Illustration Motifs for Effective Medical Volume Illustration

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The enormous amount of 3D data generated by modern scientific experiments, simulations, and scanners exacerbates the tasks of effectively exploring, analyzing, and communicating the essential information from these data sets. The expanding field of biomedicine creates data sets that challenge current techniques to effectively communicate information for use in diagnosis, staging, simulation, and training. In contrast, medical illustration succinctly represents essential anatomical structures in a clear way and is used extensively in the medical field for communicative and illustrative purposes.[1]

Thus, the idea of rendering real medical data sets using traditional medical illustrative styles inspired work in volume illustration.[2] The main goal of the volume illustration approach is to enhance the expressiveness of volume rendering by highlighting important features within a volume while subjugating insignificant details, and rendering the result in a way that resembles an illustration. Recent approaches have been extended to interactive volume illustration[3,4] by using PC graphics hardware volume rendering to accelerate the enhanced rendering, resulting in nearly interactive rates.

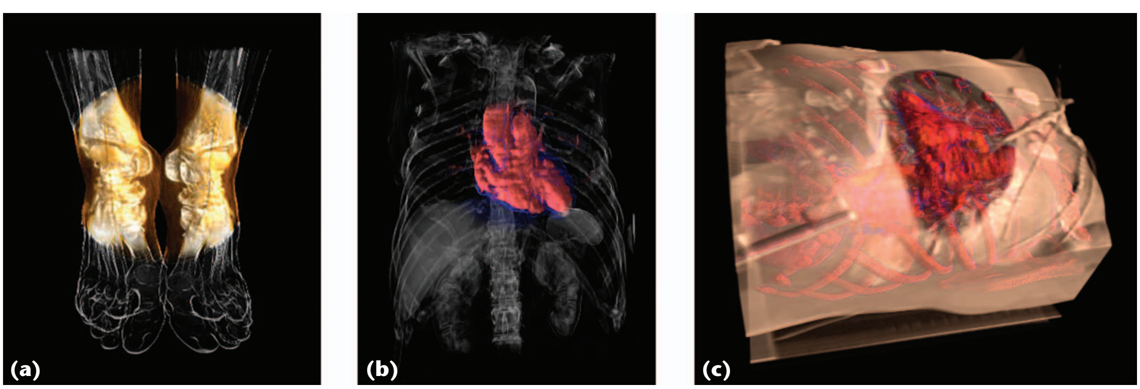
Our work goes beyond previous work in developing illustration techniques to create a flexible illustration system that incorporates domain knowledge of illustration styles. Our new volume rendering techniques enable emphasis and subjugation of information to create images with an appearance similar to medical illustrations, as shown in Figures 1 and Figure 2 (next page). By selective application of enhancements and incorporation of rendering techniques to direct visual focus and to several illustrative style profiles, our system can semiautomatically create visualizations of volume data in a variety of illustration motifs. In collaboration with a trained medical illustrator and medical visualization developer, we have designed a framework for use in various medical illustration tasks. See the "Previous Work" sidebar for a discussion of other systems.

A system that builds upon and extends recent work in volume illustration produces images that simulate pictorial representations for scientific and biomedical visualizations.

Basis and goals of traditional illustration

Most volume illustration work is directed at replicating traditional scientific illustration techniques. However, we want to look at the problem on a different level, considering the entire illustration process.

The fundamental goals of visualization are insight and communication; therefore, visualizations must allow a rich and varied repertoire for clear



1 Medical illustrations of the (a) tarsal joints of the foot, (b) anterior view of the heart, and (c) surgical view of the heart.

2 **Foot bone structure by our volume illustration system with visible human foot data set.**

and concise depictions of complex phenomenon to aid in the task of sense making. The visualization challenge then becomes providing a diverse set of tools that allows for a wide variance of approaches to the information, one that not only allows you to see the information, but also facilitates thinking about the information.

All of these techniques include the variation, emphasis, and subordination of spatial information (pattern and form), light frequency (color), and temporal sequence (motion). Artists and illustrators manipulate line, shape, color, space, and pattern in pictorial representation to depict and convey meaning and aesthetics. These cues help create the perception made by our neural mechanisms that process form, color, and movement.[5] Therefore, through visual cueing, not complete replication, the artist or illustrator manages the image so another brain can recreate a reality similar to the one conceived by the originator. The brain relies heavily on symbolic information to impart a deeper and more extensive meaning. Through emulation of previously adopted schema in our nonrealistic volume rendering, we have generated preliminary data to study if these motifs can be effective in facilitating comprehension of large, complex 3D data sets, and to explore how levels of representation can be employed to facilitate transitions from novice to expert in complex, interactive surgical training environments.[6]

Studies in flight simulation have demonstrated that novices are overwhelmed by complexity, where experts will not attend to schematic or simplified representations. Similarly, surgical residents are often initially overwhelmed with information when they try to orient themselves during an actual surgery. Therefore, a medical illustration guide[7] gives direction for surgical illustration as follows: "A drawing of surgery removes inessentials. It eliminates distracting background and simplifies and emphasizes information." The main value of our illustrative approach is the ability to initially select the appropriate level of complexity based on the target

Previous Work

Our approach for volume illustration is based on standard volume rendering algorithms enhanced with nonphotorealistic techniques, as proposed by Ebert and Rheingans.[1] There are many other developed volumetric techniques that greatly aid the process of volume exploration and illustration. In particular, Höhne et al.[2] have developed a framework for generating volume-based, 3D interactive atlases from cross-sectional images; Weiskopf et al.[3] present interactive clipping for texture-based volume rendering using arbitrary geometry; and Hadwiger et al.[4] describe two-level volume rendering with various enhancements for presegmented data sets.

The need to focus the viewer's attention on a particular part of the volume has been previously implemented through a user-controlled focal region used as an enhancement tool,[5] where the enhanced isosurface rendering algorithms are applied to the data contained in the sphere-bound volume of interest using high-resolution rendering inside and coarse rendering outside.

We are employing an analogous interface to these focal area rendering techniques, achieving similar effects for interactive volume rendering. However, our system allows more flexible rendering motifs to be selected in the focal region and the outside volume.

Virtually all of this previous work describes parameterized rendering systems that focus mainly on the quality of the image, requiring the adjustment of many parameters. This usually makes these systems difficult for the end user to manipulate. Therefore, we have created a compact high-level interaction mechanism that provides different sets of basic settings and illustration motifs to create a more natural, controllable system for illustration generation.

These illustrations are applicable in many areas in medicine, such as clinical research, resident surgical training, and general medical education.

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user's expertise level for use in both medical education and surgical training. These selections will be employed in our studies to evaluate the efficacy of levels of representation for facilitating complex structural anatomy and procedural techniques for surgical residents.

Illustration system overview

Our volume illustration system is a combination of existing volume visualization algorithms; new extensions to volume rendering techniques; a high-level, more natural user interface; and a domain-specific illustration specification framework. One of the main issues in the design of such a system is providing high-level control of the visualization parameters. As volume visualization systems incorporate more enhancement, rendering, and shading techniques, the number of user-adjustable parameters tends to increase dramatically.

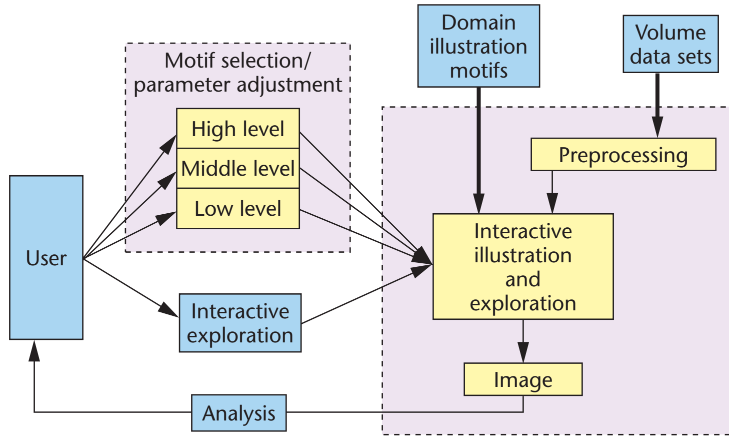
In such a system, to create the most appropriate rendering of the data set for a given application, the user must search a high-dimensional parameter space, which makes the system nonintuitive and extremely difficult to use. Therefore, through our interdisciplinary efforts, we have created a new, more natural specification interface with intuitive and understandable parameters.

Our system objective is to provide an intuitive interface for users with various backgrounds to quickly generate the required results and to keep the performance acceptable for the application. The results are images and animations used for educational, training, and simulation purposes. The interface incorporates three levels (low, mid, and high) of interaction. The low-level interface is for software developers, experienced illustrators, and system builders. The mid-level interface is for illustrators and experienced end users who want to make adjustments once they understand the controls. The high-level interface is designed for the end user, and in our current application focus, it would be for medical students, surgeons, and surgical residents.

We have designed our illustration system on schema found in perception and subsequently exploited through illustrative techniques. One primary perceptual principle used by illustrators is visual focus: The most important information in the illustration will be rendered to facilitate orientation and to hold the viewer's attention. The surrounding details are de-emphasized (subjugated) to provide context, while not overloading the viewer's attention. Therefore, a simple focal volumetric region is used to determine the spatial distribution of illustrative techniques to be applied.

Our spatial focusing method is designed to reflect the attentive focus that results from foveal viewing, similar to the Magicsphere.[8] Our method attenuates on the edge similar to the acuity of foveal vision and is meant to direct and focus the attention of the viewer. Traditional medical illustration often uses this technique. Other approaches include using anatomical objects as the basis of focus and context, but they also require segmented data sets. To make our system most generally applicable, we provide spatial focusing. However, segmentation information can be readily used in our system if it's available.

We also classify illustrative techniques in terms of their use for color perception and form perception. We use variances to emphasize or de-emphasize form, using a repertoire of volume rendering enhancements—such as stipples, lines, and continuous shading—as well as illumination and contrast. Finally, interactivity is crucial to use our shape-from-motion perception and to improve our understanding of these complex 3D data sets. Subsequently, we ensure the interactive performance of our system by adjusting the rendering quality to meet the interactivity requirements.



3 Interactive volume illustration system.

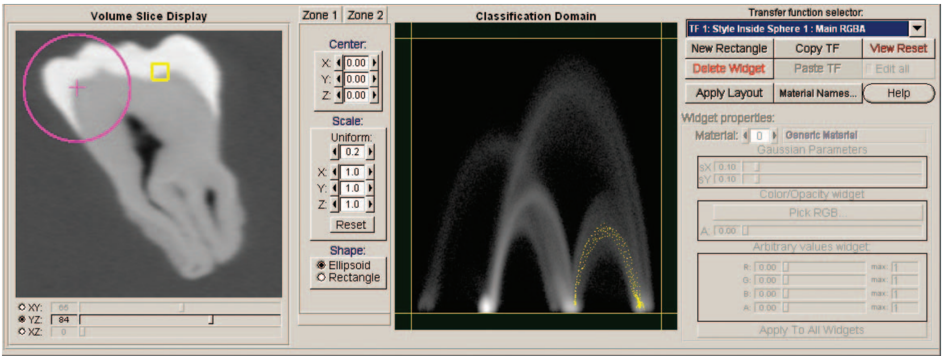
High-level control of the visualization process is achieved through the use of illustration motifs, the sets of rendering parameters that define an illustrative approach. Since we are incorporating traditional medical illustration motifs, we can capitalize on the familiarity of these motifs and presentation methods with medical professionals. The motif specification contains a compact set of core parameters and specification of the target application, providing the user with a much more manageable set of understandable controls.

An overview of the components of, and user interaction with, the system is provided in Figure 3. While our initial system includes motifs specific to medical illustration and several medical visualization applications, the motif specification interface lets us easily incorporate additional domain motifs and target applications. We describe the user interaction with the system through our new interface in the "Application interface" section.

Medical motifs

Artists employ various techniques to manipulate or guide the viewer's attentive focus. These techniques—based on physiological principles—include brightness and complexity, with complexity composed of increased variations of feature detail (pattern and texture, color, and position). For the end user to perceive the detailed picture of a specific portion of the volume, an artist will apply high-quality, structure-emphasizing techniques to this area, while providing a sketch of the outer area. The high-quality artistic rendering lets the user perceive all necessary details (conscious attention), while the outer sketch provides context. This context is perceived unconsciously, but still compellingly represents the outer environment for reference.

We, therefore, introduce different styles for the region



4 **Left side shows the cross-section window with the zone of interest (purple circle) and a probe (yellow square). Right side shows the low-level interface with transfer function editor with a map of the classification domain and widget controls. The classification domain map shows the probing result (yellow dots).**

of interest renderings and the outer context renderings. To begin the process, an illustrator first must select the regions of the volume to emphasize or de-emphasize. The general volumetric selection process is a complicated user-interface problem, so we do not use volume marking directly. Instead, we employ known methods traditionally used in volume rendering: spatial focusing, transfer function selection, and segmentation.

We implemented our spatial focusing method with a simple ellipsoidal and rectangular focal area for general data sets, as shown in Figure 4. It allows segment-based focusing for segmented data sets. This focusing is useful for specification of the region of interest and the outer context for applying different rendering styles.

Transfer function selection is based on the idea that separate materials in the volume correspond to different value ranges in volume data values, and in its first and second derivatives.[9] While this might or might not be true for all problems, transfer function selection has proven useful for material-based volume classification. To define the material, we can select the appropriate ranges in the transfer function domain.

The segmentation, when available, essentially provides the process with an extra volumetric map, which identifies a material or part to which each voxel belongs. Creating a meaningful segmentation for the volume has to occur as a preprocessing stage using a variety of techniques.

Once the selection stage is complete, the user needs a simple and understandable way to communicate illustration parameters to the rendering system, while only needing to know the general requirements of the target application. In our system, the motifs can describe a wide variety of effects, including

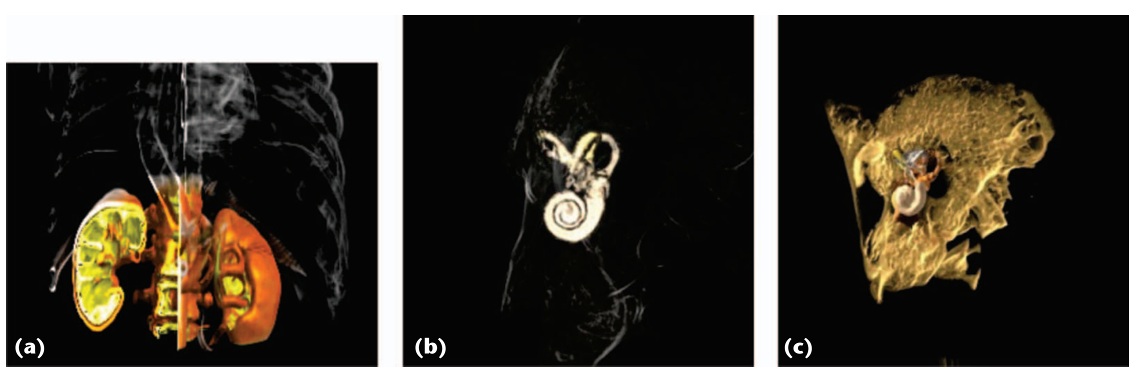
- highlighting a selection to emphasize and focus the viewer's attention,
- removing layers of occluding material while exposing the important objects, and
- providing a chalk sketch of the outer shape of the body part to visualize only the contours, limiting visual confusion.

These capabilities are exposed through the multilevel user interface described in the "Application interface" section.

As mentioned previously, we can view a motif as the settings template used as a basis for a particular illustration style. In our current system, motifs are characterized by the meaning of the zone of interest and by styles, defined inside and outside of the zone. The power of these motifs is to exploit a single database for a wide variety of rich and complex representations.

A simple example is the anatomical illustration motif. This motif's zone means attentive focus. Inside this zone, the settings are set to render the full detail of the illustrated feature (using Phong illumination, boundary enhancement, and so on), while outside features that define general shape are drawn as a sketch (using black or white and boundary and silhouette enhancement). Figure 5a shows an example of using this motif.

For another example set of motifs, we describe two motifs used for surgery simulation. Our approach uses the trainee's level of expertise as a basis for motif classification. As previously mentioned, novices are frequently overwhelmed by the quantity and complexity of data presented during training and must learn to develop their attentive focus for the surgical target and unconsciously orient the contextual structures in the data for reference. Therefore, for a novice surgery simulation motif, a zone of interest is placed in the surgery



5 **Motif examples: (a) anatomical illustration motif for kidney illustration, and (b) novice and (c) expert motifs for surgery simulation in the otic capsule of the inner ear.**

target area. To define styles, we note that there needs to be a silhouetted context for subjugation of details outside of this zone, while we use an illustrative rendering with color cues inside the zone to enhance the important structures (Figure 5b). In contrast, an expert has the necessary experience to subjugate the data details that provide context and can quickly focus on the specific portion of the data and relevant structures. Thus, in our expert surgery simulation motif, we provide more detailed rendering with the selective choice of color and illumination enhancements for structure identification (see Figure 5c). However, even if experts are introduced to new information (outside of their own expertise), they might need to start at either the schematic or intermediate level to structure their mental representation. Therefore, we also need the ability to switch from novice to intermediate to expert levels of representation.

Application interface

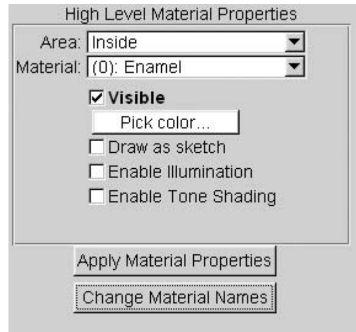
Our volume illustration system provides three levels of user interaction for different classes of users. The three levels balance the level of control with the flexibility and ease-of-use of the system.

The high-level interface is for novice users or end-application users who wish to interact quickly with the system and produce images from the included high-level motifs—for example, a surgical resident or attending physician who wants to create images for patients or general surgical education. The user can specify the type of illustration motif (for example, anatomical illustration) and select different materials within the data to be emphasized. Figure 6 shows the high-level interface.

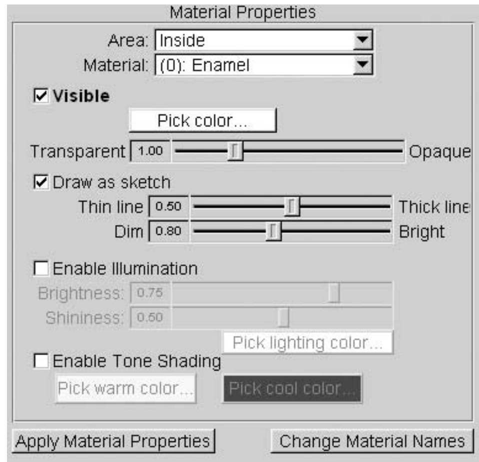
The mid-level interface, shown in Figure 7, allows more experienced users (for example, medical illustrators) to create and fine-tune the high-level motifs, and make general adjustments to the application of illustration techniques. This level of interface is the most frequently used, as it allows fine adjustment of all rendering parameters at a manageable level. Using simple spinner controls with intuitive parameter names, the user can specify the approximate magnitude of various effects based on the position of the voxel (in different areas or for different volume segments) and on the voxel data values.

Finally, the low-level interface lets expert users navigate the data thoroughly, identify new materials, name them for easy identification in the high and mid levels, adjust existing material properties and specification, and modify all the parameters of the transfer functions. The main part of this level is the 2D transfer function editor, similar to one described elsewhere.[9] It contains the map of the classification domain, with a 2D histogram displayed as background for reference, and allows the user to select domain regions by creating widgets and assigning parameters to them.

Another part of the interface is the cross-section display window, which lets the user see a gray-scale image of an arbitrary cross-section of the volume, and is accessible from all interface levels. This window can be used for two purposes. First, the user can use this view (on any level) to specify the position of the region of interest by placing its center point on the cross-section. Second,



6 High-level control panel.

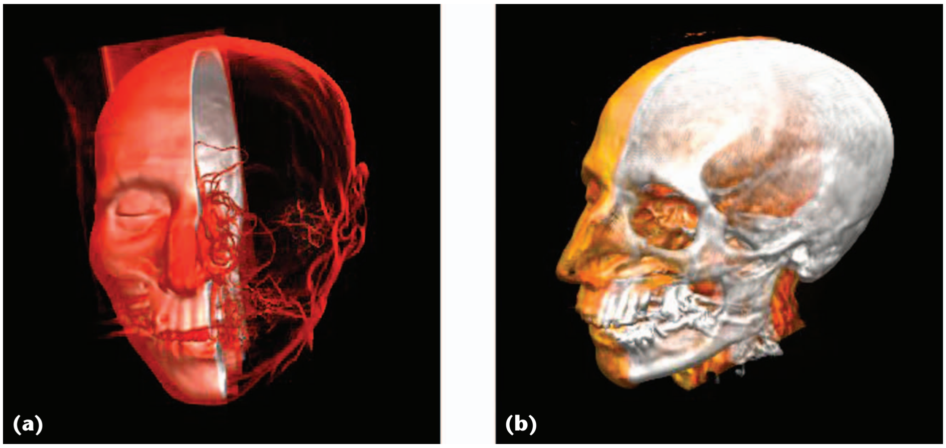


7 Mid-level control panel.

when using the low-level interface, the user can probe the volume to identify materials in the volume: After clicking on the window, the voxels from the small neighborhood of the corresponding point are projected on the 2D classification domain and displayed as points in the transfer function editor window. Figure 4 shows the cross-section display window along with the low-level control panel, containing the transfer function editor.

A user can employ the low-level interface to identify the materials in the classification domain, then use the mid-level interface or the high-level interface. After the user changes settings using the higher levels, the system automatically regenerates the transfer functions. However, the user can still edit the transfer functions in the transfer function editor, and, thus, the low-level interface can also help fine-tune the result and individual parameters of each illustration technique.

To facilitate the rendering's parameterization, users can create rendering profiles based on illustration motifs, target application of the final image, and specific data sets. These profiles contain user settings on all levels, including high-level flags, mid-level parameters, and low-level specifications of transfer functions. Users can create these profiles based on previous illustration work with a particular data set, or data sets produced using the same acquisition technique (for example, a normal CT scan, a contrast-enhanced CT scan, or a T1-weighted MRI scan). Of course, knowledge of patient-to-patient variance and domain expertise is needed to adjust the profiles to provide the most optimized data representation.



8 (a) CT head with silhouette effect on tissue, and (b) CT head with clipped tissue.

Rendering overview

The following section describes the rendering process implemented within our system.

Renderer

We use texture-based volume rendering in combination with programmable fragment programs for our volume illustration system. Before rendering, the system converts the volume data into two 3D textures, which it uses in fragment shaders as sources for voxel value and voxel gradient (the gradient volume is precomputed). The textures are standard OpenGL 1.4 RGBA textures with 8 bits per component. All the computations inside the fragment program use 32-bit floating-point precision, and for higher blending precision, we use 32-bit floating-point buffers (for example, the Nvidia OpenGL extension, available on FX boards).

For volume rendering, the system slices the volume by view-aligned quadrilaterals that are rendered in back-to-front order and blended together to form the final image. As each slice is being rendered, the application level program clips the slice against the volume boundary, while shading occurs at the fragment level. Thus, to change the motif parameters, we only need to change the input of the fragment program, without reprocessing the data. The illustration techniques are easily adapted to modern graphics hardware, where enhancement calculations occur on the fragment level.

Our basic set of illustrative enhancements include the following feature and orientation enhancements: boundary enhancement, sketch enhancement, color distance attenuation, aerial perspective, null halos, Phong illumination, and tone shading. We have developed an interactive implementation of these techniques based on recent work described elsewhere.[4]

All of the transfer functions are stored as 2D-lookup tables consecutively packed into a 3D texture. In the fragment shader program, when the value needs to be calculated, a 3D lookup is used, with the transfer function arguments as the first and second coordinates and transfer function ID as the third coordinate.

Multilevel transfer functions

To create a system that has the power of scientific illustration, we need to render different objects, materials, and regions within the data set using different illustration techniques. Traditional transfer functions do not have the flexibility and capabilities needed. Therefore, we have developed a collection of hierarchical transfer functions that we will refer to as *multilevel transfer functions*.

One of the basic components of the illustration process is to first identify the different materials within the data set. In volume rendering, we can use multiple scalar values per voxel for material classification. The basic scalar value is the voxel value (x-ray absorption for CT data sets, hydrogen density for MRI data sets). Other commonly used scalar values are the first and second derivative magnitudes.[9] The Cartesian product of the domains of these chosen local voxel values forms the classification domain, and the number of considered values determines the dimensionality of the classification domain. Currently, we use a 2D domain of voxel density and gradient magnitude. With segmented data sets, we use the segmentation data to separate the materials instead of the transfer function on the classification domain.

Traditionally, transfer functions are used only to map classification domain values to the color and opacity of samples. Thus, changing the transfer function specification highlights some materials, hides others, and assigns different colors to different materials. While these capabilities provide good cues for initial volume exploration, they are not sufficient for effective illustration. We call the traditional transfer function the *basic transfer function*. Other transfer functions in our multilevel set are classified later based on their purpose (illustration goal) and classification domain (voxel value).

We need the ability to render different materials in different styles. Since style is defined as a set of volumetric enhancement effects applied to a sample, we use a set of transfer functions that map classification domain values to the magnitude of a particular effect and, thus, make it possible to distinguish the materials, not just by opacity and color, but also by rendering technique. These functions form a group of *selective enhancement transfer functions* (for example, see Figure 8a).

To direct the viewer's visual focus, the rendering algorithm must apply different styles based on the voxel position (for example, whether or not the voxel is inside the region of interest). To accomplish this, we use a *style selection function*. Here, a style selection function is a condition that determines which style to apply to a voxel based on its position. If the current voxel is in the boundary zone (for example, close to the boundary of the region of interest), appropriate interpolation of the two styles is calculated and used as the result.

The data flow inside the fragment program is illustrated in Figure 9. The style selection chooses the set of selective enhancement transfer functions, and those functions determine sample color and opacity. By using this approach, which can apply different styles to the different zones, we can render the image with a combination of various effects and illustration techniques and, thus, generate images similar to the various styles of medical and technical illustration.

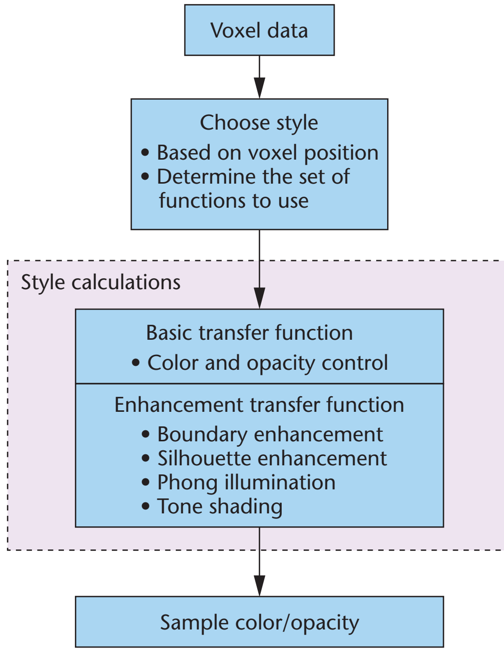
Initial results

To demonstrate the illustration capabilities of our system, we have used four representative data sets for illustration: the visible woman feet CT data set (Visible Human Project), a contrast enhanced abdominal CT data set (Dr. Elliot Fishman, Johns Hopkins University Medical Center), a temporal bone micro CT data set (Kim Powell, Cleveland Clinic Foundation), and a virtual colonoscopy data set (Dirk Bartz, University of Tubingen). We selected the example regions of interest in collaboration with medical experts, who provided insight into the significance of various anatomical structures. We generated all the images by loading the appropriate motif and adjusting rendering parameters on the interface's three levels.

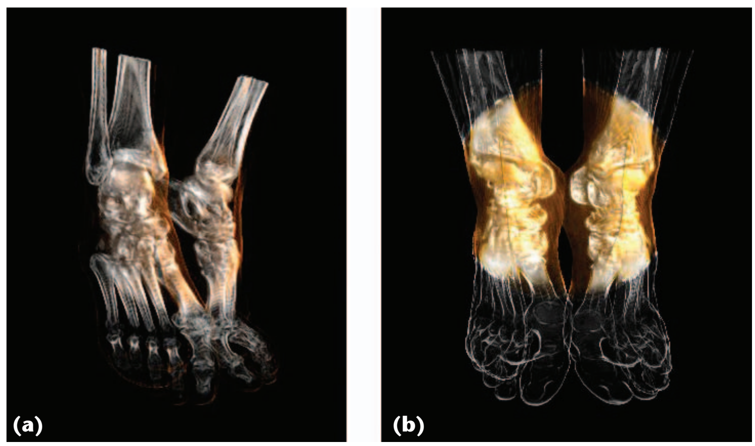
We designed the anatomical illustration motif to mimic traditional medical illustration found in medical anatomy texts.[1] As previously mentioned in the description of the motif, the main idea is to draw the focal region in full color, while subjugating the outer tissue through sketching for reference. Surgical simulation, on the contrary, has the goal of providing realism by showing an image similar to the appearance of the patient on the operating table, with different levels of subjugation of the unneeded details. The novice surgical illustration motif level shows only the relevant anatomical structures, while the expert level shows all of the patient data with minimal, selective enhancement to increase the simulation's realism.

Figure 10 shows two anatomical illustrations of the visible woman feet CT data set. These images are based on the anatomical illustration motif, and employ an illuminated realistic volume rendering inside the zone of interest and varying levels of silhouette and boundary enhancement to sketch the surrounding structures. The region of interest emphasizes and focuses attention on the tarsal (ankle) bones of the foot. The silhouette technique (stronger in Figure 10b) is employed to subjugate the outlines of the surrounding bones and surface of the feet.

We generated Figures 11a through 11d (next page) with our anatomical illustration motif. Here, we use it to focus attention and illustrate the chambers of the heart (Figure 11a); kidneys with a cutaway view for detailed structure (Figure 11b); and major components of the circulatory system plus the liver, spleen, and kidneys (Figure 11c). We de-emphasized the surrounding structures, however, they serve to orient the user and provide location. Figures 11a through 11c once again use sketching of the outer context and more realistic illuminated volume rendering for organs and systems of interest. Figure 11d shows a false-colored, simplified illustration of the gross anatomy of the chest and abdominal cavity created from this same data set, with the digestive organs removed. The relationship of the lungs, spine, and aorta are clearly shown in the middle top of the image, while the liver (green), spleen (blue), and kidney (blue/red) are highlighted in the lower half of the image.



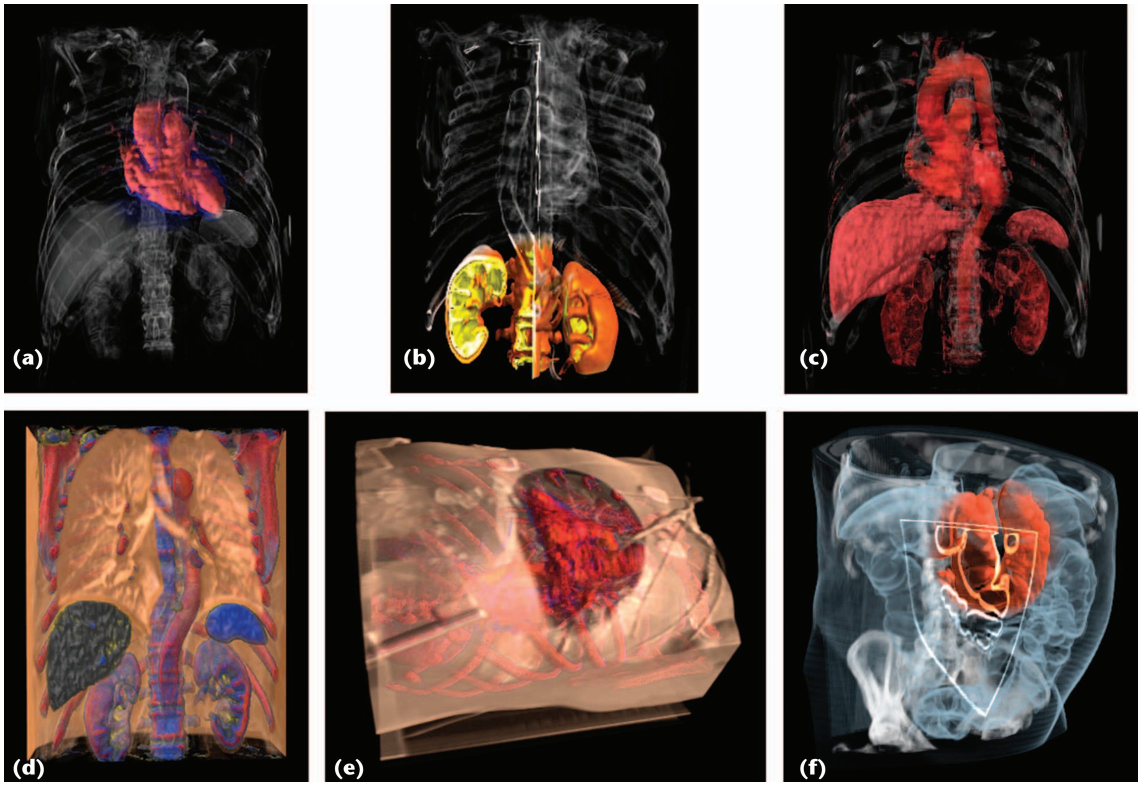
9 Illustrative calculations on the fragment level.



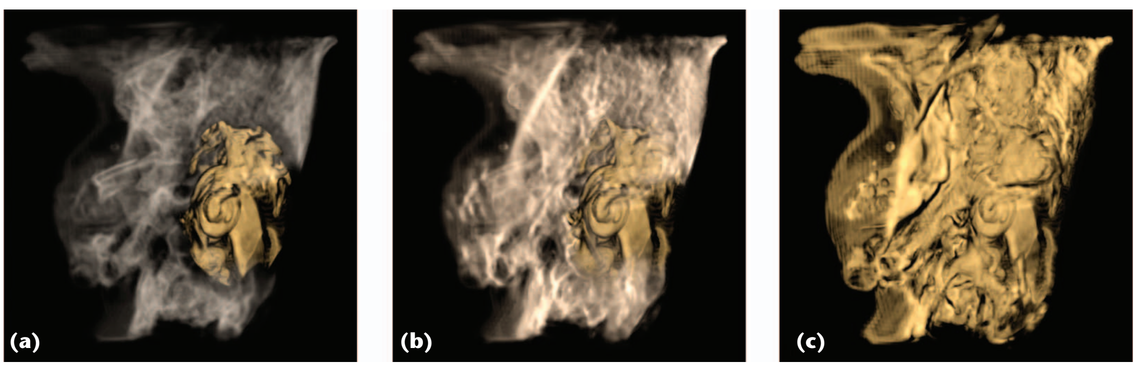
10 (a) Visible woman feet data set illustration highlighting tarsal (ankle) joints adjusting rendering parameters on all of the three levels of the interface. (b) Illustration using same data set with stronger silhouette technique.

In contrast to these anatomical illustrations, the illustration in Figure 11e shows the same data set rendered using an intermediate surgical illustration motif, where the structure of the heart chambers are drawn in reference to the body, and occluding tissue is removed. A portion of the left ventricle has been removed and the heart is more transparent than in reality to create an illustration for an annular ring or valve replacement surgery.

Figure 11f shows an anterior view of the colon, where a part of the transverse colon is highlighted in red and a portion of it is cut away with three extra clipping planes to show internal structure. The motif used there has two zones. The first zone highlights in red the volume region of interest and is placed on the bent region of the colon. The second zone is a rectangular region and is used to cut away the front portion of the body (inside this region, everything has zero opacity).



11 Abdomen CT data set illustrations: (a) heart chambers; (b) kidney structure; (c) circulatory system, liver, spleen, and kidneys; (d) false-colored chest and abdominal cavity illustration; (e) heart chambers surgical illustration; and (f) colon illustration with bent region highlighted and cut with clipping planes.



12 Temporal bone illustrations: (a) cochlea structure enhanced; (b) cochlea structure slightly enhanced, with more realistic appearance; and (c) nonenhanced realistic rendering.

Enhanced contour lines along the cut show the intestine detail. We generated this image using an augmented shader for contour enhancement on the edge of the zone.

Figures 11a through 11d use an objective view, common in anatomical illustration, while Figure 11e uses the surgeon's subjective view, as used in surgical illustrations.

Figure 12 contains several renderings of a micro CT-scan of a temporal bone. These images emphasize important parts of the bone and the cochlea structure, which is occluded by the surrounding structure and is, therefore, difficult to visualize with traditional methods. Figure 12a shows a novice surgical simulation view where the cochlea is shown in detail while the rest of the bone is simplified to aid navigation and orientation. Figure 12b shows more detail of the entire structure—the cochlea part is enhanced but does not stand out as much—while Figure 12c shows a nonenhanced rendering of the data set, much closer to a real surgical view.

We generated all images in Figures 10, 11, and 12 on a Pentium 4 1.5-GHz PC with 1.5 Gbytes of RAM and a GeForce FX 6800 Ultra card (128 Mbytes of VRAM), using 500 slices, and a screen area of approximately 400×400 pixels. For these settings, current performance is about 4 frames per second. However, in the preview mode, we use one simplified transfer function to color the volume, which speeds the rendering to 20 fps for the same settings.

The majority of the enhancement calculations occur at the fragment level, so the more effects we include, the more texture lookups performed in a single pass and the longer the fragment program. The performance also directly depends on the screen size and the number of slices.

Future work

We have received encouraging feedback from clinicians who teach and from medical students, indicating that our system would be useful for providing training modules for medical education and in surgery simulation for training surgeons.

In continued collaboration with field experts in medical visualization, we will include more volume rendering enhancements in the toolkit, which will extend the current illustration approaches to provide more flexibility for various applications. We also plan to extend this work to real-time interactive training systems. For instance, one of the authors (Stredney) is involved in a study that is developing and validating an interactive temporal bone dissection simulator. This system emulates temporal bone dissection, which is used to gain proficiency in a temporal bone surgical technique. We believe it could prove useful to dynamically adjust the region of interest and level of detail based on the user's level of expertise.

This would allow for increased system usage for both novice training, by employing schema to control emphasis and subjugated areas, and for providing the expected complexity and sophistication required by experts for preoperative assessment and treatment planning. ■

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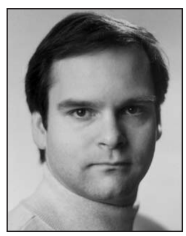

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