



## Illustrative PET/CT Visualisation of SIRT-Treated Lung Metastases

Nico Merten<sup>1</sup>, Sylvia Glaßer<sup>1</sup>, Bianca Lassen-Schmidt<sup>2</sup>, Oliver Stephan Großer<sup>3</sup>,  
Jens Ricke<sup>3</sup>, Holger Amthauer<sup>3,4</sup>, Bernhard Preim<sup>1</sup>

<sup>1</sup> Department of Simulation and Graphics, Otto-von-Guericke University, Magdeburg, Germany

<sup>2</sup> Institute for Medical Image Computing, Fraunhofer MEVIS, Bremen, Germany

<sup>3</sup> Department of Radiology and Nuclear Medicine, University Hospital Magdeburg, Magdeburg, Germany

<sup>4</sup> Department of Nuclear Medicine, Charité, Berlin, Germany

### **To cite this version:**

Merten, N., Glaßer, S., Lassen-Schmidt, B., Großer, O. S., Ricke, J., Amthauer, H., Preim, B.  
Illustrative PET/CT Visualisation of SIRT-Treated Lung Metastases . *Eurographics Workshop on Visual  
Computing for Biology and Medicine (VCBM)*. Pages: 99–104. Bergen, Norway. 2016.

DOI: 10.2312/vcbm.20161276

## Abstract

We present an illustrative rendering pipeline which combines anatomical information from CT scans with functional information from PET scans. To treat lung metastases with Selective Internal Radiation Therapies (SIRTs), combined PET/CT recordings are used for treatment planning and intervention validation. We firstly extract surface meshes from the lung lobes and trachea from the CT scan. In addition, the radiation activity of the therapeutic agent  $^{90}\text{Y}$  is acquired from the PET data. To convey all this information in one view, we use illustrative rendering techniques, combining Order-Independent Transparencies with Boundary Enhancements and Silhouettes. Our methods are evaluated by clinical and visualisation domain experts. This study indicates an excellent spatial perception and evaluation of tumor position, metabolic and therapeutic agent activity, when transparencies and boundary enhancements are used to render the surrounding lung lobes.

## 1 Introduction

Whereas chemo- and radiation therapy as well as surgery are currently the most common types of lung tumor treatment, there is a high need and interest in evaluating the effectiveness of different therapies in this clinical context. A clinical research question is whether Selective Internal Radiation Therapies, which are commonly used as therapy for liver tumor treatment, are suitable for treating lung metastases. For therapy planning and intervention validation, multiple PET/CT examinations are acquired before and after the treatment. This is done because CT scans provide detailed anatomical information due to their high spatial resolution, whereas the PET scans reveal functional information, like abnormally high metabolic processes of tumours.

These recordings are arranged in 2D image stacks. Although it is possible to simultaneously analyse two images by superimposing greyscale CT scans by colourmapped PET scans, a physician has to explore the stacks slice by slice. With an increasing slice number, the physician's involvement to explore every slice increases as well. Therefore, tools in clinical use offer helping functionalities, but physicians still have to mentally fuse all informations from different image modalities. Especially for the human lung this is a challenging task due to its complex anatomical structure: It consists of five lobes which may differ remarkably in shape and size for each patient.

With a 3D visualisation of the image stacks the spatial orientation is provided to support the physicians. Thus, we support the mapping of the 2D information to the patient's anatomy in the thoracic region. We developed such an illustrative and multimodal visualisation, which makes it easy to distinguish the lung lobes and shows functional information from the PET scans in one view; the results can be seen in the figures throughout this paper.

With this, our work conveys the following contributions:

- An illustrative rendering technique, combining order-independent transparencies with boundary enhancements and silhouettes for PET/CT scans for the human lung, and
- an evaluation with clinical and visualisation domain experts, which confirms and reveals the strengths and weaknesses of our novel visualisation, respectively.

## 2 Medical Background

Treating cancer or metastases with standard therapies may be clinically unfeasible for the following reasons:

- The diameters of the lesions are too large to use radiofrequency ablation (RFA) [Yan et al., 2006],
- the metastases are too diffuse to apply a stereotactic irradiation or CT guided brachytherapy [Ricke et al., 2005], or
- the remaining capacity and functionality of the lung would be too low after a surgical resection [Ricke et al., 2013].

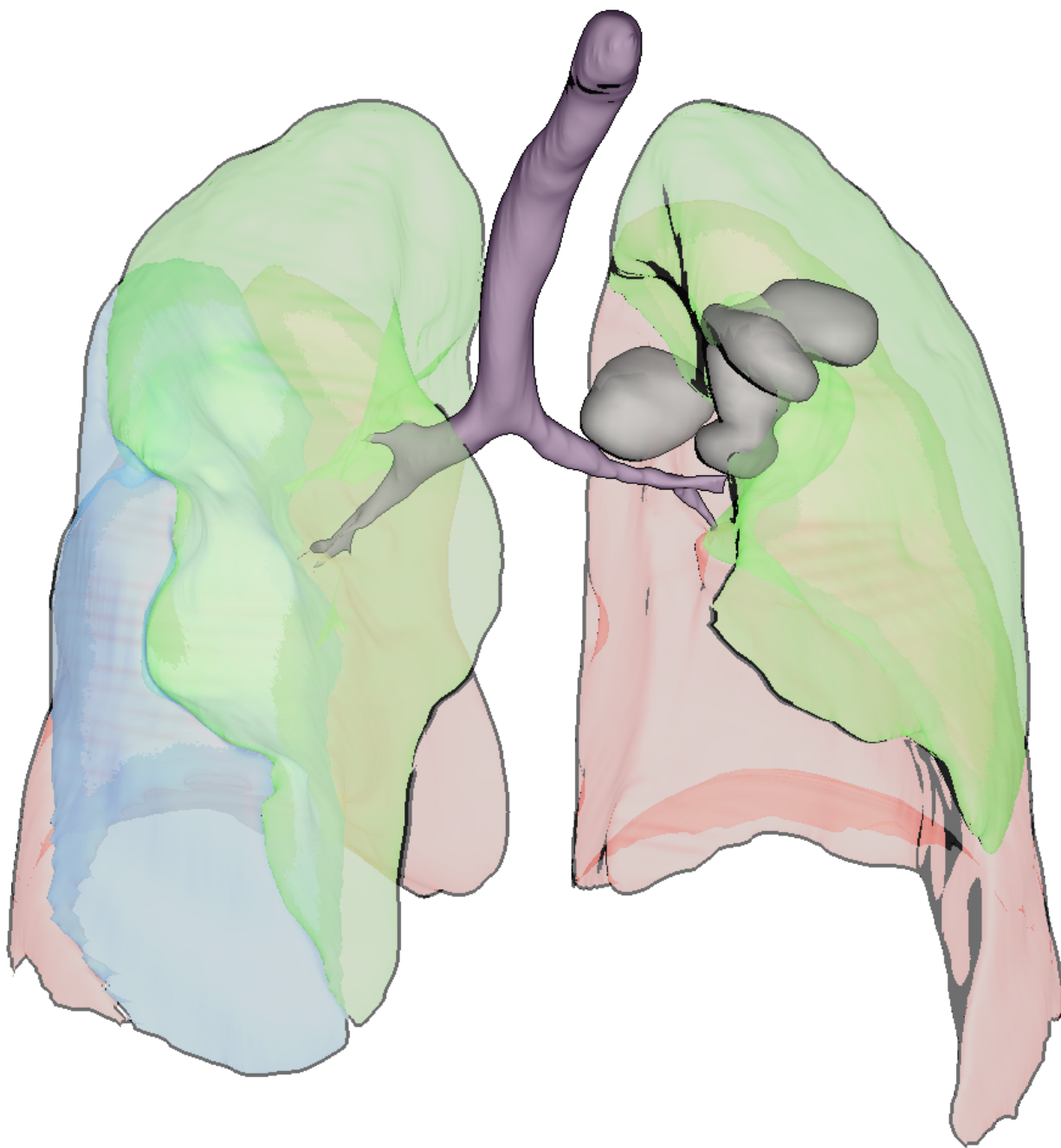


Figure 1: When using our illustrative rendering technique, the user can interactively change the transparencies and colours for the pulmonary lobes and trachea, which we obtained from the a CT scan, and the accumulated activity of the therapeutic agent  $^{90}\text{Y}$  in grey, which was used as tracer in a PET scan. Additionally, the width of depth dependent boundary enhancements and strength of normal dependent silhouettes can be adjusted.

To assess whether SIRT could be used to treat lung metastases, Ricke et al. conducted a study with two patients [Ricke et al., 2013]. They were in palliative care, since they also suffered from diffuse colorectal or renal cancer metastases beyond the lung metastases and “both provided informed consent regarding the experimental nature of this new therapeutic technique”. The achieved results look promising, because targeted lesions remained stable or devolved into remission after the intervention, whereas untreated ones became massively progressive in growth. Moreover, the functionality of any lung was impaired [Ricke et al., 2013]. During the SIRT the surgeon uses a catheter, trying to bring resin  $^{90}\text{Y}$  microspheres as close as possible to a lesion via an bronchial artery. From there, the agent irradiates its surrounding tissue.

Our work is based on a selection out of eighty image data sets from various imaging modalities, including:

- *Computed Tomographies (CTs)* of the thorax and abdomen,
- $^{18}\text{F}$ -FDG and  $^{90}\text{Y}$  *Positron Emission Tomographies (PETs)*,
- *Single-Photon Emission Computed Tomographies (SPECTs)* following the angiographic application of an perfusion agent and standard lung perfusion/ventilation SPECTs, and
- various *Digital Subtraction Angiographies (DSAs)*, *Radiographs* and *Magnetic Resonance Imagings (MRIs)*.

Before and after the SIRT multiple CT-only scans were acquired. CT scans can be obtained for the whole body or parts of it, wherein the various inlying types of tissue absorb the transmitted radiation differently and due to these differences, rays may be attenuated differently strong, resulting in contrasts between various tissues in the resulting images.

PET scans use emitting beta particles for image acquisition. These particles originate from radioactive decaying nuclides, also called tracers or markers, which are injected into the patient prior to a scan. In contrast to  $^{18}\text{F}$ -FDG PET scans, where the tracer is a substance similar to glucose that reveals tumorous metabolic activity,  $^{90}\text{Y}$  PET scans show the emitted radiation from the therapeutic agent. Additionally, PET scanners have a lower spatial resolution than CT scanners, which makes them not suitable to acquire anatomical information [Bailey et al., 2005, Lawonn et al., 2015].

Using combined PET/CT scanners comes with advantages and disadvantages: The overall acquisition time is decreased, but the overall radiation dose per scan is increased. To tackle the latter, the CT radiation is reduced (*low-dose* CT), but this also affects the resulting image quality negatively. Griffeth et al. present a larger list of clinical and technical pros and cons, plotting them against clinical case studies [Griffeth, 2005].

## 2.1 Requirements

Superimposed 2D PET/CT images are used in the diagnostic, treatment-planning and validating stages of a SIRT [Ricke et al., 2013]. 3D visualisations could improve the spatial orientation, making it possible to oversee the pulmonary lobes and PET information at a glance. Such a visualisation must have the following requirements:

- *Requirement 1*: All lung lobes should be visualised so that they are clearly recognisable individually.
- *Requirement 2*: The rendering has to be adjustable so that the *PET information* is clearly visible in the lung lobes.

This PET information can either be the metabolic activity of the metastases or emitted radiation of the therapeutic agent.

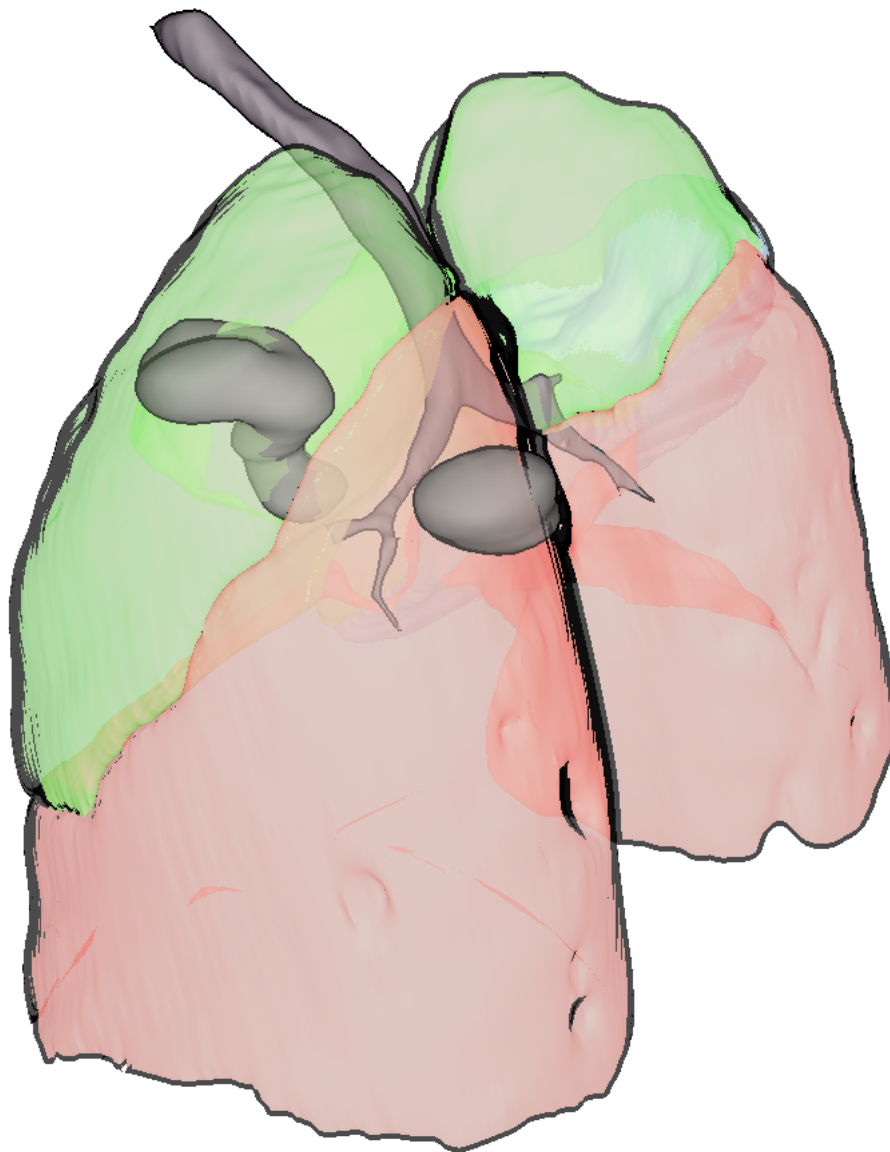


Figure 2: Another result of our approach: “Depth gradients” result in contours, which outline the lung lobes, and “normal similarities” lead to silhouettes, which show irregularities on the surfaces.

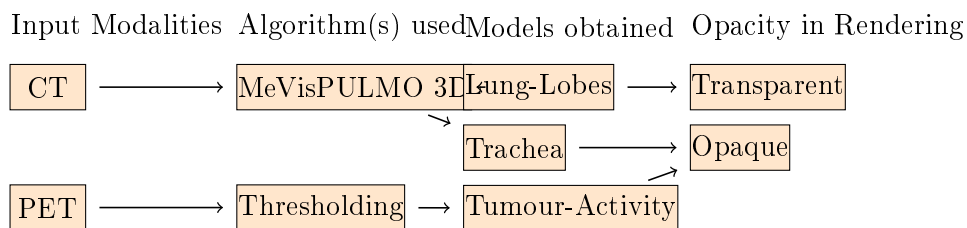


Figure 3: An overview of our image processing pipeline: The shown programs and algorithms are used on the input image data to obtain models of specific anatomical structures. These can be rendered transparent or opaque.

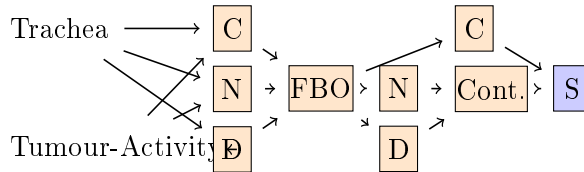


Figure 4: The colours **C**, normals **N** and depth values **D** of the opaque geometry are written to a frame-buffer object **FBO**. Then the normals and depths are used to compute the contours **Cont.**, which are combined with the colours and rendered to the screen **S**.

### 3 Related Work

Three-Dimensional visualisations of two or more scans at the same time may be technically possible, but may overload the view. One possible solution is to use a Focus-and-Context Metaphor: Lawonn et al. [Lawonn et al., 2015] show that this method is useful when used for big data sets like whole-body scans. In contrast, we visualise smaller thorax image data and use *Order-Independent Transparencies* (OITs). There are different approaches to implement OITs and we adapted the method of Barta and Kovács [Barta and Kovács, 2011]: A linked list is indexed to compute the outgoing transparent colour.

Furthermore, we added boundary enhancements and silhouettes to our visualisation to make it easier to distinguish the different lung lobes. For illustrative effects in *Direct Volume Rendering* (DVR), like ridge and valley enhancements, Kindlmann et al. [Kindlmann et al., 2003] developed multi-dimensional Curvature-Based Transfer Functions. Bruckner and Gröller [Bruckner and Gröller, 2007] don’t compute but estimate the curvate at each ray casting step, thus improving the performance of the previous method. Furthermore, they include the contour colour in their Style Transfer Functions, which offers a lot of freedom regarding the interchangeability of different transfer functions and therefore different rendering styles. Since we used an *Indirect Volume Rendering* (IVR) approach, we implemented the image-space based contours by Jainek et al. [Jainek et al., 2008]: “Depth gradients” and “normal similarities” are thresholded to determine if a fragment is a contour. The mathematical background is described in [Fischer et al., 2005].

### 4 Implementation

We mainly used VTK nodes in MeVisLab 2.8 [Ritter et al., 2011] and OpenGL as well as GLSL under C++.

Figure 3 shows how we acquired our 3D models and what opacity will be applied for rendering: To obtain the lung lobes and trachea from a CT scan, we used a prototypic version of MeVisPULMO 3D 3.7 [Kuhnigk et al., 2005, Lassen, Bianca and van Rikxoort, Eva M and Schmidt, Michael and Kerkstra, Sjoerd and van Ginneken, Bram and Kuhnigk, Jan-Martin, 2013]. The resulting label images are processed in our *Indirect Volume Rendering* (IVR) pipeline, where surfaces have to be extracted before rendering. This leads to a moderate amount of pre-processing for our work.

To obtain the tumorous activity from the PET scan, we use an adjustable high pass filter on the grey values. This is possible, since the highest grey values in the image form visual clusters in the areas where the therapeutic agent accumulated; 3D surfaces are also extracted from these high pass filtered images. The rightmost column in Figure 3 shows each model’s opacity in the rendering. Before rendering the transparent lung lobes, the opaque models with their boundary enhancements and silhouettes have to be rendered in a two step process, which is shown in Figure 4: First, the colours **C**, normals **N**, and depths **D** are rendered to a framebuffer object **FBO** with multiple attachments. In the second step these variables are used to compute the “depth gradients” and “normal similarities” to decide if a fragment is a contour or silhouette **Cont.**, or neither of both. If so, the fragment is darkened for rendering on screen **S**.

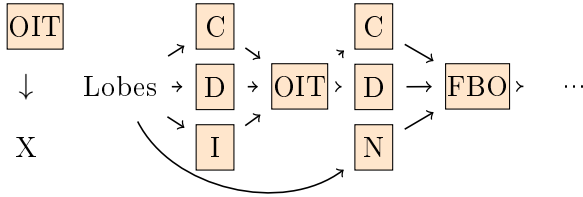


Figure 5: The order-independent transparency buffers **OIT** are cleared ( $\downarrow\mathbf{X}$ ). Then the colours **C** and depth values **D** of the lung lobes and linked list indices **I** are written to the buffers. Analogous to Figure 3, a **FBO** is used to compute the contours and silhouettes.

clinical votes				visualisation votes			
comp.	op.	tr.	und.	comp.	op.	tr.	und.
1	5	0	1	1	4	0	0
2	3	1	0	2	2	2	0
3	4	0	1	3	3	0	1
4	4	1	0	4	3	1	0

Table 1: For each column-wise comparison (**comp.**) from Figure 6 the experts where asked, which rendering style is more suitable to differentiate the lung lobes: Opaque (**op.**), transparent (**tr.**), or they remained undecided (**und.**).

Now the transparent lung lobes can be rendered (see Figure 5): The linked list works on order-independent transparency buffers **OIT**, which have to be cleared ( $\downarrow\mathbf{X}$ ) before they can be used. The colours **C**, depth values **D**, and linked list indices **I** are written to the buffers. When the buffers are accessed, the indices point to the next colours and depths for the actual processed fragment, thus forming an entry. These entries are collected, sorted, and colour-composed and the result is written to an **FBO** with the model depth values and normals. Then, the contour and silhouette generating process from Figure 4 is repeated.

## 5 Evaluation

To assess our work and to pinpoint downsides in an early stage of development, we drafted a questionnaire to see how well we fulfilled our two requirements; this questionnaire was filled out by five clinical and four visualisation domain experts. We came up with two sets of questions, each set focusing on one requirement.

For the first requirement, we created two series of opaque and transparent renderings of the lung lobes (see Figure 6). First, we paired the renderings column-wise and the results in Table 1 show that the opaque renderings seem more suitable to distinguish the lung lobes. We then paired the renderings row-wise and asked the experts to rank the visibility of the lung lobes between 1 (“*very bad*”) and 5 (“*very good*”); the statistical results can be seen in Table 2. Three clinical and visualisation domain experts stated that the boundary enhancements and silhouettes influenced their ranking for the opaque renderings. Similarly, all experts stated that they were influenced when they ranked the transparent renderings. Therefore, we conclude:

- The lung lobes have a higher visibility when rendered opaque,
- the influence of boundary enhancements and silhouettes is higher for the transparent renderings than for the opaque ones, and

rendering	$\mu_{clin}$	$\sigma_{clin}$	$med_{clin}$	$\mu_{vis}$	$\sigma_{vis}$	$med_{vis}$
<b>opaque renderings</b>						
leftmost	3.8	1.30	4	3.75	0.5	4
	4.4	0.55	4	4.75	0.5	5
	4	1.22	4	3.5	0.58	3.5
rightmost	4.6	0.45	5	4.75	0.5	5
<b>transparent renderings</b>						
leftmost	2	0	2	1.5	0.58	1.5
	3.2	0.45	3	3.25	1.71	3.5
	2	0	2	4	0	4
rightmost	3.8	0.45	4	4	0.82	4

Table 2: The means, standard deviations and medians of the domain experts’ votes when they compared the renderings row-wise.

- rendering everything with a low opacity while not using boundary enhancements leads to the worst result.

To validate the second requirement, we wanted to know if multiple PET regions are spatially distinguishable in our visualisation and if the boundary enhancements, silhouettes, and trachea, which we used as spatial reference, affect this decision. Therefore, we introduced two PET regions (see Figures 1 and 2), which differ in size and position, and how to locate them and the trachea in 2D CT images. For the questions we presented superimposed 2D PET/CT images next to our visualisation and assured that the trachea is partially visible in the images. This was done for every main orientation and one time with and without boundary enhancement and silhouettes, thus leading to six combinations per expert. The corresponding results can be seen in Table 4 and the results of the final questions are listed in Table 3. Therefore, we conclude:

- Utilising colour as a visual variable to distinguish the lung lobes is a suitable method,
- using transparencies seems to be a slightly better approach than BE/S to locate and distinguish multiple PET regions, and
- adding BE/S to the rendering effects the error rate only slightly.

## 6 Conclusion and Future Work

We presented an illustrative visualisation technique for PET/CT for the human lungs. First, we explained how we obtained surface models of the lung lobes and trachea from the CT scan and PET regions with an high accumulation of antherapeutic agent, which we then rendered with order-independent transparencies and screen-space boundary enhancements and silhouettes and the results were evaluated by clinical and visualisation domain experts.

In the future we want to work on the following topics:

- The combination boundary enhancements and silhouettes lead to no benefit. Thus, we want to utilise different screen-space or object-based shading methods.



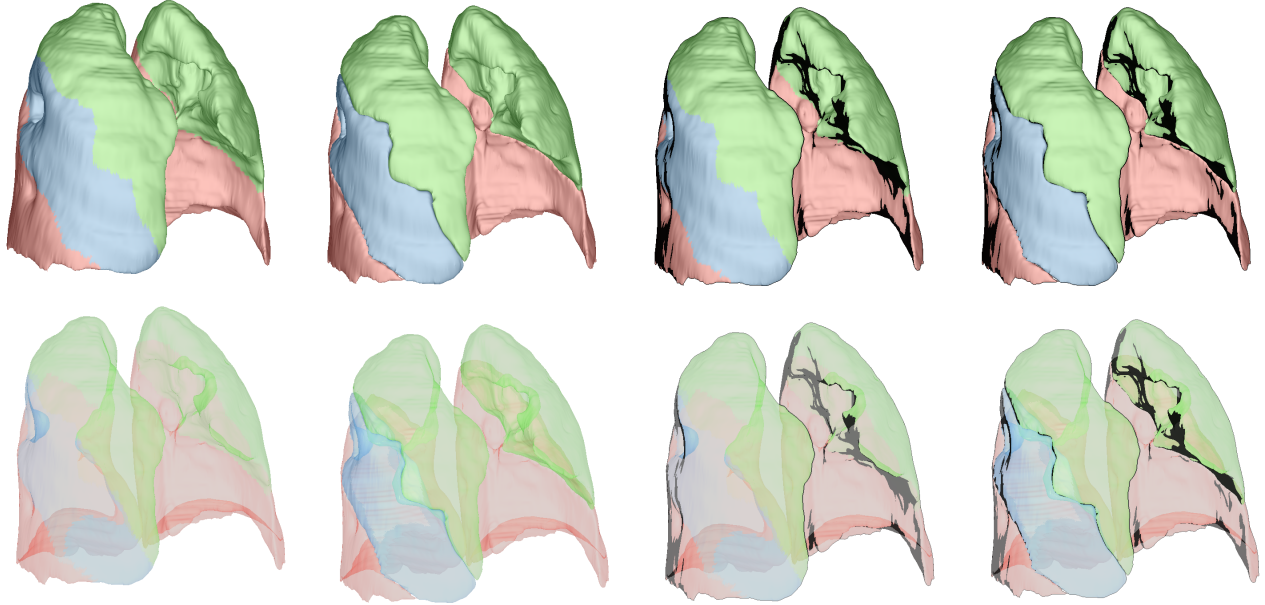


Figure 6: The series of opaque and transparent lung lobe renderings which we used in our questionnaire. The pose is identical and the threshold for the “depth gradients” and “normal similarities” is constant for renderings of the same column.

domain	question	$\mu$	$\sigma$	<i>med</i>
clin.	colour-code lung lobes reasonable ?	5	0	5
vis.		4.75	0.5	5
		yes	no	und.
clin	BE/S reasonable?	4	1	0
vis		0	1	3
clin	transparencies reasonable?	2	0	3
vis		3	1	0

Table 3: The final questions and answers from our questionnaire.

clinical domain						visualisation domain					
without BE/S		trachea used?		trachea aid stat.		without BE/S		trachea used?		trachea aid stat.	
✓	✗	und.	yes	no	$\mu$   $\sigma$   <i>med</i>	✓	✗	und.	yes	no	$\mu$   $\sigma$   <i>med</i>
11	3	1	6	9	4.2   0.98   4.5	8	2	2	2	10	2   1.41   2
with BE/S		BE/S influence?		influence stat.		with BE/S		BE/S influence?		influence stat.	
✓	✗	und.	yes	no	$\mu$   $\sigma$   <i>med</i>	✓	✗	und.	yes	no	$\mu$   $\sigma$   <i>med</i>
10	3	2	3	12	3.7   0.58   4	9	2	1	1	11	3   0   3

Table 4: It was tested, if the experts can distinguish the two PET regions correctly (✓), falsely (✗), or if they remained undecided (**und.**) when our visualisation was presented with or without boundary enhancements and silhouettes (**BE/S**). When they were used, we asked the experts if they were influenced by them and calculated the shown statistics if they voted yes. Furthermore, we were interested if the trachea was used as spatial reference and calculated the same statistical values, if they voted yes.

- We prototypically included the pulmonary blood vessels in our work, but our region-growing approach results in an leakage, where the blood vessels, metastases, and sometimes surrounding structures like ribs are merged. But the vessels are important for planning the SIRT, thus we want to use different segmentation methods and test how DSAs can be included in our work.
- Here, we evaluated our method with only one  $^{90}\text{Y}$  PET/CT scan, but there are more  $^{90}\text{Y}$  and  $^{18}\text{F}$ -FDG PET/CT recordings in our data base we will work with, after we revised our method.

## 7 Acknowledgements

N. Merten was partially and S. Glaßer was fully funded by the BMBF (*STIMULATE*-OVGU: 13GW0095A).

We want to thank S. Krass and J.-M. Kuhnigk at Fraunhofer MEVIS for providing us a MeVisPULMO 3D prototype.

Finally we want to thank our clinical experts I. Apostolova, P. Gensecke, D. Kupitz and C. Wetz from the University Hospital in Magdeburg and visualisation experts B. Behrendt, B. Köhler and P. Saalfeld from the Department of Simulation and Graphics for their time and helping feedback.

## References

- [Bailey et al., 2005] Bailey, D. L., Townsend, D. W., Valk, P. E., and Maisey, M. N. (2005). *Positron emission tomography*. Springer.
- [Barta and Kovács, 2011] Barta, P. and Kovács, B. (2011). Order independent transparency with per-pixel linked lists. *Budapest University of Technology and Economics*.
- [Bruckner and Gröller, 2007] Bruckner, S. and Gröller, M. E. (2007). Style transfer functions for illustrative volume rendering. In *Computer Graphics Forum*, volume 26, pages 715–724.
- [Fischer et al., 2005] Fischer, J., Bartz, D., and Straßer, W. (2005). Illustrative display of hidden iso-surface structures. In *Proc. of IEEE Visualization*, pages 663–670.
- [Griffeth, 2005] Griffeth, L. K. (2005). Use of pet/ct scanning in cancer patients: technical and practical considerations. *Proceedings (Baylor University. Medical Center)*, 18(4):321.

- [Jainek et al., 2008] Jainek, W. M., Born, S., Bartz, D., Straßer, W., and Fischer, J. (2008). Illustrative hybrid visualization and exploration of anatomical and functional brain data. In *Computer Graphics Forum*, volume 27, pages 855–862.
- [Kindlmann et al., 2003] Kindlmann, G., Whitaker, R., Tasdizen, T., and Möller, T. (2003). Curvature-based transfer functions for direct volume rendering: Methods and applications. In *Proc. of IEEE Visualization*, pages 513–520.
- [Kuhnigk et al., 2005] Kuhnigk, J.-M., Dicken, V., Zidowitz, S., Bornemann, L., Kuemmerlen, B., Krass, S., Peitgen, H.-O., Yuval, S., Jend, H.-H., Rau, W. S., et al. (2005). New tools for computer assistance in thoracic ct. part 1. functional analysis of lungs, lung lobes, and bronchopulmonary segments 1. *RadioGraphics*, 25(2):525–536.
- [Lassen, Bianca and van Rikxoort, Eva M and Schmidt, Michael and Kerkstra, Sjoerd and van Ginneken, Bram and Lassen, Bianca and van Rikxoort, Eva M and Schmidt, Michael and Kerkstra, Sjoerd and van Ginneken, Bram and Kuhnigk, Jan-Martin (2013). Automatic segmentation of the pulmonary lobes from chest CT scans based on fissures, vessels, and bronchi. *IEEE Transactions on Medical Imaging*, 32(2):210–222.
- [Lawonn et al., 2015] Lawonn, K., Smit, N., Preim, B., and Vilanova, A. (2015). Illustrative multi-volume rendering for PET/CT scans. In *Proceedings of the Eurographics Workshop on Visual Computing for Biology and Medicine*, pages 103–112. Eurographics Association.
- [Ricke et al., 2013] Ricke, J., Großer, O., and Amthauer, H. (2013). Y90-radioembolization of lung metastases via the bronchial artery: a report of 2 cases. *Cardiovascular and interventional radiology*, 36(6):1664–1669.
- [Ricke et al., 2005] Ricke, J., Wust, P., Wieners, G., Hengst, S., Pech, M., Hanninen, E. L., and Felix, R. (2005). CT-guided interstitial single-fraction brachytherapy of lung tumors: phase I results of a novel technique. *CHEST Journal*, 127(6):2237–2242.
- [Ritter et al., 2011] Ritter, F., Boskamp, T., Homeyer, A., Laue, H., Schwier, M., Link, F., and Peitgen, H.-O. (2011). Medical image analysis. *IEEE pulse*, 2(6):60–70.
- [Yan et al., 2006] Yan, T. D., King, J., Sjarif, A., Glenn, D., Steinke, K., and Morris, D. L. (2006). Percutaneous radiofrequency ablation of pulmonary metastases from colorectal carcinoma: prognostic determinants for survival. *Annals of surgical oncology*, 13(11):1529–1537.