

A Realistic Model of the Inner Organs from the Visible Human Data

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Abstract. The computer-based 3D models of the human body reported to date suffer from poor spatial resolution. The Visible Human project has delivered high resolution cross-sectional images that are suited for generation of high-quality models. Yet none of the 3D models described to date reflect the quality of the original images. We present a method of segmentation and visualization which provides a new quality of realism and detail. Using the example of a 3D model of the inner organs, we demonstrate that such models, especially when combined with a knowledge base, open new possibilities for scientific, educational, and clinical work

1. Introduction

While in classical medicine, knowledge about the human body is represented in books and atlases, present-day computer science allows for new, more powerful and versatile computer-based representations of knowledge. Their most simple manifestations are multimedia CD-ROMs containing collections of classical pictures and text, which may be browsed arbitrarily or according to various criteria. Although computerized, such media still follow the old paradigm of text printed on pages accompanied by pictures. This genre includes impressive atlases of cross-sectional anatomy, notably from the photographic cross-sections of the Visible Human Project (1-3). In the past years, however, it has been shown that pictorial knowledge, especially about the structure of the human body, may be much more efficiently represented by computerized *3D models* (4), which can be constructed from cross-sectional images generated by computer tomography (CT), magnetic resonance imaging (MRI), or histologic cryosectioning, as in the case of the Visible Human Project. Such models may be used interactively on a computer screen or even in "virtual reality" environments. If such models are connected to a data base of descriptive information, they can even be interrogated or disassembled by addressing names of organs (4-6). They can thus be regarded as a "self-explaining body".

Until now, the Visible Human Project has not reported 3D models that reflect the rich anatomical detail of the original cross-sectional images. This is due to the fact that, for the majority of anatomical objects contained in the data, the cross-sectional images could not be converted into a set of coherent realistic surfaces. If, however, we succeed in converting all the detail into a 3D model, we gain an unsurpassed representation of human structure that opens new possibilities for learning anatomy and simulating interventions or radiological examinations. This paper presents a new technique for segmenting and modeling the 3D anatomy of the Visible Human data that leads to a nearly photorealistic computer based model.

2. Earlier Work

Work on 3D anatomical reconstruction from spatial sequences of cross-sectional medical images goes back to the late seventies (7). Since then, techniques have been improved continuously (8-10). However, the impact of these techniques on practical medicine remains limited, because the procedure for creation of 3D models is rather complex. The process of 3D visualization requires - in contrast to classical 2D imaging - a processing step that identifies the regions in the data volume that correspond to anatomical objects. Otherwise we could not unveil their surfaces or remove objects obscuring the ones behind. This step is called *segmentation*. A common approach to 3D visualization which tries to avoid this step is *volume rendering*. Instead of an explicit identification of organs, transparency values are assigned to the image volume according to the color values or color changes at the object borders. In the case of the Visible Human data, this method (11) yields semitransparent views with acceptable quality e. g. for the outer surface, the muscles and the skeleton. It fails, however, to display internal structures properly. In addition, organ borders are not explicitly indicated, thus making the removal or exclusive display of an organ impossible.

Segmentation, i. e. the exact determination of the surface location of an organ is crucial to its realistic display. Complete automatic segmentation using methods of computer vision fails, since the capabilities of computers are far inferior to those of a human observer. The brute force approach to segmentation is manual outlining of objects on the cross-sections (11). Besides the fact that this procedure is tedious and very time consuming, it is largely observer-dependent and thus does not yield exact and coherent surfaces. Furthermore, despite the high resolution of the data set, important details such as nerves and small blood vessels cannot clearly be identified, because their size and contrast is too small even at the high resolution of the Visible Human data set.

3. Material and Methods

We therefore aimed at a method that yields surfaces for the segmentable organs that are as exact as possible and textured with their original color. In order to arrive at a

complete model, we decided to model non segmentable objects like nerves and small blood vessels artificially on the basis of landmarks present in the image volume.

Data. Photographic cross-sectional images from the male Visible Human were used to create models of the head, neck, and torso as well as the corresponding inner organs. The original data set consists of 1871 photographic cross-sections with a slice distance of 1 mm. The cross-sections themselves have a spatial resolution of 1/3 mm. For the model of the inner organs, the resolution was reduced to 1mm for reasons of data storage and computing capacity. From 1049 such slices, an image volume of 573x330x1049 volume elements ("voxels") of 1 mm³ was composed, where each voxel is represented by a set of red, green and blue intensities ("RGB-tuple"). The Visible Human data set also includes two sets of computer tomographic images of 1mm slice distance, one taken from the fresh, the other (like the photographic one) from the frozen cadaver. Both were transformed into an image volume congruent with the photographic one.

Segmentation. The image volume thus created was segmented with an interactive tool, which is an extension of an earlier development for RGB data (13). It can be regarded as an "electronic sculpturing tool". On a cross-section, an expert "paints" a typical region of the organ under consideration. All voxels in the volume with similar RGB-tuples are then collected by the program to form a "mask". This mask usually needs to be refined by repeating this procedure in order include the target organ completely. The resulting cluster in RGB space has an ellipsoid shape, due to the slight correlation of the colors; this cluster is then converted into the mathematical form of an ellipsoid, which facilitates subsequent computations. There are, of course, other regions with the same characterization present in the volume. If they are not connected to the target organ, it can be isolated easily; if not, 3D interactive cutting tools are used.

Graphic modeling. There are many anatomical constituents, such as nerves and small vessels, which are too small to be segmented adequately, but need to be included in a comprehensive anatomical model. For these, we have developed a modeling tool that allows us to include tube-like structures into the model. Ball-shaped markers of variable diameter are imposed by an expert onto the landmarks still visible on the cross-sections or on the 3D image; these markers are automatically connected to form tubes of varying diameter. Unlike the segmented objects, which are represented as sets of voxels, the modeled structures are represented as composed of small triangles.

Knowledge modeling. Each voxel of the spatial representation of anatomical data thus gained is connected to a knowledge base containing object descriptions within the structure of a semantic network (4,14,15). Different networks were created for different views (e. g. systematic or topographic anatomy). Within the views, the anatomical constituents are linked by relations like *part of*, *has part*, *branching from* or *branching to*.

Visualization. The 3D visualization algorithm we have developed is characterized by the fact that it renders *surfaces* from *volume* data. This is different from the volume rendering typically used for visualizing the Visible Human data set. As in volume rendering, the program casts rays from an image plane onto the image volume in viewing direction. However, the rays stop at the first encountered object. Surface texture and surface inclination (important for proper computation of light reflection) are calculated from the RGB-tuples at the segmented border line. The decisive quality improvement is achieved by determining the object surfaces with a spatial resolution higher than the resolution of the original voxels. While such subvoxel resolution may be achieved easily by sampling with high rates in volume rendering, the determination of distinct adjacent *surfaces* in subvoxel resolution is a major problem that has been solved only recently (16). This makes the high resolution visualization of distinct surfaces possible, which is the characteristic feature of our approach.

The objects modeled with the surface modeler are visualized with standard computer graphics methods within the context of the volume objects. The visualization program, an extended version of the VOXEL-MAN system (4), runs on UNIX workstations. Because of the high resolution and the sophisticated algorithms, the computation of a single image may take several minutes, even on a high end workstation. The model is therefore being made available for interaction and exploration via precomputed "Intelligent QuickTime VR Movies" (17), which may be viewed on any personal computer.

4. Results

Using the methods described above, we have built a model of the organ systems within the torso of the male Visible Human. It contains more than 850 *three-dimensional* anatomical constituents (*not* just labeled cross-sections) and more than 2000 relations between them.

The following features of this model represent innovations:

- Because of the exact segmentation and the visualization method developed, the visual impression is one of unsurpassed realism;
- There is, to date, no computer model of human structure that contains so many *three-dimensional* organs;
- The model is space-filling i. e. any voxel is labeled as an element of a 3D object;
- The integrated formal organization of pictorial and descriptive information allows a virtually unlimited number of ways of using the model.

The model is a general-knowledge representation of gross anatomy, from which all classical representations (pictures, movies, solid models) may be derived via mouse click. In addition, the model may be used interactively for teaching and simulation of diagnostic and therapeutic procedures. While the underlying principle was reported earlier (4), the model we describe is the first to offer sufficient detail and comprehensiveness to serve these purposes seriously. FIG. 1 gives an impression of image quality and the degree of detail.

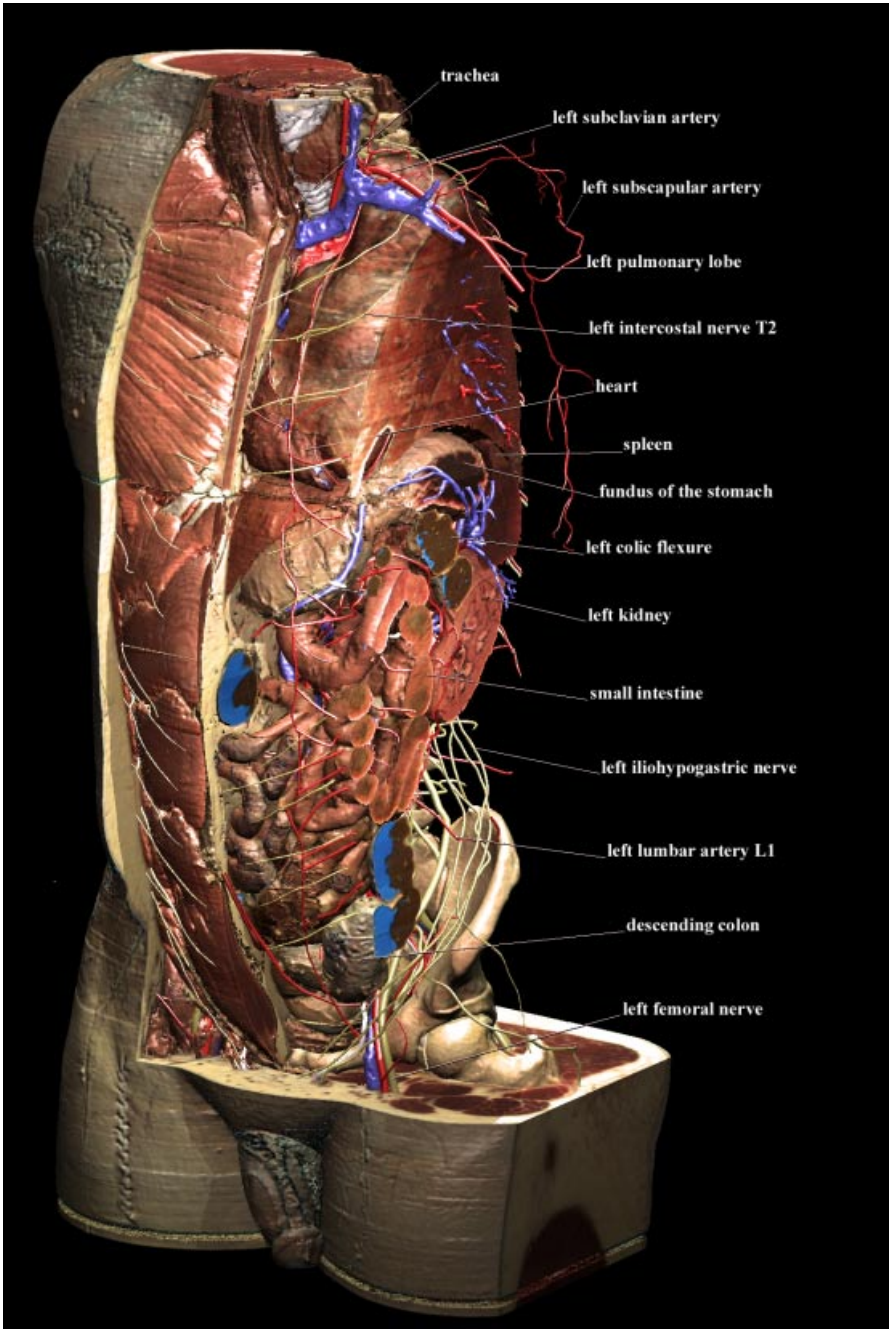


Fig. 1. The model can be viewed from any direction, cuts may be placed in any number and direction and objects may be removed or added. Annotations may be called by mouse click.

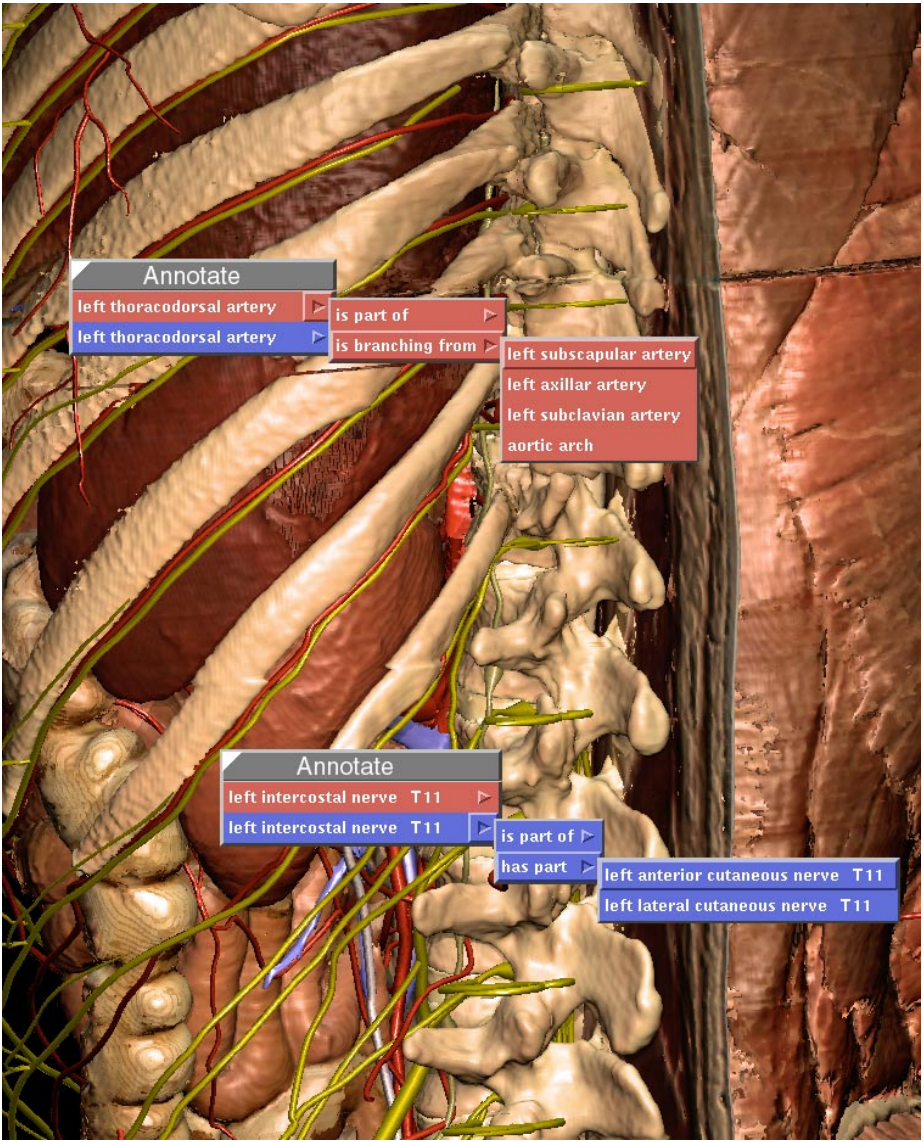


Fig. 2. Inquiring the semantic network behind the pictorial model according to different “views”. The user has clicked onto a blood vessel and a nerve and received information about systematic(red) and topographic anatomy(blue).

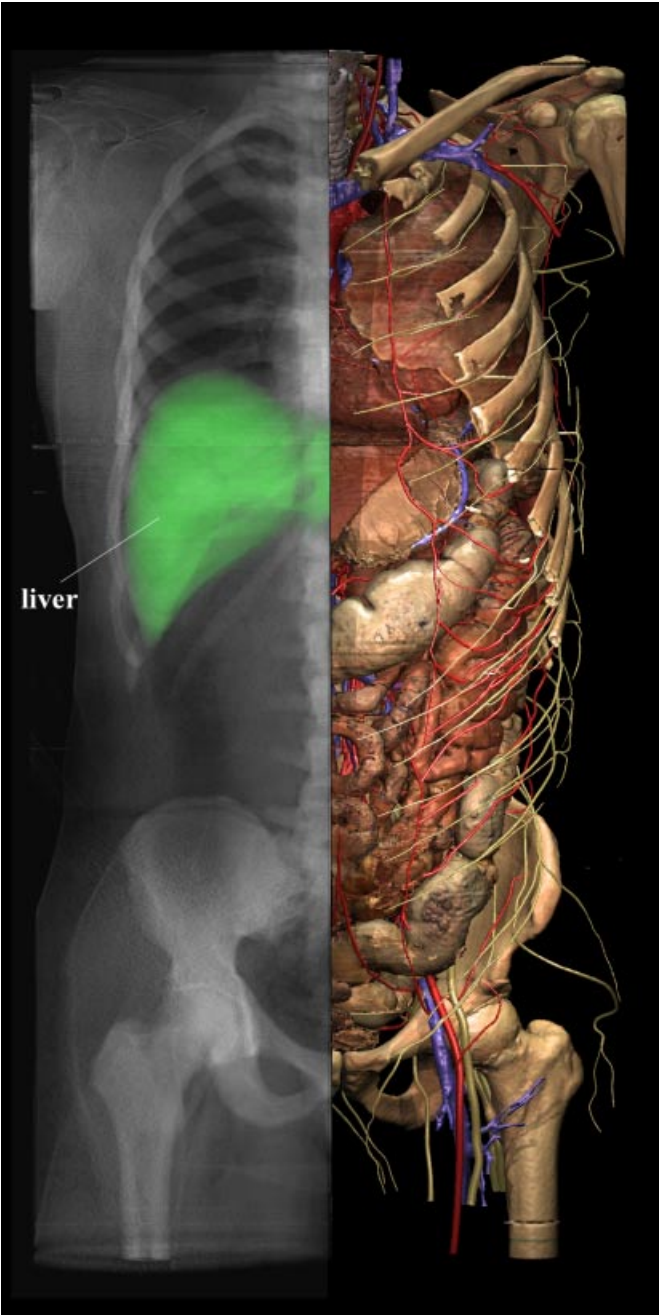


Fig. 3. Different viewing modes such as X-ray imaging may be chosen from any direction and for any part of the image. The X-ray image may be interrogated as to which object contributes to the image.

Since the model is volume-based, cut planes (which can be placed in any number and direction) show the texture of the original cross-sectional images and thus look realistic (FIG. 1). This virtual dissection capability not only allows an interactive dissection for learning purposes, but also simulates the rehearsal of a surgical procedure. In addition, the image of a “self-explaining body” allows us to inquire about complex anatomical facts. FIGures 1 and 2 show different possibilities for presenting these explanations. The more traditional way of annotating structures of interest is demonstrated within the user-specified 3D scene in FIG. 1. These annotations can be obtained simply by pointing and clicking with the mouse on the structure of interest. However, pressing another button of the mouse will result in popup menus shown in FIG. 2; these offer structured knowledge about anatomy and function. Such information is available because every voxel, and therefore any visible point of any user-created 3D-scene, is linked to the knowledge base.

A special feature of the model involves the possibility of simulating radiological examinations (FIG. 3). Since the absorption values for every voxel are available in the original tomographic data, artificial X-ray images from any direction can be computed. Based on the information of the model, both the contributing anatomical structures and the extent of their contribution to the final absorption can be calculated. Similarly, the information present in cross-sectional radiological images (Computer Tomography, Magnetic Resonance Imaging, Ultrasound) can be clarified by presenting them in the corresponding 3D context.

5. Discussion

Computer-based models of the human anatomy created to date are more like sophisticated video games than they are professional tools for medical education and practice. We have presented a general approach for creating models that have the spatial resolution, the degree of detail, and the organization suitable for useful application in educational, scientific, and clinical work. This has been demonstrated with the example of a 3D model of the inner organs derived from the Visible Human data set. The versatility of the approach makes it suitable for anatomy and radiology teaching as well as for simulation of interventional procedures. Last, but not least, it can be used to provide patients with necessary information. A first version of a 3D anatomy atlas based on the described concept has been published recently (18).

Yet there are still improvements to be made. Like all postmortal images, those of the Visible Human suffer from postmortal artifacts, such as collapsed blood vessels. These artifacts cannot be corrected completely. One more severe limitation is the fact that the data is derived from one single individual. The interindividual variability of organ shape and topology in space and time is thus not yet part of the model. Inclusion of variability into 3D models is a difficult problem not yet generally solved. So far most progress has been achieved for 3D atlases of the brain (19).

However, the current model should be an excellent basis for further developments. One such development is the inclusion of physiology, e. g. the modeling of blood flow or propagation of electrical fields throughout the body. Applications such as the

computation of body surface potential maps (20) should profit from an increased level of detail. Furthermore, because of the more detailed characterization of tissues, surgical simulation involving soft tissue deformation could be made much more realistic (20). This approach is thus an important, albeit early step towards computer models that not only look real, but also act like a real body.

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