Knowledge-Based and 3D Imaging Systems in Medical Education

A. Pommert, M. Riemer, T. Schiemann, R. Schubert, U. Tiede, K. H. Höhne

Institute of Mathematics and Computer Science in Medicine (IMDM)
University Hospital Eppendorf, Martinistr. 52, 20246 Hamburg, Germany
e-mail: pommert@uke.uni-hamburg.de

Computer-aided instruction systems are often based on conventional hypermedia techniques, which offer a convenient access to logically related informations. As a major drawback, however, these systems provide only predefined texts or images, which often do not match the student's needs.

In this paper, two fundamentally different methods for building education systems are reviewed, based on recent knowledge-based and 3D imaging techniques. Intelligent tutoring systems provide a means to model, investigate and explain more abstract knowledge, while 3D anatomical atlases can be used to create arbitrary views of the human anatomy, providing a "look and feel" close to a real dissection. Both concepts are supporting a "learning by doing" approach. Advantages and current problems are discussed.

Keyword Codes: I.2.4; I.4; J.3; K.3.1
Keywords: Knowledge Representation; Image Processing; Life and Medical Sciences; Computer Uses in Education

1. INTRODUCTION

Up to now, teaching of anatomical, functional and pathological medical knowledge follows the rules developed at the beginning of medicine. A student gets a more abstract knowledge from lectures and text books, while he acquires an imagination of the spatial properties of the organs by dissecting cadavers and from anatomical and other medical atlases. Integration of this knowledge acquired from such fundamentally different sources is a difficult and mostly tedious task.

In order to facilitate learning, a large number of medical instruction systems have been developed on the basis of *hypermedia* techniques, which allow an integration of texts, images, video sequences, and other types of data [5]. These systems provide a rich structure of references between logically related informations. Comfortable tools are available, easing both design and use of hypermedia applications. As a major drawback, however, a hypermedia screen usually can only display predefined texts or images. User interaction remains thus basically the same as studying a conventional book.

For teaching more complex skills, it would certainly be desirable that a student could really "work" with the things he is interested in. In this paper, two complementary methods are reviewed which support this "learning by doing" on different levels of abstraction: intelligent tutoring systems, and 3D anatomical atlases. The latter, which we developed in the last three years at our institute, is presented in some detail. It is shown how both methods and hypermedia techniques might eventually be merged.

2. INTELLIGENT TUTORING SYSTEMS

In contrast to conventional hypermedia systems which can only present predefined information, the aim of *intelligent tutoring systems* is to interact more flexibly with the student, very much like a real teacher would do it [8,14]. These systems are especially useful for teaching complex cognitive skills, such as decision making in medical diagnostics. For example, a tutoring system may present a simulated patient case with randomly generated complaints, comment on the student's steps and results, suggest and explain what to do next, or (if the student does not succeed) show how a diagnosis could be obtained. It should be noted, however, that applications remain limited to such domains which can be formalized.

Some major components of an intelligent tutoring system are a *knowledge base*, which explicitly models the knowledge to be communicated, an *interpreter* which can draw conclusions from the knowledge, and an *explanation component*. Quite interestingly, this is exactly what makes an *expert system* [15]. In the medical community, acceptance of expert systems for diagnostic purposes has been limited, partly because modeling medical domains and expert behavior proved too complex for realistic applications [11]. However, complete coverage of a large domain is not so important for tutorial purposes. A successful example is ILIAD (Applied Informatics Inc., Salt Lake City, UT), which runs on Macintosh computers, and is actually an expert system on internal medicine. It can work on cases entered by the student, or create simulated cases. Quite realistically, the system evaluates the student's performance in terms of costs of investigations, which the student needs to obtain a diagnosis. It could be shown that the students skills are considerably improved after training with this system [4].

Other major parts of an intelligent tutoring system are a *didactics component*, planning the tutorial actions, and a *student model*, representing the student's state of knowledge. Both are currently subject to intensive basic research [8].

3. 3D ANATOMICAL ATLAS

All anatomical atlases based on conventional hypermedia techniques share the drawback that they can only provide predefined views of the human anatomy. It is thus not possible to look at an object from a different view angle, or to create other views, according to own ideas and needs.

Recent advances in image processing and computer graphics suggest a much more powerful method for creating anatomical atlases. *Three-dimensional (3D) imaging* (also known as *volume visualization*) provides various ways to realistically display anatomical objects from image volume data, as obtained in computed tomography (CT) and magnetic resonance imaging (MRI) [6,13]. These techniques are increasingly used in clinical practice, both for diagnostic and therapy planning purposes.

While interpretation of a 3D image is left to the observer in clinical applications, using this technique for teaching purposes requires that the data structure also contains some knowledge about spatial and "symbolic" properties of the objects represented in the image volume. In particular, both directions of knowledge acquisition must be possible:

- access symbolic knowledge in the context of a 3D image (e.g. by automatically annotating or describing a currently visible object)
- visualize symbolically defined views (e.g. “show all gyri which are involved in a certain function”)

In the following, basic principles of the 3D anatomical atlas are presented [2,9].

3.1. Modeling

The basic idea is to describe the anatomy in a two-level data structure (fig. 1), which we preliminary call an “intelligent volume”. The lower level is a discrete data volume, as obtained from a medical imaging system. In addition, a set of attributes is assigned to every *voxel* (volume element), indicating its membership to anatomical regions under various aspects (e.g. macroscopic anatomy, functional anatomy). This level is equivalent to the previously described *generalized voxel model* [1].

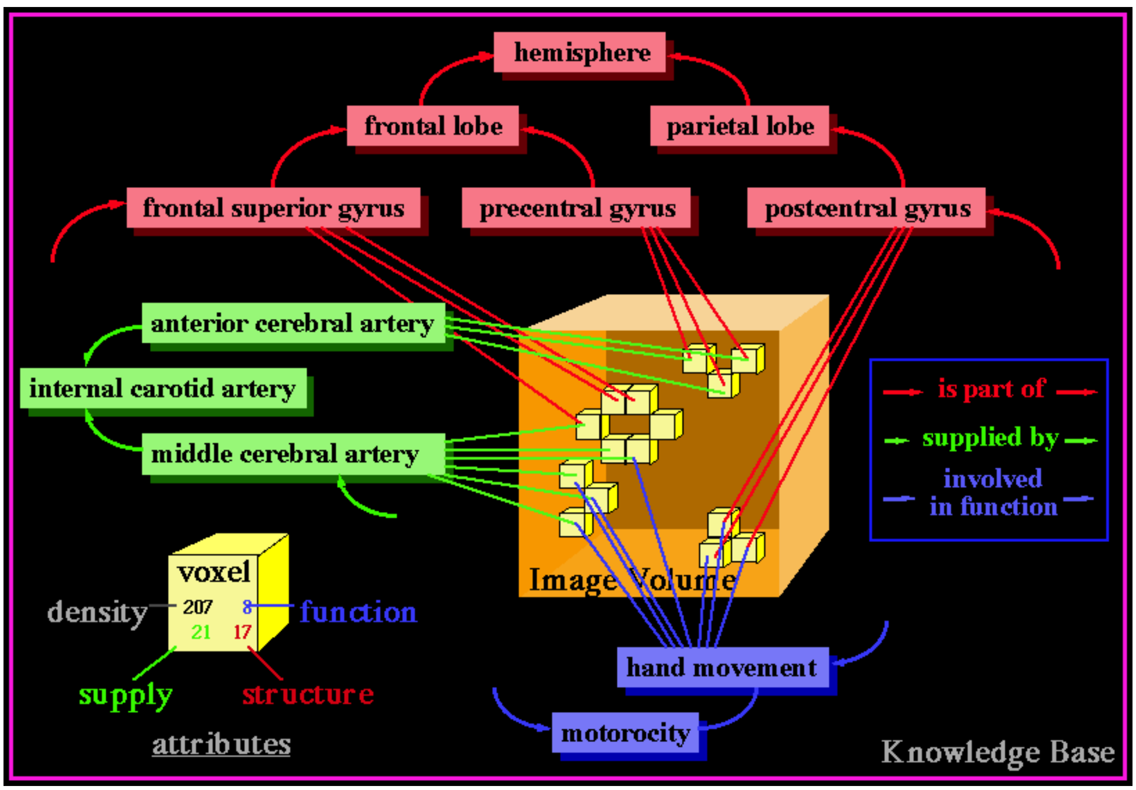

Figure 1. Basic structure of an “intelligent volume”. Besides an intensity value (e.g. from CT or MRI), every voxel holds a set of attributes, indicating its membership to various anatomical regions. Logical relations between different objects are modeled using a semantic net.

On the upper level, properties and relationships of the basic regions are modeled as a semantic net [15]. This more abstract "symbolic" knowledge includes names, synonyms and colloquial terms in various languages, references to texts and histological images, and visualization parameters for 3D display, such as colors and shading methods. Using different link types, both hierarchical and functional relationships can be represented, e.g. "right precentral gyrus *PartOf* right precentral lobe", "long bone *IsA* bone", or "right visual nerve *PropagatingTo* optic chiasm".

This model is not yet adequate to cover the various "views" used in medicine. For example, the optic chiasm is part both of the brain and of the visual system. In order to avoid a confusion of meanings, a number of further attributes for objects (e.g. special or general anatomy) and links (e.g. macroscopic, microscopic or functional anatomy; topographic or systematic order) have been introduced. For a detailed discussion of semantic modeling, we refer to [7].

3.2. Preparing an "intelligent volume"

In order to prepare an "intelligent volume" from a raw data set, both the symbolic and the spatial properties of the objects have to be defined. Most of the symbolic properties, however, are valid for the human anatomy in general. Thus, if a symbolic description of a part of the body has been defined, it can be used again for any data set of the same body region. Thus, an ever growing *generic model* of the human anatomy is obtained.

Since locations of objects are a property of the data set, assignment of the object membership labels has to be done again for every case. In order to obtain a really space-filling model (see below), it is important that these labels are assigned to every voxel in the data. This is usually a very time-consuming process. While a large number of automatic segmentation systems are available, results are mostly not satisfactory for typical data sets. We therefore use an interactive system, based on simple, but fast operations, which provides a comfortable user interface [3]. The whole procedure is described in detail in [10].

3.3. Exploring the model

Using this method, we started by preparing two atlases of the head, based on MR and CT data. In the first case, approximately 150 structural, 50 functional and 30 blood supply areas mainly of the brain were segmented and symbolically described. Anatomical terms were defined in Latin, English, French, German and Japanese. Additionally, a large number of textual descriptions and histological images were prepared. The whole work took an expert several months. For the second data set, about 50 constituents mainly of the skull were segmented and described.

After an "intelligent volume" has been prepared, it can be explored using the program VOXEL-MAN/atlas. It is currently running on various workstations (DEC, SUN, HP, SGI). In contrast to conventional hypermedia atlases, it offers a large number of tools which can be used to create views, according to a student's own ideas and needs. In the following, a short overview is provided. For an extended presentation, we refer to [12].

A typical scene with the brain atlas is shown in fig. 2. Similar functions are grouped into menus. The "change view and light" menu may be used to define "cameras" with individually adjustable view direction, resolution, focal length, and magnification, which appear as windows (fig. 2, at right). Different light sources may be used to illuminate the scene.

The major exploratory functions are grouped on the "services" menu which is always visible (fig. 2, at left). As a consequence of the space-filling model, the contents of the knowledge base may be accessed at every point of the 3D image. Symbolic descriptions can thus be obtained by simply clicking on the image. Object names appear on a popup menu, (fig. 2, at right)

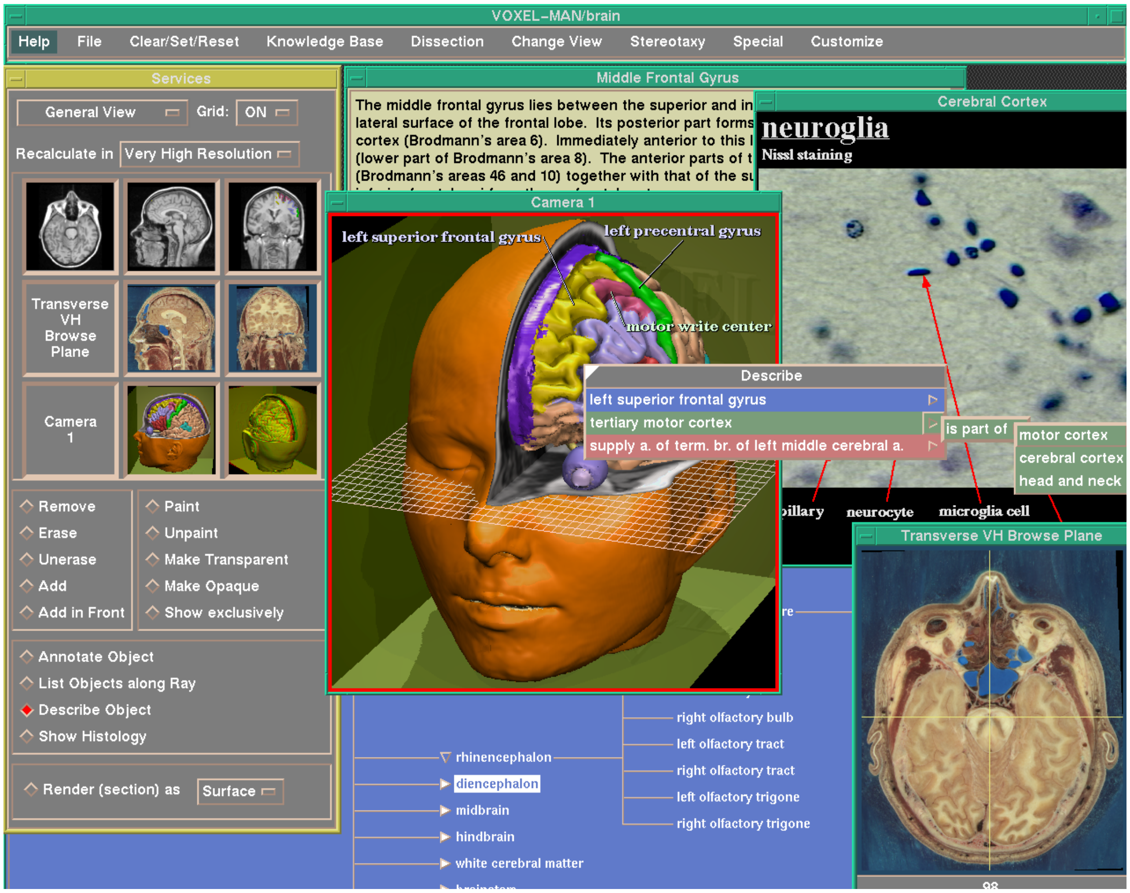

Figure 2. User interface of VOXEL-MAN/atlas. Objects may be addressed by selecting their names from the knowledge base, or by clicking on an image. The view may be changed e.g. by rotating the scene, or by defining cut planes.

together with the names of the objects they are related to, ordered by anatomical domains and link types. By choosing a name, objects may be automatically annotated, removed or added like in a construction kit, painted, made transparent, or additional texts and images may be requested (fig. 2, at center).

The same functions may also be activated for objects which are not currently visible, using the knowledge base. The menu “knowledge base” provides various representations of the symbolic knowledge. In order to keep the presentation simple, only subtrees of the whole net are shown, which the user may modify by expanding or collapsing nodes, according to his needs (fig. 2, bottom).

Using the “dissection” menu, arbitrary cut planes through the volume may be defined (fig. 3). All functions which are activated using an image will thus only be effective in one sector on one side of the plane. With the radiological display mode used here, the original intensities from the underlying data set are mapped onto the cuts.

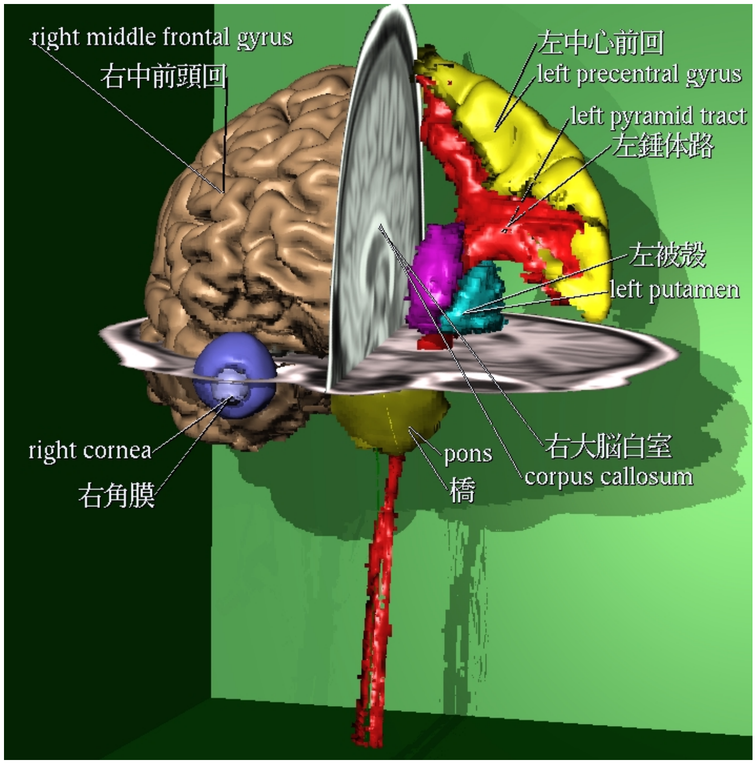

Figure 3. Preparation of a pyramid tract, using exploratory functions such as dissection and removal. English and Japanese annotations were automatically created by clicking either on an object surface or on a cut plane.

Both atlases of the head are already being used at about 50 institutes and hospitals. A number of atlases for other regions of the body are currently being prepared (fig. 4).

4. CONCLUSIONS

As has been shown, both intelligent tutoring systems and 3D anatomical atlases are very powerful tools for teaching complementary aspects of medical knowledge. Possible user interactions are by far exceeding those of conventional instruction systems, based on hypermedia techniques. Intelligent tutoring systems are covering the more abstract properties, while 3D anatomical atlases allow a student to create anatomical views, according to his own ideas and needs. With the tools presented, they provide a “look and feel” that comes close to a real dissection. Experience shows that students very much enjoy to work with these new techniques.

A common drawback, both of tutoring systems and 3D atlases, are the high costs for preparing such systems. Since these systems may be copied in arbitrary numbers, however, this is not a major concern. Another problem, the high computational needs, will be less relevant with increasingly powerful computers becoming available.

An very interesting question is of course how the capabilities of intelligent tutoring systems

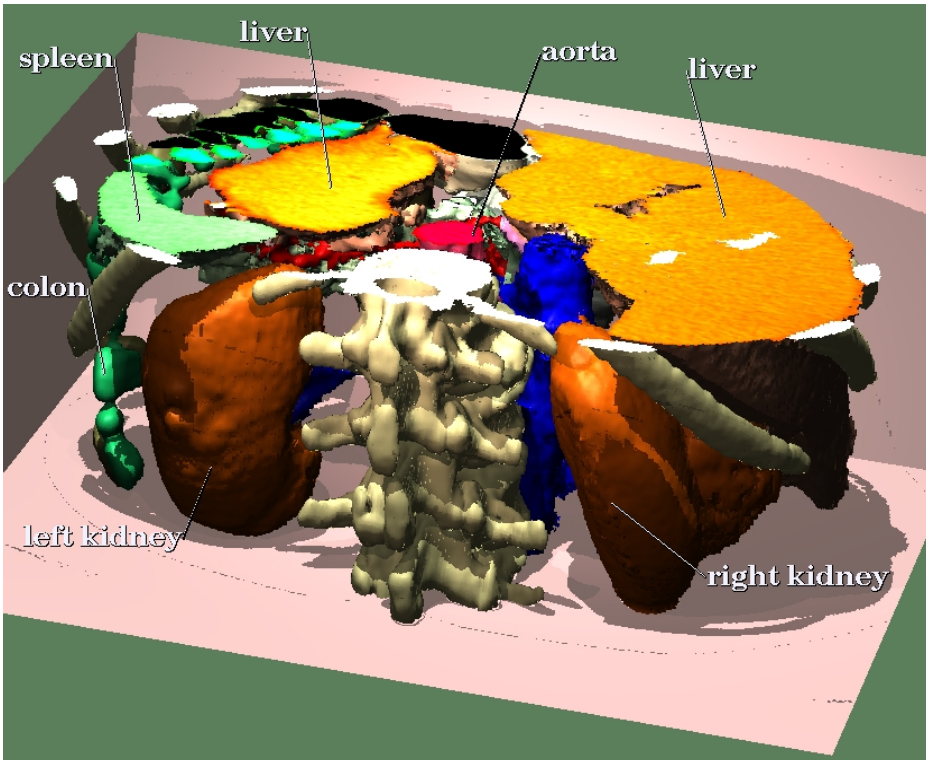

Figure 4. Without modifying the program, new atlases can be created by transforming data sets to "intelligent volumes". The upper abdomen shown here is based on a spiral CT data set, obtained in clinical routine diagnostics.

and 3D anatomical atlases could be joined. As has been shown, both structured and unstructured medical knowledge may be assigned to any point in space, and accessed in the atlas. References to conventional hypermedia systems may thus easily be included into the system. The same mechanism can also be used to relate the rules defined in an expert system to the objects defined in an atlas. For example, patient's complaints could be "visualized" by painting the regions which may have caused them; vice versa, the consequences e.g. of a surgical intervention simulated with the atlas could be explained. Creating such integrated systems will be a major task in the future.

ACKNOWLEDGEMENTS

We are grateful to W. Lierse, late head of the Department of Neuroanatomy, and to all members of our department who supported the atlas project. Japanese translations are courtesy of S. Eiho, University of Kyoto, and M. Shimizu, University of Kyushu, Fukuoka. The original MRI data set used for the brain atlas was kindly provided by Siemens Medical Systems, Erlangen.

REFERENCES

1. K. H. Höhne, M. Bomans, A. Pommert, M. Riemer, C. Schiers, U. Tiede, and G. Wiebecke. 3D-visualization of tomographic volume data using the generalized voxel-model. *Visual Comput.*, 6(1):28–36, 1990.
2. K. H. Höhne, M. Bomans, M. Riemer, R. Schubert, U. Tiede, and W. Lierse. A 3D anatomical atlas based on a volume model. *IEEE Comput. Graphics Appl.*, 12(4):72–78, 1992.
3. K. H. Höhne and W. A. Hanson. Interactive 3D-segmentation of MRI and CT volumes using morphological operations. *J. Comput. Assist. Tomogr.*, 16(2):285–294, 1992.
4. M. J. Lincoln, C. W. Turner, P. J. Haug, J. W. Williamson, S. Jessen, R. M. Cundick, K. Cundick, and H. R. Warner. Iliad's role in the generalization of learing across a medical domain. *Annu. Symp. Comput. Appl. Med. Care, Proc. SCAMC*, 16:174–178, 1992.
5. J. Nielsen. *Hypertext and Hypermedia*. Academic Press, San Diego, CA, 1990.
6. A. Pommert, M. Bomans, M. Riemer, U. Tiede, and K. H. Höhne. 3-D imaging in medicine. In Allen Kent and James G. Williams, editors, *Encyclopedia of Computer Science and Technology,* volume 28, pages 341–370. Marcel Dekker Inc., New York, 1993.
7. A. Pommert, R. Schubert, M. Riemer, T. Schiemann, U. Tiede, and K. H. Höhne. Symbolic modeling of human anatomy for visualization and simulation. In Richard A. Robb, editor, *Visualization in Biomedical Computing 1994, Proc. SPIE 2359,* pages 412–423. Rochester, MN, 1994.
8. F. Puppe. Intelligente Tutorsysteme. *Info.-Spek.*, 15(4):195–207, 1992.
9. R. Schubert, M. Bomans, K. H. Höhne, A. Pommert, M. Riemer, T. Schiemann, U. Tiede, and W. Lierse. A new method for representing the human anatomy. *Comput. Med. Imaging Graph.*, 17(4/5):243–249, 1993.
10. R. Schubert, K. H. Höhne, A. Pommert, M. Riemer, T. Schiemann, and U. Tiede. Spatial knowledge representation for visualization of human anatomy and function. In H. H. Barrett and A. F. Gmitro, editors, *Information Processing in Medical Imaging, Proc. IPMI '93,* volume 687 of *Lecture Notes in Computer Science*, pages 168–181. Springer-Verlag, Berlin, 1993.
11. W. B. Schwartz, R. S. Patil, and P. Szolovits. Artificial intelligence in medicine: Where do we stand? *New Engl. J. Med.*, 316(11):685–688, 1987.
12. U. Tiede, M. Bomans, K. H. Höhne, A. Pommert, M. Riemer, T. Schiemann, R. Schubert, and W. Lierse. A computerized three-dimensional atlas of the human skull and brain. *Am. J. Neuroradiology*, 14(3):551–559, 1993.
13. U. Tiede, K. H. Höhne, M. Bomans, A. Pommert, M. Riemer, and G. Wiebecke. Investigation of medical 3D-rendering algorithms. *IEEE Comput. Graphics Appl.*, 10(2):41–53, 1990.
14. E. Wenger. *Artificial Intelligence and Tutoring Systems*. Morgan Kaufmann, Los Altos, CA, 1987.
15. P. H. Winston. *Artificial Intelligence*. Addison-Wesley, Reading, MA, 3. edition, 1992.