based or in other words piecewise.

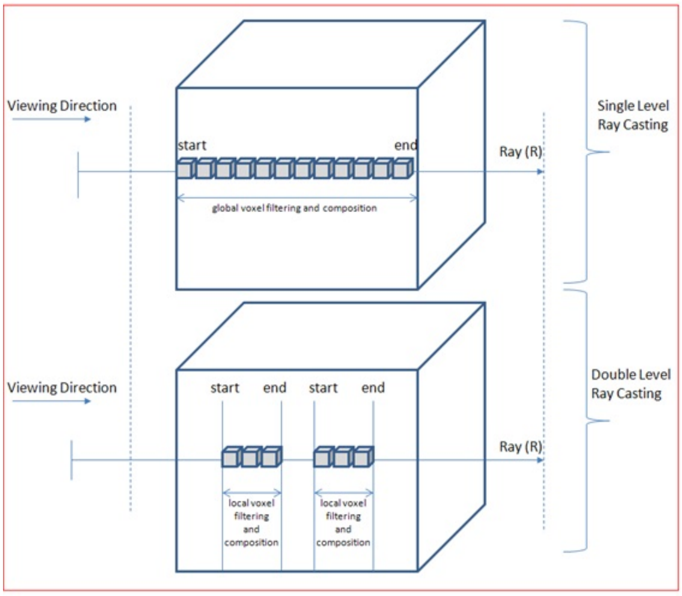

Fig. 2: (a) single level implementation of ray casting (b) Double level implementation of ray casting (this work's proposed solution).

4 Proposed Solution

Figure 2 compares the implementation of our proposed solution with standard ray casting. As may be noticed instead of only one start and end to the rendering we have multiple.
In Figure 2 by single level ray casting and double level ray casting we refer to a global traversal based rendering and a mixed traversal (multiple local traversals embedded in a global traversal) based rendering respectively. A modeling point of view is broad therefore we could not model some of the narrower differences between our implementation and ray casting implementation. However, we can shortly enlist them:
First, voxels are segmented and tagged by IDs.
Second, the color and opacity are not assigned to voxels before interpolation. Interpolation takes place based on ID tags rather than RGBA values.
Third, composition task is not only controlled by sampling interval but also with volumetric depth.
Fourth, there is more than one filtering (interpolation) option available.

Fifth, Instead of a global transfer function local transfer functions are used. Our proposed solution is implemented on a gray level medical dataset. There are five representative groups available in this section, each of which is comprised of three related figures. For instance, Figures 3, 4 and 5 are considered a group. Again, Figures 6, 7 and 8 are considered another group. Each group starts with a figure demonstrating image segmentation results followed by another figure demonstrating image annotation and ends by a figure displaying the volumetric visualization result. The reason behind this arrangement is that we can initially pseudo color the organ(s) we have identified then approximate the validity of identified organ(s) based on annotations provided by the radiologist and finally allow a visual judgment of the three dimensional shape. The organs that we have tried to visualize include liver, thoracic aorta, lung, chest and spinal cord bones.
Table 1 compares between this work's proposed solution and ray casting.

Table 1: A comparison between this work and ray cating.

Distinctive Features	**Ray Casting**	**This Work**
Sampling Rate	arbitrary	arbitrary
Sampling Nature	point	point
Interpolation	tri-linear	N. N. approx / optimized tri-linear
Kernel	linear	linear
Exceptionality	-	viability of multiple rendering modes
Selected Voxels	all	segmented
Acceleration	early ray termination	ID based space skipping
Accuracy	floating point	floating point

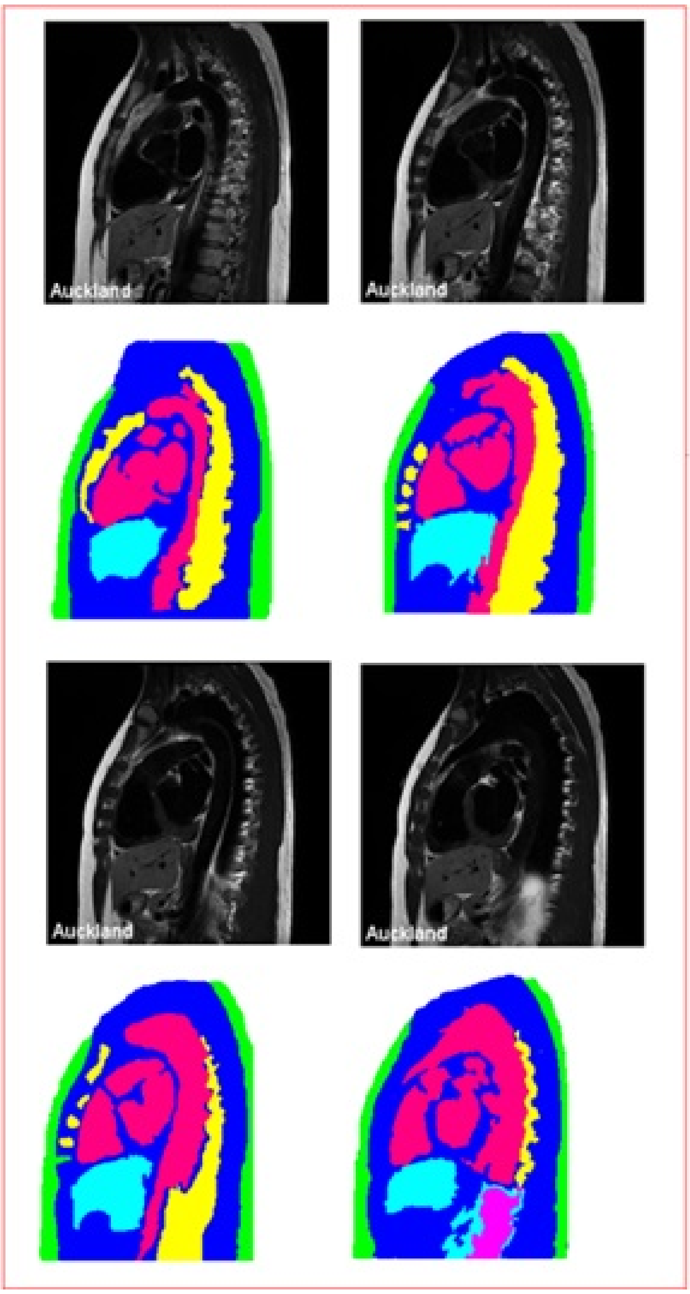

Fig. 3: Sagittal slabs of heart-abdomen. Left ventricle, right ventricle, descending thoracic aorta, chest and liver are segmented.

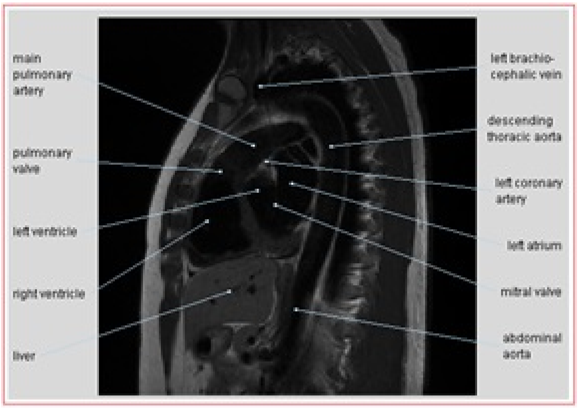

Fig. 4: Radiologist annotation of sagittal heart-abdomen slabs [5].

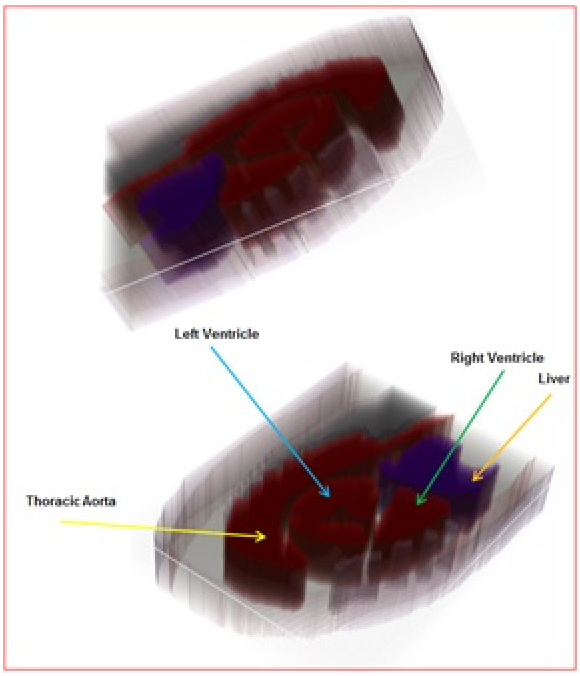

Fig. 5: Volumetric visualization of left ventricle, right ventricle, thoracic aorta and liver

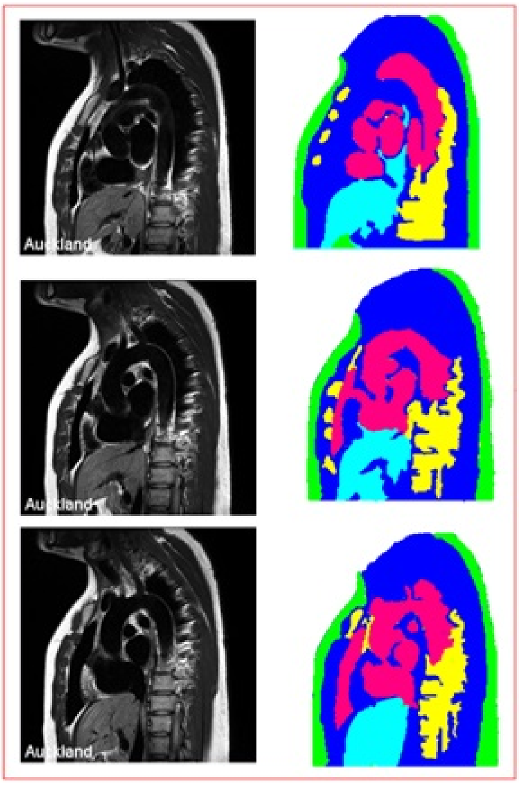

Fig. 6: Sagittal slabs of heart-abdomen. Thoracic aorta, left atrium, aortic root, right atrium, liver and chest are segmented.

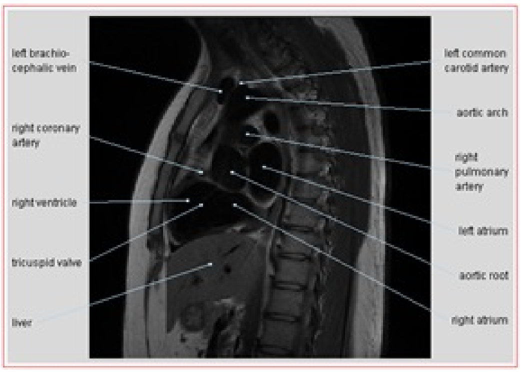

Fig. 7: Radiologist annotation of sagittal heart-abdomen slabs [5].

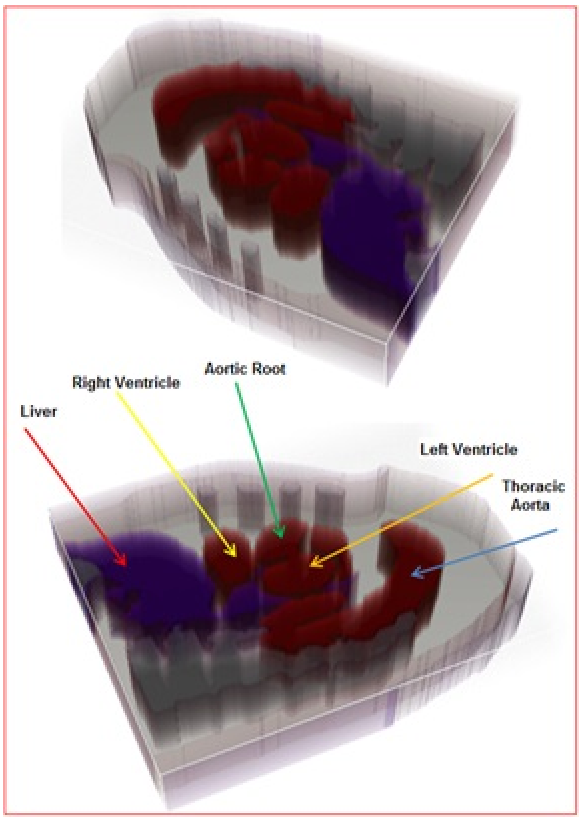

Fig. 8: Volumetric visualization of thoracic aorta, left atrium, aortic root, right atrium and liver.

5 Conclusion

An overall integrated approach for enhancing the visualization effect of ray casting is proposed in this chapter. It is broadly shown that how ray casting could be modified to accomplish both adaptation of a viable segmentation design and optimization of rendering pipeline.

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