NPR, Focussing and Emphasis in Medical Visualizations

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Abstract. Emphasis and focussing techniques are designed to consider the importance of objects within the rendering process. Such techniques are essential in medical education and therapy planning systems. Non-photorealistic rendering techniques, such as silhouette lines, are essential in this context as they convey the shape of objects without occluding large areas. We discuss emphasis and focussing by means of NPR in medical visualizations. We introduce techniques which emphasize a selected object in 2d as well as 3d visualizations.

Keyword: Non-Photorealistic Rendering, Emphasis Techniques

1 Introduction

Visualizations are generated for a certain purpose. In medical applications, this purpose is often part of a diagnostic or therapy planning scenario where medical volume data are employed. In these scenarios, it is essential to adapt the appearance of objects or regions to their relevance for the specific task. As an example, it is often useful to focus on certain anatomic structures whereas other objects or regions only serve as orientation aid which are displayed less pronounced. A medical visualization system might "know" what is relevant, after the user selected an object either immediately within the visualization or indirectly via its name in a list. Emphasis techniques modify the currently selected object (CSO) or other objects such that the shape of the CSO can be clearly recognized and its location in the overall model becomes obvious. Emphasis is similar but different from focussing. Focussing is guided by a degree-of-interest function (*doi*) where *doi*-values are assigned to each object or region of an information space [Fur86]. Emphasis on the other hand is based on a binary decision whether an object or region should be highlighted or not. If segmented objects are available the CSO has *doi*-value 1, whereas other objects have a *doi*-value 0. Hauser recently showed in a series of research projects how the *doi*-concept from information visualization can be successfully applied to scientific and medical visualization [Hau03].

In this paper, we discuss emphasis and focussing techniques and consider 3d as well as slice-based 2d visualizations where these techniques should be applied simultaneously. The design of emphasis techniques for 3d visualizations is challenging because relevant objects might be far away (and thus too small) or even occluded [Sel91]. Most of the techniques discussed here require segmentation information concerning relevant objects. As a family of visualization techniques, we discuss non-photorealistic rendering (NPR) techniques inspired by traditional medical applications. We extend our previous work [Pre02] on emphasis techniques in several ways:

- The simultaneous application of emphasis techniques within 2d and 3d visualizations is discussed. Emphasis techniques which allow to correlate 3d objects with the slices of radiological data are introduced.
- Silhouette and feature lines are discussed with respect to emphasis purposes.

This paper is organized as follows: We start with a discussion of emphasis and focussing techniques in Sect. 2. In Sect. 3, we briefly survey NPR techniques designed for medical visualization. Sect. 4 presents concepts for hybrid combinations of rendering styles. The correlation between slices of radiological data and derived 3d visualizations is crucial. Therefore, we discuss emphasis in 2d and 3d visualizations (Sect. 5). Advanced regional and global emphasis techniques are presented in Sect. 6

2 Emphasis and Focussing Techniques

Emphasis and focussing techniques have to fulfil the visualization task of showing and highlighting important objects. Among the large variety of possible visualization techniques, those are preferred which are recognized at a first glance (preattentive vision, [Tre85]). Research in visual perception indicates that there are visualization parameters which are recognized without attention. As an example, objects shown with highly saturated colours are recognized immediately. Another effective focussing technique is blurring where only important objects are rendered sharply whereas others appear blurred, similar to blurred regions in photographies [Kos02]. This technique may have a great potential for medical 3d visualizations. However, it has not been applied in this area.

The most common approach to medical visualization is volume rendering where the opacity transfer function (OTF) is used to specify which range of intensity values is important (and rendered opaque) and what is less relevant (and more or less transparent). Because intensity values are often insufficient to discriminate anatomic structures, gradients have also been considered. Levoy suggested gradient-magnitude weighted transfer functions where homogenous regions (characterized by low gradient magnitude) are rendered transparently and high opacity values are assigned to areas with large gradients [Lev88]. The general concept here is to support multiple levels of importance (focussing). Emphasis techniques – as has been elaborated above – are guided by a binary decision on importance. Emphasis with an OTF would require a threshold which results in isosurface rendering. Recently, more sophisticated emphasis and focussing techniques such as cutaway views and importance-driven volume rendering have been introduced [Die03], [Vio04]. These are discussed in Sect. 6.

Local, regional and global emphasis techniques. To support a structured view on emphasis techniques and meaningful combinations of them, we introduced a classification [Pre02]. Basically, we differentiate between local, regional, and global emphasis techniques. While local techniques only influence the CSO, regional and global techniques also have an influence on nearby objects or even the whole dataset. As an example for regional techniques, objects or regions occluding the CSO might be rendered transparently. An example of a global technique is the adaptation of the viewing direction to show the CSO unoccluded. Regional and global techniques are justified to emphasize occluded objects. For visible objects, the side-effects of regional or global techniques for other objects can be avoided. Therefore, it is useful to perform an analysis concerning the visibility of the CSO to decide whether to apply such a technique.

The space of potentially useful emphasis techniques for medical volume data is huge. The discussion in this paper is by no means complete. We shall give examples of viable and appropriate solutions, discuss their limitations and we hope to inspire new research concerning the evaluation of existing or the development of novel techniques.

3 Non Photorealistic Medical Visualization

Approximately in 1990, non-photorealistic rendering (NPR) emerged in computer graphics. The goal of NPR is to provide a wider range of rendering techniques to express various effects and to simulate styles from traditional scientific illustration. Directing attention to relevant features, on the one hand, and omitting unimportant details on the other hand may be achieved by carefully distributing strokes and points instead of shading surfaces. NPR also provides facilities to expose features of complex surfaces which have been obscured which is essential in the context of emphasis techniques.

The pioneering work [Sai90] was entitled "Comprehensible rendering of 3D shapes". Silhouette and feature lines were generated to emphasize the shape of objects, and hatchings were employed to highlight the curvature of objects and to convey the texture of objects. Silhouettes are essential in shape recognition because they provide cues for figure-to-ground distinction [Ise03]. Silhouettes, feature lines and hatching bear a great potential to convey complex shapes of anatomic and pathologic structures.

3.1 Emphasis and Non Photorealistic Rendering

NPR provides a wide range of techniques which might be employed for emphasis purposes. In photorealistic rendering, emphasis might be achieved by adapting the position of the virtual camera or by placing a spot-light source. The rendering process itself, however, regards all edges and faces as similarly important. Nothing is left blank even if it is less relevant. Partial visibility of an outer object to reveal inner structures can only be achieved by semitransparent rendering. This method, however, strongly degrades shape perception. The potential of NPR is to emphasize important features and to remove extraneous detail. As has been pointed out by Viola et al., NPR permits sparse visual representations of objects which consume less screen space than shaded surfaces [Vio04]. The adjustment of the level of sparseness, is probably the most essential aspect of NPR for emphasis of objects.

NPR offers many degrees of freedom to emphasize objects or regions. The CSO might be enhanced by silhouette and hatching lines, while others are not. The negative side of this freedom is that good choices for many parameters are needed. More degrees of freedom make it more difficult to adjust a visualization. While artists may take hours to produce expressive images, medical visualizations are often generated under time-pressure. Also, medical visualizations should be precise and reliable. Our view on NPR and its potential is focussed on these aspects. Techniques which require considerable and non-trivial input by the user (for example specification of hatching directions) are not considered. Also, rendering styles which are more artistic than precise are omitted. Browsing through medical illustrations gives an idea about useful rendering styles for medical education and therapy planning (see Fig. 1).

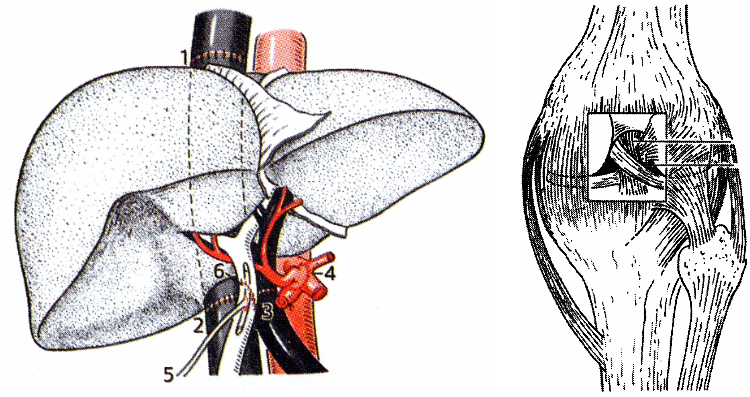

Fig. 1: The left image uses silhouettes and points to convey the shape of the liver. The local density of points is adapted to the curvature of the organ and simulates a lighting effect by "stippling". Small dots of ink are placed onto paper such that their density gives the impression of tone. The right image presents muscles in the knee region. A quadrilateral cutaway-view reveals deeper structures. (From: Sch03]).

3.2 Volume Illustration

For medical applications, volume data such as CT and MRI are employed for the visualization. NPR visualizations which are generated directly based on such volume data. are referred to as *Non Photorealistic Volume Rendering* or as *Volume Illustration* [Rhe01]. We prefer the term Volume Illustration because medical volume rendering is non photorealistic anyway.

As there are no object boundaries in volume data, the gradient magnitude is used as indicator for silhouette and feature lines. The gradient magnitude is approximated by differences between adjacent voxels. Silhouette lines are generated between adjacent voxels where the gradient magnitude is large and the cross product of camera direction and the gradient direction is close to 0. In principle, this allows to generate silhouette lines easily (only a threshold for the gradient magnitude has to be supplied). This method has been introduced in [Cse01] and was illustrated by means of images which exploit the large gradient between air and skin in CT data. However, for many regions in the human body contrasts in CT and MR data is considerably lower than at the air-skin boundary and correct silhouettes cannot be identified easily. In MRI data with its inherent inhomogeneity, feature lines might pronounce irrelevant discontinuities. Therefore, we focus on emphasis techniques where explicit information concerning object boundaries is available from a segmentation process.

3.3 Hatching Volume Models

Recently, first attempts have been made to provide hatching based on volume data [Don03]. Segmentation information is used to reliably calculate silhouettes and principal curvature directions. With volume hatching, strokes are generated which take the intensity values of the volume data into account. Also, by contrast to surface hatching, interior voxels close to the surface make a contribution to the hatching. Based on gradient estimation schemes the local orientation of a surface in the volume data is approximated to calculated lighting information. Thus, the depth cues provided by shadings are also provided. Hatchings based on volume information produce smoother hatching lines compared to purely surface based methods. Dong et al. describe a method where smooth patches are fitted to the intensity values of 8 adjacent voxels. By contrast to a polygonal isosurface with its discontinuities in the surface normal these patches provide smooth transitions of the surface orientation (Fig. 2 gives an example).

Hatching and emphasis. Hatching may be enabled to emphasize the CSO's shape in addition to a shading method. Hatching may be more or less pronounced (more and denser hatching lines) depending on the importance of an object.

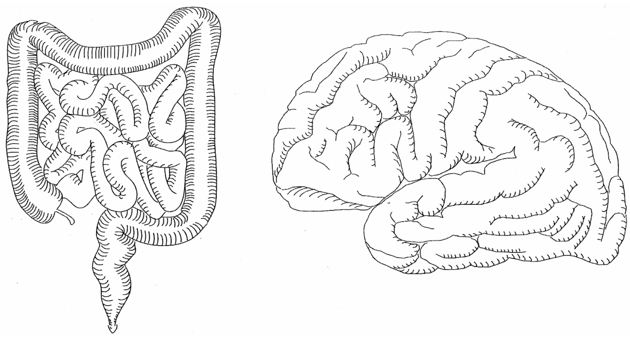

Fig. 2: Volumetric hatching examples where the principal curvature direction is used to guide the orientation of strokes. Left: the digestive tract, extracted from CT data. Right: Human brain from MR Data (From: [Don03]).

4 Emphasis with Hybrid Visualizations

The combination of different rendering styles provides interesting facilities to adapt a medical visualization to the importance of anatomic and pathologic structures. NPR might be used to depict anatomic context, either as single rendering mode or in combination with strongly transparent surface rendering. As an alternative, volume rendering might be employed for the anatomic context. Surface rendering and high opacity might be used for important objects (which we shall refer to as *focus objects*)[1]. In Fig. 3, we show some combinations of rendering styles designed for a medical education system

[1] By contrast to the CSO there might be several focus objects. Often they are located close to each other.

(LiverSurgeryTrainer, [Bad04]). Focus objects are the liver and the intrahepatic structures; the skeleton serves as anatomic context.

A relevant yet difficult question concerns the appropriateness of the images in Fig. 3. Many variants have been discussed with surgeons and the images in Fig. 3 have been regarded as suitable. But is there any best image? An encompassing user study might give some hints. Probably, different viewers strongly differ in their choice. As a consequence, it should be easy to generate such images and it should be easy to save parameters as individually preferred style for reuse in other images.

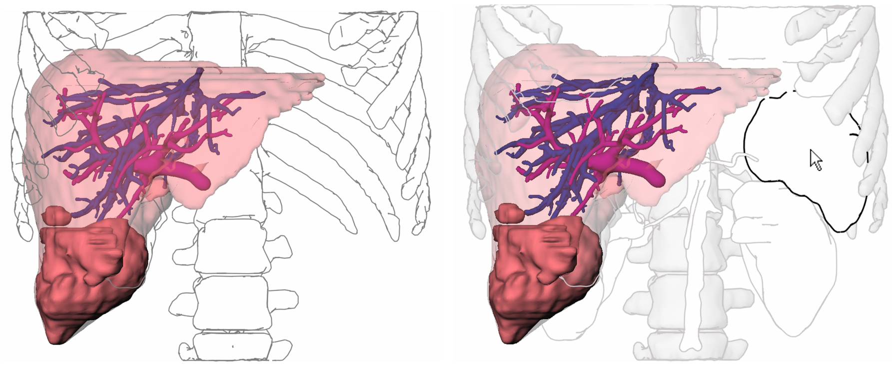

Fig. 3: Focus objects are depicted as surface rendering. Context displayed exclusively with silhouettes (left) and with transparent surfaces combined with silhouettes (right). The right image also illustrates the adjustment of silhouette rendering to user interaction. The silhouette colour is changed to provide more contrast for the currently selected object.

Hadwiger investigated silhouette rendering based on segmentation results and combined this technique with other visualization techniques (such as Maximum Intensity Projections) [Had03]. The generation of hybrid visualizations is technically demanding because the sequence of rendering steps must be considered to ensure that depth relations are correctly depicted.

5 Synchronized Emphasis in 2d and 3d Visualizations

The interpretation and analysis of medical volume data requires 2d cross section views as well as 3d visualizations. 2d and 3d views as well as the synchronization between them are also essential for the emphasis of objects in medical applications. If an object is selected in a 3d visualization the 2d view should be adapted to make the selected object visible and recognizable. On the other hand, an object which is selected in a 2d visualization or by its name in a list should be emphasized in a 3d visualization. The use of colours and silhouettes should be synchronized in 2d and 3d visualizations. This however is insufficient if the CSO is not visible in the other view. In the following, we discuss how the 2d view might be adapted to make the CSO visible. This discussion is based primarily on [Doe02]. In the 3d view, it is more advanced to assess the visibility of the CSO. We discuss such techniques in Sect. 6.1.

If the CSO is not included in the current 2d view, different slice(s) must be selected. This can be achieved by choosing one slice - representative for the CSO - or by splitting the 2d view into several subviews to accommodate all slices where the CSO belongs to. The splitting of the 2d view is only applicable if the CSO is small (a few slices). The realization of this strategy raises a number of questions:

- What is a good slice to display the CSO in a 2d visualization to emphasize it?
- How to emphasize the CSO in the selected slice?
- How to indicate where the particular slice is located with respect to other slices which include the selected object? Or in other words, how to convey the range of slices to which the CSO belongs.

Each of these questions is difficult and good strategies strongly depend on the size and shape of selected objects.

5.1 Slice Selection

The slice selection can be accomplished by calculating the centre of the object's bounding box (BB).[2] The slice which contains this point is selected (usually *z*-coordinate of the BB centre). There are some arguments against this strategy. First, the BB centre might not be a representative point in case the CSO has an elongated long bulge in a certain direction. Second, the BB centre not necessarily belongs to the CSO. This situation is frequent in case of branching and concave objects such as vascular trees. Concerning the first problem, the centre of gravity (COG) is a better candidate to guide the slice selection. The computational effort is similar to the BB computation. However, also the COG may be outside the selected object. As a suggestion, a vertex may be searched with minimal distance to the COG. The slice containing this vertex is displayed.

5.2 Emphasis in the 2d Slice

A wide range of possibilities exists to emphasize an object in a 2d slice view. Our choice should consider that similar emphasis techniques should be applicable in both the 2d and 3d view. The following list presents just some examples:

- Draw a crosshair cursor through a representative point (COG, BB centre) of the object.
- Draw a rectangle indicating the object's bounding box.
- Use a special highlight colour to depict the object's silhouette.
- The object might be filled with a special highlight colour.

Each of these techniques might be combined with each other. While the first two techniques support the understanding of the CSO's size and position, the last two techniques convey the shape of the CSO. Since the correlation to the underlying data is essential, the lines (techniques 1-3) should be thin and filling (technique 4) should be used as a

[2] In the following, we use the term *bounding box*. The bounding box may be either the axis-aligned bounding box (AABB) or the oriented bounding box (OBB) (which takes longer to compute but represents shapes better.

semitransparent overlay, thus, blending the fill colour with the original data. Each of these techniques can be applied or easily extended to a 3d emphasis technique.

5.3 Range Visualization

The selected object belongs to a certain range of slices. For simplicity, we assume that the CSO is included in sequential slices only (which is often the case but exceptions may occur). Assume, that our object starts at slice s_1, proceeds to slice s_2 with some intermediate slice $s\_{selected}$ ($s_1 <= s_{selected} <= s_2$) which is currently displayed. The 2d view should indicate the location of $s_{selected}$ with respect to s_1 and s_2.

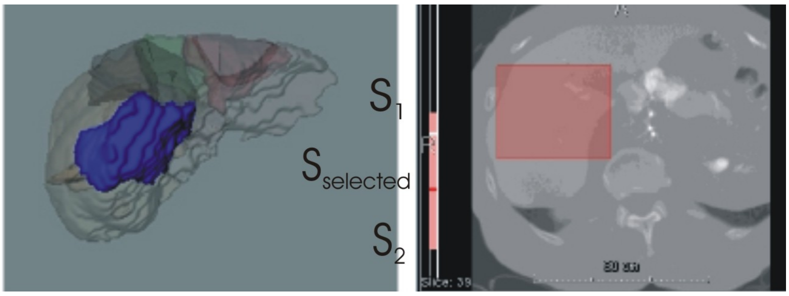

Fig. 4: Synchronized emphasis with an indication for the range of selected slices with a vertical bar attached to the 2d viewer.

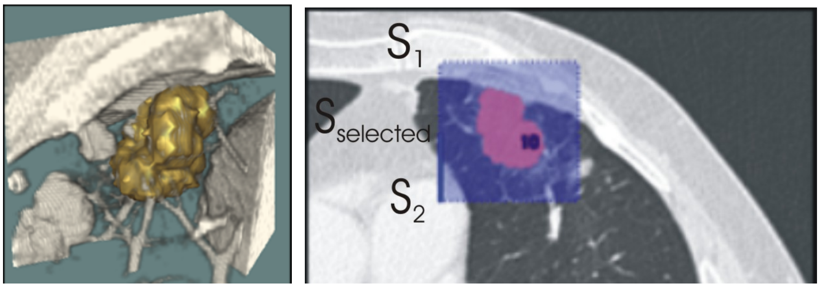

Fig. 5: Synchronized emphasis of a lung tumor. Left: Local volume rendering combined with surface rendering of the tumor. Right: The range of slices indicated by means of a rectangle around the tumor. The size of the thick lines conveys how many slices before the selected slice also contain the tumor. (Courtesy of Volker Dicken, MeVis Bremen).

One technique to indicate the position of $s_{selected}$ and the range of slices is to enhance the 2d viewer with a vertical bar which contains a rectangle representing the range of slices (s_1, s_2) and a horizontal line indicating the current slice (see Fig. 4). A drawback of this technique is that the vertical bar might be far away from the CSO forcing the user to focus on another area on the screen. As an alternative, the range visualization might be included close to the CSO immediately in the display of the radiological data [Dic03]. This could be accomplished using a rectangle around the respective object with a modified vertical line. This line should be subdivided such that it reflects the distance from $s_{selected}$ to s_1. In Fig. 5, a thick line is drawn from the rectangle's border representing $dist(s_{selected}, s_1.)$ and a thin line representing $dist(s_{selected}, s_2.)$.

6 Regional and Global Emphasis Techniques

Most local emphasis techniques, such as the modification of the CSO's colour or the inclusion of crosshair cursors and bounding boxes, are only effective if the CSO is visible. Some local emphasis techniques are effective even for hidden objects, such as the use of an inset and the generation of shadow volumes for the CSO [Pre02].

We shall focus here on regional and global emphasis techniques. In general, these should only be applied if the CSO is invisible or very small because the resulting image changes considerably and requires substantial image interpretation effort. Therefore, we first discuss some object-based techniques to estimate the visibility of objects.

6.1 Visibility Analysis

A visibility analysis of the CSO should deliver which portion of the CSO is visible and also give an estimate of the size of the visible portion. These values may be used to decide whether local techniques are sufficient.

Visibility analysis is a wide area of research. In the context of medical visualization, we can restrict ourselves to static scenes. In principle, visibility can be estimated on the fly or be precomputed in a preprocessing step. [Zha97], for example, precompute hierarchical occlusion maps. In the context of emphasis techniques, a visibility analysis should deliver also those objects or regions which compromise the view on the CSO. We call these objects *occluder*. Occluders have to be removed or at least modified such that the viewer can see through them.

A variety of methods exists which perform a visibility analysis. As with many other algorithmic problems, methods differ in their exactness and in their computational effort. A computationally expensive method is to check the visibility of every vertex of the CSO. For complex objects (> 100 K polygons), this is currently not feasible in near real time [elS01]. In the following, we will discuss two simple algorithms which make it possible to adjust the trade-off between exactness and computational effort.

6.1.1 Visibility Analysis by means of Nested Boxes

Similar to the ray traversal during ray tracing, we trace rays and use bounding boxes to assess the visibility of an object [Doe02]. We start with the AABB of the CSO and trace 9 rays from the camera position to the 8 vertices of the AABB and the centre of the AABB. In this process, we analyze whether the bounding box is hit first or whether other objects are in front of it. This gives a first estimate on the visibility of the CSO. However, this estimate is not very precise. Even if most of the tests yield that other objects are hit first, the CSO might be completely visible. Also the opposite might happen. We improve the expressiveness of the test by considering smaller boxes. By contrast to the AABB these boxes also represent regions inside the CSO.

Finally, it is evaluated which objects hide the CSO, which portion of the CSO is visible. With the number of boxes used we may adjust the computational effort. An adaptive variant is possible where we terminate the algorithm in case we have sufficiently clear results. Since we consider not vertices of the CSO but only nested boxes as representative of the CSO the results are only estimates.

6.1.2 Scanning Visible Bounding Box Faces

We briefly discuss a second visibility analysis method which also employs the CSO's bounding box. This approach is more precise because it shoots more rays and considers actual vertices of the CSO. We consider the visible faces of the AABB and shoot rays through a grid on each visible face. If the viewplane is parallel to one of the AABB's faces exactly one face has to be considered. Otherwise, two or three faces of the AABB are visible. For each ray, we determine whether they intersect the CSO. Fig. 6 illustrates that some rays miss the CSO. Only if the CSO is actually intersected, it is registered which occluders were eventually hit first [Doe02]. The resolution of the grid and the extent of the CSO determine the number of rays which have to be analyzed and thus the computational effort.

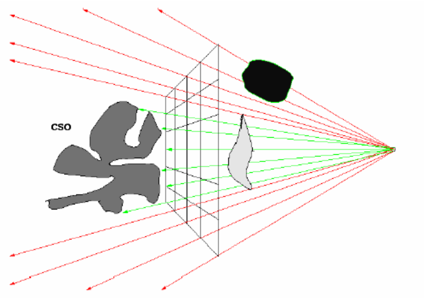

Fig. 6: Visibility analysis by tracing rays from the camera (centre of projection) to visible faces of the CSO's bounding box. The black object is not an occluder although it is hit first by some rays. The light grey object actually degrades the visibility of the CSO.

6.1.3 Discussion

The algorithms described above are simple and easy to implement. A variety of more sophisticated algorithms is available. As an alternative to the bounding box, the bounding sphere or ellipsoid might be employed. The ray shooting process in the second process might be improved by adaptive refinement where adjacent rays produce different results. We also did not consider the current transparency of objects. If an occluder is already strongly transparent it might remain unchanged. For medical visualization, a combination of precomputed visibility and on-the-fly estimation might be very effective. Often, some large objects (such as organs or the skull) contain many other objects. These large objects are occluders for all internal objects independent from the viewing direction. Having analyzed this in advance, the online analysis might consider the occluders known from preprocessing.

6.2 Cutaway Views and Importance-Driven Rendering

There are several possibilities how the visibility analysis might be employed. If the CSO is sufficiently visible a local technique should be used. If the CSO is heavily occluded, objects in front of the CSO might be rendered transparently or a combination of semitransparent rendering and silhouette rendering might be employed. As an alternative to the modification of objects, the modification of occluding regions is often appropriate. These regions are removed or at least shown strongly transparent. Such visualizations are called cutaway illustrations. In the following, we consider cutaways where the cut-region is completely removed.

Compared to transparent renderings, cutaway views exhibit a sharp contrast between foreground and background objects. Ambiguities with respect to spatial ordering are avoided with this technique [Die03]. To indicate that an illustration technique is applied, the shape of the regions should differ strongly from the shape of anatomic or pathologic structures. While technical illustrators often create zig-zag-shaped cutaway views (these differ from shapes in technical domains), regular shapes such as prisms or cylinders are useful for medical visualization. Cutaway views may be generated in the context of volume rendering as well as in the context of surface rendering. Cutaways in volume rendering require to voxelize the clip geometry. Based on a voxel representtation, volume rendering is modified such that voxels in the clip region are discarded. Similar to other emphasis techniques, cutaway views have a limited applicability: Primarily small and compact objects may be emphasized with cutaway views. For objects with a branching structure, a large AABB results and this technique is less appropriate.

Recently, cut-away views have been generalized to importance-driven volume rendering [Vio04]. Here, less important parts of the data are suppressed, for example by employing transparency. Importance-driven rendering is based on a visibility priority which is assigned to each object. It is thus more general, than an emphasis technique for the CSO only. Similar to cut-aways, importance-driven rendering is most suitable to focus on smaller objects (Fig. 7). If objects with high priorities occlude each other, the object with maximum priority is drawn (*maximum importance projection*).

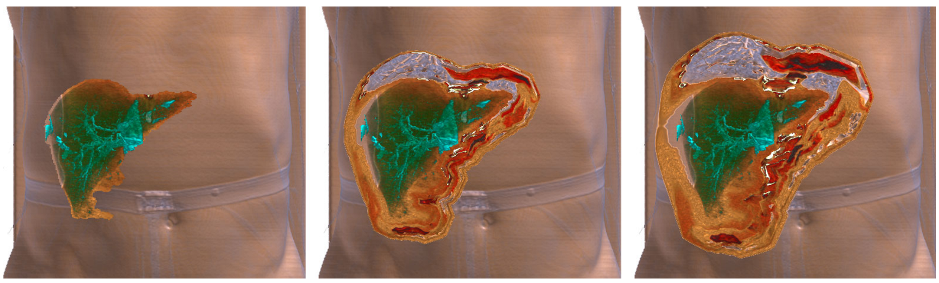

Fig. 7: Importance-driven volume rendering is employed to highlight the liver and intrahepatic structures. (From: [Vio04])

A similar effect to importance-driven volume rendering can be achieved with surface rendering. In order to emphasize objects we determined spheres centred at the object's centre of gravity and render the vertices within the sphere semitransparently. Similar to importance-driven volume rendering, a smooth transition between opaque and strongly transparent objects is feasible.

Cutaway-views for Surgery Planning. Cutaway-views may be used to systematically explore pathologic structures, such as liver and lung metastasis or enlarged and potentially malignant lymph nodes. Patients usually have several of these pathologic variations at the same time. For the exploration, cut-away views should be combined with an interaction technique to “step” through such pathologic variations, for example with the <tab> key. There must be an appropriate sequence in which these metastasis are emphasized. The size of these variations, as an indicator for the importance is a candidate to establish a sequence.

Fig. 8 gives an example for semi-transparent cutaway views designed for highlighting enlarged lymph nodes in the neck area. These images have been generated for neck dissection planning where enlarged lymph nodes play a crucial role. The images represent results of in-depth discussions with surgeons concerning appropriate visualizations to explore the complex anatomy in the neck region. The emphasis technique applied here attempts to optimally convey the spatial relations in the area around the pathology to support the decision whether it can be removed. In addition to visual emphasis, additional textual information, such as size and volume, should be displayed for the selected lymph node in order to further support the specification of the surgical strategy.

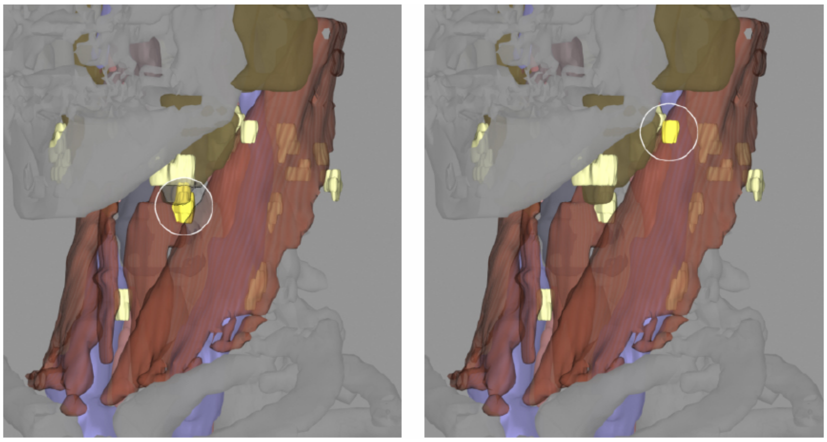

Fig. 8: Lymphnodes, muscles and vascular structures in the neck region. In both images, a lymph node is emphasized by means of a cylindrical cutaway view. (Courtesy of Arno Krüger, Otto-von-Guericke University of Magdeburg)

7 Concluding Remarks

We discussed emphasis techniques in medical 3d visualizations, characterized by complex spatial relations and often complex shapes of the relevant structures. We focussed on the emphasis of a single object. Only some of these techniques can also be applied to emphasize multiple objects. One general goal of emphasis techniques is to reduce side-effects on other objects. With respect to this goal, techniques which affect regions instead of whole models are superior. In Sect. 6, such techniques were discussed.

The role of NPR was discussed with a focus on feature and silhouette lines. These techniques are either used to depict anatomic context or to render focus objects comprehensible. The use of NPR makes additional demands on the object shape: simple isosurfaces of binary segmentation results have to be post-processed to reduce artifacts. Synchronized 2d and 3d visualizations are essential for many tasks in medical visualization, such as measurements, virtual resection (see [Pre03]). Synchronizations are also essential for emphasis: For radiologists and surgeons it is crucial to recognize the relation between a 3d object and its appearance in the original radiological slice data which they have to treat as the "truth".

The work presented here is driven by two applications: The development of visualization and interaction techniques for liver surgery training [Bad04] and the development of intervention planning software [Pre03]. The selection and emphasis of individual objects are essential tasks in these applications.

Further Research. NPR, emphasis and illustration techniques have a high potential in medical applications. Although a variety of techniques is available there is still need for more and refined techniques; as an example NPR techniques are also (potentially) useful in 2d visualizations. Evaluation studies are needed to discuss the effect of these and other techniques for certain classes of anatomic structures and visualization tasks. Vascular structures, muscles, organs, pathologic lesions probably require different techniques and parameters for their visualization in emphasized and de-emphasized states. As another area of future research, it should be explored how the analysis of object shapes might be used to decide on appropriate emphasis techniques. Long elongated objects probably require other techniques than small compact objects and other techniques than branching structures.

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