

Visualization Blackboard

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Visualizing the Visible Human

Visualization of the human body and its inner structure has challenged artists and scientists for centuries. For 500 years, since Leonardo da Vinci, drawings have been the main resource for learning anatomy because they allow the mixture of realism and abstraction suitable for didactic purposes. With the discovery of x-rays 100 years ago, it became possible to look into the living body.

Only since the 1970s have computer tomography (CT) and magnetic resonance imaging (MRI) made it possible to acquire image data in three dimensions. Based on these techniques, 3D computer graphics generated the first models of the living body. These represent a tremendous advance for diagnosis and surgical planning, but the resolution is still poor when viewed from an anatomist's point of view.

Visible Human data set

The National Library of Medicine's Visible Human Project provided much more realistic data—the Visible Human data set, created at the University of Colorado School of Medicine.¹ This project produced transverse cross-sectional photographic images of a male cadaver with a resolution of 0.33 mm and slice distance of 1 mm. Figure 1 shows an example image from the Visible Human.

The images come as 24-bit RGB data together with high-resolution CT images from the frozen cadaver (resolution of approximately 0.53 mm and slice distance of 1 mm) and several sets of MRI from the fresh cadaver (lower resolution and slice distance up to 5 mm). The CT and MRI data are coarsely registered with the optical data.

Voxel-Man atlas project

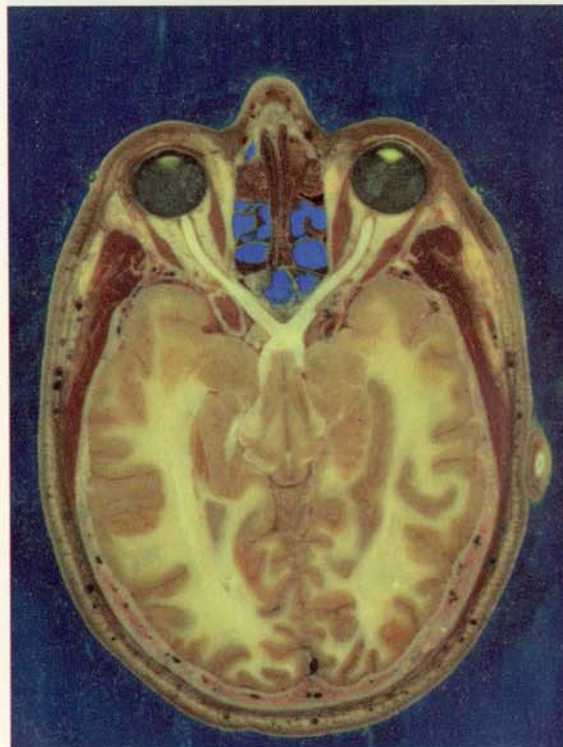
Our objective is to generate a high-resolution volume model using the framework developed in our Voxel-Man atlas project.² The volume model consists of an image volume and congruent label volumes (for example, the domain structure, function, and blood supply) and a semantic network model containing the descriptive knowledge for these domains. The Voxel-Man environment allows interactive exploration both pictorially using volume graphics (change view, remove, add, dissect, make transparent, and so forth) and by interrogating the knowledge base (what is this, what is it part of,

where does it go to, and so on).

For our experiments, we worked with the Visible Human head (277 slices). We reduced the slice resolution by a factor of three, resulting in a volume size of 36 Mbytes instead of 323 Mbytes, which today's workstations can hardly handle. We improved registration using an interactive landmark-based tool,³ yielding a registration error of about one voxel in each dimension, to create a combined display of different modalities in a single view.

Making a volume model

Making a volume model suitable for volume graphics display from the cross-sectional data involves two major steps: (1) segmentation to determine the voxel sets belonging to an object and (2) volume graphics rendering of the object itself, especially the surface. While there are standard methods at hand for modeling scalar image volumes, we had to modify them to handle multiparametric images.

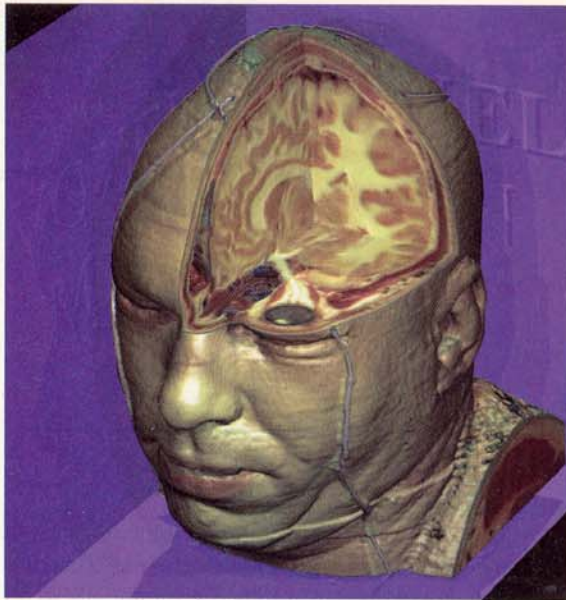


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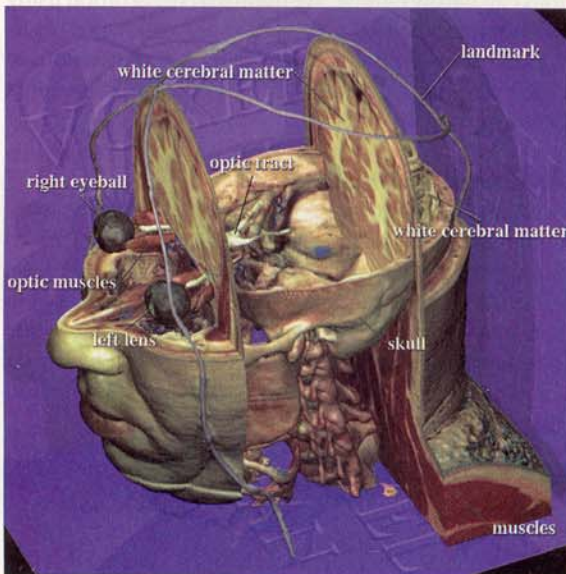
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1 Original
cross-section of
the Visible
Human data set.

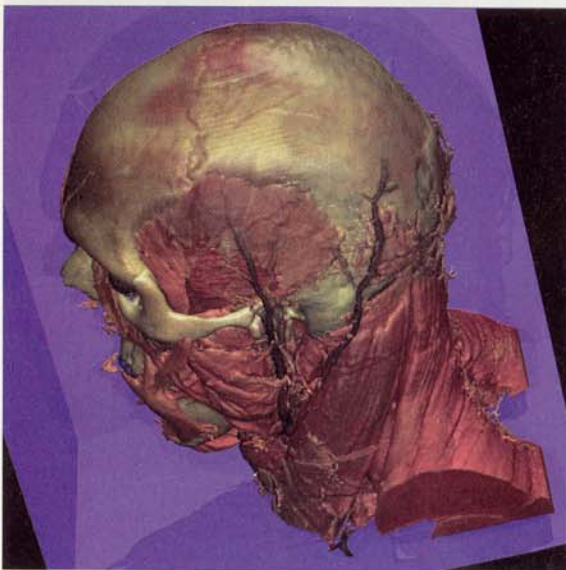
2 Reconstruction of the outer surface with three orthogonal cuts.



3 Different modes of visualization: multiple surfaces, cut faces, cross sections.



4 Reconstruction of muscular and vascular anatomy.



We segmented objects interactively as described elsewhere.⁴ However, instead of specifying an intensity range to characterize an object, the user outlines an area of the object, from which a classification procedure generates an ellipsoidal region in RGB space. This characterization works well for many anatomical constituents, but not all of them. For example, it doesn't always exactly discriminate the brain surface, despite the nominally huge feature space.

We based object rendering on an existing method,⁵ which proved most suitable for voxel-based data, and adapted it in the following way:

- Instead of assigning an artificial color, the RGB tuple at the surface location is used in the Phong illumination model. This gives the objects a much more realistic appearance.
- The surface normal is calculated as the normalized sum of the intensity gradients of each RGB component.
- Rendering parameters can be taken from different data sets, depending on the object (for example, bone surface and surface normal from CT data and color from RGB data).
- The surface location is interpolated using the neighborhood of the labeled voxel and the RGB ellipsoid derived in the segmentation step. This method significantly reduces aliasing artifacts both in static images and animations.

Results

Using these techniques, we produced pictures that demonstrate the perspectives and also some problems with the volume-oriented visualization of the Visible Human data set. The simplest approach to 3D visualization just segments the outer surface (which is easy, because the background has unique color) and views the cut planes with the skin surface serving as a coordinate system, as shown in Figure 2. The voxel-based surface shading works nicely, but the color interferes with the background color. This is due to the partial-volume effect that prevents segmentation from exactly matching the surface.

The substantial advantage of a volume model, however, is that it allows arbitrary combinations of surfaces and cut faces, thus mimicking real dissection as seen in Figure 3. There are surfaces (for example, optical tract, white matter, and bone), cut faces, and also thin cross sections. We segmented all objects from optical data, except bone, which we took from CT data. Small registration errors resulted in partly incorrect color of the skull surface.

The prominent color of muscles makes them fairly easy to segment. Figure 4 shows parts of the head and neck musculature together with some vascular structures. The enlarged section in Figure 5 shows the spatial resolution achievable (with the reduced data set).

One attractive feature of a volume model is the possibility of combining radiological imaging with 3D anatomy, as shown in Figure 6. One of the cut faces shows the MRI appearance, while one sector is imaged as an artificial x-ray image.

Conclusion

Our experiments show that the Visible Human data set, when used in a state-of-the-art visualization environment, represents a new quality of anatomical imaging. Not all problems of segmentation and rendering artifacts are solved yet. Applications like neuroanatomy and neurosurgery require the use of full-resolution data. However, the huge amount of data prevents real interactive generation of pictures with the quality shown here. However, the latter problem at least will become obsolete as computers continue to increase in power. We feel certain that anatomical drawings like those of da Vinci will be replaced by 3D models (Figure 7), which can be explored by methods of interactive computer graphics. ■

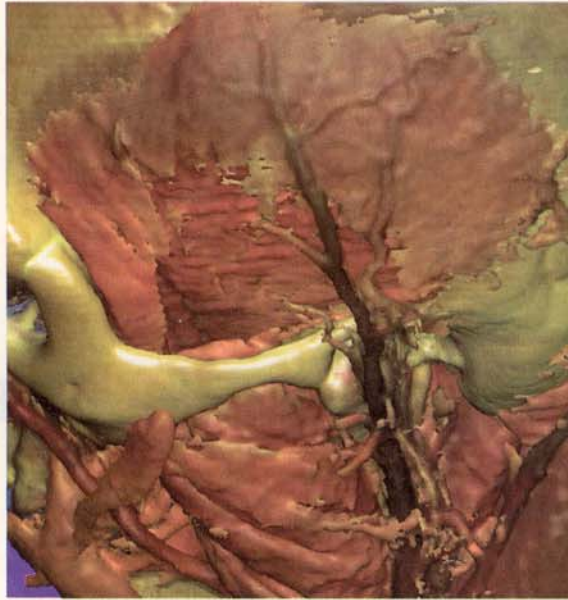
Acknowledgments

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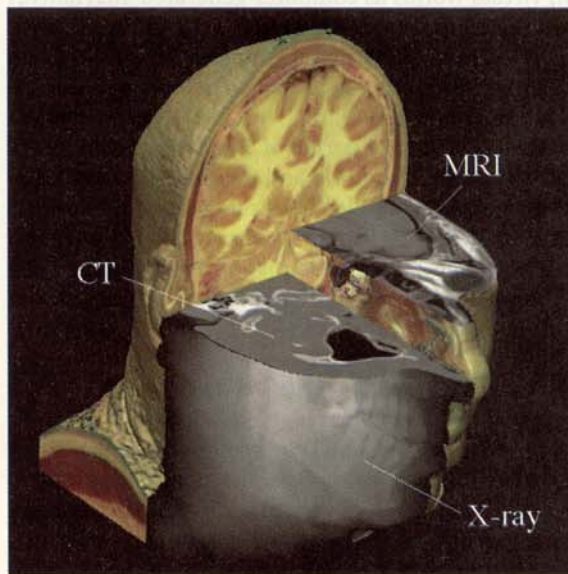
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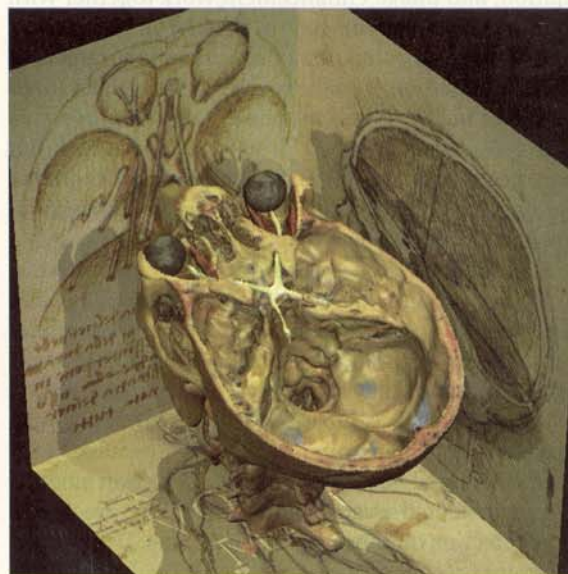
Further information can be obtained via the World Wide Web at <http://www/uni-hamburg.de/~medizin/idv>.



5 Detail of Figure 4.



6 "In place" view of radiological imaging modalities.



7 A comparison of classical skull images from Leonardo da Vinci with a 3D model.