This paper appears in: Proceedings IEEE Conference on Multimedia and Expo, 2000

A Web-based CBIR-Assisted Learning Tool for Radiology Education – Anytime and Anyplace

*C. R. Shyu, A. C. Kak, C. E. Brodley, C. Pavlopoulou, M. F. Chyan** *L. S. Broderick*

School of Electrical and Computer Engineering
School of Education*
Purdue University
West Lafayette, IN 47907, USA

Department of Radiology
University of Wisconsin Hospital
Madison, WI 53792, USA

ABSTRACT

In this paper, we propose a web-based learning tool for assisting and enhancing radiology education. Central to the learning tool is our recently developed content-based image retrieval (CBIR) system for medical image databases. In contrast to the learning resources available through traditional radiology curricula, our learning tool represents a more flexible, instantly updateable, and a richer learning environment that can be used anytime and anyplace. Experts from diverse disciplines -- radiology, computer vision, and education -- had to pool their knowledge and resources together to bring about the development of this learning tool.

1. INTRODUCTION

Traditional radiology is both experience based and textbook based. For commonly occurring cases of pathology, a radiologist can quickly issue forth his/her diagnosis on the basis of a visual assessment of the image. But when the form of pathology in an image is uncommon, a radiologist may have to resort to an atlas of images and arrive at a diagnosis by comparing the image of the patient with the images shown in the atlas.

This is particularly true in the domain of high-resolution computed tomography (HRCT) images of the lung, where the detection of pathology is relatively easy, but its precise characterization much more difficult. When faced with an abnormal area within the lung, it is not uncommon for a radiologist to page through a book and to compare the patient image with the images illustrated in the book in order to arrive at a differential diagnosis. There are several drawbacks to this approach. For one, it is tedious, as there can be several hundred images in the book to compare with the patient image. Moreover, it relies on static knowledge, as the books cannot be updated as quickly as on-line information.

Instruction in radiology is beset with some of the same difficulties. The instructor often has to rely on his/her memory to decide what images to show to the students in order to exemplify a certain disease. In addition to using images from a published atlas (that may not reflect the latest advances in the field), the instructor may pull some images from the in-house records at the hospital.

Fortunately, these difficulties in the practice and teaching of radiology can be alleviated by the advances that are taking place in the content based retrieval of images from large medical image databases[2][4][5][7]. The original motivation for these developments was to enable the physicians to improve their diagnoses by making available to them a tool that they could use to retrieve from a database of images (and treatment histories) that are most similar to the image of the patient. To obtain precise retrieval results, in our retrieval system ASSERT[7], retrieval is carried out purely on the basis of the similarity of pathology bearing regions (PBR).

Imagine a tool based on the ASSERT system in the hands of a radiology instructor. After a database was constructed, the instructor could use ASSERT to retrieve as many images as needed to teach all the different ways in which a particular disease may manifest itself in images. By using side-by-side displays of images corresponding to related but not identical pathologies, the instructor could inculcate in the students a keener sense of how to differentiate between such pathologies. The instructor could also query the database for the treatment histories and the demographic information associated with the images. The demographic information could be extracted from the in-house radiology information system (RIS) coupled to the image database through relational links. Most importantly, the image database would reflect absolutely the latest state of medical knowledge.

The above mentioned advances in image database technology have taken place concomitantly with the explosive growth in web-based retrieval of information over the internet. So it makes sense to combine the two and develop a learning tool for radiologists that could be accessed locally or remotely for either diagnosis or learning.

There are many advantages to teaching through the web. First of all, web-based curricula can be accessed twenty-four hours a day. All that a radiology student needs to access the teaching material is an internet connection and a computer with a web browser. Secondly, web-based teaching enhances the level of interaction not only between the students and the instructor but also between the students themselves through e-mail and discussion groups. It is believed that these additional modes of interaction are more likely to foster strategic thinking needed for problem solving [1].

Although our learning tool could be made to work with any of a large number of medical imaging modalities, this paper will focus on just HRCT images of the lung. In the rest of this paper, we present the architecture of the learning tool that includes our CBIR engine, two learning modules, a scoring module, and a monitoring module. Finally, we present a method for evaluating the process of learning through our tool.

2. SYSTEM ARCHITECTURE

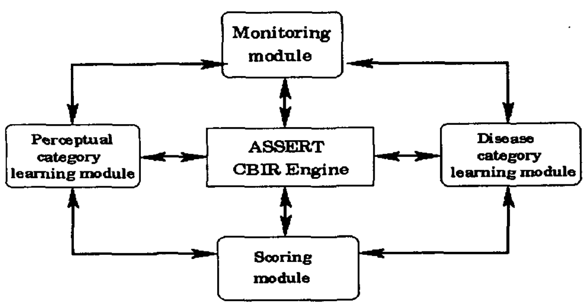

Figure 1. *The architecture of the learning tool.*

The architecture of our learning tool includes a CBIR engine, two learning modules, a scoring module, and a monitoring module. The CBIR engine, the two learning modules, and the scoring board are discussed further in the rest of this section.

2.1 Retrieval Engine – ASSERT

As shown in Figure 1, the heart of the learning tool is our CBIR engine – ASSERT. Compared to other recently developed CBIR systems in medicine, the uniqueness of ASSERT system is its physician-in-the-loop approach. When an image is first entered into the database, an expert physician circumscribes in the image those regions that show pathology. (Since automatic delineation of pathology bearing regions (PBR's) is still beyond the capability of computers, it is essential to delegate this task to a physician.) In the database, along with each image is stored its PBR's and their many shape, density, texture, and locational properties. When it is desired to retrieve database images that are most similar to the image of a new patient, the physician first outlines the PBR's in the new image. (As mentioned previously, the detection of PBR's is easy; it is their characterization that is difficult.) The computer then compares the properties of the PBR's in the new image with the properties of such regions in the database images.

The interface used for this interaction between a physician and the CBIR system is shown in Figure 2. In addition to prompting a physician to circumscribe the PBR's and the relevant anatomical landmarks, the interface also gives the physician an option with regard to the specific method used for image retrieval. The retrieval methods currently available are 1) the K-nearest neighbor; 2) the customized queries method described in [3], and 3) the multi-dimensional hashing method presented in [7]. The interface is a Java applet, enabling its use remotely through a web browser. It is implemented in a modular way to facilitate incorporation of new retrieval algorithms as when they become available. (Our project web page is http://rvl1.ecn.purdue.edu/RVL/CBIR/CBIRmain.html.)

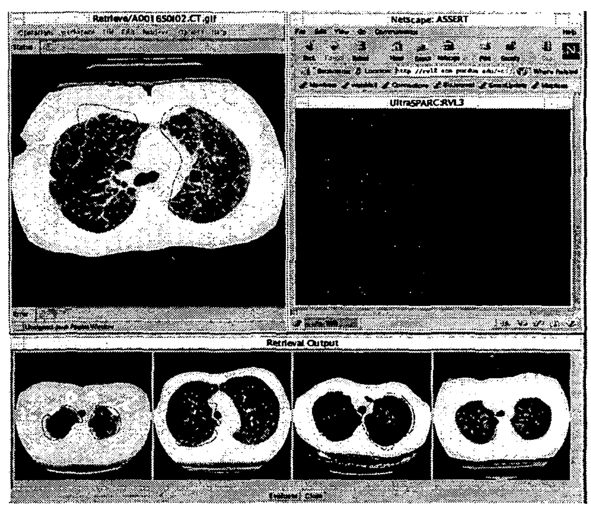

Figure 2. *Graphical interface of ASSERT system.*

An important intermediate step in the retrieval process is the characterization of a PBR with regard to its perceptual category. Perceptual categories are the labels assigned by expert physicians to the visual manifestations of the different diseases in the images.

(The experts believe that the process of diagnosis is improved if a PBR is first categorized with regard to its perceptual category.) These perceptual categories, shown in Figure 3 are also of immense importance from the standpoint of designing vision algorithms for extracting features from the PBR's. For lung HRCT images, there are four major categories [6]: *linear and reticular opacities*, *nodular opacities*, *low-density areas*, and *high-density areas*. As shown in Figure 3, under each major category, there are several subcategories. The category Linear and Reticular Opacities is characterized by thin and straight ribbon structures in web-like formations or thin and round structures surrounding areas of low x-ray attenuation (meaning low opacity). The category Nodular Opacities are round nodules-like regions of high attenuation. The category Low-Density Areas consists of basically shapeless regions of low attenuation. Finally, the category High Density Areas consists of regions of high attenuation. The sub-categories are further specializations of these four major categories. While some diseases correspond to individual sub-categories, others show up in the form of multiple sub-categories present simultaneously.

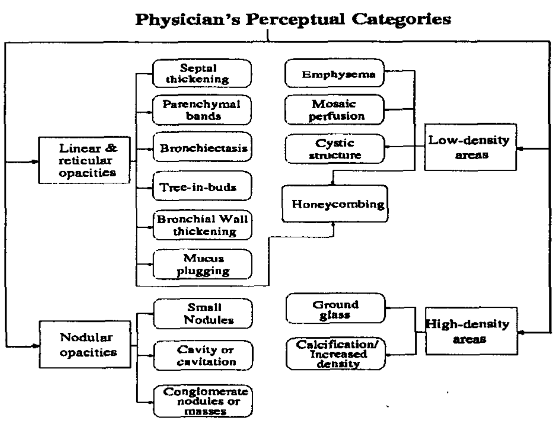

Figure 3. Perceptual categories used by physicians to detect the presence of lung diseases.

2.2 Learning Modules

Our learning tool contains the following two learning modules: a module for learning the perceptual categories and a module for learning the disease categories. The operation of these two modules is facilitated by a relational database that provides access into the ASSERT image database on the basis of either disease categories, or perceptual categories, or a mixture of the two.

1. *Perceptual category learning module*: Easy to assimilate textual descriptions of the different perceptual categories are placed on the web, along with the best exemplar images, one per category. For example, for the "Lung Cyst" category, its description could be as simple as "*Lung cysts are thin-walled, well-defined and circumscribed lesions containing air*". This description is linked to the most prototypical image containing one or more PBR's corresponding to the perceptual category "Lung Cysts." If the student wishes to see additional example images containing PBR showing the same perceptual category, these can be obtained by querying ASSERT. The most exemplar image is selected by an instructor. The student can also request, by clicking on appropriate buttons, comparative learning of the various perceptual categories. For comparative learning, the images for all the chosen categories are shown simultaneously.
2. *Disease category learning module*: The learning of disease categories is made complicated by the fact that some of the diseases exhibit multiple perceptual categories. Furthermore, not all of the various perceptual categories associated with a disease may show up simultaneously in a given image. For example, the disease *idiopathic pulmonary fibrosis* manifests itself in the form of the following perceptual categories: *linear and reticular*, *high-density areas*, and *cystic structure*, but not all three may appear simultaneously in an image To address this problem, the disease category learning module provides multiple best exemplar images for each disease. Each exemplar image corresponds to a different combination of the perceptual categories associated with that disease. The learning of the various diseases can also be carried out in a comparative mode as before.

Each learning module also contains on-line practice images that the students can use for improving their performance.

2.3 Student Performance Evaluation Module

A student's performance is evaluated by posting on the web two types of test images: images with pre-marked PBR's and images without any delineation of pathology by expert physicians. For the former set, the students are required to state the perceptual and the disease categories associated with the PBR's in the images. For the latter set, the students must first mark the PBR's, and any visible and relevant anatomical landmarks (such as the lung fissures), and subsequently enter the perceptual and disease categories. After a session of evaluation, the students are provided with correct answers. When the students are also asked to mark the PBR's and anatomical landmarks in images, at the end of evaluation they are shown these markings as generated by expert physicians.

At this time, the scoring is straightforward. For images with pre-marked PBR's, we use 1-0 scoring, meaning that a correct answer gets the student one point and a wrong answer zero points. For the image set for which the student must also generate the PBR and anatomical landmark markings, points are given in proportion to the overlap between the students markings and those of an expert physician. In the future, we will be experimenting with the assignment of scores that are weighted according to the level of difficulty that expert physicians associate with a particular diagnosis.

Our future plans also call for setting up a discussion board on the web and a weekly posting of a new HRCT image. Prospective students will be invited to enter their diagnoses and to have it compared with the diagnosis as provided by an expert physician. The students will be asked to also enter what led them to a particular diagnosis. These entries we believe will be conducive to on-line discussion that would profit all.

3. EDUCATION CONCERNS

In designing our web-based learning tool, we have been influenced by the fourteen learner-centered principles (LCPs) as listed by the American Psychology Association [10]. Bonk and Dennen [1] have discussed how these LCPs can be incorporated in web-based distance learning. Since space limitations prevent us from fully discussing the manner in which our learning tool agrees with all relevant LCP's, we will mention here just two. We believe that our learning tool exhibits the principle "*Construction of Knowledge*" which states "The successful learner can link new information with existing knowledge in meaningful ways." Obviously, a radiology student or a novice physician should be able to use our tool to extend his or her past associations between diseases and how they show up in images to the HRCT domain. Our learning tool also helps students with regard to the principle "*Strategic thinking*" which states "The successful learner can create and use a repertoire of thinking and reasoning strategies to achieve complex learning goals." By taking a student first through the learning of individual perceptual category and then through the learning of disease categories, we believe that the physicians will be better able to determine what perceptual strategies to invoke in order to discern the visual detail needed for establishing the presence or the absence of a particular disease.

4. SUMMARY

We have discussed in this paper a web-based learning tool for teaching radiology students (and novice physicians) the evolving art and science of diagnosing pathology in HRCT images of the lung. What makes our system particularly relevant is that while it is relatively easy to detect pathology in such images, the characterization of that pathology is daunting to all but the expert-level physicians. It is not uncommon for physicians to refer to published atlases of images in order to characterize the image of a new patient. Our learning tool, designed around our content-based image retrieval system, does away with the need for hardcopy atlases and provides a more immediately updateable system for training.

5. ACKNOWLEDGMENTS

This work is supported by the National Science Foundation under Grant No. IRI9711535 and the National Institute of Health under Grant No. 1 R01 LM06543-01A1.

REFERENCES

[1] C. J. Bonk and V. Dennen, "Teaching on the Web: With a Little Help from My Pedagogical Friends", *Journal of Computing in Higher Education*, Fall 1999, Vol. 11(1), pp. 3-28.

[2] W. W. Chu, C. C. Hsu, A. F. Cardenas and R. K. Taira, "A knowledge-based image retrieval with spatial and temporal constructs", *IEEE Transactions on Knowledge and Data Engineering*, Vol. 10, No. 6, 1998, pp. 873-888.

[3] J. G. Dy, C. E. Brodley, A. C. Kak, C. R. Shyu, And L. S. Broderick, "Customized query approach to CBIR ", in *SPIE Storage and Retrieval for Image and Video Databases VII*, San Jose, CA, 1999.

[4] P.M. Kelly, T.M. Cannon, and D.R. Hush, "Query by image example: the CANDID approach", in *SPIE Vol. 2420 Storage and Retrieval for Image and Video Databases III*, San Jose, CA, 1995. pp. 238-248.

[5] F. Korn, N. Sidiropoulos, C. Faloutsos, E. Siegel, and Z. Protopapas, "Fast and effective retrieval of medical tumor shapes", *IEEE Transactions on Knowledge and Data Engineering*, Vol. 10, No. 6, 1998, pp. 889-904.

[6] W. R. Webb, N. L. Muller, and D. P. Naidich, *High-resolution CT of the Lung*, Lippincott-Raven, Philadelphia, 1996.

[7] C. R. Shyu, C. E. Brodley, A. C. Kak, A. Kosaka, A. M. Aisen and L. S. Broderick, "ASSERT: A physician-in-the-loop content-based image retrieval system for HRCT image databases", *Computer Vision and Image Understanding*, Vol.75, Nos ½, July/August, pp. 111-132, 1999.

[8] C. R. Shyu, A. C. Kak, C. E. Brodley, and L. S. Broderick, "Testing for human perceptual categories in a physician-in-the-loop CBIR system for medical imagery", in *Proc. IEEE Workshop of Content-Based Access of Image and Video Databases*, Fort Collins, CO, June 1999.

[9] Stern EJ, Swensen SJ. *High-resolution CT of the Chest*, Lippincott-Raven, Philadelphia, 1996

[10] "Learner-Centered Psychological Principles: A Framework for School Redesign and Reform", this article is available in http://www.apa.org/ed/lcp.html, November 1997.