EVALUATING VISUALISATION AND NAVIGATION TECHNIQUES FOR INTERPRETATION OF MRA DATA

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Abstract: We argue that a more systematic treatment of the many existing options for medical volume visualisation is desirable. We show that combining the most common medical visualisation and navigation techniques in a systematic way leads to a meaningful set of interesting and sometimes novel UI techniques. We also propose a technique for using generated data and tasks suited to non-medical users for conducting user experiments. We evaluate the UI techniques qualitatively to arrive at a set of promising techniques for future research.

1 INTRODUCTION

The domain of magnetic resonance angiography (MRA) involves computer-aided interpretation of 3D (greyscale) volumes, using specialised visualisation techniques. In this domain, user interfaces (UIs) are still designed in a rather ad hoc way. There are few comparative usability evaluations between different visualisations, or evaluations taking a broader look at for example navigation or editing techniques. We propose an experimental framework enabling more systematic experiments, including a taxonomy of medical interpretation tasks, and combinations of visualisation and navigation techniques, based on known medical practice. The tasks we will focus are verification of automatic analyses of blood vessels (Zudilova and Sloot, 2005), in particular the vessel centerline (a curved line going through a particular vessel), and the vessel segmentation (a mesh describing the surface of a particular vessel).

Medical experts and expert-annotated medical data are hard to get, so we argue that using computer-generated data and non-medical users greatly facilitates usability experiments. This approach is, however, only rarely found (Moise et al., 2005). We designed an algorithm for generating vascular-like structures and mock automatic analyses with artifically introduced errors. Tasks and data are simplified so they can be performed by non-medical users.

2 THE FRAMEWORK

The framework can be subdivided into task, visualisation method, and navigation method. We consider the following subtasks:

- Interpreting the overall 3D structure and locating a particular vessel in 3D space (**overview**).
- Viewing fine greyscale details at relevant locations around the centerline and segmentation (**greyscale**).
- Seeing deviations of the centerline (**deviate C**) and segmentation (**deviate S**) from the greyscale data, indicating problem areas.

2.1 Visualisation

The most commonly used MRA visualisations are described below; see also figure 1. First we have the **slice** visualisations, only showing a slice of the data:

- **Cross-section** - shows the volume data that intersects an arbitrary plane. One particular cross-section that is often used is a close-up cross-

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section of the vessel at a particular point on the centerline.

- **CPR** (Curved Planar Reformatting) (Kanitsar, 2004) - a curved cross-section following the curvature of the vessel.

Secondly we have the **volume** visualisations showing the entire volume:

- **DVR** (Direct Volume Rendering) (Mueller et al., 2005). This involves rendering the volume as a semi-transparent 3D object, representing the greyscale values as densities. Various enhancements exist, such as shading and colour mapping.
- **Isosurface** (Preim and Oeltze, 2007). This involves converting the greyscale volume to a plain mesh surface by connecting the points which have a particular greyscale value. A lot of the data is lost in this visualisation, however.
- **MIP** (Maximum Intensity Projection) (Preim and Oeltze, 2007). This involves creating a 2D projection in which each pixel value is the brightest value found in a ray cast into the scene from that point. Unlike DVR or isosurface, there is no visual cue indicating which parts of the visible structure are in front or behind others.

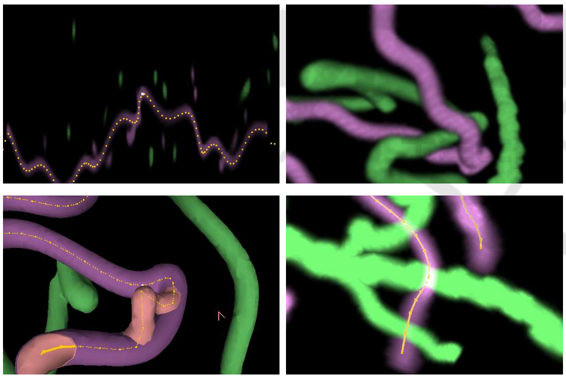

Figure 1: Top left: CPR with centerline. Top right: DVR. Bottom left: isosurface with segmentation and centerline. Bottom right: MIP with centerline.

In cross-section and CPR, the centerline can be shown by projecting it onto the slice plane, and the segmentation is typically shown by only showing the lines that intersect the slice plane. In the volume views, both centerline and segmentation can be shown in an obvious manner. Additionally, occlusion cues can be used for displaying centerline and segmentation in some cases. Isosurface enables the easiest occlusion cues, but they are also possible with properly thresholded DVR.

It is also possible to combine multiple visualisations by integrating them into a combined visualisation. We came up with the combinations below (see also figure 2). As far as we know, these combinations form novel medical visualisation techniques, except the volume-volume combination.

- **Isosurface-slice** - isosurface with any slice visualisation as integrated 3D figure. To compensate for the incompleteness of isosurface data, isosurface is integrated with a slice visualisation, drawing the slice as an oriented plane in the 3D view.
- **CPR-volume** - CPR with any volume visualisation, with the volume view simply drawn over the CPR. A particular centerline point is chosen for which both views are made to coincide graphically. Additionally, the orientation of the 3D view around the centerpoint is equal to that of the CPR.
- **Volume-volume** - any volume visualisation with any volume visualisation. One visualisation is drawn regularly, one or more others are drawn as oriented planes inside the main visualisation. For example, there may be three separate oriented planes on the back faces of the cube surrounding the rendered volume. This type of visualisation is used by the QMRAVWI application (de Koning et al., 2003) developed at Leiden University medical center (LUMC).
- **Isosurface-DVR** - isosurface with DVR as integrated 3D figure.

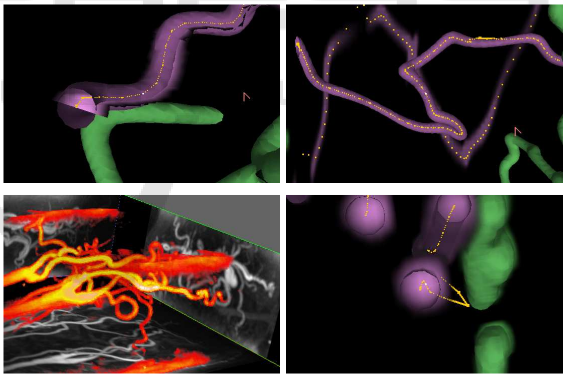

Figure 2: Top left: isosurface-slice (using CPR for slice). Top right: CPR-isosurface. Bottom left: volume-volume (DVR-MIP). Bottom right: isosurface-DVR.

2.2 Navigation

Designing appropriate navigation techniques can be difficult and needs to be studied separately. For 2D representations, navigation consists of panning and zooming. For 3D representations, this includes 6 degrees of freedom (6 DOF) camera manipulation, plus optional zooming. The 6 DOF can be separated into 3 DOF positioning and 3 DOF rotation.

We distinguish several common types of (position) navigation:

Table 1: Table summarising all navigation types and their decomposition into different degrees of freedom. The valid types are given in boldface. Legend: *1D, 2D, 3D*: positioning in resp. 1,2,3 dimensions; *rot*: 3DOF rotation; *axis*: 1DOF rotation around vessel axis. Note that zooming is possible and useful in all cases, and adds one extra DOF to the total.

visualisation →	3D				cross-section	CPR
position↓ rotation→	Free	Centerline	Flyby	Flythrough	(none)	(axis)
Free	**3D + rot**	not useful	not useful	not useful	**2D**	**2D + axis**
Centerline	**1D + rot**	**1D + rot**	**1D + axis**	**1D**	**1D**	**1D + axis**
Pickray	**2D + rot**	pick confusing	cannot pick	cannot pick	N/A	N/A

1. centerline-based navigation: the user can cycle through the points of the centerline forwards and backwards. The view is centered around the currently selected centerline point (the focus point).
2. free navigation: The position can be determined freely rather than being fixed to a centerline point.
3. pickray navigation: A coordinate is selected by clicking on the centerline or vessel wall. The camera will navigate to the selected point.

Rotation in 3D can be treated separately. There are several obvious options:

1. free rotation angle
2. rotation angle always follows angle of centerline. This is a relatively novel navigation technique for MRA. We distinguish several variants:
   - centerline: the user can freely specify a relative rotation angle.
   - flyby: the camera is perpendicular to the centerline, looking at the vessel from "above". This orientation is less useful for isosurface-DVR or isosurface-slice because the isosurface obscures what is inside the vessel.
   - flythrough: the camera is oriented parallel to the centerline, and we zoom in close, like virtual angioscopy (Giachetti et al., 2001). This orientation is less useful for DVR or MIP.

We summarise all possible combinations of rotation and position navigation in table 1. The table summarises which ones are valid and potentially useful, and how many DOF each requires.

3 RESULTS

Most combinations of the given visualisation and navigation techniques form meaningful and sometimes novel interaction techniques. We have made a qualitative assessment about the suitability of each combination for each task, see table 2. For each visualisation, a rating was given in the range *not possible* to *excellent*, and we summarise what kind of navigation was necessary to perform the task. With help of this assessment, we can select the most promising techniques for future user experiments. Based on the table, we conclude that the most promising visualisation techniques overall are isosurface-slice, volume-volume, and CPR-volume.

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Table 2: Table summarising all visualisations. Legend: Task type: C=centerline; S=segmentation. 3D cues: C=centerline occlusion or S=segmentation occlusion. Navigation type: F=free, C=centerline-based, P=pickray. F=C means that F and C are very similar. Rotation type: F=free, C=follow-centerline, B=flyby, T=flythrough. The indications (b) and (t) mean that resp. the flyby and flythrough orientations are less useful. Note that good and excellent ratings are printed in boldface.

visualisation	3D cues	navigation	rotation	
cross-section	**C –**	**F=C –**	**– – – –**	
overview:	not possible			
greyscale:	fair; well visible but extensive centerline-based navigation required.			
deviate:	**good**; excellent for both C and S but extensive centerline-based navigation required.			
CPR	**– –**	**F=C –**	**– – – –**	
overview:	poor, rotation around vessel axis required			
greyscale:	**good**, rotation around vessel axis required			
deviate C:	**excellent**, error can be seen immediately as a veering away or gap in the vessel			
deviate S:	**good**, only for too-wide or too-narrow type errors, rotation around vessel axis required			
DVR	**C S**	**F C P**	**F C B (t)**	
overview:	fair, little navigation required			
greyscale:	fair, rotating and zooming required			
deviate:	fair, rotating and zooming required			
isosurface	**C S**	**F C P**	**F C B T**	
overview:	**good**, little navigation required			
greyscale:	not possible			
deviate C:	**excellent**, occlusion cues help see if the centerline is in front of or behind the vessel, so little navigation required			
deviate S:	**good** if isosurface is representative of the segmentation location, rotating and zooming required			
MIP	**– –**	**F C P**	**F C B (t)**	
overview:	fair, rotation required, sometimes hard to see what's in front or behind			
greyscale:	fair, rotating and zooming required			
deviate:	fair, rotating and zooming required			
isosurface-slice	**C S**	**F C P**	**F C (b) T**	*Note: "slice" may be cross-section or CPR*
overview:	fair, little navigation required. For CPR, the slice plane may make visual scene harder to interpret			
greyscale:	**good**. Requires close-up view and centerline-based navigation.			
deviate C:	**excellent**, occlusion cues help see if the centerline is in front of or behind the vessel, so little navigation required			
deviate S:	**good** if isosurface is representative of the segmentation location, navigation required			
CPR-volume	**C S**	**– C –**	**– – B –**	*Note: "volume" is DVR, MIP, or isosurface*
overview:	fair to **good**, little navigation required			
greyscale:	**good**, navigation same as particular volume visualisation method			
deviate:	**good** to **excellent**, similar to CPR			
volume-volume	**C S**	**F C P**	**F C B T**	*Note: "volume" is DVR, MIP, or isosurface*
overview:	**excellent**, the cube backface projections help locate a point precisely, except when zooming in closely.			
greyscale:	fair, rotating and zooming required			
deviate:	fair to **excellent**, inherits properties from both visualisation methods used			
isosurface-DVR	**C S**	**F C P**	**F C (b) (t)**	
overview:	**good**, little navigation required			
greyscale:	fair, though not as good as DVR by itself, rotating and zooming required			
deviate:	**good**, similar to isosurface, though not as good.			