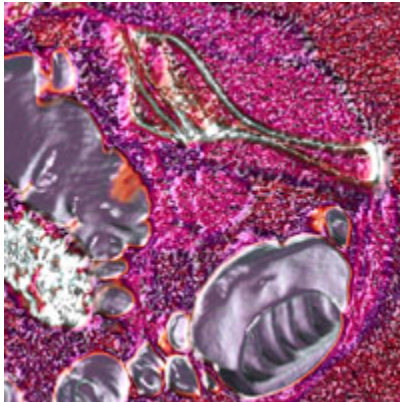
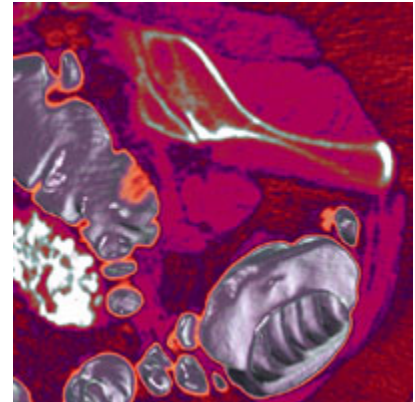


Emissive Clip Planes for Volume Rendering – Supplement.

More material than fit on the one page version for the SIGGRAPH 2003 Sketch by Jan Hardenbergh & Yin Wu of TeraRecon, Inc.



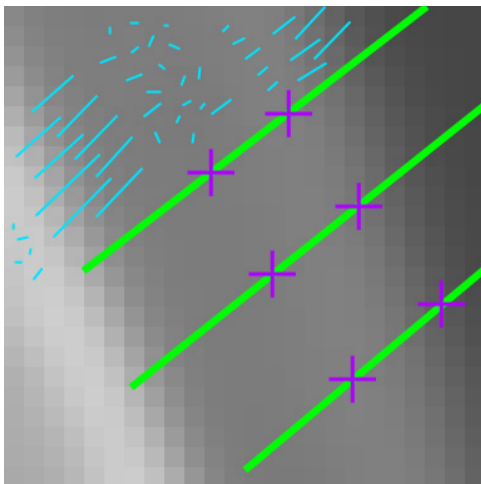
Left Image: The clipped volume data shows random lighting. The colon walls are lit correctly.



Right Image: The clipped plane is rendered with emissive illumination. This removes the random lighting. The colon walls are the same.

We present the emissive clip plane as a pragmatic solution for two illumination problems when cutting through a volume. First, noisy gradients create random lighting; second, back facing surfaces reveal dark areas. Both lighting and clipping are advantageous features of volume rendering, a solution that allows them to be used together is very desirable.

The random lighting comes from illuminating a homogeneous material using an estimated gradient. The gradient is derived from neighboring voxels. VolumePro[1][2] uses the central difference to estimate gradients, but any algorithm will have the same problem. Since the neighbors are very similar values, but with some noise, the resulting gradients have random orientations. When these gradients are used as the normal in the Phong illumination model[3], the result is also random.



In volume data, the surfaces are implicitly defined by regions with larger gradients. Those surfaces pointing toward lights get brighter. The back facing surfaces will not be lit, but they are still visible as dark regions. We wish to remove the lighting effect at the clip plane surface.

In the picture to the left, the green lines represent rays being cast through the volume. The blue lines represent gradients. Where they are long, we see nice clean surfaces. Where they are short and at random orientations, we see random lighting. However, these random regions are usually behind clean surfaces, so, we only see them when we cut through the clean surface.

It is still most common to view the original scanned slices.

Perpendicular slices can be created without resampling the data. Multiplanar Reconstruction (MPR) algorithms create slices through the volume at any angle. Since it is a single slice, no lighting is desired.

The emissive clip plane solves both of these problems by overriding the lighting parameters immediately adjacent to the clip plane with purely emissive illumination. Emissive is used in the OpenGL[4] sense -

the resulting color is the color from classification with no additional modification. We use the term clipping as a general term for any sort of cutting operation that makes the volume transparent on one side.

Lighting Reveals Shape.

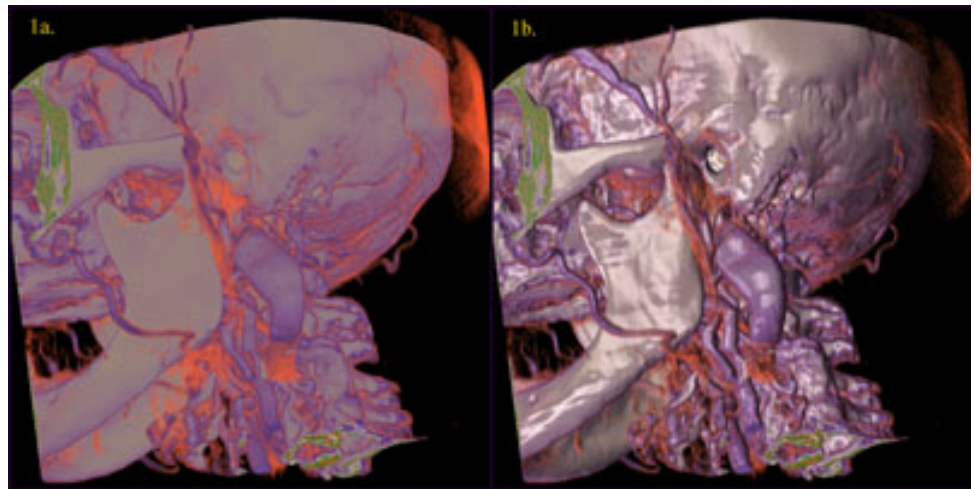
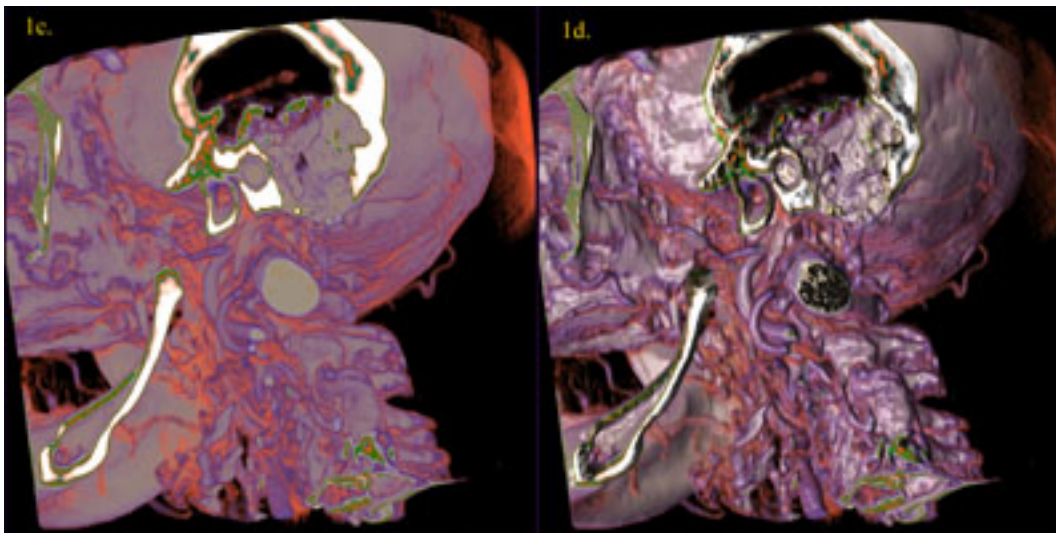


Image 1a is not lit, rather it uses emissive illumination. Image 1b is lit with diffuse and specular reflections.

Illumination was known to dramatically improve the "realism" of 3D computer graphics [5] very early on. Lighting is also a key feature in volume rendering[6] where we are often more concerned with visualization than with realism. How humans perceive "shape from shading" is an active research topic in cognitive psychology[7].

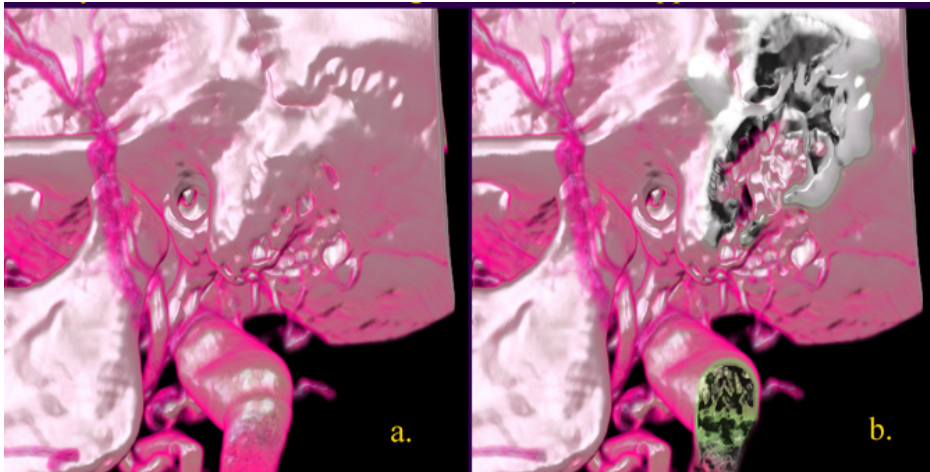
Clipping reveals inner details.



To the left, Image 1c is clipped revealing the interior structure. Image 1d is both lit and clipped, thus revealing the problem we are solving.

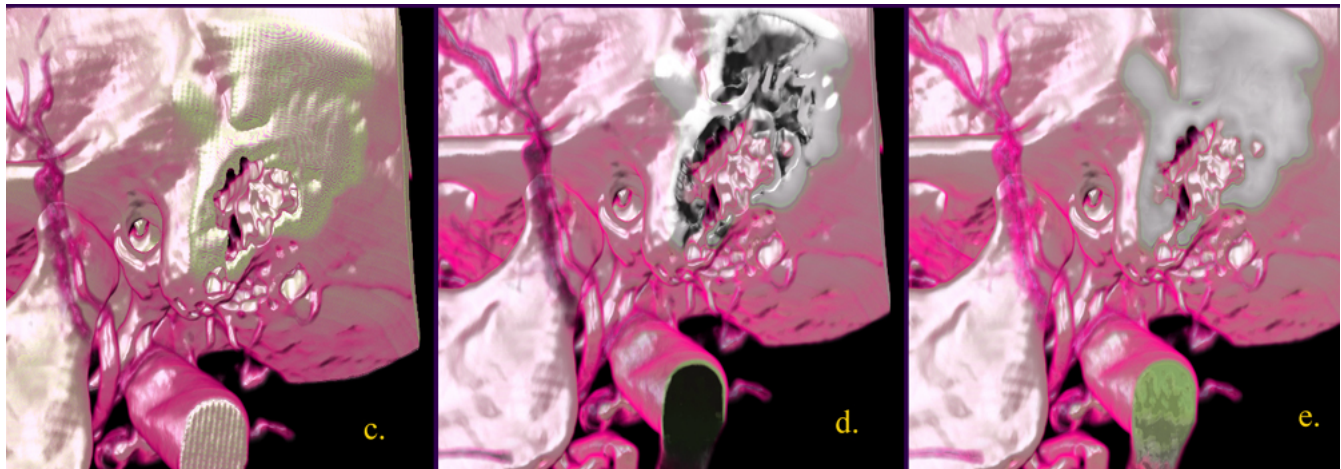
Volume data is most often captured using Computed Tomography (CT) scan, which uses X-Rays to penetrate the surface of objects and measure the density through out an object. Many other modalities create volume data: PET, MRI, Ultrasound. Sampling in three dimensions is the key distinguishing feature of volume data. The internal structures can be shown by adjusting the transfer function (the density to RGBA mapping) used in classification. The surfaces can be shown using the gradient magnitude to modulate opacity and cutting through the volume reveals the inside.

Other Solutions to the Problems of Illuminating Clip Planes



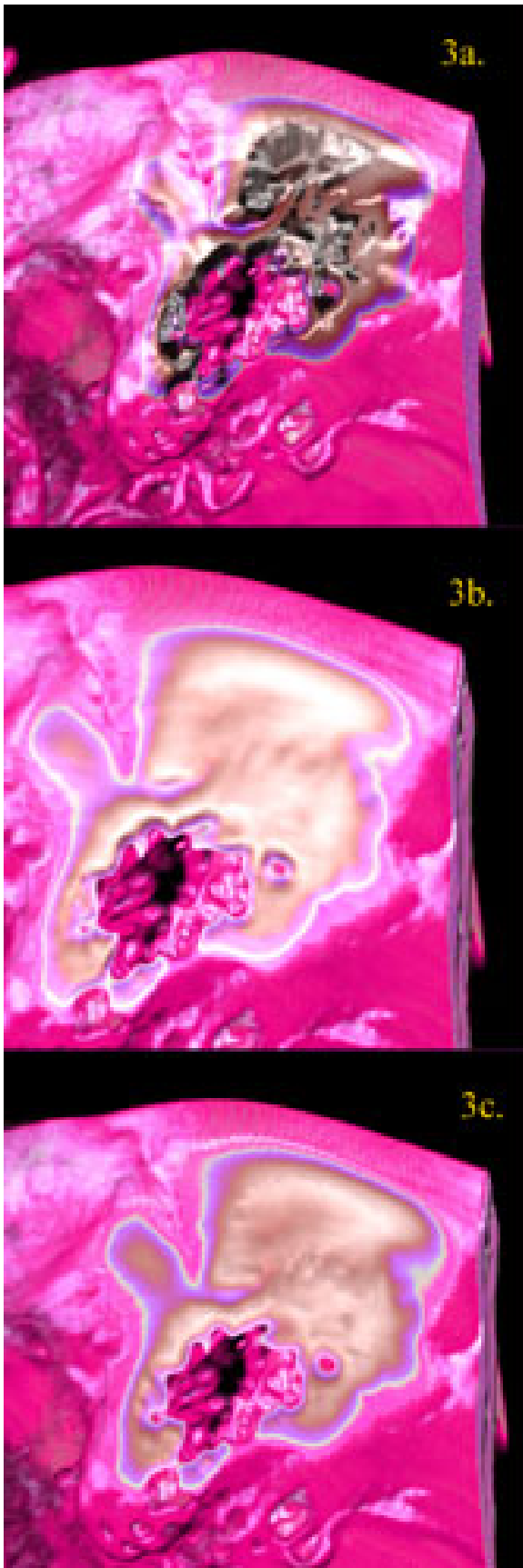
Here are two “before” pictures that show the lighting before clipping – image a. to the left and the result of clipping – image b.

The first solution we tried was to simply ignore the clipped voxels. While this did a good job with the lighting, it introduced a new problem in the most common case. Samples are created along rays through the volume. These samples are interpolated from neighboring voxels and then rendered. Near the clipped surface we used zero value voxels for the interpolation and as result, showed incorrect materials. This is illustrated below in image c. This would be avoided if we classified (assigned RGBA values based on voxel value) before interpolating and clipping. The VolumePro 1000 implements this, but, it is much more common to interpolate the samples and then classify



In Image d. we have used the gradient magnitude to modify the lighting. In this case we have removed the illumination effect of the very smallest gradients. This removes the random lighting of homogeneous materials. In this case the result is too dark. Joe Kniss et al.[7] also articulated the problem of trying to illuminate a homogeneous region of a volume. Their solution is to use the gradient magnitude to interpolate between results of the lighting calculation and the unlit sample. This general solution would give us the correct result for the vein, however, it does not affect the cut through the skull. In this case the gradients a valid and strong.

Image 2e. shows the emissive cut plane for this test case.



Modifying Gradients

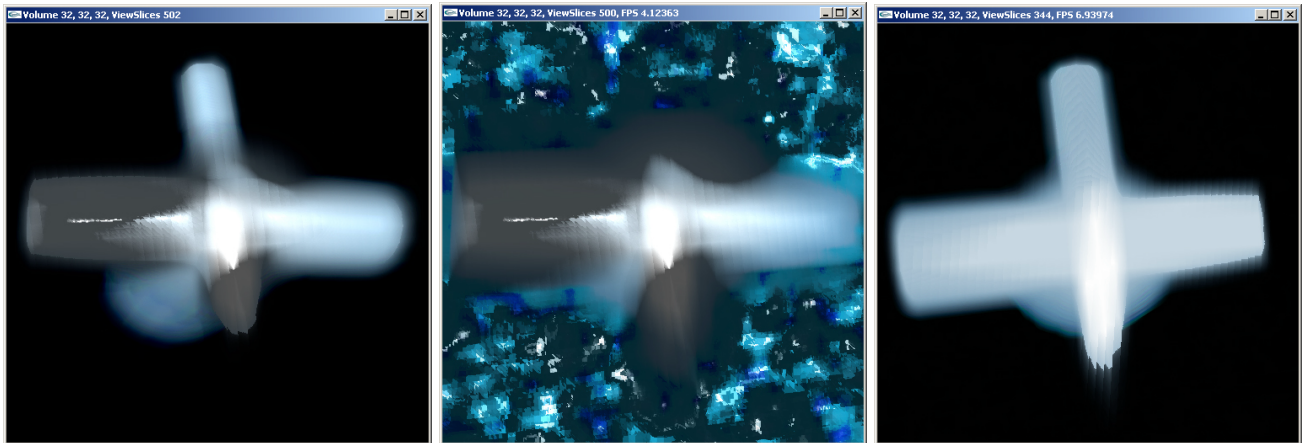
The first image is with no gradient modification. To solve the darkness at the cut surface we tried a number of methods of modifying the gradients. The simplest is just to replace the estimated gradient with the clip plane normal. This is shown in the second image. We see a sharp cut surface but lose the details on surface. We also tried blending the plane normal with the estimated normal. The most promising blend approach was based on decomposing the estimated gradient into two components: one component along the normal of the clipping surface and the other, the tangent is on the surface. The blended normal is composed of the cut plane normal and the tangent component of the estimated gradient. The third image shows cut surface effects while preserving some gradient details on the clipping surface.

While modifying the gradient gave us most of what we wanted it is very expensive to do in hardware, especially the decomposing and blending of gradients. However, the strongest reason to reject gradient modification is that customers did not like the specular reflection on the cut plane, but they still wanted it on the volume itself.

For the simple case of just replacing the normal, one can do a cheap version using a two pass render if the hardware implements lighting via lightmaps, which most hardware does. In this case, you simply compute the desired lighting on the plane and replace all of the values in the light maps with that value.

Images from other hardware

This problems we solving and the solution are common to any volume rendering algorithm that uses gradients for lighting and has the ability to cut into the dataset. Here are some images from ATI's Radeon 8500. On the left is an image with lighting turned on and a cut. Since this is an artificial dataset, we do not see the random effect, but, the backfacing problem is evident. In the middle the object is more opaque to display the noisy lighting surrounding the object. On the right is an emissive image.



The conclusion can be found in the SIGGRAPH 2003 Sketch: References

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All images were rendered using the TeraRecon VolumePro 1000. CT dataset of the head, courtesy of Massachusetts General Hospital.