Volume Visualization for Improved Radiation Treatment Planning in Oncology

Stefan Großkopf

Introduction
Modern methods of radiation treatment in oncology enable the precise destruction of tumor tissue and minimize side-effects on the surrounding tissue by irradiating rays from different angles that intersect in the tumor area. The radiation treatment planning (RTP) procedure that is performed prior to each treatment thus plays an important role in preventing the damage of vital structures near to the tumor. Within modern clinical settings, computer-based planning programs are applied to simulate the irradiation procedure and visualize the distribution of the irradiation. Up to now, the physician has had to review all slices in order to find areas of high irradiation dose in order to improve the treatment plan. Computer graphics technology offers the potential to compare and improve more therapy alternatives in a shorter period of time if the technology can be used to speed up the evaluation of the radiation treatment plan by presenting all relevant information at once. Therefore, 3D visualization can take over an important role in this area of medicine.

Within the presented project that is jointly carried out by the German Cancer Center (DKFZ) in Heidelberg, the Interactive Graphics Systems Group of the Department of Computer Graphics at Darmstadt University of Technology, and the Department of Cognitive Computing & Medical Imaging of the Fraunhofer Institute for Computer Graphics, we are developing and integrating improved analysis and visualization technology applied to 3D tomographic data into the planning program VIRTUOS that has been developed and is applied in routine clinical work at DKFZ.

Radiation Treatment Procedure
The RTP is based on tomographic data sets of the patient that are acquired prior to the treatment. Nuclear Magnetic Resonance imaging (MRI) is usually used in order to study the shape and location of the tumor and the organs at risk because of its high contrast of soft tissue for that modality, while an additional X-ray computer tomography (CT) data set is acquired, which is necessary to estimate the absorption of the treatment ray by the tissue. In the first step, the MRI data set is segmented to accurately determine the location and shape of the organs at risk and to determine the target area. From contours extracted from the 3D, the shape of the organs is reconstructed.

In a subsequent simulation process, the dose distribution is calculated. The result is a 3D volume data set that contains a predicted irradiation dose for every volume element (voxel). Based on segmentation information and dose distribution, it is finally possible to calculate the total absorbed dose of the treatment rays for the target area and the organs at risk. Additionally, it is necessary to review the spatial distribution in order to see underdosed areas (cold spots) within the target and overdosed areas (hot spots) within the organs at risk. This is conventionally done in 2D by reviewing the dose distribution graphically overlaid on the individual slices as isodosis lines or color information.

Since all data sets, as well as the irradiation scene, is originally in 3D, the planning procedure can be improved by the 3D visualization of all relevant data sets at once. 3D visualization has proven to be especially useful for studying the relationship between the radiation angles and hot and cold spots.

The RTP program VIRTUOS that is applied in routine clinical work at DKFZ additionally offers a view for finding irradiation angles with minimal side effects. Therefore, the organs at risk are projected into the coordinate system of the treatment device which allows one to easily find angles where no organs at risk will be affected by the treatment ray.

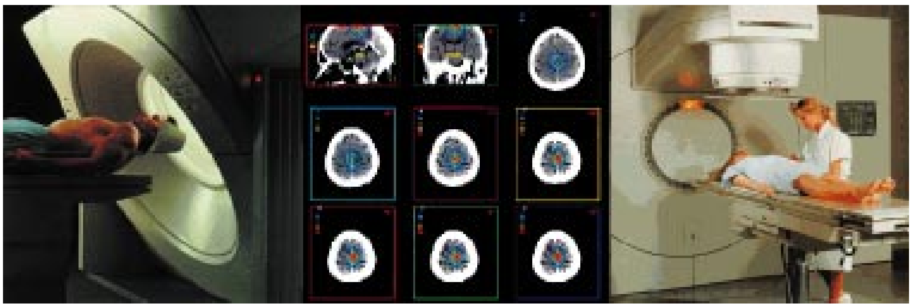

Figure 1: Stages of radiation treatment (left to right: image acquisition, planning and treatment simulation based on tomographic data the dose distribution is overlaid to the slices, treatment on a linear accelerator)

Segmentation
The segmentation procedure is mainly performed manually in clinical settings supported by techniques similar to drawing programs. Automatic methods based on image processing algorithms are still seldom applied since their results are error-prone and may change

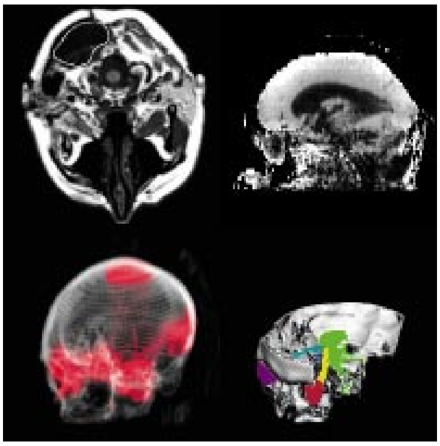

Figure 2: Segmentation using an active contour model and volume rendered tomographic data sets

depending on image quality. Image noise and mechanical tolerances of the imaging device, as well as small patient movements, may reduce image quality. As a result, images may not accurately reflect organ and tumor boundaries and thus the fully automatic extraction of organs or the tumor area is a rather complicated procedure that has not yet been solved for arbitrary data sets and arbitrarily shaped objects.

However, the manual outlining also has its limitations. The segmentation result is dependent on the operator's experience and may in addition change for every trial by the same operator.

Within this project, the application of active contour models (ACM) for segmentation has been evaluated. ACMs offer a compromise, since their semi-automatic segmentation requires user input which restricts the result to some possible locations that are finally adjusted by local image features. The general idea behind ACMs is the autonomous adaptation of a template to the shape and location of an object depicted in an image. After initialization, the ACM is deformed to fit the actual object boundaries by simulating the physical properties of an elastic material or a fluid. The templates may be contours taken from an atlas (in the case of at-risk organs) or an initial user sketch (in the case of the tumor) that cannot be sketched particularly accurately due to the limitations of input devices and that are adapted to image features by the ACM mechanism.

Direct Volume Rendering

The most common method for visualizing 3D scenes in the area of computer graphics are surface rendering techniques. For this technique, the surface of the depicted objects has to be represented by a triangular mesh. It is a fast method, since it is supported by the specialized PC graphics hardware. Nevertheless, the rendered images may lack important details and may be falsified due to inaccuracies caused by the segmentation process. Thus, for medical applications it is only suited to previewing.

Direct volume rendering (DVR) on the other hand is, due to its high degree of detail, an established visualization method in medical imaging. It is a technique for displaying volume data without any explicit generation of an intermediate data set. DVR is based on casting rays through the volume and extracting features of the volume. Thus the whole information inherent in the 3D data set is used for the calculated 2D display so that the observer performs the selection of information that is done for the surface rendering prior to the visualization.

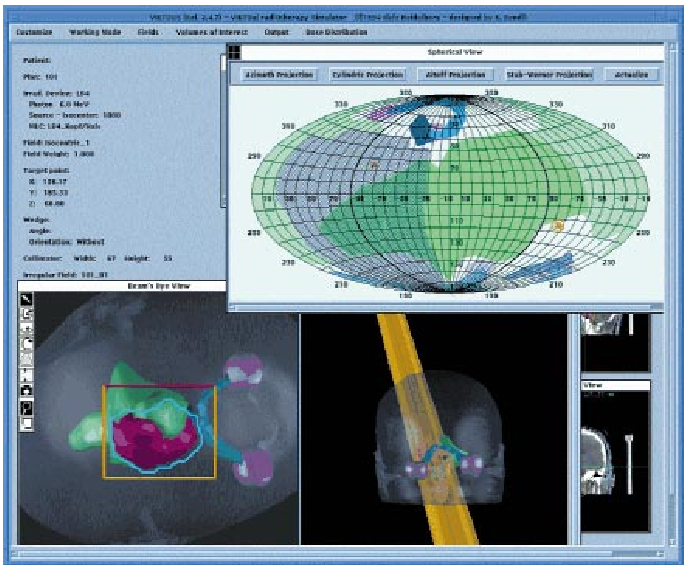

Figure 3: User interface of RTP program VIRTUOS (DKFZ Heidelberg)

Point of contact

Stefan Großkopf
Technische Universität Darmstadt
Department of Computer Science
Interactive Graphics Systems Group
email:
Stefan.Grosskopf@gris.informatik.tu-darmstadt.de