Abstract. We discuss interaction tasks and interaction techniques for the planning of soft tissue operations as for example oncologic liver and lung surgery. We focus on techniques allowing to explore the relevant anatomical and pathological structures, to integrate measurements directly in 3d visualizations and to specify resection volumes. The main contribution of this paper is the introduction of new techniques for 3d measurements and for virtual resection. For both interaction tasks, dedicated widgets have been developed for the direct-manipulative use. In contrast to surgical simulators, which are used in order to educate future surgeons, we concentrate on surgeons in the clinical routine and attempt to provide them with preoperative decision-support on the basis of patient-individual data.

The selection of the interaction tasks to be supported is based on a questionnaire in which 13 surgeons described their praxis of surgery planning and their requirements for computer support. All visualization and interaction techniques are integrated in a software, named SURGERYPLANNER, which exploits the results of image analysis achieved in an earlier project as input.

Keywords: 3d interaction, visualization, medical graphics, computer-assisted surgery

1 Introduction

The treatment of malignant diseases targets at the complete destruction or removal of all tumors together with a sufficient tumor-free margin. At the same time life-critical anatomical structures must be saved. The appropriate therapy depends on tumor size, number and location in relation to anatomical structures.

In this paper, we focus on the planning of interventions to treat solid malignant tumors in organs, such as the liver, the lung, and the kidney. The anatomy of these organs is characterized by hierarchical vessel systems. Since vessel systems are tree-like structures, a therapy which destroys a large blood vessel would at the same time interrupt the blood supply for a large part of the organ involved. In order to assess the risk of such a procedure, the volume of the organ which remains intact is a relevant measure. The main problem in the process of therapy planning is the high variability in the shape and size of anatomical structures, therefore, a clinically relevant visualization for planning must be based on patient-individual data.

Currently, the treatment is planned based on CT- and MR-images. This leads to several problems: the spatial relationships between vessels and tumors are difficult to judge. The volume of tumors, the vessels involved in the therapy of a tumor and the region which is supplied by the involved vessels can only be estimated roughly.

In this paper, we discuss interaction techniques to provide decision support for the above-mentioned questions. These are integrated in the SURGERYPLANNER three main components:

- a flexible 3d visualization for the exploration of relevant structures,
- a resection planning module which provides tools in order to explore a resection strategy (e.g. to simulate the removal of parts of an organ) and
- a measurement module which provides dedicated 3d widgets for the most crucial measurement tasks, such as distance measurements.

While the visualization component exploits well-known techniques, novel approaches are described for virtual resection as well as for 3d-measurements. SURGERYPLANNER is intended to support preoperative decision-making and to explain it to a patient.

2 Medical Background

The main issue of segment-oriented surgery is to account the individual vessel anatomy. As an example, we describe the anatomy of the liver which is characterized by four hierarchical vessel systems: the portal veins, the liver veins, the arteries and the bile ducts. Similar requirements exist, however, for minimally-invasive therapies, where tumors are destroyed, for example by heat. Therefore, we use the more general term therapy planning.
ative planning the portal venous system plays a key role because it defines the functional units of the liver – the segments. Hepatic veins drain the liver. According to the wide-spread Couinaud model [4] the liver consists of 8 segments which are defined as the regions supplied by a third order portal branch (third order refers to the bifurcation). Similarly, the lung anatomy is characterized by the bronchial tree and consists of 18 segments. Liver and lung segments are important to describe the location of a tumor and to perform a resection. Unfortunately, segment boundaries are not recognizable in clinical CT data. Vessel systems enter an organ in the central part and bifurcate in their course to the periphery, where the vessel diameter reduces. Whether a tumor can be treated surgically often depends on the distance between the tumor and a major blood vessel (diameter > 2 mm).

In order to get a better understanding of the requirements, which surgeons actually have in practice, we have polled surgeons by sending out some 30 questionnaires, from which 13 have been returned (all 13 are male, average age 42 years, experience in tumor surgery on the average 10 years). All surgeons indicated that the spatial relationships between vessels and tumors are difficult to judge and that a 3d visualization and quantitative analysis (for example distances) would be helpful for this purpose. Almost all, 12 of the 13 surgeons, indicated they would appreciate trying out resection strategies preoperatively which reveals that it is often not obvious, how to resect a tumor. In particular, if more than one tumor has to be treated, it is difficult to judge whether these should be removed with a large cut, or with individual cuts for each tumor. The design of the SURGERY PLANNER and the focus on the specification of resection volumes as well as the integration of measurements are based on this survey.

3 Prior and Related Work

The work presented here is related to the field of surgery simulation. Surgery simulation is concerned with the modelling of surgical devices, the detection of collisions between surgery devices and tissue, the modelling of the elasticity of different tissue types, and finally with the simulation of deformations and cutting procedures. In [3] for example, deformations are simulated with finite elements which facilitate a precise imitation of the realistic behavior at the expense of high computational costs. Mass-spring models, on the other hand allow near real-time interaction [12]. Recently, a framework for physically based modelling and cutting of soft tissue has been presented [1]. A sophisticated system for liver surgery simulation has been developed at INRIA [2, 8] which is based on the Visible Human dataset created by the National Institutes of Health. This work contributes to tion based on the interaction with virtual models.

In contrast to surgery simulation our focus is directed by the requirements of (experienced) surgeons to the term therapy planning instead of simulation. The difference, for therapy planning, relevant is: Is a malignant disease curable? Which appropriate? Which volume must be resected? cations must be considered? To answer these cal data of the individual patient are require main difference in comparison to surgery is only often only one typical non-pathological dataset is er. Concerning the major 3d interaction task support, namely virtual resection and 3d-relevant work exists to our knowledge with usability aspects. If it is possible at all to int measurements in a medical visualization simple lines for the specification of angles) are used. tages of this approach are that lines are hard to it is very difficult to evaluate the placement of lines in relation to anatomical structures.

Computer support for planning liver and lung surgery planning. The identification and segmentation of organs and of the tumors inside it, as well as the definition, require excellent radiological data and a dicated methods which still form an area of active research.

The work presented here relies on image p rithms developed in our group in an earlier include algorithms for organ and tumor segmenation, vessel analysis and segment app. [13], [14]. These algorithms have been careful tests on CT lung images [6] as well. Vesse analysis is performed by a skeletonization, which presents the branching hierarchy. Based on an sement diagram, i.e. regions supplied by a subtree structures, are approximated. Segment approximations which have been evaluated [5] and [6].

While this paper is focussed on the int ques for therapy planning, an alternative appro to let the planning system “suggest” resection lines for the specific question is given. We have described this approach and its limitation

4 Visualization for Therapy Planning

In the image processing stage, the organ (liver) tumors and the segments are identified in the data (often – 100 slices with 512×512 pixels
liver surgery planning the portal venous system and the hepatic veins are separated and the individual branches of the vessel system are detected. For lung surgery planning the bronchial tree is segmented and analyzed with similar methods [6]. A tagged volume represents the voxel-object relationship.

4.1 Visualizing Anatomical and Pathological Structures

The SURGERYPLANNER uses the segmentation information represented in the tagged volume to allow the user to design a 3D visualization. An OPENINVENTOR viewer with the usual features for camera control is used to explore the medical data. The viewer used in the SURGERYPLANNER extends the features of the ExaminerViewer in two ways: it provides a shadow projection on a camera-fix plane, and it supports 3D interaction with several 3D input devices. A library developed in-house with support for wire-frame, surface and volume visualization is used for rendering. For the exploration of the data the following interaction tasks are supported:

- assign presentation variables to individual objects,
- filter objects (select the objects to be displayed),
- add annotations,
- add margin objects,
- compare different views of the data.

Assign presentation variables. Presentation variables include rendering styles, colors of vessel systems and segments, transparency values (for organs and segments) to reveal structures inside. Default values for these variables, in particular colors, are derived by analyzing wide-spread textbooks (e.g. [9] and [10]). Fig. 1 and Fig. 2 present typical visualizations.

In order to simplify the design of a visualization, objects are categorized (categories include vessels, tumors, segments, organs). Every adjustment of annotation styles or presentation variables can thus be applied to the whole category which makes it easier to generate consistent visualizations.

Filter objects. Facilities to filter objects are mandatory, because often some 50 objects result from the image processing stage which should not be displayed simultaneously.

Add annotations. Annotations are used to integrate alphanumeric information from the image processing stage. This includes the volume of an object (often important for tumors) and the extent of the axis-aligned bounding box. The object name, and an additional note may be included. Annotations are presented using 2D text which remains visible and legible after 3D transformations. As default, annotation is added to the object to which they refer by lines near the bounding box of the whole model. Volumetric text does not occlude the visualized surface.

Add margin objects. Surgical interventions target at the removal of malignant tumors with an additional margin (often 1 cm). To support this, the user can add margin objects for each selected visualization object. A margin is displayed transparently or as wire-frame to reveal what is inside (see Fig. 3, next page).

4.2 Synchronization of Different Views

In the process of therapy planning a variety of views is generated: the viewing direction is changed, different objects become visible, and resection tools (see Sect. 5) are applied. For many visualization goals no single visualization is appropriate. Therefore, it is crucial to allow the user to have multiple views which can be flexibly parameterized.

In each viewer all visualization parameters can be assigned independently. To support the comparison of different views (recall the interaction tasks specified in Sect. 4.1), the user can define synchronizations between the viewers. For example, if a viewer is synchronized for example concerning filter operations (see Fig. 6). Moreover, it is possible to define synchronizations between views. When a user changes the viewpoint of one viewer, the other viewers are updated automatically.

Fig. 1: Semitransparent liver segments with the portal venous system and three tumors rendered as surfaces. The visualization reveals the tumor-segment relationship and the vessels in the surrounding of each tumor. Additional annotations like the tumor volume might be displayed at the periphery of the viewport.

Face-based rendering is employed, while the vessels are smoothed for a better recognition of the branching pattern.

For the comparison of different views the following interaction tasks are supported:

- adjust viewer parameters (e.g. shadow color).

For these tasks individual dialogs with carefully selected default values have been developed.

Add margin objects. Surgical interventions target at the removal of malignant tumors with an additional margin (often 1 cm). To support this, the user can add margin objects for each selected visualization object. A margin is displayed transparently or as wire-frame to reveal what is inside (see Fig. 3, next page).

The comparison of different views is discussed in Sect. 4.2.

Viewers may be synchronized for example concerning filter operations (see Fig. 6). Moreover, in which affects the content of a viewer, it can whether these settings should be applied to all viewers (regardless whether synchronizations apply).
4.3 Cutting Arbitrary Regions

Since surgeons want to try resection strategies, we developed techniques to remove arbitrary regions from a volume. Efficient removal of arbitrary regions from a volume has been described in [17]. We follow a different approach using implicit functions to define resection regions analytically. A large variety of 3d objects, such as wedges and cylinders, can be conveniently defined with implicit functions.

The basic strategy of our algorithm is as follows: a convex resection region $R$ is defined by an implicit function. With a transformation $T$ the resection region is mapped into a binary mask volume $M$, the size of which corresponds to the data volume $V$. For each voxel $v = (v_x, v_y, v_z)$ in $V$ the corresponding voxel $m = (m_x, m_y, m_z)$ in $M$ is $\text{TRUE}$ if $m$ belongs to $T(R)$. In order to quickly identify the voxels which belong to $T(R)$, an additional data structure, a brick volume $B$, is introduced. In $B$ one item represents a brick of $M$ with the original size of 12x12x12 voxel. $B$ is used to record which region in $M$ has been processed. Since $R$ is convex it is often sufficient to check the vertices of a brick whetl to $T(R)$. If the test yields $\text{TRUE}$ for all vertices filled iteratively. If the test yields $\text{FALSE}$ for whole brick is outside $T(R)$. Only if the test $\gamma$ some vertices and $\text{FALSE}$ for others, the brick is recursively subdivided 3x3x3-sized cubes (which are filled or skipped depending on the test of the central voxel), $\alpha$ individual voxels. The latter high-quality not for updating the resection region during into only applied when the user stops moving theLike a recursive fill, the algorithm starts at a $T(R)$, considers its brick, and recursively vi $\alpha$ bricks (with subdivision if required), until a $T(R)$ are processed.

With this approach the resection region represented in $M$ and can be modified with image processing techniques (for example erosion, close gaps). All voxels in $M$ belong, be combined, with boolean operations which incide conditions which determine whether actually drawn (this flexibility is used for see Sect. 5.3). In an 8-bit mask volume, 8 in overlapping) resection regions can be managed to $R$, two options are available: (1) the old mask and only $T(R')$ will be cut, or (2) $T(R)$ remain as deleted. In the latter case, the movement trace of arbitrary shape. Note, that this trace i to be convex, thus every possible resection can be

5 Specification of Resection Regio

In order to define a region which should be res two different approaches are possible:

- to define polygons or parametric curves which are moved along a straight line (extrusions) to define resections via Extrusions

Extrusions are widely used in geometric model to define 3d objects. Extrusions allow the user to define a regular shape (e.g. a prism as a simple solid) with very little interaction. However, resection vol not bounded by planar faces, but instead are

Fig. 2: The lung with its segments (colored according to [10]) and the bronchial tree reconstructed from high resolution CT-data. Courtesy of Stefan Krass, MEVIS

Fig. 3: Frontal view to the lower left part of the liver. A 1 cm safety margin around a tumor is defined and visualized with contour lines. This allows to assess which vessels (portal venous system) would be affected by a resection of the tumor with that margin.
ped since the course of vessels and the shape of tumors are considered. The combination of extrusions to define a resection volume, such as a liver segment (recall Fig. 1), is tedious and counter-intuitive. Therefore, an extrusion may be suitable as an initial resection volume, but should be fine-tuned with eraser tools. In the SURGERYPLANNER, a simple mechanism is realized which facilitates the extrusion of polygons, where the user can specify the depth range involved.

5.2 Specification of Resections with 3d Erasers
The use of erasers has complementary advantages and disadvantages compared to the use of extrusions: arbitrarily shaped regions can be specified more naturally and more precisely, however, with considerably more interaction effort. Two aspects are crucial for this type of interaction:
- The rasterization of the 3d eraser and its trace in the mask volume (recall Sect. 4.3) must be fast enough to allow real-time interaction.
- The shape and size of the 3d erasers must be flexible in order to facilitate a course as well as a detailed specification of the resection volume.

Two general approaches are feasible for the use of 3d erasers. The first is strictly adhered to the direct-manipulative interaction style: the eraser is visualized explicitly and moved by an appropriate 3d widget with handles for 6 degree of freedom-translation. We will refer to this approach as explicit resection. A conventional 2d input device as well as a 3d input device may be employed for this interaction. The second approach is less direct: the eraser can be translated by moving a (usual) 2d mouse and holding a mouse button pressed. Neither the 3d eraser nor handles are visible. This second approach, which we call no-widget-resection, is motivated by the desire to have an unobstructed view to the visualization.

5.2.1 Explicit Resection
We developed different 3d erasers: wedges, cylinders and spheres. Wedges are inspired by wedge-resections which are a typical kind of resection in liver and lung surgery. Erasers can be parameterized within appropriate dialogues and can be transformed in a 3d visualization by means of manipulators provided by the graphics library OPENINVENTOR (see Fig. 4). The properties of an eraser determine its visualization (color, rendering style) and its initial orientation and position.

3d erasers and their manipulators should be recognizable but should not occlude the resection region heavily. As a trade-off semi-transparent erasers and erasers which are visualized via their outlines are used. Manipulators provide support for all transformation tasks: translation, rotation and scaling. After the size has been adjusted, an eraser is primarily translated and less often rotated.

5.2.2 No-Widget-Resection
To avoid the occlusion of the scene with an associated manipulator, the no-widget-resection approach employs only a cross-hair symbol representing cursor position. The shape, size and orientation of the eraser can be chosen in the same manner as in Sect. 5.2.1. In the virtual model that part of the scene is marked as deleted which corresponds to the parameters. If the cursor is moved to a position where it has not been before, the scene is deleted. If the cursor arrives at a position, a deeper part of the volume is deleted. The interaction becomes faster (and more predictable) if the effect of the virtual resection can be restricted to a range of transparency values. Thus, a transfer function may be used such that structures of little importance for therapy planning are displayed strongly transparently. Transfer function the virtual resection might be applied only to those voxels with transparency values above a threshold. Thus, little time is wasted to virtually resect.

\footnote{A transfer function defines the mapping of intensity values of the original data to grey values and opacity values.}
6.2.3 Comparison of Virtual Resection with 3d Erasers

The no-widget-approach is less intuitive since neither a widget nor handles for its movement are displayed. In the explicit resection-approach the user also has more feedback, as the user can watch the eraser’s movement (which makes her aware if a delay occurs). Therefore, real-time demands are of higher importance for the no-widget-approach.

The explicit resection approach can benefit from 3d input devices and facilitates direct-manipulative scaling and rotation of the eraser whereas in the no-widget-approach the eraser can only be translated. As translations are the dominant transformation in virtual resections this is less important.

Despite these disadvantages, informal tests indicated that the no-widget-approach is the superior solution, because the interaction is more efficient. As the visualization is not occluded, the results of the virtual resection can be better evaluated. Moreover, every movement of the cursor really changes the resection volume. By contrast, in the explicit resection approach the user may delete the same region again and again until she becomes aware that the eraser must be translated.

5.3 Selective Resection

Resection volumes can be applied selectively to different structures so that certain objects are visible, even if they belong to the resection region. Such visualizations have been used for anatomy education and are described in [16]. In the context of therapy planning it is extremely valuable to see a tumor and major blood vessels in a region where a resection is intended. The user can thus assess the distance between the tumor and the boundary of the resection region as well as the vessels involved in this resection.

5.4 Use of Resection Tools

The typical use of 3d erasers proceeds in the following way: the user starts with a medium-sized eraser and moves it to remove a tumor. In this process, it is often necessary to rotate the whole model to evaluate what has been removed. After a rough boundary has been specified it is refined with a smaller-sized 3d eraser. Gaps in the resection region may be ignored as these may be filled automatically in a post-process. As the resection volume is explicitly represented, 3d image-processing techniques, like dilation and erosion can be applied to extend/shrink the resection volume globally.

For the use of explicit 3d erasers a two-handed interaction with the system is possible, with one hand controlling the resection (with a 3d input device), and the other to simultaneously control the camera (with a 2d mouse). A better controlled if manipulations are applied simultaneously which display the virtual model from different viewing angles. These views should be concerning geometric transformations (recall Sect. 4.2).

Concerning the usability of virtual resections it is also important to discuss resection strategies by drawing in original 2d data.

Fig. 5: The resection specified in the right 3d viewer is also marked in the slice view on the left 2d viewer as blue region. The crosses indicate the current position in either view.

Fig. 6: Two synchronized views for the specification of a resection. The left view contains the bones and other structures as anatomical context, while the right view contains only the structures relevant to plan the movement of the resection tool. Direct volume rendering and surface are overlaid.

6 Measurements in 3d Visualizations

Currently, it is common practice in radiologic to use 2d measurement tools to define distances, areas, or angles in planar slices of radiologic images.
however, gives only a rough estimation for questions such as the minimal distance between two 3d objects, or the extent of a 3d object. Therefore, 3d measurement tools are required to integrate measurements in 3d visualizations. The development of 3d measurement tools to be used in the context of a complex 3d visualization is difficult because the user has to be provided with enough depth cues to assess the position and orientation of such a measurement tool (otherwise the precision pretended by exact numbers is misleading). Therefore, a “simple” transition of line-based 2d measurement tools into 3d is not sufficient.

The interactive use of measurement tools is the most flexible approach, however, it requires a certain effort on the user’s part. Therefore, we carefully analysed which interaction tasks are of primary importance in order to support these tasks by an automatic approach. These tasks include the definition of the extent of objects as well as distance measurements. Of paramount importance for the risk analysis is the minimal distance between pathological structures and risk structures. For the following, we assume that the segmentation information has been converted into a boundary representation. The measurement tool described in this section are part of a library of 3d measurement tools, which also comprises 3d widgets for angle and area measurements.

6.1 Interactive Distance Measurement

An interactive distance line widget for distance measurements consists of a small cone (3d representation of arrowheads) and a small cylinder (3d representation of the line). With this design the distance line is a recognizable 3d object. As an additional orientation aid distance lines may cast a shadow. The placement of the number is adapted to the line length: if the line is long enough the cylinder is interrupted for the placement of the number in the center (see Fig. 7). Otherwise the number is placed near one of the endpoints of the distance line. The distance line as a whole as well as individual endpoints can be translated by an appropriate dragger. The distance line is created with rubberbanding, and the distance number is updated continuously. In order to ease the translation of the measurement instrument, snapping is included. With this feature the endpoint translated by the user is attracted by the surface of an object. Snapping is motivated by the fact that the most common measurement tasks include the determination of the distance between object surfaces.

The calibration of distance measurement facilities is based on the header information of radiological data which includes the size of a voxel (for example 0.7×0.7×2 mm with the larger value representing the distance between slices).

6.2 Determination and Visualization of the Object Extent

For preoperative planning the extent of pathologies is important. It is used to define the stage disease which is relevant for any therapy decision of a tumor is defined as the longest side of the oriented bounding box (OBB). The OBB of object o is defined as the Jacobian matrix of the covariance symmetric 3x3-matrix) is calculated taking the vertices of o. The normalized eigenvectors of right-angled coordinate system with origin at gravity. The normalized eigenvectors of A matrix, which is known as the Jacobian matrix. The process is known in image processing as principal component analysis [15]. In order to get the exact extent in each of the 3 directions, o is transformed to o’ by rotating o. As o’ is axis-aligned, the axis-aligned bounding box of o’ can be easily determined. The length of the ABB represent the length of the main axis.

Fig. 7: Distance lines with their shadow projections. The placement of the number depends on the available space. The measurement is determined by the voxel size of the underlying data.

Fig. 8: Eigenvectors of an object are defined using the covariance matrix (left). Object o is rotated according to the Jacobian matrix (right). Object and the main axis is visualized with distance lines (middle). Object is rendered semitransparently (see Fig. 9, next page).
6.3 Determination and Visualization of Minimal Distances

Minimal distances between the structures which need to be treated and structures at risk are crucial for therapy planning. Therefore, we provide a feature to define automatically the minimal distance between two selected objects. The minimal distance between two polyhedra \( A \) and \( B \) might occur at faces, edges or vertices. Here, we simplify the task by considering only vertices and searching for the vertices \( a_{\text{min}} \) and \( b_{\text{min}} \) with minimal distance. This simplification introduces an error which can be neglected for objects in medical data as they consist of thousands of vertices resulting from equal sampling.

The brute-force method for this purpose is to calculate the distance between all vertices \( a_i \) of object \( A \) and \( b_j \) of object \( B \), and then to minimize. This simple approach is too slow, if objects with many vertices occur. Methods for the efficient determination of minimal distances have been developed for collision detection in dynamic scenes (e.g. \cite{7}). These algorithms employ hierarchical data structures (decomposition of the scene) and hierarchies of enclosed objects to quickly reduce the number of vertices to be considered. The construction of these hierarchical data structures, however, takes considerable time which is acceptable for dynamic scenes (where the distance calculation is often repeated). For the calculation of distances between objects in static models of the patient anatomy the additional effort is not justified.

We briefly sketch an algorithm which is based on the observation that the minimal distance between the polyhedra \( A \) and \( B \) is smaller or equal than the distance between the centers of gravity \( \text{COG}_A \) and \( \text{COG}_B \). After \( \text{COG}_A \) and \( \text{COG}_B \) are determined the distance between \( \text{COG}_A \) and \( a_i \) is calculated (for each \( a_i \)). Each \( a_i \) with

\[
dist (a_i, \text{COG}_A) > \text{dist} (\text{COG}_A, \text{COG}_B)
\]

is not considered in the further procedure. Similarly, the distance between \( \text{COG} (A) \) and \( b_j \) is calculated. All \( b_j \) with

\[
dist (b_j, \text{COG}_B) > \text{dist} (\text{COG}_B, \text{COG}_B)
\]

are excluded from the further process.

\[1\] The notion \( \text{dist} (a,b) \) represents the Euclidean distance.

The brute-force method for this purpose is to calculate all possible distances (with the length of the OBB-axes). By visualization is cluttered, these planes are excluded from the further process.

After one step the number of vertices to average approximately reduced to one half. This is repeated by calculating COGs for the reduced set. The process is finished if the number of points below a given threshold. For the remaining vertices the brute-force approach of minimization of all possible distances is applied. The algorithm works well, except where the convex hulls overlap. In this case a new point cannot be applied. The minimal distance between two objects is visualized by a distance line (recall Sect. 6.1). This task could be further supported: for all objects a certain diameter around a tumor (for example 3 cm) the minimal distance is calculated and visualized.

6.4 Use of Measurement Tools

3d widgets for measurement in 3d visualization developed using graphic primitives by OPENINVENTOR are manipulated using compositions of OPENINVENTOR opens. Measurement tools are automatically named. The minimal distance between two objects is derived from the type and a sequential number of the tool and can be selectively displayed and hidden. The minimal distance can be displayed together with the viewing direction at the time of its specification. Later, the measurement might be stored and can be selectively displayed and hidden. Measurement tools use 2d text for the numbers. Thus the numbers are manipulated using compositions of OPENINVENTOR opens.

Fig. 9: The extent of a tumor is determined by defining the oriented bounding box (OBB). The extent is visualized by three orthogonal distance lines (with the length of the OBB-axes).

Fig. 10: The minimal distance between a vessel and in the liver) and a tumor is automatically determined.
7 Conclusion and Future Work

We presented new interaction techniques for virtual resection and 3d distance measurements using dedicated 3d widgets. An efficient algorithm for cutting arbitrary regions is used for interactive resection. The resection tools follow two paradigms, extruded shapes and interactive “erasers”. While interactive response is maintained through limiting the erasers to a convex shape, arbitrary resections are supported by “eraser” traces. Tools for the interactive and automatic measurement of 3d objects have been presented with focus on their application for therapy planning. These new techniques have been integrated with known techniques for the visualization and annotation of medical volume data in the SURGERYPLANNER. This system provides a reliable base to aid in the complex decision making process regarding the operability of patients with solid tumors inside the liver and lung. Several patients have been resected virtually with the SURGERYPLANNER. The selective application of resection tools and synchronization mechanisms are essential for the usefulness of the system. The system has been informally tested by some of our colleagues with focus on the visualization and resection tools.

In practice, it is intended such that a radiologist operates the system and a surgeon tells her what she likes to see. In this way interventions are planned today: radiologists – specialized in the use of dedicated workstations – demonstrate surgeons clinical data in the desired way.

The support provided by the SURGERYPLANNER is considerable but still has some limitations. The system does not guide the surgeon during the operation. Intraoperative support, as already realized in neurosurgery, is difficult to realize in soft tissue surgery due to the surrounding problems with intraoperative registration of these elastic organs. Future work will concentrate on an in-depth evaluation in the preoperative use of the SURGERYPLANNER. The evaluation shall focus on questions like which kind of visualization and interaction techniques are used frequently, how precise are interactive 3d measurements, and how does the preoperative planning influence the decisions taken by a surgeon.

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