Interactive Medical Volume Visualizations for Surgical Online Applications

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Abstract. For surgical planning, the exploration of 3d visualizations and 2d slice views is essential. We introduce a new technique to bring visualizations of 3d scenes of any kind and 2d image stacks generated by CT or MRI into the web. We pre-render 3d scenes from different perspectives and show these images during user interaction in a Flash based framework. Therewith we can create a 3d spatial relation. We support different zoom levels and can provide different presets for visualizations. The new technique is used to provide complex and enhanced 3d visualizations for surgical therapy planning and educational purposes as well as for evaluation of new visualization techniques.

1 Introduction

The exploration of 3d visualizations plays a growing role in surgical planning and its training, since they provide a good spatial impression and a three-dimensional overview of complex organs and pathologies. 3d visualizations are used to assess infiltrations of anatomic structures, viable access paths and security margins. Especially for difficult cases, anatomical structures and pathologies are segmented to provide more quantitative information like distances and volumes and to separate different tissues that can be hardly distinguished due to similar values in the 2D slices.

For clinical routine there are many applications available to support the operation planning process, especially radiology workstations and applications running on the medical doctor's local computer. Due to the demand for higher flexibility and better integration in the hospital's IT infrastructure, web-based applications come more and more to the fore. Web-based applications can be used from nearly every computer. For education web-based lectures, e-books and multimedia material are widely used. Even if many applications can be transferred into the web by now, advanced 3d visualization and extended 2d slice views are still neglected. This is caused by the still very high demands of 3d visualizations on the underlying computer and graphics power.

To provide interactive 3d visualization to the user, a common approach is to adapt and re-implement the underlying visualization techniques for an online available browser plug-in like Java or VRML. A main drawback of these strategies is their limitation to single visualization techniques and the costs of the reimplementation for each new technique. Furthermore, volume visualization techniques, that are widely used by medical doctors, are mostly hardware accelerated and therewith not directly useable in an online environment (see Fig. 1 and 2).

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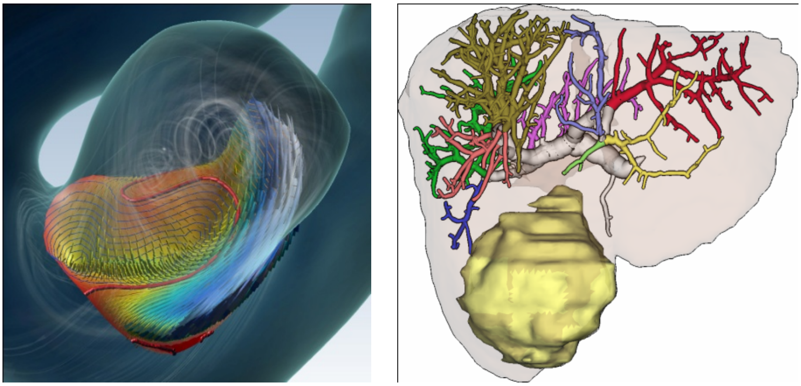


Fig. 1. Left: A 3d volume rendering visualization of an aneurysm with streamlines showing the inner vessel blood flow. Right: A 3d visualization of a liver with vascular structures and a tumor. The vascular structures are enhanced by illustrative rendering techniques.

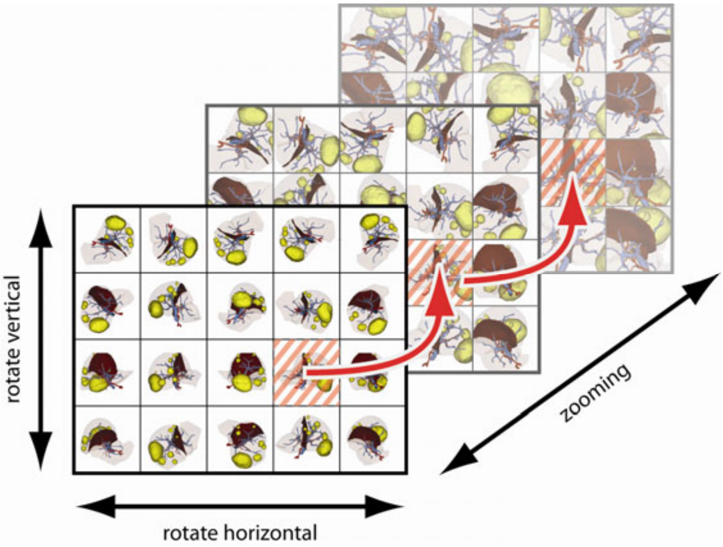


Fig. 2. The images are stored in different matrixes. Rotating the scene, the images from one distinct matrix are shown. For other interactions like zooming another matrix is used and the image that corresponds to the current viewpoint is loaded from that matrix.

We developed a new technique based on pre-rendered images of a 3d scene. Navigating through our images, the user gets a 3d impression of the scene and its objects. Our new format contains different extensions that are important for our medical users to get a better insight in the shown structures. We enable different levels of zooming and the change of the visualization within certain constraints: The user can show and hide important structures and load different states of a visualization. Since we use pre-rendered scenes, we can provide any imaginable visualization technique in our medical web applications. Therefore, we can also show 2d slice stacks for example from CT or MRI scans with colored overlays of segmented structures or textual annotations. The drawbacks of the technique are their lower flexibility with respect to visualization changes (like color changes or structure disabling) - this drawback can be overcome with careful and profound considerations during the pre-rendering process. We will discuss this in detail later.

2 Related Work

There are many formats and techniques to provide three dimensional scenes and objects interactively in the web. Among them are the popular VRML (Virtual Reality Modeling Language) and its successor X3D [1]. Other solutions, like Acrobat3D [2] or Google's O3D [3] are emerging. To show and interact with scenes based on these techniques, web browser plugins are needed. Even if, e.g., X3D is fully implemented in the newest browser versions as part of HTML5 (e.g., in Firefox 4 beta 9), the scope of current 3d implementation for the web is still very narrow.

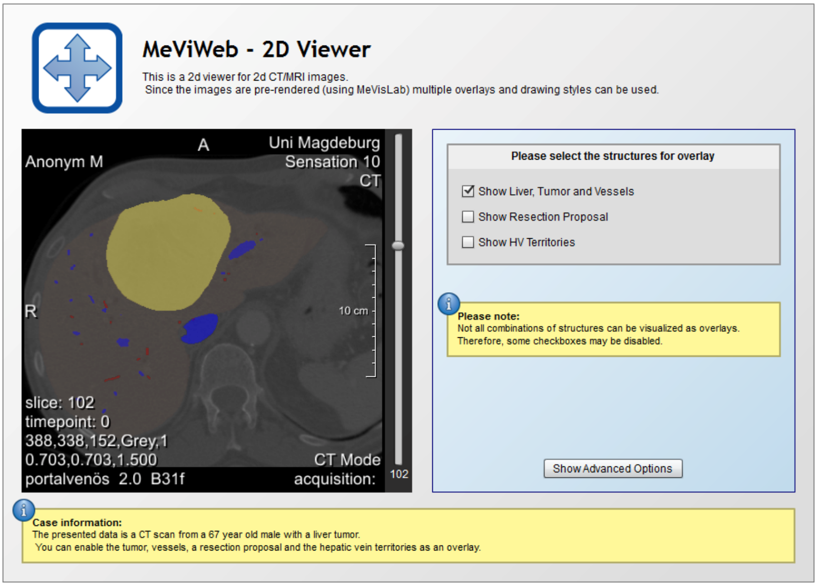
Another big problem of common techniques is that they are limited to rendering polygonal scenes. Many applications like walk-through games or exploration of 3d mechanical models fits this constraints. But special rendering techniques like direct Volumerendering (e.g., [4]), streamline visualizations (e.g., [5]) or illustrative techniques (e.g., [6]) are not realized yet. There are some approaches, which tried to integrate volume rendering in to VRML [7]. This technique, however only provides a very low functionality with basic rendering algorithms.

To provide 3d impressions of products in online shops, the Quicktime VR Object Movie format was developed by Apple [8]. The 3d impression of single objects was imitated by a set of single photos that were taken from different perspectives. Navigating with the mouse in the images, the corresponding images to the current camera position are shown. Depending on the discretization of the images the user can get a real three dimensional impression of the object. The constraints of the approach are the limited degrees of freedom: The camera cannot be freely moved. Real zooming is not provided as well as the scene itself cannot be changed (e.g. a change of the color of the object or the blending of objects). A closely related technique is the Quicktime VR format. It is used to show full panoramic views based on a set of photos taken from within a virtual sphere.

3 New Datastructure for 3d Images and 2d Slices

Instead of adapting existing plugins, like VRML, we chose an approach that is independent from the used visualization technique and refer to it as Object Movies. Object Movies were primarily developed and used to provide 3d impressions from real objects like products in an online shop. Several images are captured from camera positions on a surrounding sphere around the object. These images are arranged in a 2d matrix, where rows represent a set of horizontal neighboring images. The user navigates in this image matrix by dragging the mouse and gets a 3d impression of the object. Current Object Movies are restricted to two degrees of freedom (DOF). The two DOF do not have to be necessarily the two rotation axes. Höhne et al. [9] used in their Voxel Man application one DOF to show different layers of anatomical structures (skin, muscles, vessels, bones). Those visualizations could only be rotated around one axis.

In our online environments, the user may explore several 3d visualizations of segmented anatomical structures. Those visualizations support the spatial impression and illustrate different surgical strategies, e.g., resection planes in the liver surgery or the blood flow in a vessel. Exploring those scenes, the user wants to zoom in/out, rotate the scene, enable/disable different structures and change the appearance of the visualization. Therefore, we enhanced the idea of Object Movies with more degrees of freedom. We use multiple 2d matrixes of images to provide additional facilities to the users. If the user rotates the scene, he navigates in one of these 2d matrixes (see Fig. 3). If he zooms in, another matrix is used and the corresponding image in this matrix is shown to the user.



MeViWeb - 2D Viewer

This is a 2d viewer for 2d CT/MRI images.
Since the images are pre-rendered (using MeVisLab) multiple overlays and drawing styles can be used.

Please select the structures for overlay

☑ Show Liver, Tumor and Vessels
☐ Show Resection Proposal
☐ Show HV Territories

Please note:
Not all combinations of structures can be visualized as overlays.
Therefore, some checkboxes may be disabled.

Case information:
The presented data is a CT scan from a 67 year old male with a liver tumor.
You can enable the tumor, vessels, a resection proposal and the hepatic vein territories as an overlay.

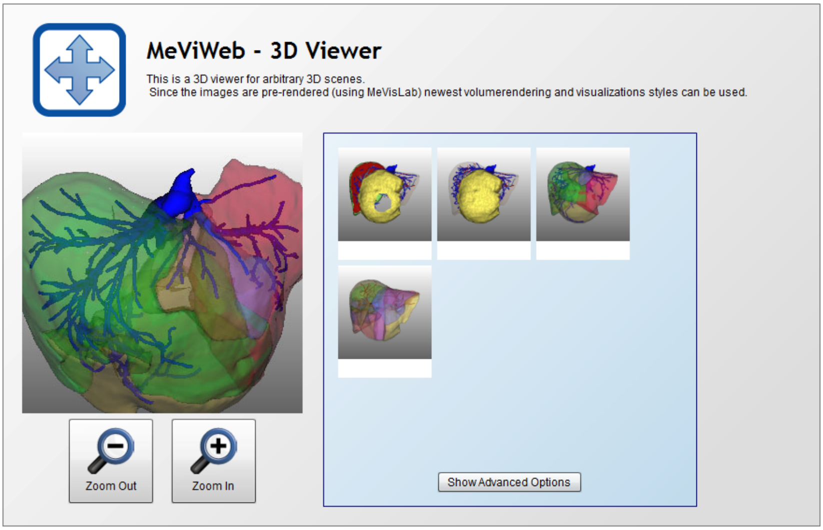
Fig. 3. This application presents a stack of slices to the user. The slices are enhanced with additional overlays. The user can enable the liver, tumor and vessels in combination with a resection proposal and the liver territories of the hepatic vein.

Depending on the angle between the different camera positions that were used for the images, the user gets a pretty seamless 3d impression of the presented scene. Our empiricism showed that an angle of about 18 degrees is appropriate. That equates 20 images horizontally and 10 images vertically. The images are pre-rendered and stored in a simple data format that enables other developers to create their own object movies.

We use FLASH to design and create the front ends of our application. FLASH is widely used plug-in and installed on many systems. Therefore, our FLASH applications can be embedded in larger websites or platforms, as we did, e.g., in an education platform for liver surgeons. Using FLASH, we can also provide our visualizations on mobile systems like Android tablets and smartphones.

3.1 2d Slice Visualizations

As we mentioned above, we are completely free in choosing a rendering or visualization technique. Hence we can use our technique also to provide advanced slice visualizations to the user. For educational purposes, our 2d slices are enhanced by colored overlay of segmented structures. These structures can be for example vital vessels, tumors or organs as context information. In addition, we add textual annotations to the slices, e.g., names of structures as well as additional information like volumes or distances between structures of risk. The user can scroll through the slices and interpret the presented information (see Fig. 4).



MeViWeb - 3D Viewer

This is a 3D viewer for arbitrary 3D scenes.
Since the images are pre-rendered (using MeVisLab) newest volumerendering and visualizations styles can be used.

Fig. 4. In the exploration part of a larger surgical training system for liver surgeons, the user can explore the 3d scene. By loading a sequence of pre-rendered images from the underlying image matrix, an illusion of rotating and zooming the scene is created.

In comparison to the 3d version, we need one dimension less since we only scroll in one dimension. But we can use the second dimension for a specialty of tomography images: In normal radiologic workstations, the user can change the windowing of a slice. We can provide several different window settings as the second dimension. Those window settings (transfer function for gray values) can be automatically derived for CT scans, where the values for each type of structure (Hounsfield Units) are well known.

3.2 Capturing of Images

The still images of the scenes are captured in a pre-rendering step before the visualization is transferred in the online system. This process runs completely automatically and needs as an input only the visualization that should be shown. The images for different zoom levels are generated automatically. Since the user of the 3d visualization later can only see visualizations that were created before, it must be profoundly considered, what different visualizations are generated. In online systems based on polygonal meshes the rendering is performed in real-time online. The user can enable or disable different objects and gets the desired results immediately. Using pre-rendered images, this is not possible anymore. Theoretically, all possible permutations of objects can be pre-rendered and shown on demand - but this is very time- and memory consuming and thus not preferred. We found, that only a few sets of combinations of structures are of interest for the user of a special application. For example, liver surgeons often only inspect the liver in combination with one of the three main vascular systems of portal vein, hepatic vein or hepatic artery. Therefore, visualizations were, e.g., the hepatic vein is shown together with the portal vein, can be neglected and must not be pre-rendered. Taking many of these considerations into account results in a huge reduction of visualizations. Finally, e.g., for our learning environment for liver surgeons only 5-10 visualizations must be generated.

3.3 Performance

The basis of our technique are huge stacks of images. For a set of five visualizations with three zoom levels, 20 images per row and 10 per column as mentioned above, we have 3000 single images. Depending on the image resolution and compression results this in a data volume between 50MB and 90MB. Transferring this amount of data can be still a problem in the context of nowadays capacities. Therefore, we only transfer images which are currently needed. The user will never use every view in every zoom level. We pre-load those images in the background of the application that are in the nearer surrounding of the current view.

4 Application Areas

Currently, we use the interactive Object Movies for different tasks: In a surgical **training system**, the students can study different cases from the area of abdominal surgery. Each case consists of information like anamnesis, tomography image data, videos and several 3d visualizations. The students can explore those visualizations (see Fig. 5), zoom in and change between different views which illustrate important aspects (different vascular systems and segmented areas). In collaboration with experienced surgical educators, for each case the necessary visualizations (shown structures etc.) were determined.

In addition, we use the presented technique to **discuss new visualization techniques** with medical partners over long distances. Since our Object Movies are independent from the visualization technique, we can present newest visualizations based on currently developed volume visualization techniques. Since new techniques often reveal their potential during the 3d exploration, we overcome the presentation of

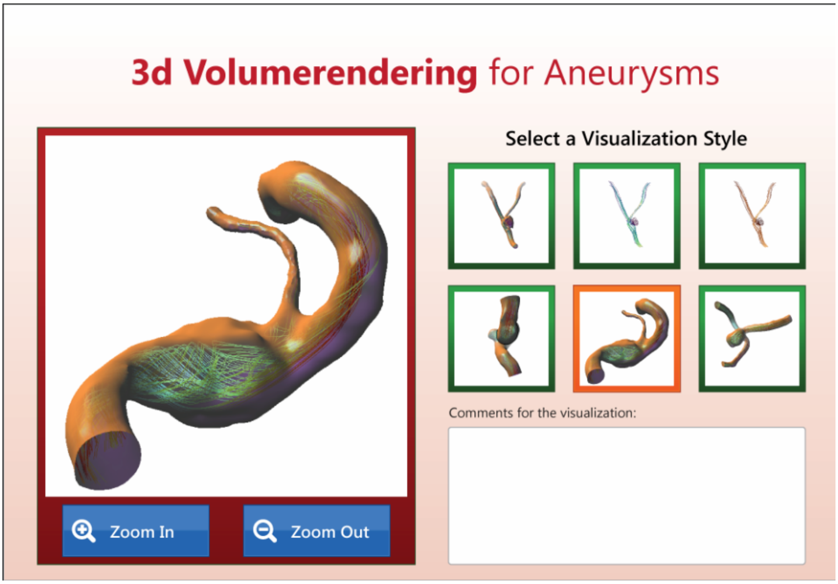

3d Volumerendering for Aneurysms
Select a Visualization Style
Comments for the visualization:
Zoom In
Zoom Out

Fig. 5. This online application is used to discuss new visualization techniques. The user can select different visualization proposals from the right, explore them and give feedback for each technique.

single screenshots or playback of movies. In Figure 6 the interface of a FLASH application is shown, where the user can interactively explore 3d models of vascular aneurysms with simulated blood flow. At every viewpoint, he can change the current visualization technique or zoom in the visualization. For each visualization feedback can be given. Since the flexible FLASH frontend we can also provide complex evaluation questionnaires in combination with the 3d visualizations. This moves our evaluation processes for many new techniques forward since we can receive more feedback from our widespread users based on real 3d impressions.

5 Conclusion and Future Work

We presented a new technique to provide 3d and 2d visualizations in the web. The technique is independent from the used rendering techniques. This enables the user to show newest visualization techniques as well as specific techniques that are too expensive to re-implement in current 3d standards for the web. Future developments should address the performance and memory consumption of the generated image data. Since adjacent images differ only in a small amount, compression techniques adapted from video streams seem to be an adequate solution for a much better compression.

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