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Accessing a WWW Reference Library of 3D Models of Pathological Organs to Support Medical Education

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Abstract. A major aspiration of the medical community is to use multimedia databases to disseminate important research or clinical information and for education. We describe a WWW reference library of 3D models of human organs containing pathological and normal organs organised in cases, together with a variety of educational and supporting tools. Although the emphasis is chiefly on the teaching of medical students and the continuing education of physicians, the library is also a potentially-valuable resource for diagnostic investigation. This paper describes the environment, methodologies and tools for supporting 3D models in medical education. The prototype of the system is currently being completed; the full system is scheduled for public access in the year 2000 through multimedia publishers.

1. Introduction

The medical community is keen to support the creation of distributed multimedia databases on the WWW for disseminating important research and/or clinical information and for education [1]. Radiological information usually comes in the form of 2D images. Radiologists' experience and long training provides them with an ability to envisage the spatial relationships associated with anatomical structures appearing in a succession of 2D scans. However, non-radiologists find it rather difficult, and the availability of 3D models can be extremely helpful in providing insights into the medical conditions displayed.

The pilot project IAEVA [2] developed an integrated methodology for constructing organised WWW databases of 3D models of pathological human organs and providing relevant retrieval and manipulation mechanisms. Other databases of 3D models usually focus on the NIH-Visible Human project, i.e. scans of a male and a female cadaver that contain no particular pathological structures [3].

The results of IAEVA are now being exploited by the development of a WWW-based medical visualisation system - primarily intended for student or continuing education - under the DGXIII EC-funded IAEVA-II project. Algorithms for accelerating transmission and manipulation of 3D models over the Internet have been developed, and advanced educational tools are now provided. The system can operate on standard configurations: PC, mouse and keyboard interaction, no dedicated graphics accelerator and no sophisticated communication connections. The distributed database allows medical providers to insert/update 3D models of human pathological organs easily through their WWW servers. However, users are unaware of this: they are simply provided with a single entry point into the database [4].

2. Construction of the 3D Models

Creating the database of 3D models requires the extraction of meaningful information, by use of interactive techniques, from sequences of 2D radiological images. Currently those captured from Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are used, but other technologies could be incorporated without difficulty.

3D surface models are employed due to their fast rendering and transmission times. Demand for *3D volumetric models* is increasing rapidly, but for Internet-based work, the sizes of the models currently prohibit general use. As soon as lines with sufficiently high-bandwidth become more widespread, volumetric models will be incorporated into the system. One available solution is the adoption of Internet via satellite at downstream speeds between 300Kbps and 2 Mbit/s. The upstream can be any PSTN or ISDN connection. If the models are stored in the main network of the satellite provider, bottlenecks are generally avoided and the highest speeds can be maintained. One of the authors is experimenting in Italy with this technology which can be very useful in locations where good lines are unavailable[5].

The processing algorithms associated with volumetric models are more demanding than those associated with surface models and, until now, their use has called for specialised hardware and large computer memory. The rapidly-decreasing cost of computer hardware and the evolution of relatively cheap, highly-specified graphics cards are making it feasible to consider using PCs for these tasks. However, within the scope of IAEVA-II – a WWW-based medical education system for standard PC configurations and Internet connections – 3D surface models are currently of higher priority than volumetric models.

The surface models are formed of polygons and are displayed using the marching cubes algorithm, which is perhaps the most widely-used method for such models [6]. Depending upon the shape complexity of the anatomical structure under consideration, hundreds of thousands (or perhaps millions) of polygons are produced.

Simplification algorithms can address polygon-count reduction [7], but adequate models may still contain an excessive number of polygons; commonly, a trade-off is made between display speed, accuracy and storage requirements.

Optimisation of rendering and Internet-transmission times for 3D models containing large numbers of polygons is achieved through *multi-resolution algorithms* [8]. For a particular 3D model, a continuous range of Levels of Detail (LoDs) is captured. For rendering, different LoDs are displayed – these depend upon the user's viewpoint and the particular interaction. For transmission, a coarse LoD is transmitted initially followed by a sequence of finer LoDs, so the quality of the model is upgraded incrementally.

One of the toughest points in constructing surface models is segmentation, that is the identification of specific structures. A completely automatic process cannot be achieved in all cases, and problems arise while dealing with MRI. The IAEVA-II project is therefore providing the physicians in charge of building the models with a set of semi-automatic tools.

3. The Database

The database could be any ODBC SQL-compliant RDBMS. In IAEVA, Microsoft SQL was used; IAEVA-II uses Microsoft Access for ease of management. As soon as the size increases, upgrading the database to a more reliable RDBMS is a straightforward task. The Internet connection is performed through ASP pages. The structure is relational, with tables for keywords (classification systems), for 2D images (raw images and thumbnails) and for 3D models, which may be stored in any other server over the Internet. Textual data about a case is stored along with author, source and reference.

To speed the navigation through the coding systems, instead of providing a dynamic access to the classification codes and their huge description tables, a full set of web pages has been generated with all the levels of the tree structure of ACR codes and MeSH terms. This generation needs to be recompiled every time a coding system releases a new version: this happens at most every year. Tests have proved that the speed advantage in using static pages overcomes the annoying process of pages regeneration, which lasts only a couple of hours every year.

At least three categories of users are allowed to search the database: final users, authorised users, medical providers. Each category has its path through a password-based mechanism, in order to allow different functionalities.

4. User Interaction

The library resides on the platforms of the two largest European medical Internet publishers and is accessible through their Web servers. Users can access it via an ordinary Internet service provider and an appropriate plug-in for their WWW browser.

Automatic presentation of the library contents is an option for inexperienced users; a searching tool on various attributes of organs and their pathologies is provided for more experienced users. Searches are conducted through keywords according to internationally-accepted medical terminology standards (Section 5).

3D models are transmitted over the Internet incrementally – crude information to which users can respond is received rapidly by transmitting the coarsest LoD for the model as shown in Figure 1. Afterwards, while users remain inactive, refinement occurs progressively; information for finer and finer LoDs is transmitted and these LoDs are displayed. This operating scenario allows, if necessary, the termination of downloading at an early stage and furthermore ensures that the final 3D model is the one desired, displayed in full detail. Results so far indicate that expected delays in response times are between 30 seconds and 1 minute.

Figure 1

Upon downloading the model required, users can perform a number of operations, view, manipulate (rotate, translate, zoom, etc.), change colour/brightness/ opacity, dissect, employ embedded hyperlinks to gain extra information, or participate in discussion groups on the particular organ pathology. To allow for real-time interactivity, 3D models are rendered by coarser LoDs during rotation, translation or zooming and once the manipulation operation is completed, the fully-detailed LoD model is again displayed almost instantly.

5. Classification and Coding Procedures

A central issue in collecting medical images for databases is classification and coding. Any efficient searching mechanism relies on the indexing system. Every image or case has a code which represents its content in a short but meaningful, unambiguous string.

There is no unique coding system available in medicine, and efforts range from simply defining some codes for statistical purposes, up to automatic extraction from natural language descriptions [9]. The problem has been addressed since the very beginning of the IAEVA project. Accepting that the most advanced automatic coding systems are still in very preliminary versions, and allowing for the multilingual scenario of the university hospitals involved in this project, we have decided to partially solve the problem by using the most common classification and terminology among the members of the consortium.

Therefore, ACR has been chosen to code every image and MeSH terms are added by the medical content providers to increase the level of detail in explaining the content. ACR is widely used by radiologists and is very simple to use for both coding and retrieval. MeSH [10], while not being a proper pathology coding system, is the standard in indexing medical literature, because it is used by the U.S. National Library of Medicine for the MEDLINE database. Through the mapping tables built by the UMLS project, MeSH terms can be cross-referenced into other classification systems. The process require manual intervention for solving ambiguities. So far UMLS has not yet implemented the latest version of ACR, but there are plans to add it in a future annual release. To facilitate the coding phase, an assisted Web-based tool has been developed which allows physicians to navigate through the tree-structured ACR and MeSH terms, which are stored using both the code and the description.

6. Interactive Questionnaires

Self-evaluation questionnaires related to 2D images, 3D models, or cases are provided to give users the opportunity of assessing their knowledge of the field. The medical providers produce the questionnaires. The general structure of a questionnaire is a multiple-response choice, with a minimum of three choices. One, more than one, or none, of the proposed choices is the correct answer. The questions number between five and thirty.

The questionnaire is generated over the Internet without any specific client software, soon after 2D images or 3D models have been provided. The questionnaire has a reference to the unique identifier of the 3D model. Other models can be associated with the same questionnaire, or other questionnaires linked to the model. The links are stored in the main database of the IAEVA-II server. The questionnaire itself is a URL and is generated using ASP technology.

The option to build a questionnaire is also given to some users (mainly teachers) for use in conjunction with the Bulletin Board System. The teacher can select a model or group of models (e.g. a case) and build a questionnaire linked to it. This relies on the structure of the BBS; it is not stored into the database. The questionnaires are not designed to act as a formal evaluating system as this would require a complex system for student identification.

7. Bulletin Board System

Any authorised user (e.g. a teacher) can start a discussion about a case, protecting the "electronic forum" with a password, sent via e-mail to his/her students. They can then study the case using the material provided by their professor, and post their comments and answers into the Bulletin Board (BBS). At the end of the pre-arranged period, the teacher can verify the students' answers, replying to individual or general questions.

The BBS is a simplified version of a typical Internet "digital forum". It is not a permanent and general source of information, but a one-time facility for a specific educational purpose. This approach relies on the importance of quality control. As IAEVA-II will be a public service, all information must be verified and controlled by a board of reviewers. The so called "public" discussion about a case will therefore not be open for writing to everybody: it will contain only the reviewers' annotations.

The teacher can also build interactive multiple-choice questionnaires for self-assessment. The results are stored in a database which can be browsed by the teacher. As it has been seen previously, there is no system available for ensuring the identity of the student, beside the name for logging in (which can be a pseudonym): therefore the whole system has a limited validity for knowledge evaluation.

8. Supporting Education

A major enhancement of IAEVA-II, as compared to IAEVA, is the provision of video-recorded short lessons by leading physicians. Some of the cases or 3D models are linked to video clips, which give the user audio explanations while showing the professor talking. We make use of streaming video technology, now capable of delivering very good audio quality and fairly acceptable motion images, while using standard Internet connections down to 20 Kbps. Microsoft Windows Media technology [11] was chosen for this purpose because it provides a complete set of free of charge tools under the Windows NT environment used for the IAEVA-II server.

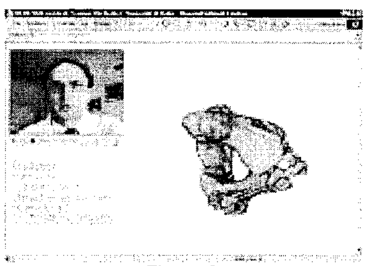

Figure 2

By adapting a methodology developed by one of the authors [12], shown in Figure 2, the images can be displayed alongside the teacher while he is discussing them. Therefore, it is possible to explain characteristics of the images as if they were being shown in a classroom.

The effort demanded of the medical providers in producing the video clip is kept to the minimum. It requires a consumer-quality video camera and a good microphone. Most of the work is done while digitally-encoding the videotape, in order to set the triggers that point to the model or the images. Tests have proved that the running video of the speaking teacher is more accepted by students than voice only.

Streaming video will also be used for a lower resolution preview of some animations generated by 3D reconstructing tools, such as a fly-through in a trachea or the rotation of the view point of a tumour in the lungs. Downgrading an uncompressed 78 Mbytes Quicktime 24 seconds movie to a RealVideo [13] 116 Kbytes file, capable of real time streaming over a normal 34 Kbps line, produced a result which was considered exceptionally good by major radiologists and physicians. Further tests with the latest compression algorithms can widen the use of such formats allowing a much wider audience.

9. Conclusions

The prototype IAEVA-II server is being completed [14] and the partners are testing all procedures. The public service will become operational in 2000 and will be run by medical Internet publishers, Euromultimedia [15] and Health Online Service [16], for their subscribers.

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