Smart Graphics in Medical Visualization

Smart Graphics in Medizinischen Visualisierungen

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Summary Smart graphics techniques have a great potential in supporting medical treatment planning and education. In particular, the use of high-level knowledge and carefully selected default values reduces the interaction effort in exploring complex 3D data sets. Automatic viewpoint selection techniques may support the exploration of patient-specific 3D models. Camera movements and other animation techniques allow to emphasize important anatomic structures and convey complex spatial relations. Illustrative rendering techniques and smart visibility techniques enable the expressive visualization of nested surfaces which is important, e. g., to understand the location of a tumor inside an organ. General smart graphics techniques, however, have to be carefully adapted to support medical applications. In-depth discussions of usage scenarios, requirements, priorities and preferences are therefore a prerequisite for successful developments. In this paper, we give an overview of smart medical visualizations. ►►► **Zusammenfassung** Smart Graphics bietet als Forschungsgebiet viele Möglichkeiten, medizinische Interventionsplanungen und die medizinische Ausbildung zu unterstützen. Die Nutzung von Expertenwissen und sorgfältig ausgewählten Standardwerten verringern den Interaktionsaufwand bei der Exploration komplexer 3D-Datensätze. Die automatische Bestimmung von Sichtpunkten kann die Exploration von patientenspezifischen 3D-Modellen unterstützen. Kamerafahrten und andere Animationstechniken erlauben die Hervorhebung wichtiger anatomischer Strukturen und die Verbesserung der Wahrnehmung komplexer räumlicher Verhältnisse. Illustrative Darstellungstechniken und intelligente Techniken zur Sichtbarmachung ermöglichen expressive Visualisierungen eingebetteter Objekte. Dies ist zum Beispiel wichtig, um die Lage eines Tumors innerhalb eines Organs korrekt beurteilen zu können. Dennoch müssen Smart-Graphics-Techniken sorgfältig angepasst werden, um medizinische Anwendungen zu unterstützen. Ausführliche Diskussionen von Anwendungsszenarien, Anforderungen, Prioritäten und Vorlieben sind daher Grundvoraussetzung erfolgreicher Entwicklungen. In diesem Artikel geben wir einen Überblick über aktuelle Arbeiten aus der Anwendung der Smart Graphics im Bereich der medizinischen Visualisierung.

Keywords I.3.7 [Computing Methodologies: Computer Graphics: Three-Dimensional Graphics and Realism] Animation, Color, shading, shadowing, and texture; I.3.6 [Computing Methodologies: Computer Graphics: Methodology and Techniques] Interaction techniques; I.3.3 [Computing Methodologies: Computer Graphics: Picture/Image Generation] Viewing algorithms; I.3.8 [Computing Methodologies: Computer Graphics: Applications] ►►► **Schlagwörter** Animation, Mensch-Computer-Interaktion, Stichpunktbestimmung, Medizinische Visualisierung, Illustrative Darstellung

1 Introduction

The use of 3D visualizations enters more and more medical disciplines and the clinical routine. Two common characteristics of nearly all medical professions with regard to 3D visualizations are (1) medical doctors operate under severe time constraints, and (2) they are mostly unexperienced in the exploration of and the interaction with such visualizations. Therefore, it is necessary to provide smart medical visualizations where the techniques and parameters are carefully adapted to the peculiarities of the data set and to specific tasks in diagnosis or treatment planning. It is important that the user of medical visualizations does not miss important structures or relations. Hence, smart medical visualizations must also support

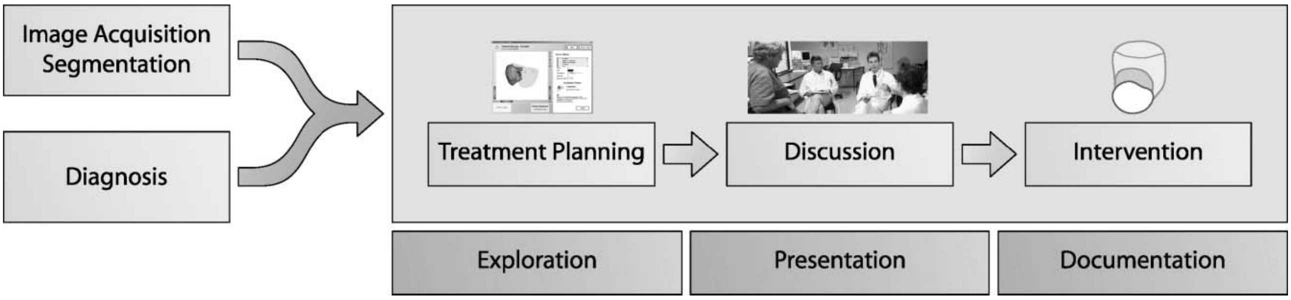

Figure 1 Medical workflow. Visualization for the clinical routine must support the smart exploration, presentation and documentation of data.

the recognition and perception of important aspects, such as infiltration of anatomic structures. Finally, the introduction of advanced medical visualization techniques requires to carefully analyze surgical workflows (Sect. 2). We present selected techniques for both issues, the exploration support and the perception guidance: Animations (Sect. 3) and automatic viewpoint selection techniques (Sect. 4) support the exploration process. Textual annotations (Sect. 5) and illustrative renderings (Sect. 6) guide the user's perception to potentially important structures.

2 Surgical Workflow

Medical visualizations are generated for and used in a workflow from diagnosis to intervention and eventually post-treatment examinations. The workflow starts with the acquisition of image data, such as CT and MRI, where the specific imaging parameters are tailored to the specific intervention planning task. These images, represented as 2D slices of the body, are segmented to identify important anatomical structures and pathologies for later inspections (see Fig. 5(b) for an example). This task is mostly performed by a technical assistant or a radiologist and not by the doctor who later delivers care. The information derived during the segmentation are used to create 3D visualizations like those in Fig. 2. Depending on the type of the segmented structures, there are many different reconstruction algorithms available [2]. Even if direct volume rendering is commonly used in medical visualization, indirect volume rendering or polygonal surface rendering is primarily used when segmented structures need to be visualized that cannot be distinguished in volume rendering.

Surgeons usually explore conventional slice images of CT or MRI data and use the diagnostic report of the radiologist to become familiar with the specific patient data. In particular in difficult cases, treatment decisions are not straightforward, e. g., when surgery has to be performed close to vital structures. In these difficult cases, 3D visualizations are utilized for improved planning. They are used together with the 2D slices to support the treatment decision, e. g., if the patient is operable, and which treatment option is most promising with respect to safety margins during the intervention and long term outcome. After this individual exploration in an interdisciplinary environment, e. g., a tumor board, the exploration outcome must be presented and difficult treatment decisions are discussed. Finally, the chosen treatment option is performed. This can be, e. g., a chemotherapy, an operation or a radiotherapy.

Visualizations are generated and used in various ways during the surgical pre- and post-operative workflow. For individual treatment planning an extended support of the explorations is necessary, since surgeons are not familiar with 3D interaction techniques. The results of this process must be reused and processed for presentation purposes as well as for standardized documentation (see Fig. 1).

3 Animation

As mentioned above, efficient visualization support is essential in clinical routine. During an interdisciplinary discussion, on the one hand it is usually not possible to explore the 3D data by navigating in the scene. On the other hand, spatial imagination benefits from movements in visualization. Pre-rendered animations can close this gap providing both a spatial imagination and time saving effectiveness. In an animation, the interesting points can be emphasized automatically and directly without the overhead of searching and navigating manually in the scene. Nevertheless, generating such animations 'by hand' is a tedious process and therefore not practicable for daily routine.

Thus, automatic generation of reproducible animations is an important issue. An early approach was presented by Butz [4], where single defined targets were used to generate an animation and they give a better impression of a scene using camera movements, zooms and cuts. The targets were defined in high-level textual descriptions. Iserhardt-Bauer et al. [6] automatically generated clinical videos for CT angiography volumes. They used volume rendering with standard transfer functions and showed the volume of interest from different standard views (like top, bottom, left and right side). This method was considered as a viable approach by medical experts [16], even if problems occurred with occlusions of structures.

Wohlfart and Hauser [19] combined animations that were designed to present a given medical visualization with interaction facilities. They borrowed ideas from story telling and defined different levels of interaction. At one

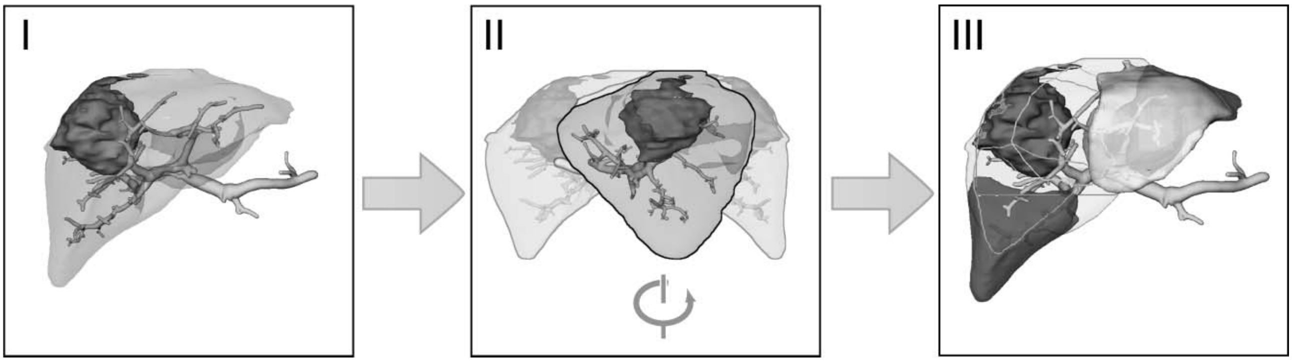

Figure 2 Screenshots from an animation for liver surgery planning. The scene is introduced (I + II) and liver segments affected by a tumor are shown as silhouettes while other segments stay semi-transparent (III).

level, the user can pause the animation for explorations and return to the animation afterwards. At another level, some parameters (e. g., color or visibility) are controlled by the animation system, while other parameters (mostly the camera) are controlled by the user himself. Nevertheless, the system is only applicable for single data sets, since the animations must be created 'by hand'. However, for educational purposes, where single medical aspects are presented with one example, it is a viable approach.

The basic ideas of [4] for generating animations based on high-level textual descriptions have been modified and refined for the peculiarities of intervention planning by the authors in 2006 [9]. Besides the automation of animation generation, we focused on reusing animations for other cases, where similar treatment decisions should be supported. We developed an animation framework based on a script language that defines the behavior of animations. The script language offers high-level commands to emphasize whole structure groups (e. g., `showEnlargedLymphNodes`) or create advanced camera flights as well as low level commands to manipulate each visualization parameter individually (e. g., `setColor 'Bone' white`). The scripts are adaptive and reusable to create many animations from similar data sets (e. g., for a liver operation planning as shown in Fig. 2). In other words: a script describes how an animation should roughly look like and what information or which structures should be shown. The adaption to the current data set is performed automatically by the animation framework.

Besides the presentation and documentation, (interactive) animations may support the interactive exploration process during intervention planning. Generated and played back in real time, those animations can, e. g., present an introduction of the visualized scene. Other applications are smooth transitions between different viewpoints or visualizations, e. g., to emphasize a new region of interest. One example for multiple transitions is an overview of the scene showing the location of a tumor inside an organ and a detailed inspection of vascular structures in the vicinity of the tumor.

4 Viewpoint Selection

One problem for creating animations automatically and for the interactive exploration is the location of good viewpoints on single anatomic and pathologic structures. Observations of surgeons using 3D visualizations clearly revealed that it is time-consuming and difficult to select viewing directions appropriate to 'answer' their specific questions, such as the optimal entry point for performing a biopsy or the optimal access to a deeply seated lesion. Good initial viewing directions or a collection of such directions are essential for them. Choosing just default viewing directions like *front*, *left* or *bottom* is not sufficient. Visualizing many structures, occlusion of structures among each another is a considerable problem.

To quantify the quality of the goodness, Vazquez et al. [17] introduced the viewpoint entropy as a simple measure. For polygonal objects, the value of the viewpoint entropy depends on the visibility of many polygons with the same projected area. This approach was refined for other mesh-depending parameters like curvature [14]. For direct volume rendering, Bordoloi and Shen [3] used the opacity and color rareness of voxels (named as noteworthiness factor) to determine viewpoint quality. For them, good viewpoints show many opaque voxels in a preferably rare color. Viola et al. [18] extended this single voxel approach to regions, where an important region is defined by voxels that are near to the view plane in the object space and in the center of the image in the image space. They calculate one good viewpoint per object in a preprocessing step and use these viewpoints to guide the user's exploration.

For medical visualization, a more elaborated approach is required. Viewing a single structure from the side of its largest visible surface is usually an optimal choice. Likewise, rare colors or opaque voxels can only be a first hint to a good viewpoint in direct volume rendering. Therefore, we introduced a new parameter-based approach for automatic viewpoint selection in multi-object scenes [10]. For many parameters (that are partially specific for medical applications) a distribution on the bounding sphere of the scene is calculated (see Fig. 3). These parameters include: the visible surface of a structure, the number,

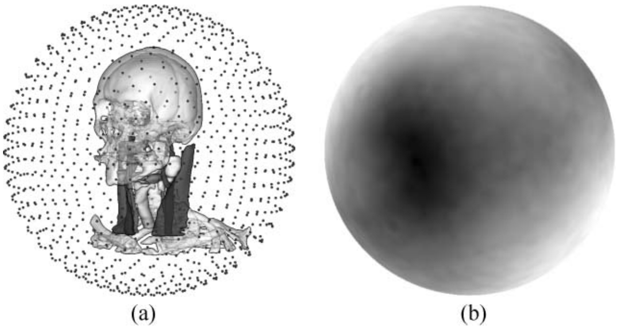

Figure 3 (a) Medical scene surrounded by potential camera positions. (b) Surrounding sphere with a single parameter (visible surface) of a structure mapped on it.

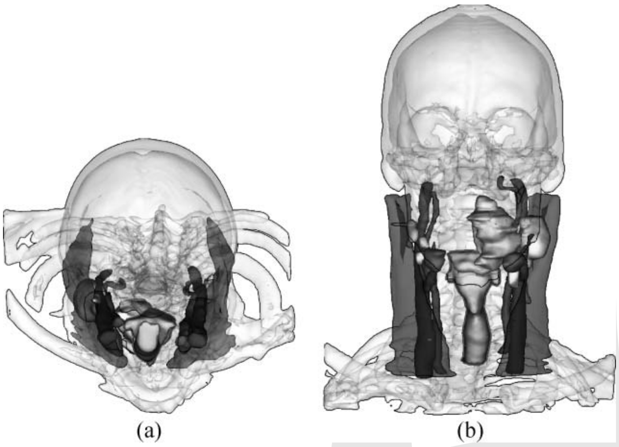

Figure 4 (a) A view on the trachea calculated only using the viewpoint entropy. (b) Viewpoint on the trachea using the multi-parameter viewpoint selection technique [10].

importance and opacity of occluders, and the preferred region. The opacity of occluders is important, since occlusion by a strongly-transparent context structure is detracting a viewpoint less than an occlusion by another important opaque structure. For the preferred region, a neck visualization may be explored from equatorial regions, while for neuro surgical applications a view from the top onto the open skull is preferred.

In Fig. 4, an inappropriate and a good viewpoint on the trachea (red silhouette) are shown. The bad viewpoint (Fig. 4(a)) was calculated using only the viewpoint entropy as a measure of goodness. The visualization preferred by the surgeons (Fig. 4(b)) shows the whole scene from a familiar viewpoint and in respect of the high transparency of the occluding bones.

5 Textual Annotations

Textual annotations play an important role in guiding perception and recognition. They help to identify single structures or refer the viewer to important points and regions of interest. Furthermore, they can present additional information, e. g., quantitative information with respect to the size of a pathology or diagnostic findings from previous examinations, e. g., with respect to the tumor type. Medical professionals are familiar with textual annotations of anatomical visualizations, since they are essential in text books. Therefore, it is helpful to integrate textual annotations in both educational systems and software applications used in clinical routine.

There are many techniques available to annotate several types of visualizations. For 2D visualizations the community focuses on map labeling, since it is the most important application area for 2D textual annotations with a lot of special cases and subproblems that are by far not solved. Ali et al. [1] achieved a substantial progress in the annotation of 3D visualizations. They identify anchor points in opaque polygonal objects and arrange the corresponding labels around the objects following different layout paradigms (e. g., circular or left-right). Crossovers between connection lines are solved. Since this approach was limited to single line labels and opaque structures, we extended it for medical scenes of semi-transparent structures and label text of arbitrary size and design. We also defined requirements and options for labels in medical visualizations.

The user is an anatomical expert and does not need a textual reference on all visible structures by default. Single annotations can better emphasize important structures and guide the user directly to a closer inspection, e. g., by clicking on the label and performing and automatic camera flight using the presented animation and viewpoint selection techniques.

Besides the name of the structure for identification, there are various features of text that can be presented in a textual annotation. In many cases, the extent and volume of single structures are crucial (see Fig. 5(a)) as well as distances between structures. Presenting this information directly in the visualization avoids the distraction of the user, when he/she looks for the data in a separate list or text.

The requirements for 3D annotations also apply for 2D slice visualizations. As in 3D, labels in 2D can support the identification of structures and they can present additional information. Since surgeons are not confronted with 2D slices every day, hints to segmented structures were considered useful for them (see Fig. 5(b)).

Since the user interacts simultaneously with the 2D and 3D visualizations, the annotations should be synchronized in appearance and textual information. This enables the user to recognize the relation between 2D to 3D, and vice versa.

6 Smart Illustrative Visualizations

Illustrative (low level) rendering techniques, such as silhouettes, stippling and hatching bear a great potential for conveying complex spatial relations. As an example, Kim et al. [7] showed that hatching lines improve the perception of complex surfaces in terms of estimating the surface orientation. In surgical planning, the complex anatomy of the particular patient, security margins around tumors or resection lines indicating the intended resection area

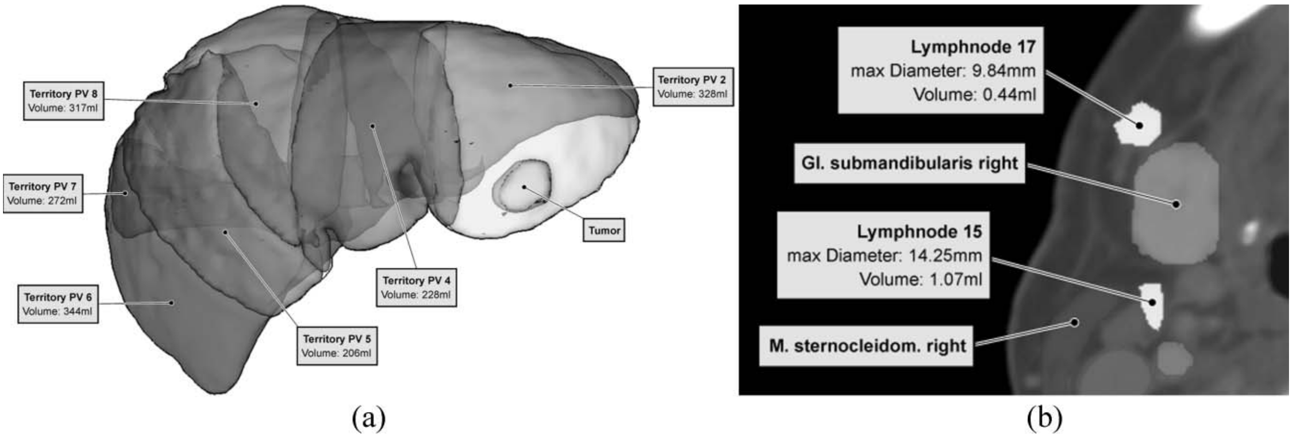

Figure 5 (a) Textual annotations in a 3D visualization for liver surgery planning. The several territories of the liver that can be segmented, are annotated with their name and volume. (b) Textual annotations in a 2D slice of the neck region. Several segmented structures are annotated with their name, while important structures like lymph nodes are labeled additionally with their maximum extent.

have to be displayed. In principle, surgical planning might benefit from incorporating illustrative rendering.

However, illustrative rendering techniques have many parameters, e. g., hatching styles, hatching direction, and hatching density. Therefore, the incorporation of illustrative rendering techniques requires to provide meaningful default values with respect to all parameters. This is difficult to achieve, since the appropriateness of the parameters strongly depends on the object shape, e. g., an elongated muscle, or a branching vascular structure, or a compact organ. Moreover, the relevance of a particular object in surgical planning determines how salient it should be displayed.

First experiments [15] were dedicated to understanding the role of silhouettes in surgery planning. It turned out that silhouettes are useful to convey the shape of larger strongly transparently rendered context objects (objects which are not in the focus), so-called context objects, such as skeletal structures. Moreover, silhouettes act as an emphasis technique when combined with opaque surface rendering to highlight small important anatomic structures, such as a tumor. In a specific application, in neck surgery planning [8], the use of silhouettes has been carefully evaluated in clinical routine and it turned out that the incorporation of silhouettes represents a useful default value for some structures. It should be noted that this represents only a very first result dedicated to one specific application. Moreover, it is not precisely clear, how the silhouettes should be rendered, e. g., line color, line style, thickness. As an example for an open question it might be better to convey the distance of parts of the silhouettes by adapting line thickness or line color so that they are considered as 3D objects.

A nice property of illustrative rendering is that it may be deliberately used to convey distances and depth information, e. g., the spatial distance of vessel branches to a tumor. This idea has been implemented and carefully evaluated with respect to liver surgery planning and intraoperative support [13].

With respect to hatching, it is of paramount importance to provide a suitable surface parameterization to automatically place hatching lines. Anatomic knowledge, such as preference directions, might be included, but this knowledge should apply to a whole category of structures and not to an individual structure of one patient. It is essential that anatomic knowledge can be effectively reused for similar cases. As an example, we presented smart hatching techniques for muscles and vascular structures (see Fig. 6) [5]. However, in case of hatching there has been no substantial evaluation with medical doctors. Therefore, the precise role of hatching for surgery planning is not clear.

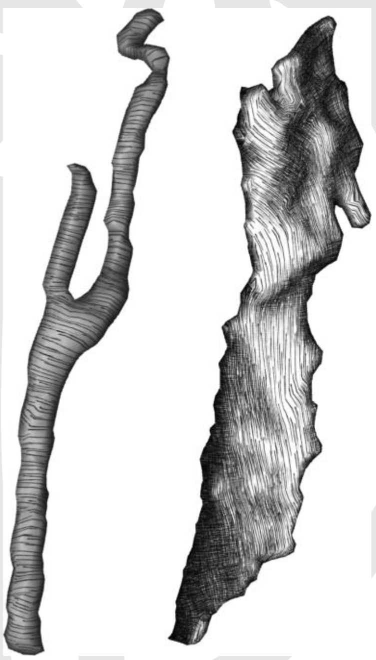

Figure 6 Different hatching style on the surface of vessel and a muscle. (image is courtesy of Rocco Gasteiger, Otto-von-Guericke-University Magdeburg)

7 Conclusion

In this paper we presented an overview of smart visualization techniques that support the medical intervention planning process. Using automatically generated animations, interactive overviews and visualization transitions as well as videos for presentation purposes can be supported. We showed that for selecting good viewpoints the 'goodness' of a viewpoint must be carefully defined. We presented a viewpoint selection technique that is specific for medical visualizations. To give the doctor more guidance and information, we showed how useful textual annotations can be. To guide the perception of important aspects and structures we give an insight in the usage of illustrative rendering techniques. All these techniques are integrated in the open-source MEDICALEXPLORATIONTOOLKIT [11].

A comprehensive survey of medical visualization can be found in Preim and Bartz [12].

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