Enabling Systems for Neurosurgery

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1. INTRODUCTION

One of the major problems in neurosurgery is to find an optimal access route towards the area of interest, e.g., a lesion to be treated chirurgically. The quality of a route depends on the type of pathology to treat, its location, the functional areas surrounding it and many other aspects. The overall goal of route optimization is of course, to treat the patient as effectively as possible while minimizing additional damage. In addition, the operation field must be sufficiently accessible to the surgeon. To identify such a route, besides other aids, radiological images of the area of interest (often CT/MR-images) are consulted, and the decision is based on the location and extent of the pathology as discernible in the images, sometimes supported by functional MRI data.

Unfortunately, two-dimensional images communicate only limited information about the spatial and structural relationships, although experienced radiologists and surgeons develop the ability to build mental models of the three-dimensional structures from the images alone. But this process takes much time and a lot of experience. Furthermore, surgeons and radiologists have to cooperate and come to a common understanding to find the optimum treatment. This proves difficult as they have radically different views on the patient. While radiologists often feel comfortable with stacks of two-dimensional images, the surgeon’s primary view is on what he finds once the skull is open. Computer technology can help to bridge the gap and shorten the discussion.

Using the experiences from other medical projects we developed a software system that is built on the paradigm of *enabling systems*. This approach focuses on the cognitive processes that take place in the mind of experts and tries to support the less experienced user with cognitive aids that help to develop expertship faster and more easily. Under this paradigm, visualizations, algorithms, and technical aids are chosen primarily with respect to their ability to enable the user to gain insight into the data and the underlying processes. In the remainder of this article we give a short introduction into the paradigm, describe the application of enabling systems to neurosurgery and discuss our current system and its properties.

2. ENABLING SYSTEMS

Systems specially designed to aid the understanding of complex phenomena via a representation of cognitive models are called *enabling systems.* They focus on the identification of mental and cognitive models that are used by experts in a given domain and attempt to communicate and teach these models to novices or less experienced users. In our case, they give the surgeons access to the radiologists expertise and vice-versa. In addition, serving educational purposes, the system should support interactive, explorative approaches including learning on-the-job [2].

In the past, we have successfully applied these paradigms to the visualization and teaching of echocardiography [2, 9]. We found that orientation and expertise can be gained substantially faster using enabling systems than with traditional approaches. One of the important parts of successful application of these principles is the availability of an appropriate user interface giving assistance in the learning. We will return to this point later.

3. APPLICATION TO NEUROSURGERY

In the context of neurosurgery, a challenging task is to locate and plan an optimal access path to, e.g., a deeply located lesion, from the outside. “Optimal” in this context means giving the surgeon good access to the operation field while causing minimal damage to the patient. Identifying an appropriate access path requires good spatial and functional orientation inside the brain accompanied by a detailed anatomical background. We chose to support planning and communication with an enabling system. As already stated, this implies the need for a flexible and interactive user interface and data presentation. As neurosurgeons typically plan access routes by the means of radiologic images, namely CT- and MR-scans, incorporation of these multimodal data into the visualization part was important.

We decided to use a texture-based volume rendering algorithm [3] to create three-dimensional renderings of the spatial data because of the algorithm’s fast rendering capabilities and its only weak dependence on the size of the volume. Unfortunately, the basic algorithm can not render important secondary visual cues like lighting and shadows, although modified algorithms have been developed that incorporate approximations to lighting and shadows into the core [1, 10]. Alternative algorithms like surface reconstruction via marching cubes [7] or volume raytracing [6] lack from low speed or introduction of derived structures (interpolated iso–surfaces) which we wish to avoid in order to give the surgeons and radiologists fast and immediate access to the original medical data. In addition, texture-based rendering can correctly render multiple volumes or surface renderings into the same window. For a snapshot of our ren–derer showing a MRI volume of the human brain together with the simulation of a laser-induced interstitial thermo-therapy (LITT) application see figure 1.

Using the aforementioned visualization system, we are able to handle and manipulate even large datasets ($\approx 128^3$ voxels) at interactive frame rates. These facilities give the interested parties some insight into the complex spatial relationships for the patient and help them to find an appropriate access route. We found that the interactive manipulation and exploration of the dataset is especially helpful during conference situations, supporting the discussion between radiologists and surgeons. In addition to rotation or zooming of the volume, arbitrary clipping planes are available. Contrast, brightness and transparency of the volume can be interactively manipulated using the corresponding look-up tables. With this direct, data centered approach we are able to give the surgeons *and* radiologists tools they can use and understand intuitively from their own background to discuss and communicate their respective findings. These direct data access aspects are crucial for the success of an enabling system.

4. DESCRIPTION OF ENABLING SYSTEM

In addition to operation planning, our system can be used during the intervention. For example, if some unexpected complications occur it may be necessary to search for alternative access routes. This of course makes it necessary that surgeons have access to the visualization system from within the operation theatre. Besides hygienic problems this also raises other technical difficulties. Mouse and keyboard are inadequate input devices for a surgeon whilst on the job. We therefore decided to keep the computer system out of the operation theatre. We instead use a LCD video beamer located in the control room to project the enlarged image through one of the glass walls This gives the whole team the chance to see and discuss the problems together. Using two projectors and a specially coated screen, even stereo projections are possible, an option tested, but not yet evaluated in this context. Input to the system is given via spoken commands which are currently executed by an operator outside the operation theatre, but we intend to use a voice input software for more tightly coupled interaction.

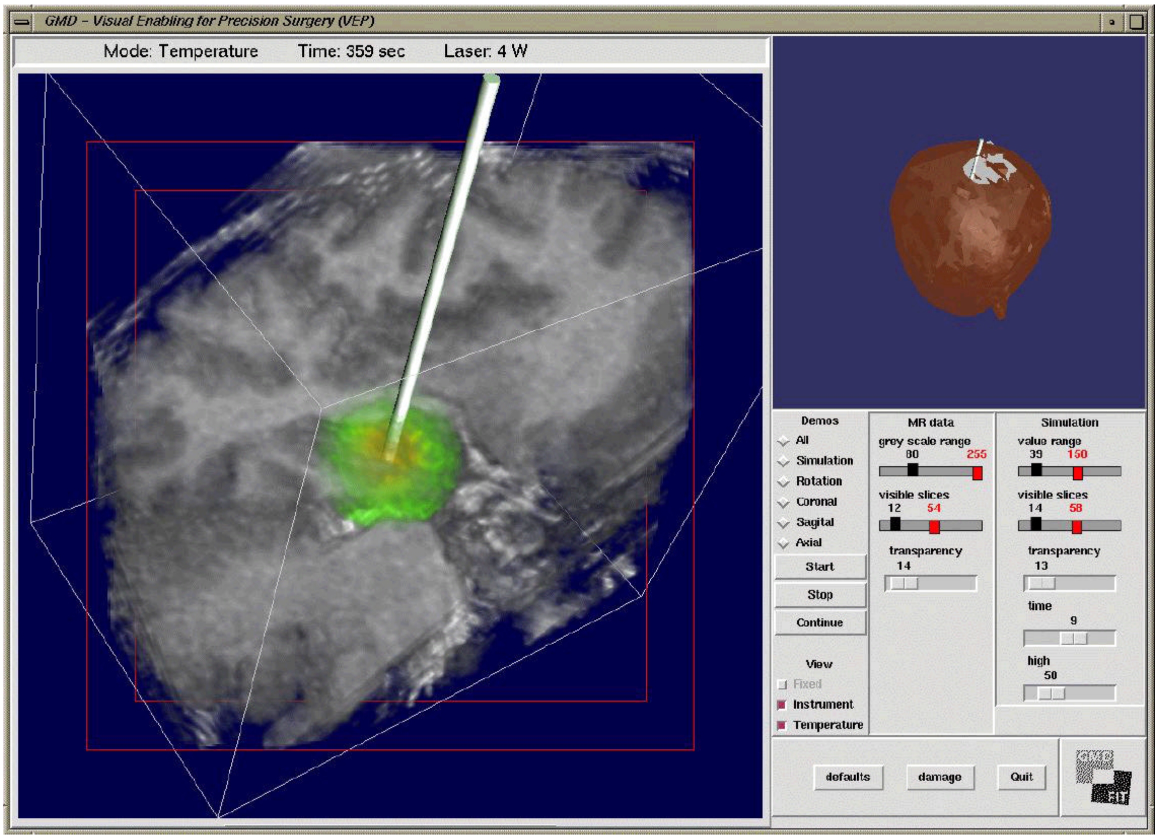

Figure 1. Snapshot of the user interface of our enabling software. In the left subwindow, a volume rendering of a brain MR-scan can be seen, overlayed with the simulation of a LITT application. In the upper right, the skin of the skull is rendered in order to communicate the spatial orientation of the volume on the left.

Other interesting options arise due to the nature of the rendering algorithm used. It is fairly easy to mix images of different modalities in the same volume (for example CT and MR data) by alternatively rendering slices from each volume. This gives the surgeons further insight in the situation that can not be gained easily from one isolated modality. Of course, this requires a proper registration between the datasets. We found that the algorithm described in [8] solves this problem particularly well, once an initial approximate registration has been set up interactively by the user. This is done preoperatively and can significantly help in the operation planning phase. This blending option can also be used in conjunction with artificial data.

We also applied this option within the framework of laser-induced interstitial thermo-therapy (LITT) [4]. LITT is a comparatively new, minimally invasive treatment for solid neoplasms. A specially designed lightguide is positioned in the center of the respective tissue structure. The region of interest is then heated using a suitable laser source. Thus, the tumor is heated by the absorbed light energy and destructed. For therapy planning, specially designed simulation software is employed [5]. A precise prediction of the therapeutic result, however, must also include exact spatial orientation of the simulation results with respect to the adjacent tissue structures to avoid relevant functional damage.

In figure 1, a simulation of a LITT session can be seen, embedded into the patient's data. Using the blended datasets, the spatio-structural relations can be appropriately judged, for example, whether the therapy erroneously affects healthy areas.

One major difficulty with texture-based volume rendering is that illumination and shadows, which are important secondary visual cues for spatial orientation, can not easily be modelled in an adequate manner. Approximate illumination has been integrated recently [10] and this helps a lot to promote further understanding of the spatial structures, but to our knowledge realtime shadow calculation methods for a texture-based volume renderer have not been reported in the literature. We found, that using an approach called shadow polygons [1], approximate shadows can be incorporated at only moderate costs which do not compromise realtime interactivity. It must be stated here that neither van Gelder's illumination [10] nor our shadows are physically correct, but only approximations. Nevertheless, both help the user to explore and further understand the data he interacts with. This focus on the cognitive portion is another key part of enabling technology.

5. CONCLUSION

In conclusion, we found that the usage of the texture-based volume rendering is a great aid in understanding and discussion of the complex spatial relationships in the patient's brain. The use of enabling technology guided us to some physically inaccurate but cognitively useful extensions of the renderer like approximate shadows and lighting. Unfortunately, such realtime rendering algorithms are limited to leading edge hardware (we use an *Octane MXI* workstation from *Silicon Graphics, Inc.*) which in turn is very expensive, but with the inclusion of three-dimensional textures in the upcoming OpenGL 1.2 standard [11], we expect other hardware vendors to support this feature in the near future, lowering the prices. In addition, the costs are offset by reduced operation planning time.

We also found that the "natural" presentation of the data as a volume significantly improved the discussion between radiologists and neurosurgeons, compared to traditional two-dimensional slice viewing. In the future we will work on a better and more intuitive user interface, including voice input and better visualization, for example using stereo projection. We also want to investigate some possible speedups, like using shadows without lighting. As existent illumination models decrease performance by a factor of about ten [10], this would be significantly faster than the "complete" solution. First experiments indicate that lighting can efficiently be faked using shadows. This is due to the fact that our shadows partly simulate the diffuse shading of the surface without actually calculating the illumination: Shadows cast onto surfaces indicate the direction of incoming light, thus giving enough cognitive hints about the diffuse illumination they would receive. Of course, the illumination model is as approximate as the shadows themselves, but as both fulfill the desired functionality, to help understand spatial orientation, both make up a usable part of the enabling system.

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