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Verantwortlich für diese Ausgabe:
Otto-von-Guericke-Universität Magdeburg
Fakultät für Informatik
Konrad Mühler
Postfach 4120
39016 Magdeburg
E-Mail: muehler@isg.cs.uni-magdeburg.de

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Abstract— Textual annotations enhance visualizations and provide additional information such as object names or measures, e.g. volumes or distances. They are essential for surgery planning, in particular for documentation and collaborative discussions. For optimal use, it is crucial that the relation between visualized objects and related annotations is unambiguous and easily perceived. We describe a framework to automatically annotate 2D slices and 3D reconstructions of segmented structures. Based on a discussion of specific requirements, we present dedicated types of annotations for medical visualizations. Furthermore, we introduce a new interaction technique for the annotation and visualization of currently hidden objects, and present an evaluation of our framework.

1 Introduction

Textual annotations are an inherent part of many visualizations in medicine, e.g., in anatomical textbooks. Anatomical structures must be identified and related to textual descriptions. In surgical planning, important structures must be identified in 2D slices and 3D reconstructions. Structures that were identified in 2D slices must be mentally mapped to 3D scenes. Thus, textual annotations may support the user to determine structures in 2D and 3D visualizations. Furthermore, textual annotations can present additional information directly in the visualization. These are, e.g., extents and volumes, distances, and comments from the radiologist. Such information is often directly relevant for treatment decisions, e.g., the extent of a tumor determines the viability of a radiofrequency ablation. Besides the use for surgical planning, annotations are essential for training systems, e.g., hints from a surgeon are shown for the trainees.

All annotations in 2D as well as in 3D should be placed automatically. An algorithm for annotation placement must incorporate several constraints: a) Annotations must neither overlap structures nor each other, b) connection lines between the annotated structure and the label text should be short and must not cross each other, and c) annotations should be aligned to achieve an aesthetical layout. These general requirements are quite similar to map labeling or graph drawing tasks. However, 3D scenes with objects of a complex topology pose specific solutions. We developed a framework to automatically annotate 3D scenes of segmented structures as well as 2D slices. We describe a new method to annotate structures in 3D that are occluded by other structures or that are located in the inner of enclosing tissue (like vessels in the liver). Furthermore, we present a new interaction technique that enables direct interaction with the annotations for the selection of invisible structures for a closer inspection. The specific annotation techniques were derived from discussions with surgeons related to surgical planning and training systems. We performed an evaluation of our techniques and provide several presets of annotation styles for different personal and application-dependent preferences.

2 Related Work

The need for automatic annotations for medical visualizations is evident. For example, MeVis Medical Solutions, a company that performs amongst others pre interventional planning tasks for liver surgery, managed more than 3.000 cases in the past years, by manual annotating about 30 visualizations for each case. Several systems were published which provide annotated medical scenes. Cai et al. [4] presented a system where medical doctors can draw primitives into a 2D slice to enhance the interdisciplinary communication. Goede et al. [6] stored manual annotations of slices separately to ease the transfer of cases. Lober et al. [10] presented a system to annotate 3D scenes for anatomical education. The labels are placed in a separate column - intersections are not avoided and the labels are only visible from the exact viewpoint they were once defined. Even in very recent systems such as the Voxel-Man 3D-Navigator for medical education [8] the labeling is straightforward and does not prevent overlapping of labels or lines. Furthermore, nearly all annotations must be generated manually.

Automatic annotation of 2D visualizations is focused on map labeling, where as many points as possible in a map must be annotated without overlapping. However, in the usual map labeling problem, all labels have equal size and are placed directly adjacent to points without any reference line (see Christensen et al. [5] for an overview). Nevertheless, only a few approaches annotate 2D regions with labels connected by lines. Bekos et al. [3] placed all labels on the right side of the visualization resulting in unnecessary long connection lines between labels and annotated regions.

A similar approach for the annotation of 3D medical scenes was presented by Preim and Raab [12] where all labels were placed in two columns left and right beside the scene. Anchor points must be precalculated in an extensive preprocessing based on a skeletonization of the target structures. Stein et al. [14] placed labels in a scene of opaque objects. The initial location of each label is close to its annotated object. Optimizing an energy function under certain constraints, the labels are repositioned considering e.g. the length of the connection line or the importance of overlapped polygons. Goetzelmann et al. [7] annotated medical objects by internal labels. The labels were deformed to fit in the object's shape and were hardly legible. Ropinski et al. [13] deformed internal labels to achieve a better depth perception of the structures. However, the internal labels are still hardly legible and restricted to short names and abbreviations. Ali et al. [1] presented a comprehensive system to annotate 3D scenes with external labels. They colored all objects in a unique color and rendered the scene into an ID buffer. A distance transformation on the ID buffer is performed to identify possible anchor points as the most inner point of each structure. A surrounding hull around the scene is computed and the labels are placed on it considering crossing lines. Labels are assumed as mass points what shrinks the approach to single line texts. The rendering of all structures into a single ID buffer limits the approach of [1] to scenes of opaque structures.

3 Methods

To annotate 3D scenes of segmented structures, we present an approach to annotate enclosed or occluded structures among visible structures. To annotate segmented structures in CT or MRI slice data, we developed a new approach that considers the peculiarities of a stack of 2D slices. In this section we describe the technical background of the algorithms after giving an insight into some medical scenarios we are dealing with.

3.1 Medical Case Scenarios

We consider visualizations based on pre-segmented structures and pathologies. This situation is typical for operation planning in many fields: **Neck dissections** are carried out for patients with malignant tumors in the neck or head region to remove lymph node metastases.

• *Konrad Mühler and Bernhard Preim are with the Department of Simulation and Graphics, University of Magdeburg, 39106 Magdeburg, Germany, E-mail: muehler@isg.cs.uni-magdeburg.de*

Algorithm 1 Create all necessary ID buffers with mutual unoccluded structures

Require: all structures s
Ensure: list of ID buffers b
clear list of buffers b
for each structure s_i **do**
  for each buffer b_j **do**
    if s_i does not overlap with a structure in b_j **then**
      add s_i to b_j
      break buffer loop and proceed with next s_{i+1}
    end if
  end for
  if s_i was not added **then**
    create new buffer b_{j+1} and add s_i to it
  end if
end for

The surgeon must explore all enlarged lymph nodes and vital structures in the surrounding to safely resect them. In **abdominal surgery**, the resection of tumors in the liver, kidney or pancreas are rather similar with respect to visualization. The surgeon must judge the feasibility of different intervention techniques with respect to safety margins. Several structures like vessels and tumors are enclosed by tissue that is often visualized as context information and shown with high transparency to reveal the inner structures. The textual annotation, e.g., of the vessel branches with their names or different territories with their volumes can speed up the exploration process.

3.2 Automatic Annotation of 3D Visualizations

When annotating 3D medical scenes of segmented structures we were confronted with the problem of annotating a combination of semi-transparent and opaque structures, where the semi-transparent ones often occlude other structures completely. As an example, in liver surgery planning, the liver parenchyma is shown as context information in combination with vessels and tumors inside (see Figure 2). These structures could not be annotated with previous approaches. Hence, we extended the approach of [1] by a multi-buffer rendering. All structures (no matter if opaque or transparent) are rendered in different ID buffers to identify possible anchor points. In the worst case, we might render each structure in an own ID buffer.

To reduce the number of buffers, all structures that do not overlap each other from the current viewpoint, are rendered together in one ID buffer (see Figure 1 and Algorithm 1). The information of mutual occlusion is generated in a preprocessing step by an approach that we adapted from Muehler et al. [11]. For example, for the visualization in Figure 2, nine structures must be annotated (all structures lie in the inner of the liver). Four ID buffers are necessary to render all structures without mutual occlusion and to identify all anchor points. Having an anchor point for every structure, we can annotate it, even if it is hidden by other structures. To annotate only structures that are hidden by a very transparent structure (and therefore clearly visible), we perform a ray casting at the anchor point's position and measure the ray attenuation from the viewpoint to the target structure indicating its remaining visibility. If this value is above a certain threshold, the structure will not be annotated with a connection line. Since a structure can be occluded at the anchor point while other parts are visible, multiple anchor point candidates are used to extend the range of possible visible anchor points (a set of three to five anchor point candidates figured out to be appropriate).

Annotation of hidden structures. For hidden structures, we introduce a new interaction technique that places a label and refers with an arrow in the direction of the corresponding structure (see Figure 3). Thus, the user gets information about the existence of the structure and is guided to its location. Clicking on the label, the camera is automatically moved to a good viewpoint that is computed by an algorithm developed by [11], where the structure is visible. This movement is performed in an animation, thus providing a smooth transition between the two viewpoints. For example, in neck surgery planning, all

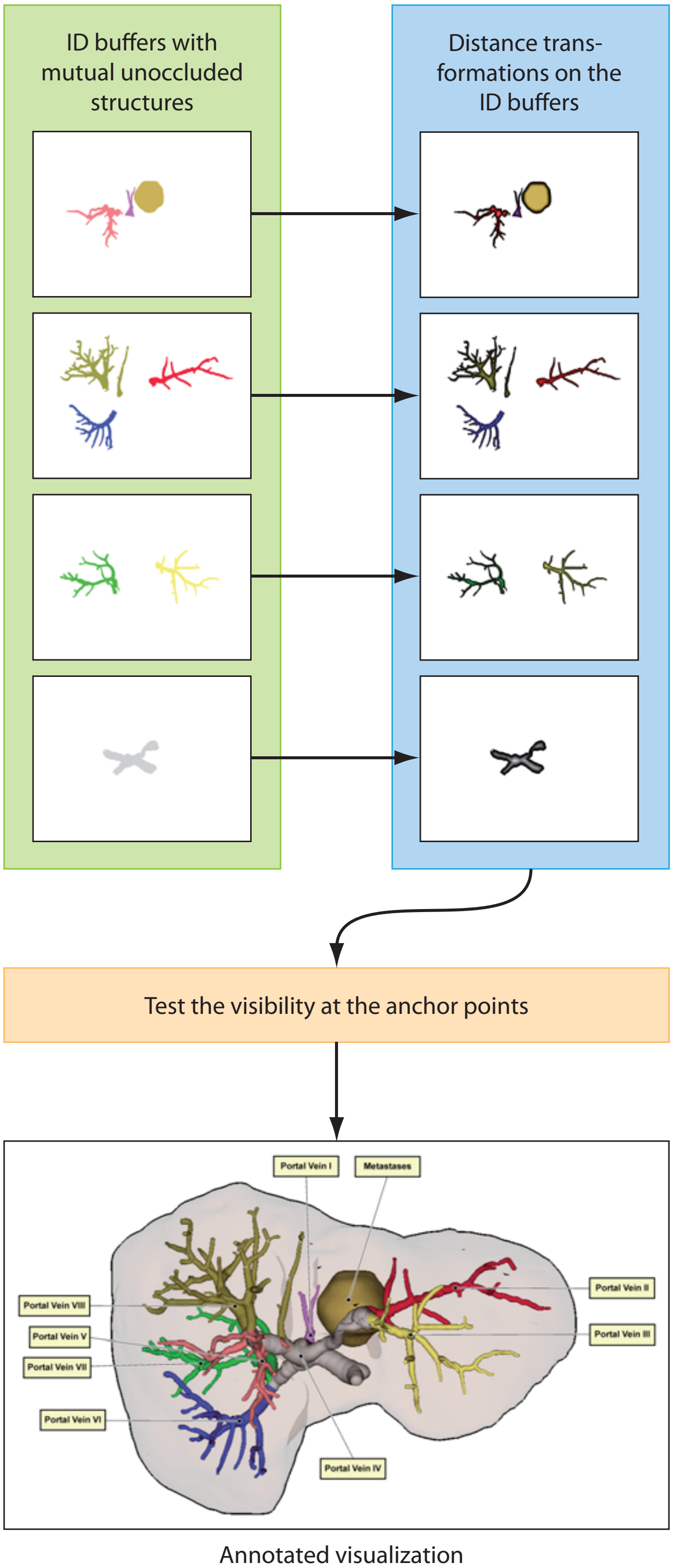

Fig. 1. All structures that do not overlap each other are rendered opaque in a unique color together in one ID buffer. A distance transformation is performed to identify possible anchor points. Finally, the visibility of each structure is determined to decide whether it will be annotated with a straight line or an arrow pointing to hidden structures.

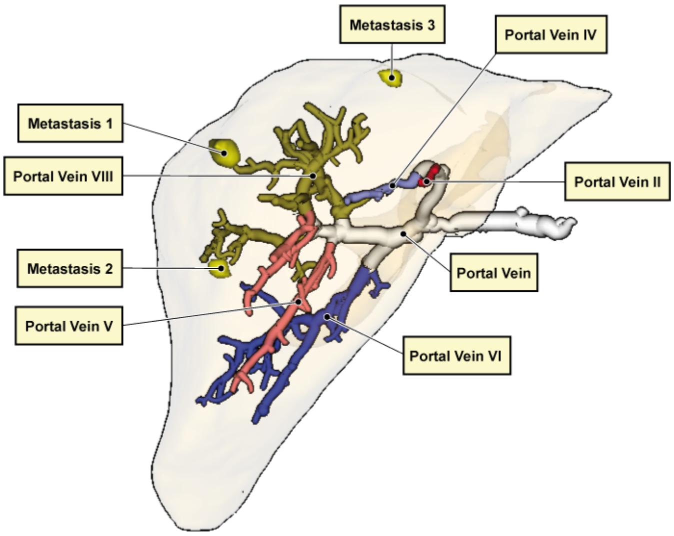

Fig. 2. Automatically annotated structures in the liver parenchyma. The structures can be annotated even if they are completely occluded by the liver.

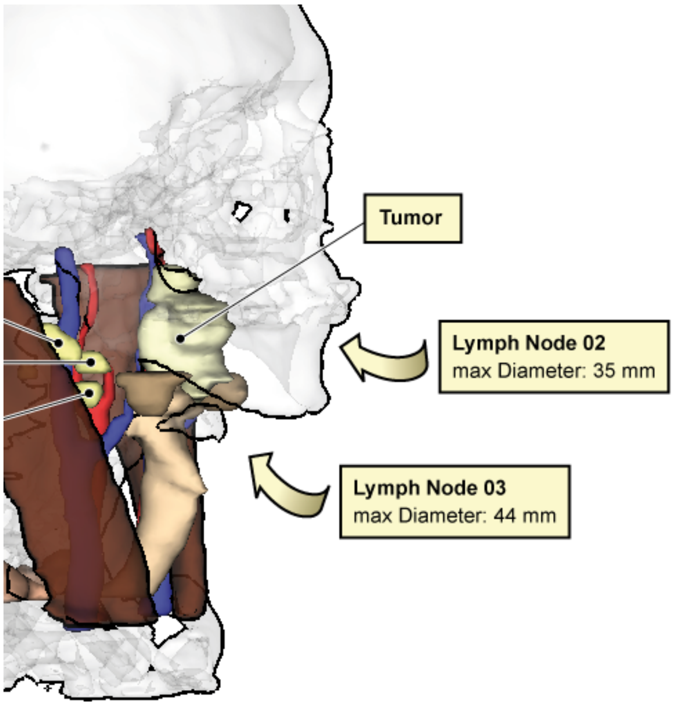

Fig. 3. Hidden structures are annotated using a bended arrow. Thus, the user knows where to look for further critical and important structures. Clicking on the annotation starts an animation that leads to a good viewpoint on the structure.

enlarged lymph nodes are annotated with its maximal diameter. Since there is nearly never a viewpoint where all lymph nodes are visible, the annotation of hidden lymph nodes with an arrow guides the surgeon not to miss any lymph nodes. Lymph nodes, that were still inspected, are marked in their annotation. Since the labels of all structures are selectable, they can be used for further interaction techniques. Small structures can be easier selected by picking their annotations or annotations can be expanded to provide further information like comments.

Annotation layout and styles. If possible, annotations are placed at a surrounding hull around all structures. If the user zooms in the scene, sometimes no free space at the surrounding hull is available to place the labels. In this case, areas that are only occluded by less important structures, such as the liver parenchyma, are interpreted as free space where an annotation is placed in a short distance to its anchor point using the distance transformations of the ID buffers (see Figure 4(a)). We use the transparency of structures as a measure for their importance (high transparency = low importance). In addition, we consider importance values defined for individual objects or categories, such as vascular structures. To enhance the mapping of the labels to the structures, we developed different styles. To convey visual togetherness of the name and additional information in a label, we can underly each label with a colored box. This also enhances the contrast between text and background if the label must be placed above a structure. We also provide an automatic colorization of these boxes with the color of the structures in the scene (see Figure 4(a)). Especially for educational environments, users cannot be assumed to be familiar with the anatomy. Hence, a symbol of the type of the structure can be added to the annotation to achieve a faster recognition of the structure (see Figure 4(b)).

3.3 Automatic Annotation of 2D Visualizations

Discussions with surgeons clearly revealed that segmented structures in 2D slices should be annotated as well. To provide this feature, the regions are determined and anchor points are calculated using a distance transformation comparable to the 3D approach. The distance transformation is concurrently used to determine the free space, where the annotations can be placed[1]. As anchor point, the point in the inner of the region with the largest value in the distance transformation is chosen. For each annotation an initial position is searched in the distance field where there is enough free space to place it without overlapping regions and where the distance to the corresponding region is minimal. This may lead to conflicts like crossing lines or overlapping annotations. These conflicts are solved by switching the annotations' positions or moving annotations apart in opposite directions searching for new possible positions in the free space.

In some cases, large regions such as the liver parenchyma block large parts of the slice - annotations would have to be placed outside the large regions, even if the annotated regions are small and lie in the inner of the large region (e.g., vessels in the liver). As a remedy, we assign importance values to the regions. Structures of interest that never must be overlaid by a label are rated high while context structures such as the liver parenchyma are rated low. Thus, the label of a more important structure can be placed inside the region of a low importance structure (see Figure 6). To prevent small structures from being overlapped by the anchor point and connection line of the corresponding annotation, we encircle small regions, e.g., "Portal Vein I" in Figure 6. To reduce the number of labels and the visual clutter in a view, labels of the same structure are grouped automatically if the distances between the anchor points are below a certain threshold.

One special aspect in annotating 2D slices is the **coherency of annotations** if the user scrolls through the volume. If for every single slice an optimal placement of all annotations is calculated, the annotations 'jump' around from slice to slice. They are unreadable and can hardly be tracked over multiple slices. Therefore, we lock a once calculated position of an annotation over multiple slices until the annotation comes into a conflict, e.g., by overlapping a region (see Figure 5). Even if the individual placement of each label in the current slice is not the best anymore, the readability of annotations and the tracking of structures are improved.

3.4 Manual Annotations

The information, that is used to annotate scenes automatically, is mostly gathered from available data like names, extensions or anatomical belongings. Nevertheless, the data may be changed and extended during the exploration process, e.g. if the medical doctor wants to add a comment to a specific pathology or mark a specific region to share this information with colleagues. We integrated tools for man-

[1] Positive values lies in the inner of the structure, negative values are free space and describe the distance to the structure.

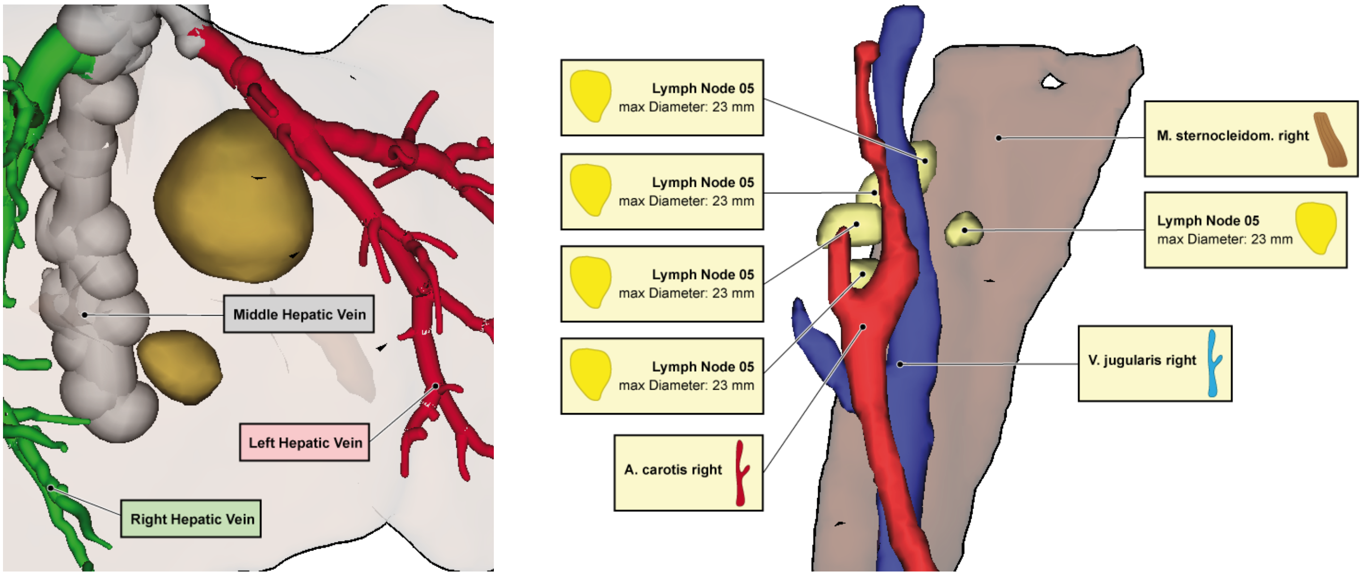

Fig. 4. (a): If no free space is available to place the annotations, they will be placed above structures of low importance. In this image, the annotations of three veins are placed above the liver parenchyma. (b): For some applications icons of the structures can speed up the recognition and mapping of the annotations.

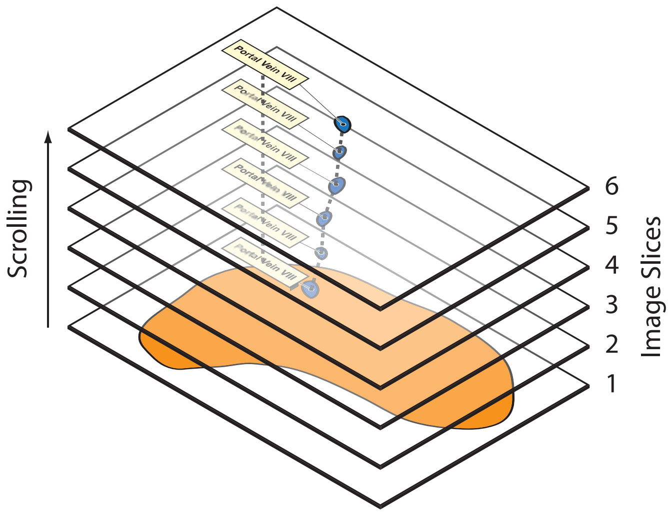

Fig. 5. Slice coherency for 2D annotations. The label's position is locked over multiple slices to support the readability and tracking.

ual annotation into our framework: The user can select and change the contents of all annotations. Furthermore, regions can be marked and annotated in the 2D slices or on 3D surfaces. To add new annotations, our medical partners preferred the 2D slices since annotations can be placed more precisely. We provide a small set of primitives like sphere and boxes that can be originated. The regions are converted in 3D meshes that are integrated and annotated in the scenes equal with the pre-segmented structures in the 2D and 3D visualizations. Manually added objects are handled as most important and will never be overlapped by labels.

4 Evaluation

We performed an informative evaluation, where we asked 38 users to judge 24 images with different label styles and placement configurations in medical 2D and 3D visualizations comparable to the images in this paper. 21 users had a good or very good medical knowledge (e.g, medical doctors or medical assistants). The styles we presented were: a) annotations without any box, b) annotations with boxed background, and c) annotations with an icon of the structure. We also presented different styles of grouped annotations and presented the new interaction technique to annotate hidden structures. We asked for a judgment of the annotations' appealing and mapping between annotations and corresponding structures on a scale from 1 (very good) to 5 (very bad). For a detailed ranking see Table 1. We also asked for comments with respect to every style. The comments were strongly diverging. They showed a strong personal preference (e.g., some strongly preferred the icon labels, some refused them). Therefore, we decided to provide a **set of presets**, where the user can choose the personal style from a set of illustrating thumbnails.

5 Discussion

We presented a framework for automatically annotating for surgical planning. Carefully selected labeling techniques for intervention planning are provided as well as techniques to handle specific characteristics of medical visualizations like coherency of annotations in 2D slices and annotation of enclosed or occluded structures. We introduced an interaction technique that reveals hidden structures to prevent its oversight. Furthermore, we enable the user to change annotation texts and to add new annotations by originating objects in 2D slices or by drawing on 3D surfaces. We performed an informative evaluation. The results indicated that the newly introduced techniques are useful and revealed a strong influence of personal preferences. Consequently, we extended our framework by facilities to provide several presets to the user. The annotation framework is integrated in several applications. In the LiverSurgeryTrainer [2] the annotations are used to provide information about several structures as well as expert comments to trainees of surgery. In the NeckSurgeryPlanner [9] our annotation facilities are used to automatically annotate structures in the neck region to support the intervention planning process in clinical routine.

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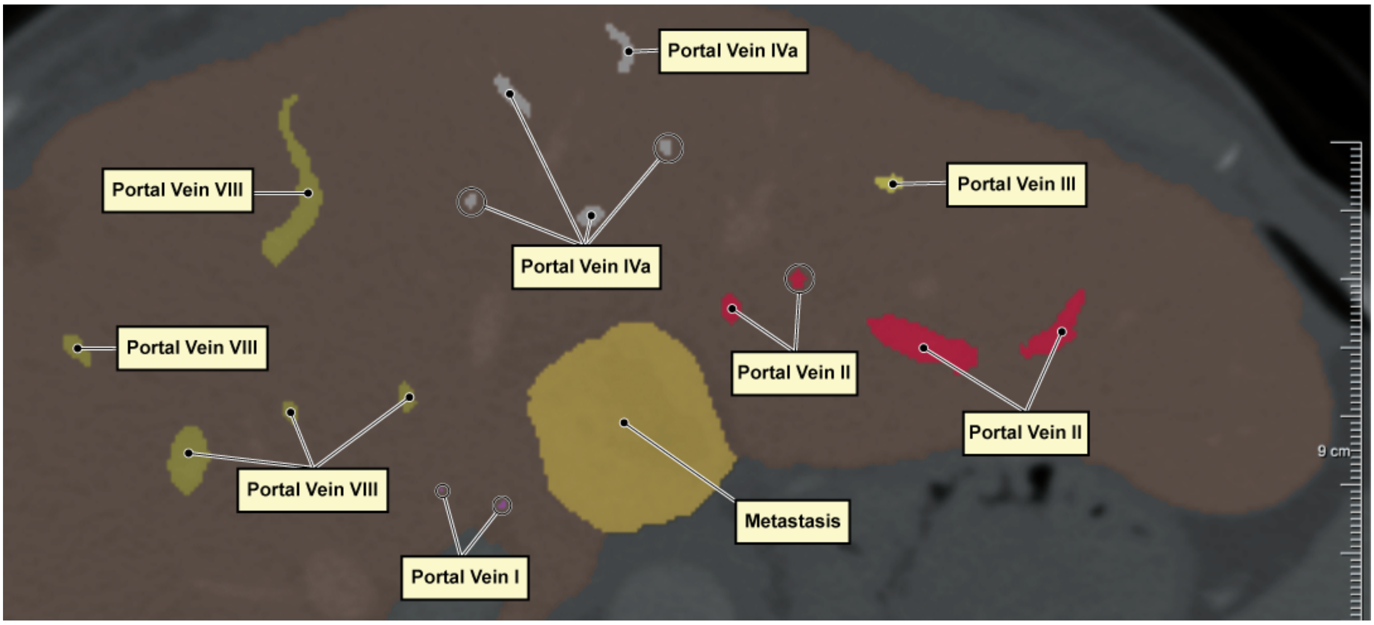

Fig. 6. Annotation of different structures in a 2D slice of the abdomen. The annotations of more important structures (vessels) are placed inside the less important structure (liver parenchyma). The numbers are related to the Couinaud segment supplied by the specific portal vein branch. Annotations of different regions of the same structure in a near surrounding are grouped together.

Type of annotation	Appealing	Mapping
Labels without boxes	2,6 ($\sigma = 0,84$)	2,5 ($\sigma = 0,84$)
Labels with uniform colored boxes	2,0 ($\sigma = 0,63$)	2,0 ($\sigma = 0,63$)
Labels with background in structure's color	2,1 ($\sigma = 1,12$)	1,9 ($\sigma = 0,89$)
Labels with icons	2,4 ($\sigma = 1,16$)	1,9 ($\sigma = 0,98$)
Ungrouped labels	3,6 ($\sigma = 0,81$)	2,8 ($\sigma = 0,96$)
Grouped labels (Most preferred grouping style)	2,1 ($\sigma = 0,59$)	2,0 ($\sigma = 0,63$)

Table 1. Results of the evaluation of 3D annotations. 1=very good; 5=very bad; The results for the 2D annotations are comparable.

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