Visualization Viewpoints: Interacting with Direct Volume Rendering

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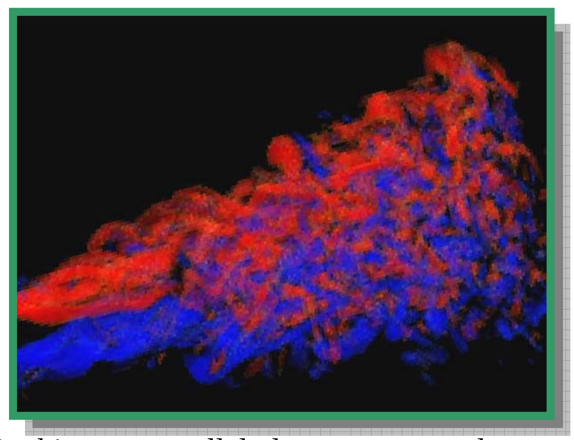
Visualization of volume data has been an active area of research for over a decade. Much work has been done with the direct rendering of complete volumes, but that process has traditionally been very slow and is thus used to obtain final images, not to perform interaction.

Interacting with volumes has instead usually been a process of finding clever ways to simplify the volume into something more rapidly displayable. This involves giving up some aspect of the full dataset. For example, cutting planes allow interaction a slice at a time. They allow the user to see all data values in that slice, but give up the full three dimensionality of the data. Isosurfaces retain three dimensionality, but sacrifice the simultaneous display of all data values. But, recent developments have emerged to allow full volume rendering to take place at interactive speeds on an ordinary desktop.



This image shows an excellent example of why direct rendering of volume data is so valuable in scientific visualization. This is a CFD application, showing the mixing of two fluids. The whole story is the mixing pattern, which neither a cutting plane nor an isosurface could adequately capture.

The first development is the 3D texture extension to OpenGL and the proliferation of OpenGL graphics accelerator cards with sufficient texture memory to actually hold full 3D textures. To render a full volume in this way, parallel planes are created through the volume in the principle direction most perpendicular to the viewer's line of site. The planes are drawn back-to-front with appropriate 3D texture coordinates. The natural OpenGL alpha blending creates a direct volume display. With today's texture memory sizes and hardware fill rates, this is enough to manipulate volumes at interactive speeds.

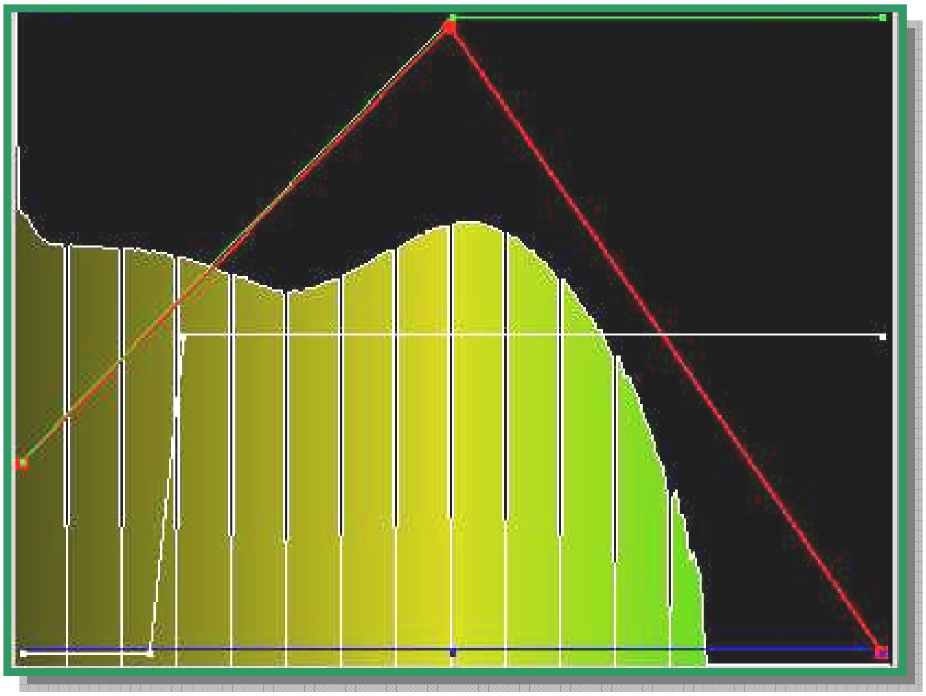
The second development has been the creation of volume rendering hardware, such as Mitsubishi's Volume Pro board. The Volume Pro board can hold up to a 256^3 texture in dedicated memory. It performs direct volume rendering by orthographically ray tracing the volume at a rate of 500 million voxel composites per second.

Visualization researchers at the San Diego Supercomputer Center have written a program called *Volume Explorer*, or *vx* for short, that performs interactive direct volume rendering on the Volume Pro board. *vx* uses OpenGL, GLUT (the GL Utility Toolkit), and MUI (Micro User Interface) to perform the graphics and user interaction around the Volume Pro card. For those interesting in trying it, *vx* can be downloaded from the Web at: http://dvl.sdsc.edu/vx.

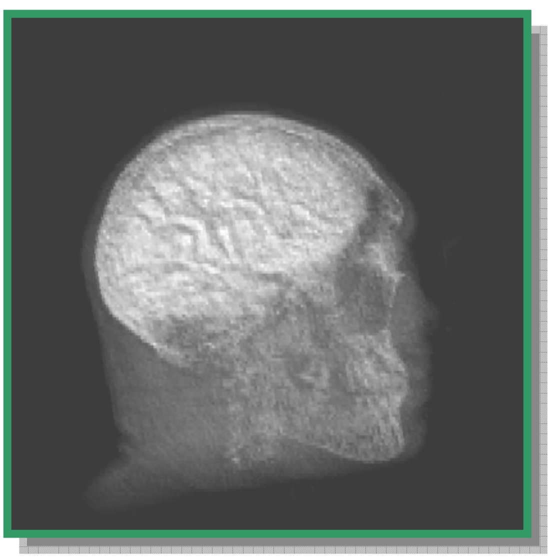
Regardless of how it is done, we have become very big fans of interactive direct volume rendering. The rest of this article shows some of our preliminary work with *vx*. All of these images are, of course, static. But, understand that on the screen they can be changed and manipulated at update rates of 30+ frames per second.

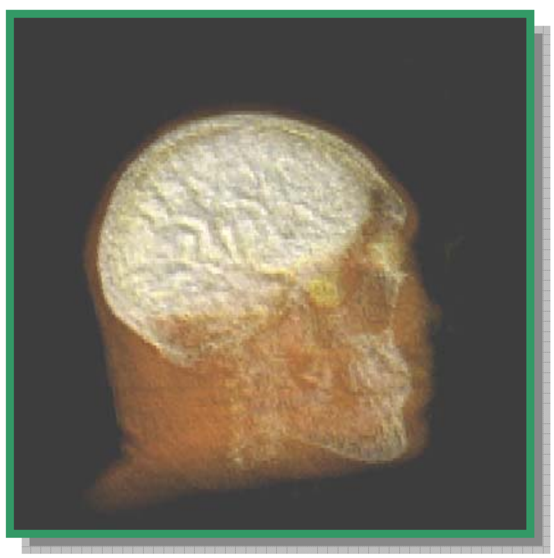
Dynamically Changing the Transfer Function

Vx has interactive controls to change the transfer function. The transfer function is a set of graphs that relate a value found in the raw volume dataset to color (RGB) and opacity (α) in the display. The transfer function can be manipulated in a number of ways to reveal and relate certain key details in the volume. The RGBα curves can be dynamically sculpted against a backdrop of the frequency histogram as shown here.

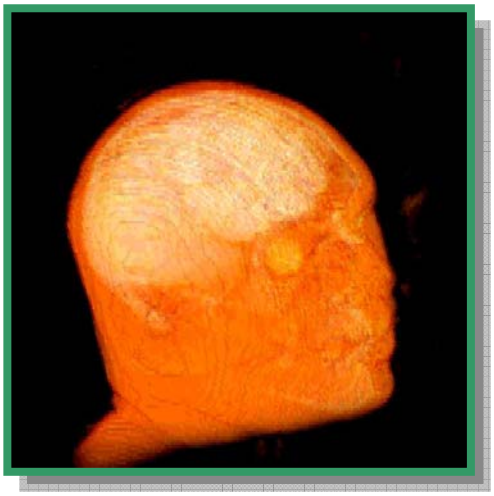


There are also some predefined transfer functions as shown below.



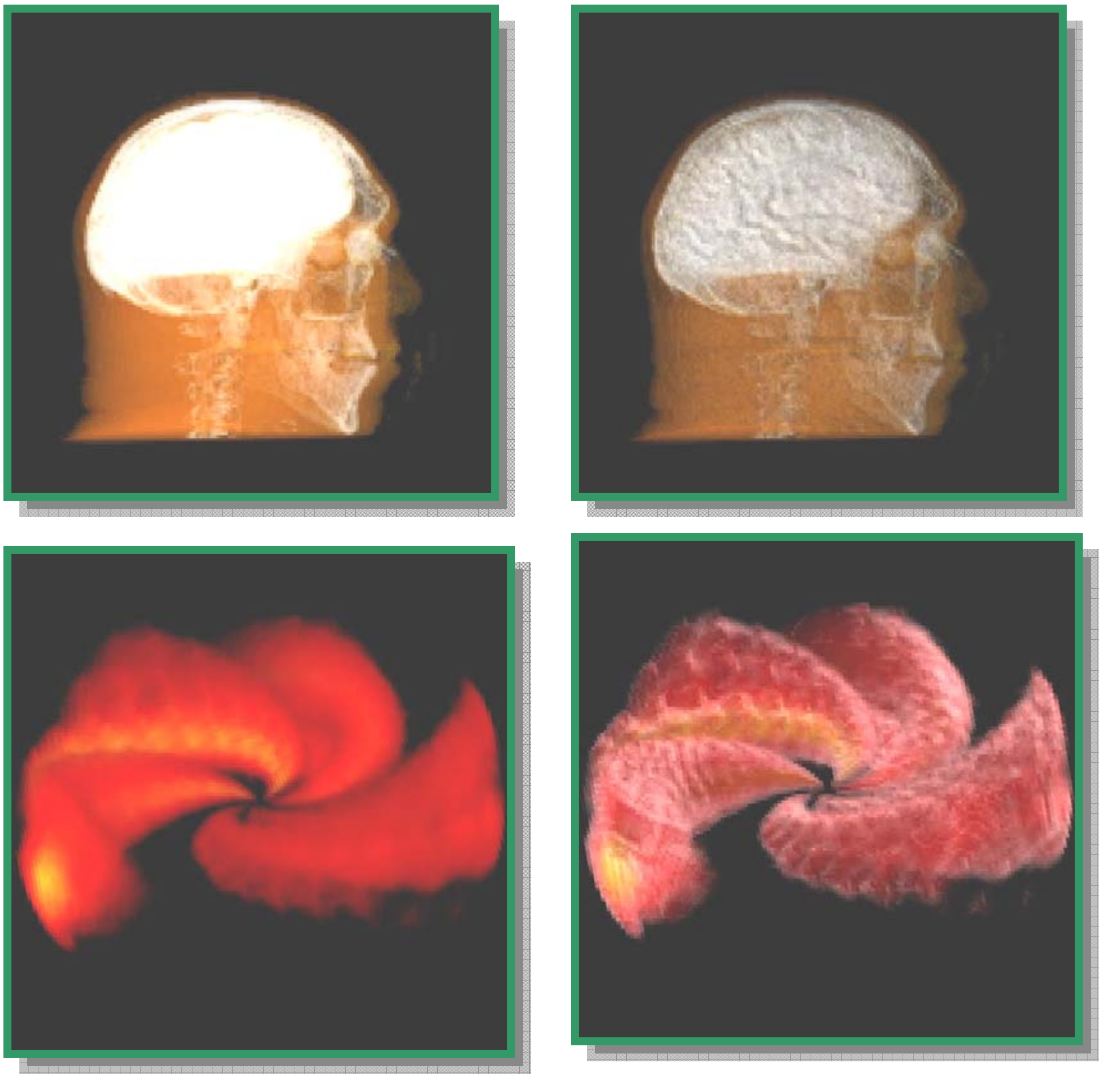


The image on the left uses grayscale, while the image on the right uses the heated object color scale. Dynamically manipulating the opacity curve is also quite useful. In the left figure below, the Visible Human Male head is shown in its entirety. On the right, the opacity curve has been changed to barely show the outside of the head.



Lighting

We have been surprised how much light source shading contributes to the understanding of direct volume rendered data. The VP card performs a Phong lighting calculation on each voxel prior to compositing it. The results below show why this is so valuable.



The pictures on the left show an emmisive rendering only, that is, just the color of the voxels' transfer function with no lighting model. The pictures on the right show the same models with the lighting model turned on.

The top row is a head shot from the Visible Human Male dataset. Note how the lighting model brings out the folding detail in the brain. The bottom row is heliospheric data from the solar wind. Notice how the lighting model brings out the "scaly" nature of the data better than the pure emissive model.

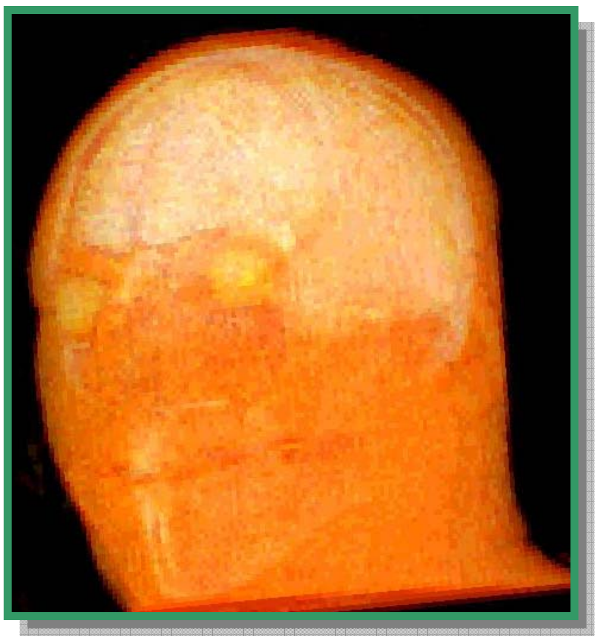
We have found the diffuse part of the Phong model to be the most useful in bringing out volume detail. Specular lighting is also available, but we find it more distracting than helpful.

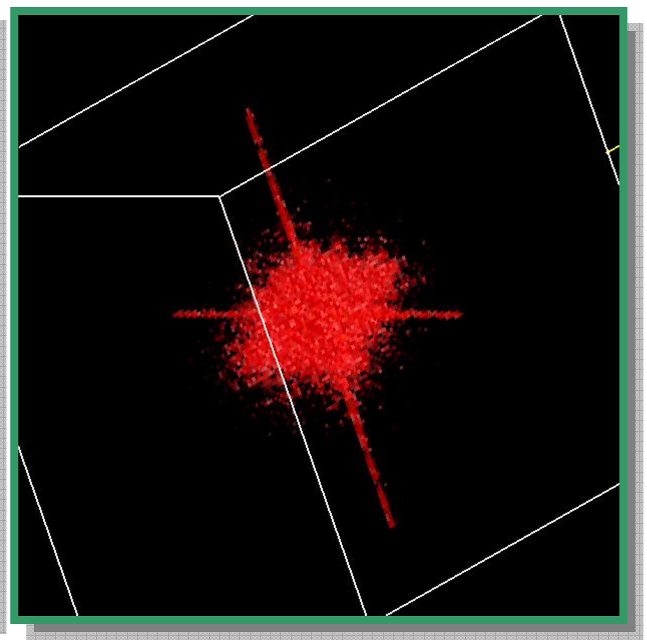
Derived Volumes

A consequence of being able to so easily interact with volume data is that we are able to explore the creating of volumes that describe other volumes, a process we refer to as *derived volumes*. As discussed at the start of this article, a typical approach to interacting with volumes has been to map them to a simpler representation such as reducing to two dimensions: $\Re^3 \rightarrow \Re^2$. Derived volumes are a $\Re^3 \rightarrow \Re^3$ process. We used to be reluctant to approach this because if interacting with volumes was so hard, why make things worse by creating more of them? Now this has become practical.

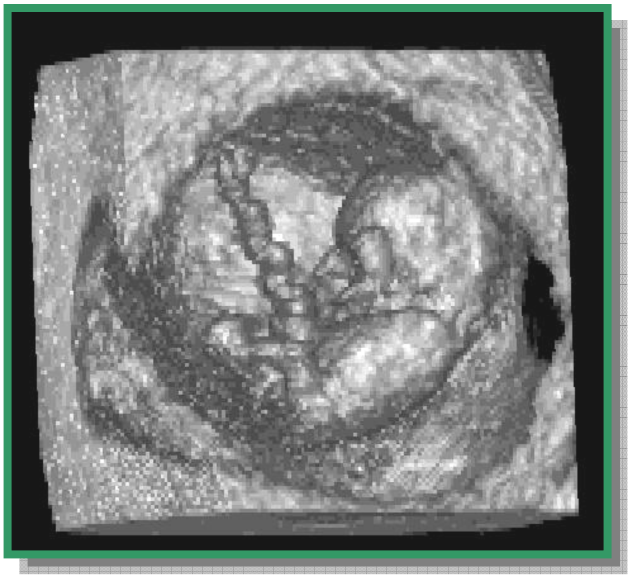
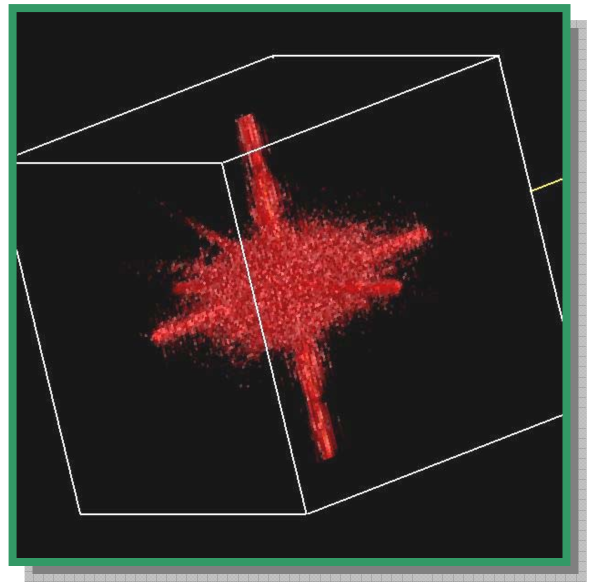
As an example, consider a volumetric Fourier analysis. Fourier analysis is typically used to show the 1D spectrum of frequencies in a 1D signal ($\Re^1 \rightarrow \Re^1$) or the 2D frequencies in a 2D image ($\Re^2 \rightarrow \Re^2$). A Fourier analysis produces the same dimensionality in the output as it had in the input. A Fourier analysis can be run on all or part of a 3D volume to produce another volume showing the spread of frequencies inherent in the data ($\Re^3 \rightarrow \Re^3$).

On the left below is the head of the Visible Human Male displayed in the spatial domain. On the right is the same data displayed in the frequency domain.





The long thin spikes that form a cross-shaped pattern indicate high frequencies exist in the X and Y directions, that is, within the scans. No such spike exists in Z, indicating (not surprisingly) that much of the high frequency detail in the scan direction has been lost in the scanning process.

The data above is a 3D ultrasound of an 8-week-old human embryo. Its Fourier analysis shows high frequency spikes in all three dimensions that are broader than the spikes in the Visible Male data. This also shows a lot of low frequency fuzziness in all three dimensions. This is probably due to the less exact nature of ultrasound and the fact that 3D ultrasound works by re-projecting a large number of individual oblique scans.

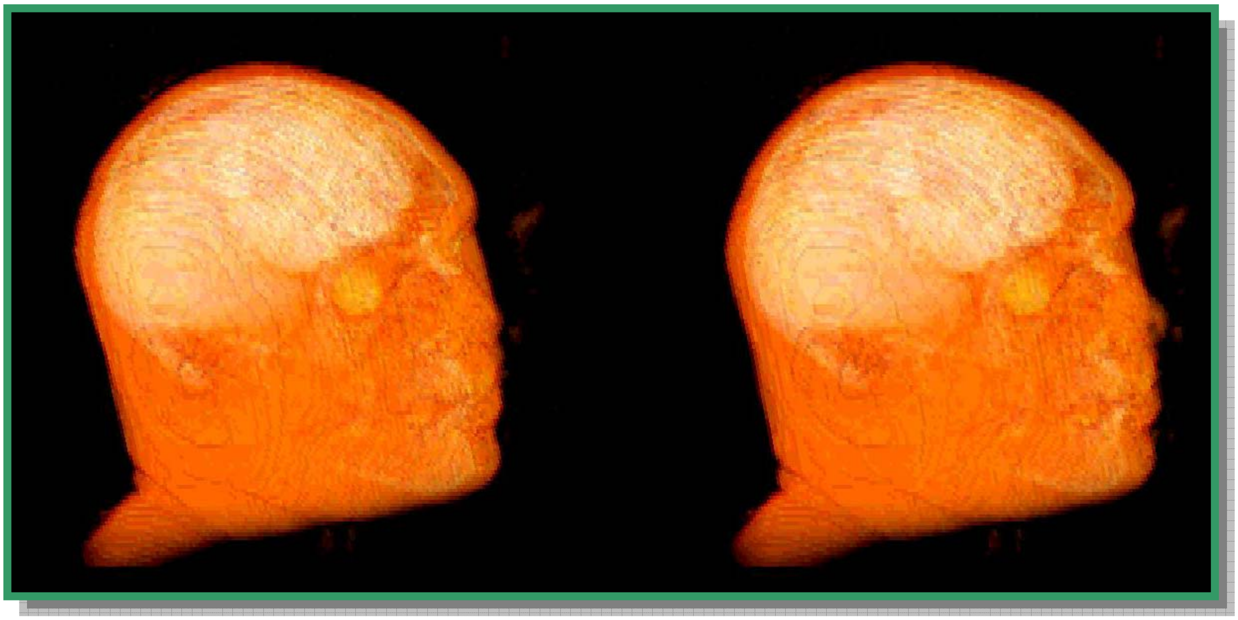
Thus, this analysis can be used on an unfamiliar volume dataset to understand some things about the inherent nature of the data prior to any interaction with it. It can also be used to intelligently pre-filter the original data or locate specific areas of interest prior to interaction. This will be especially important in large datasets. We are currently looking at what other derived volumes are useful.

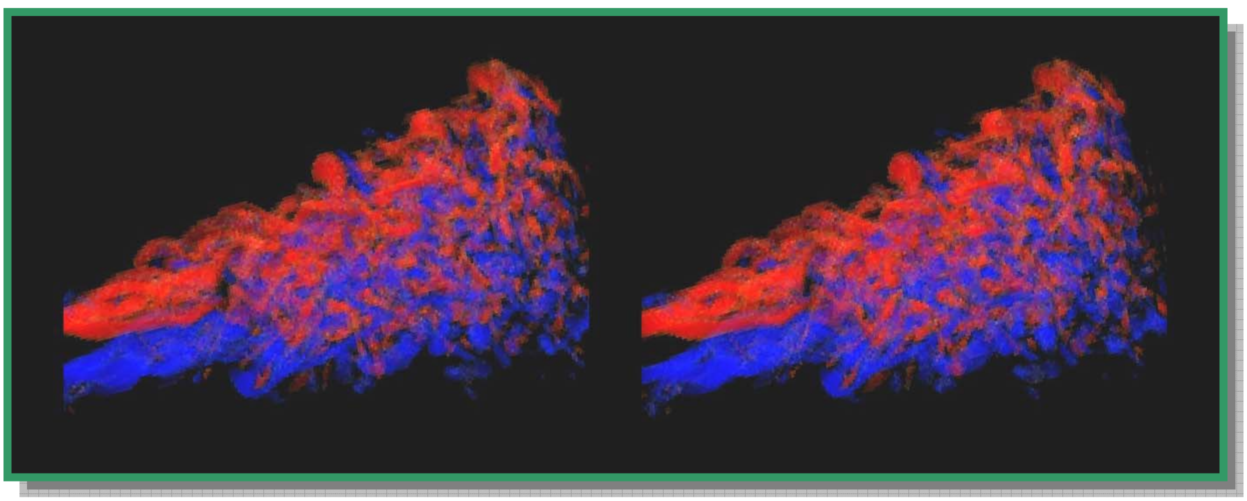
Conclusions

The ability to interact with direct volume renderings opens up a number of possibilities that we have not been able to consider before. As scientific visualization is often referred to as a large bag of data manipulation and display tricks, this allows us to augment and enhance what is already in the bag.

Just for Fun

Below are stereopairs of the Visible Male head and the CFD mixing application. They are arranged to use cross-eyed viewing method. Enjoy!





Acknowledgements

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The CFD data is courtesy of Dr. Sutanu Sarkar, UCSD Mechanical and Aerospace department.

The 3D ultrasound data is courtesy of Dr. Tom Nelson, UCSD Radiology department.

The solar wind data is courtesy of Drs. Bernard Jackson and Paul Hick, UCSD Center for Astrophysics and Space Science.

The Visible Human Male data is from the National Institute of Health.

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