Developing a Comprehensive System for Content-Based Retrieval of Image and Text Data from a National Survey

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ABSTRACT

The article describes the status of our ongoing R&D at the U.S. National Library of Medicine (NLM) towards the development of an advanced multimedia database biomedical information system that supports content-based image retrieval (CBIR). NLM maintains a collection of 17,000 digitized spinal X-rays along with text survey data from the Second National Health and Nutritional Examination Survey (NHANES II). These data serve as a rich data source for epidemiologists and researchers of osteoarthritis and musculoskeletal diseases. It is currently possible to access these through text keyword queries using our Web-based Medical Information Retrieval System (WebMIRS). CBIR methods developed specifically for biomedical images could offer direct visual searching of these images by means of example image or user sketch. We are building a system which supports hybrid queries that have text and image-content components. R&D goals include developing algorithms for robust image segmentation for localizing and identifying relevant anatomy, labeling the segmented anatomy based on its pathology, developing suitable indexing and similarity matching methods for images and image features, and associating the survey text information for query and retrieval along with the image data. Some highlights of the system developed in MATLAB and Java are: use of a networked or local centralized database for text and image data; flexibility to incorporate new research work; provides a means to control access to system components under development; and use of XML for structured reporting. The article details the design, features, and algorithms in this third revision of this prototype system, CBIR3.

Keywords: Content-Based Image Retrieval (CBIR), NHANES II, Anterior Osteophytes, Medical Image Databases, Medical Image Informatics, Image Segmentation, Shape Similarity, Procrustes Distance, Fourier Descriptors, Polygon Approximation.

INTRODUCTION

Developing reliable content-based image retrieval is an area of high research interest with its promise to enable near automated indexing of images and retrieval based on visual similarity[1]. Biomedical images, however, are often a part of a larger text record related to an individual. As such, traditional text database systems which allow image retrieval via keyword based searches would benefit greatly with a content-based image retrieval (CBIR) component. Similarly CBIR systems would, in turn, be able to take advantage of easily computable text information related to an image. Such a development would also help in overcoming the high cost and imprecise nature of manual annotation. At the Lister Hill National Center for Biomedical Communications, an R&D division of the U.S. National Library of Medicine a center in the National Institutes of Health, we maintain a collection of 17,000 digitized spine X-rays from the Second National Health and Nutritional Examination Survey (NHANES II). Access to the text and image data from NHANES II is being provided by our R&D biomedical multimedia database system, Web-based Medical Information Retrieval System (WebMIRS)[2]. WebMIRS provides access to sub-sampled image data available with each survey participant's record.

Nhanes II: NHANES II was conducted 1976-1980 and included participants aged 6 months to 74 years. For the NHANES II survey, the records contain information for approximately 20,000 participants. Each record contains about two thousand data points, including demographic information, answers to health questionnaires, anthropometric information, and the results of a physician's examination. In addition, approximately 10,000 cervical spine and 7,000

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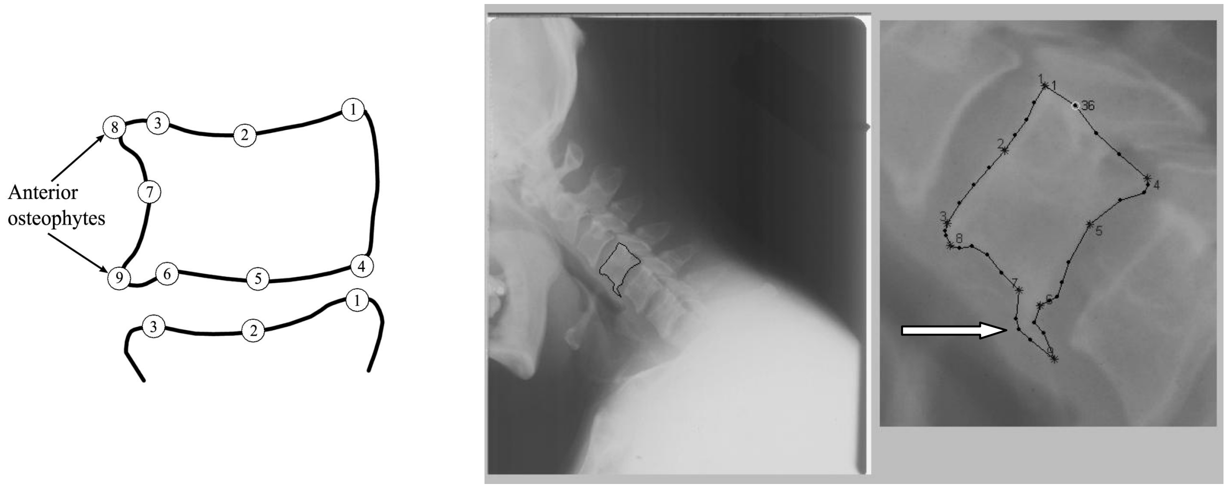
Medical Imaging 2005: PACS and Imaging Informatics, edited by Osman M. Ratib, Steven C. Horii, Proceedings of SPIE Vol. 5748 (SPIE, Bellingham, WA, 2005)
1605-7422/05/$15 · doi: 10.1117/12.596587

lumbar spine x-ray films were collected on survey participants aged 25-74. No X-rays were taken on pregnant women, and no lumbar X-rays were taken on women under 50. The pathologies of interest on these X-rays were osteoarthritis and degenerative disc disease.



(a) (b)

Figure 1. (a) Anterior Osteophytes illustrated on vertebral body outline. Points marked indicate regions of interest. (b) Spinal X-ray image showing segmented vertebra and a localized view showing inferior AO on vertebra with 36 boundary points superimposed.

The NHANES II X-rays serve as a rich data source for research into pathology-based retrieval of biomedical images. For example, an osteophyte, a bony protuberance on normal bone surface, is a characteristic feature of degenerative joint disease of the spine. After careful study of the NHANES II image collection medical experts have previously determined that the anterior osteophyte (AO) is a pathological feature that can be reliably and consistently detected in the data set, along the anterior superior or inferior edges of the vertebral bodies. An example of superior and inferior AO is illustrated in Figure 1(a) and shown in 1(b). Points 2-3-8-7 describe a superior anterior osteophyte on a sagittal spinal X-ray and points 7-9-6-5 describe an inferior anterior osteophyte. In such cases, only a small region of the vertebral body is pertinent to the pathology. Methods for querying vertebrae through visual means for pathology, such as AO, would be immensely useful to epidemiologists, radiologists, bone morphometrists, medical students, and researchers of musculoskeletal diseases[2].

CBIR on Spine X-ray Data: To enable CBIR on spine X-ray images appropriate features need to be captured from the vertebral image. In this case, the pathology in a vertebra can be captured in the outline of its body seen in a 2D projection in the sagittal spinal X-ray. Analysis of this outline could enable computer methods to retrieve vertebral images that are pertinent to a visual query expressed with a user-sketch or an example image. These features then need to be indexed along with the supporting text information. For retrieval, same features are extracted from the query image and then matched with the indexed features. These and other steps in the development of CBIR were implemented as separate tools as a part of our ongoing research efforts[3]. Prototype systems CBIR and CBIR2 provided concepts into the design of a more formal CBIR system. CBIR3 is our first step into a networked CBIR system that is extensible, supports a centralized database, and most of the tools developed in our research. It has the capability to add new tools with relative ease. This article describes the features and developmental decisions for CBIR3.

DESIGN GOALS

A typical CBIR system appears to be monolithic software. It is, however, usually a collection of several separate programs that address the various steps in a CBIR[4]. We set our design goals for the prototype CBIR3 system to allow for the required flexibility while keeping data centralized. In our design, the system should:

- Be developed such that it is extensible and not cumbersome to include new research software and results.

- Be flexible to allow new image types and modalities. System should also be extensible to include new pathologies for the new image types. This requirement lays importance on the design of the database for such data.
- Be operable in two modes; one would be a “Demo” mode that would run tested and completed components and the other an “R&D” mode that would allow access to unfinished or under development parts of the system.
- Use unique user logins and record of credentials to authorize access to specific parts of the system and data.
- Provide a bank of automated or semi-automated segmentation tools / methods for extracting appropriate features from the images. It would be beneficial if these could be operated in batch mode to minimize expert supervision.
- Be connected with a suitably designed database to store the text data and a record of the extracted features.
- Provide a validation utility to review, edit and validate extracted features and pathology.
- Adopt suitable image feature and image indexing techniques. More importantly if more than one approach exists, a bank of techniques should be made available for use with different image types.
- Provide a capability to provide standardized exchange of data between this and other programs.
- Provide a capability to mark / annotate unique characteristics on an image using manual or automated techniques.
- Allow rich query mechanisms that support query-by-shape, query-by-image, and hybrid text-image queries.
- Allow export of query results and images in standardized formats.
- Allow improved interactivity with relevance feedback type mechanisms.

The CBIR3 system addresses several goals list above. Future versions plan to expand on the existing capabilities and aim to address other requirements as well.

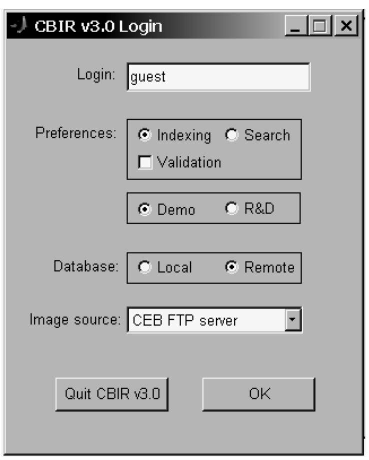


Figure 2. CBIR3 login screen. Allows selection of use path (Indexing or Retrieval) in Demo or R&D mode using Local or Remote Databases for text and images.

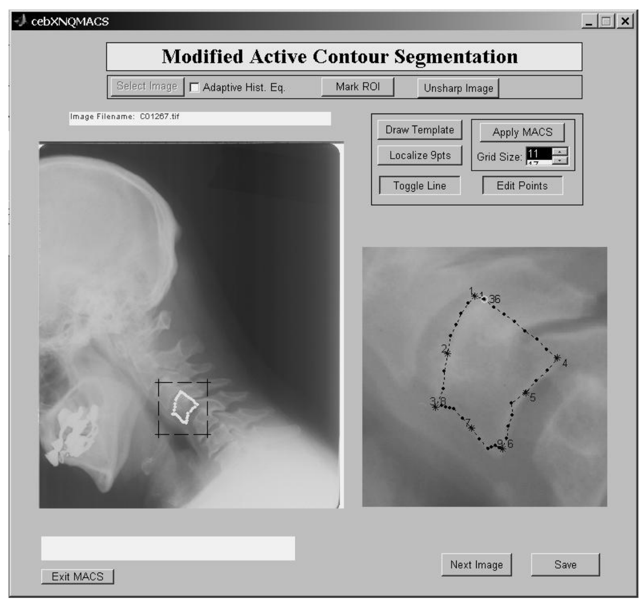


Figure 3 Segmentation Method 1: Active contour segmentation with orthogonal curves. Tool also includes software for automatic localization of 9 landmark points.

SYSTEM DESCRIPTION

Until recently, images from the collection could only be searched only through text keywords via the WebMIRS system. Earlier revisions of our prototype CBIR system could provide content-based access to the spinal X-rays, but were only able to support queries on a limited selection of NHANES II text dataset for a small selection of images that were stored locally on a client workstation. In addition, the features used by the CBIR systems were limited. CBIR3, for the first time, enables hybrid content-based searches of images and text on the collection through a single system interface. For this it supports a unified and centralized text and image database, where the latter also records individual image features, observations, etc. The software also permits output of entire image record which includes image name, type, vertebra information, all segmentations, and pathology information as well as information in single vertebra record as an XML file. Individual results from a search can also be output as XML, Excel or plain text. The following subsections highlight the features of various functions in the system.

1. Login

CBIR3 system adds several new features over the earlier version[5]. It provides a unique login to each user, shown in Figure 2 (a). Information about the user, including qualifications, is stored along with other tables in a MySQL database. These are used to provide certain rights and privileges on the system. In addition, the system stores certain information for returning users.

On the login screen the user can select the desired system use task (Indexing, Validation, or Search). In the indexing mode, the system presents the user with a variety of techniques for feature extraction. The typical user of the indexing system would be a trained technician who would mark the relevant image features. Validation is a sub-mode within Indexing where an expert can validate these technician extracted features and marked pathology. The expert can also review or edit these before validation.

The system design allows the system to execute in two different modes called "Demo" which will allow only more mature parts to be invoked, and "R&D" which allows access to parts under development. This flexibility allows testing of new features and methods on live data. A protocol has been developed which replaces common I/O functions on test programs that operate on local files for testing with a standardized network I/O interface. This enables testing on programs that couldn't be easily tested as a part of the complete system. A centralized data repository used by the system can reside on a remote server or be served locally. Similarly the images can be stored locally or be served remotely. Their locations can be specified via an initialization file. Additionally, the system is being developed to be shareable with fellow researchers as an executable. Parts that would allow access to the image database over the external Internet are under development. The system currently operates over the network within the center's intranet.

2. Indexing and Validation:

In the indexing mode the system provides methods for extracting features from the images. For this it provides the users a list of available segmentation methods which currently include an Active Contour Segmentation (ACS) method that uses orthogonal curves[6,7] and Live Wire[8], shown in Figure 3 and Figure 5, respectively. Work is underway to adapt Active Shape Modeling[9,10] and Active Appearance Modeling[9] methods into the system. To select an image for segmentation, the user can query the database for a particular image or can request the system to fetch images from it in a sequential fashion. The system also logs the last indexed image for a particular user allowing her to restart the activity at a later time. Each segmentation method allows the user to also automatically localize 9-points[11] according to the model used by radiologists.

The segmentation program has also been modified to operate in a batch mode allowing experts to concentrate on initial marking and final review and validation activities. The actual segmentation will be conducted in a batch mode and the validation software will be used to allow experts to validate the automatic segmentations. Live wire algorithm is also being enhanced to allow mid-segmentation editing and operation on color images. We have also developed an image viewer and data collector for the modified Active Contour Segmentation software that allows the user to zoom in and out of a region of interest and also apply some image enhancement techniques.

The system supports a separate validation sub-mode within the indexing mode of operation for which a segmentation reviewer has been developed, shown in Figure 6. A medical expert can review, correct, and enhance segmentations, and also supply pathology information. In addition to editing a segmentation, currently, up to 8 additional edge enhancements can be marked either manually or using live wire technology. These enhancements can include among others, small indentation called Schmorl's nodes[c], double edge information. The double edge is the further (or nearer) edge of a 3D object seen in a projective image, such as an x-ray. This information can be critical for medical reviewers

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[c] Schmorl's Node (*or Nodule)*: prolapse of the nucleus pulposus through the vertebral body endplate into the spongiosa of the vertebra. (Stedman's Medical Dictionary – 26th Edition, Williams & Wilkins, Baltimore, Maryland, USA, 1995, pp. 1215)

and could also assist in achieving in better retrieval results. It is a research goal for us to enable matching a shape with enhancements and/or double edges. A screen shot for the enhancement tool is shown in Figure 7.

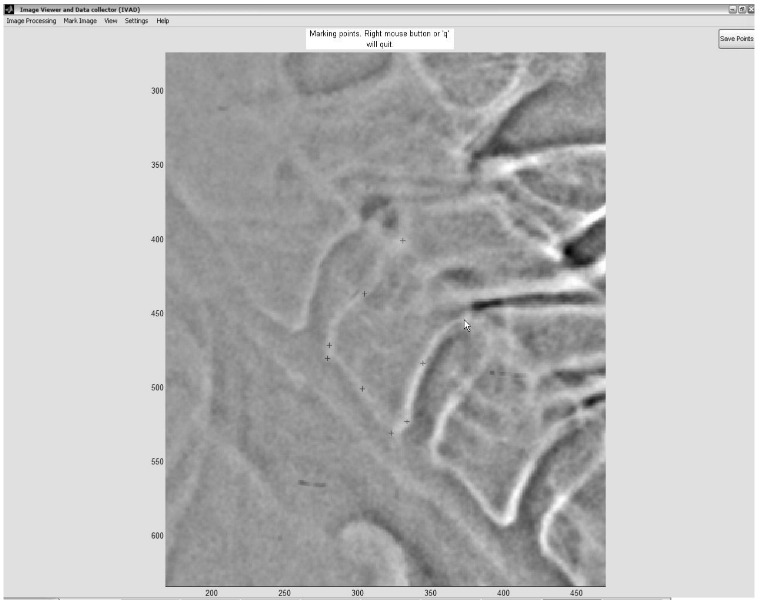

Figure 4. Image Viewer and Data Collector: Provides tools for image enhancement and boundary marking.

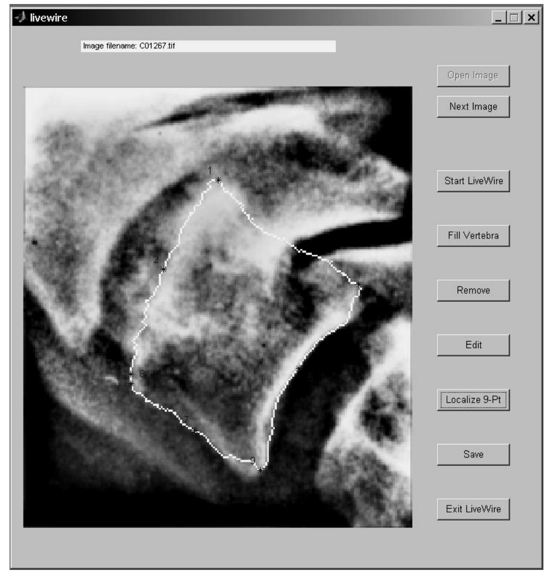

Figure 5 Live wire segmentation with 9 point data marked through automatic localization algorithm.

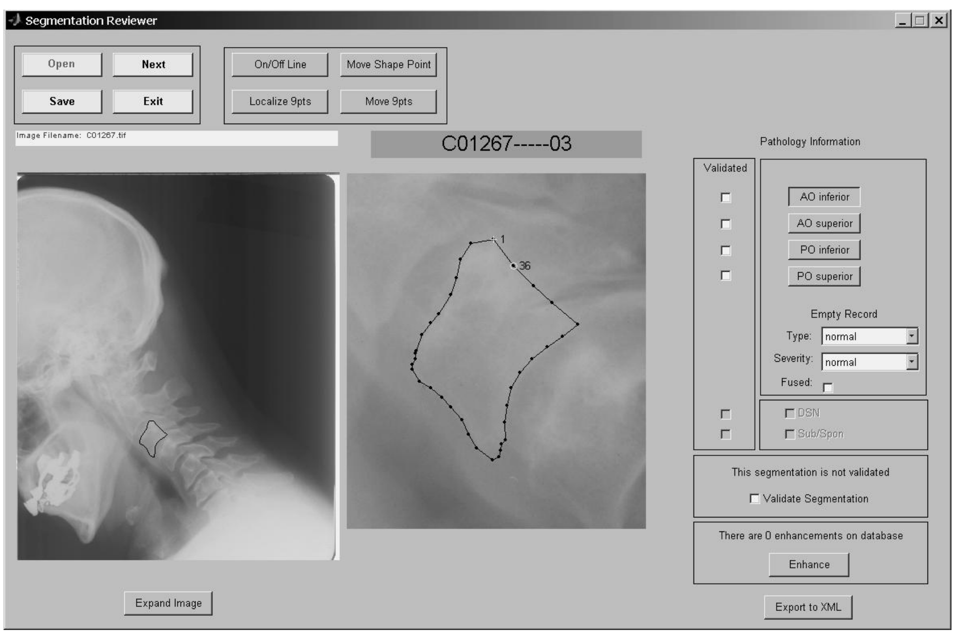

Figure 6. Validation and review software screenshot.

3. Search Mode

In this mode the user can pose text and image queries to the database. The text queries can be made via the familiar WebMIRS interface which is modified for this system and shown in Figure 8. Here, the user can select from several text categories and create and SQL-like query using the logical operators AND and OR. In addition, one can also add restrictions and range queries on certain fields. Having created such a query, it is further possible to restrict the number of results on the main Search screen, as well. The software also allows for the use of hyphen and commas to indicate range and separate different number patterns, respectively. The user can create queries by selecting a shape from the database (using text-based criteria such as image name, image type, vertebra name, segmentor or segment date), sketch one or provide an image. The queries may be whole or partial shape. An example depicting cervical vertebra C4 shapes is shown in Figure 9.

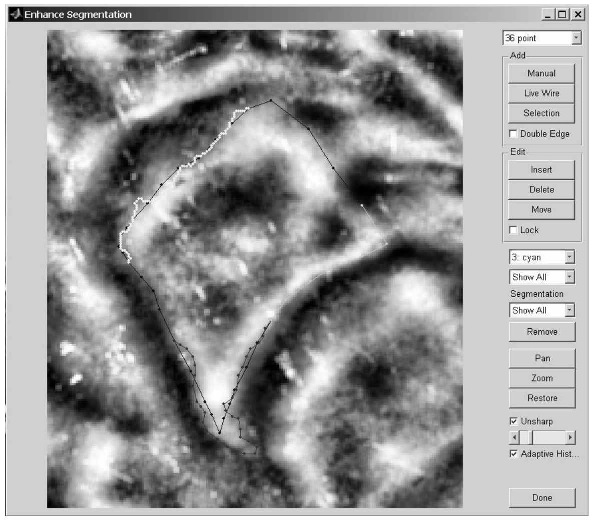

Figure 7. Enhanced edge markup software screenshot.

A novel feature in the search mode main screen, shown in Figure 10, is the ability to mark multiple partial shape features, though currently only a single partial shape method can be queried. Matching of multiple partial shapes is under development. The user can also select a shape matching method, shape segmentation type (9-point, 36-point, or variable point length). Partial shape matching[12] is currently done on fixed point shape descriptions using the Procrustes Distance[13]. A dynamic programming based method for partial shapes[14] has been developed and will soon be a part of CBIR3. The system allows queries to be saved for future reuse. The user can also select the desired shape matching method which are currently a combined method using Polygon Approximation[15] and Fourier Descriptors[16] and another that uses the Procrustes Distance.

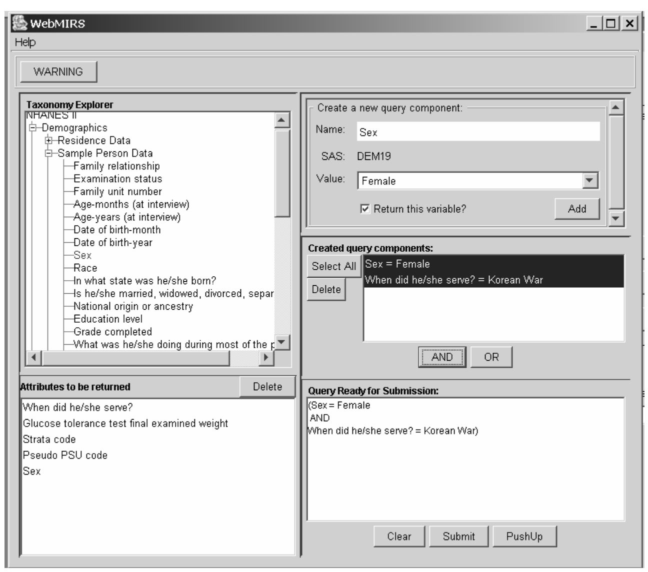

Figure 8. Modified WebMIRS interface for text queries.

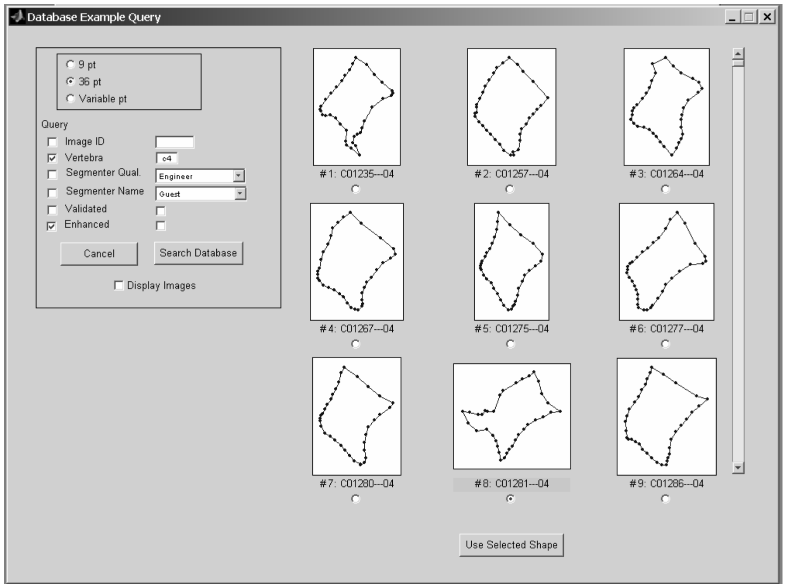

Figure 9. Selecting vertebra query shape from the collection in the central database.

4. Results

The results screen, shown in Figure 11, allows the user to view the top 9 results at a time from the query response. Additional results can be viewed by scrolling down one row or one page at a time. The shapes are ranked in order of decreasing similarity and presented without image crops. If a partial shape query was made then the portion of the shape that matched is indicated in red. Individual image crops for the shapes can be requested using check-boxes provided. The results table shows the text results which can be saved as XML. Individual vertebrae and pathology information can be examined in greater detail using the validation and review software. Information herein specific to the vertebra being reviewed can also be saved as XML for further analysis.

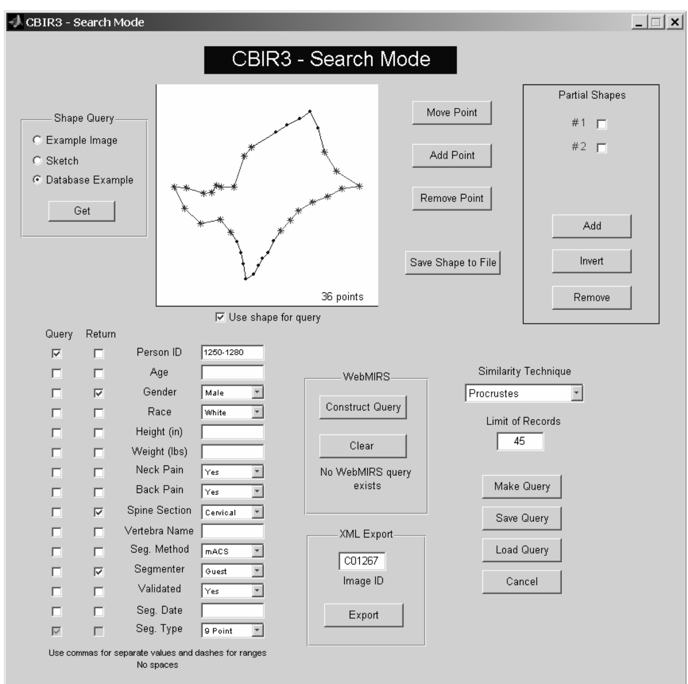

Figure 10. Query screen for CBIR3

ADVANTAGES

The CBIR system described above enables the capability to perform simultaneous hybrid text and content-based image queries on the entire NHANES II data using a combination of the prototype software and the familiar WebMIRS interface. The only limiting factor in retrieving image data is the number of available segmentations which already exceed 4500 shapes or over 900 images. These are expected to grow by another 1250 images or 6000 shapes and will be independently validated by pair of radiologists in the near future. Querying such a large collection and studying the pathology in the distribution has not been possible in the past. In order to achieve this, following enhancements were made to the CBIR system design:

- The system has an entirely centralized database to store shapes, text data, and images. This database can be located on a remote server or be served from the local machine.
- It incorporate results from several research efforts in segmentation, and shape matching. In addition it supports flexibility to add new R&D work with relative ease. This will enable testing of new work on live data and present a true picture of its performance in evaluations. Since not all new work may be presentable, the system provides means to control access to unfinished components of the system.
- It provides a means to review and validate image segmentations, add pathology information, enhance segmentations with dense localized segmentations, and mark double edges. All of these have been important topics which haven't been addressed to date. Having validated segmentations and truth set marked by medical experts is crucial to obtaining a real picture of algorithm performance on testing.
- It permits querying on both text and image data from the collection and combines the queries using logical and range operations.

In addition to the above novel contributions, the system allows individual query and sequential modes for viewing images in indexing and validation modes. The system also incorporates a new improved 9-point localization[5] to automatically generate 9-point segmentations from dense segmentations and a fast polygon approximation algorithm. In search mode, the system lays a foundation for future work on multiple partial shape retrieval. It also localizes partial shape queries to an interval of interest along the vertebra boundary.

CONCLUSIONS AND FUTURE WORK

Though CBIR3 addresses many of the design goals listed above, several areas need to be improved to make the system truly usable in an external setting. These challenges are in various stages of development and are planned for future versions of the system. The tasks planned for future work include:

- Enable different image types, modalities, and pathology.
- Allowing multiple partial shape queries with user specified degrees of importance and use of logical operators.
- Expand querying capability to include topological image feature relationships.
- Implementing relevance feedback for improved user interaction and an option to retain user preferences for future use.
- Developing and implementing an effective image and image feature indexing mechanism.
- Developing an extensible database design to allow for different image types, modalities, and pathology.
- Enable validation and query using stylus-based hand-held devices, such as personal digital assistants (PDA).
- Develop an external internet based interface for the software to make it a shareable resource.

We have described the building of a comprehensive system that addresses many of the weaknesses of the previous CBIR system. Not only is this new system an improved CBIR, but it also serves as a foundation to build new improvements. Importantly, it allows simultaneous hybrid text and image queries on the entire NHANES II text database using the familiar WebMIRS interface. We expect that the development of this system will greatly facilitate our work in evaluating the effectiveness of alternative modes of image indexing and retrieval. Such an effort is imperative for use of CBIR in practical systems in the future.

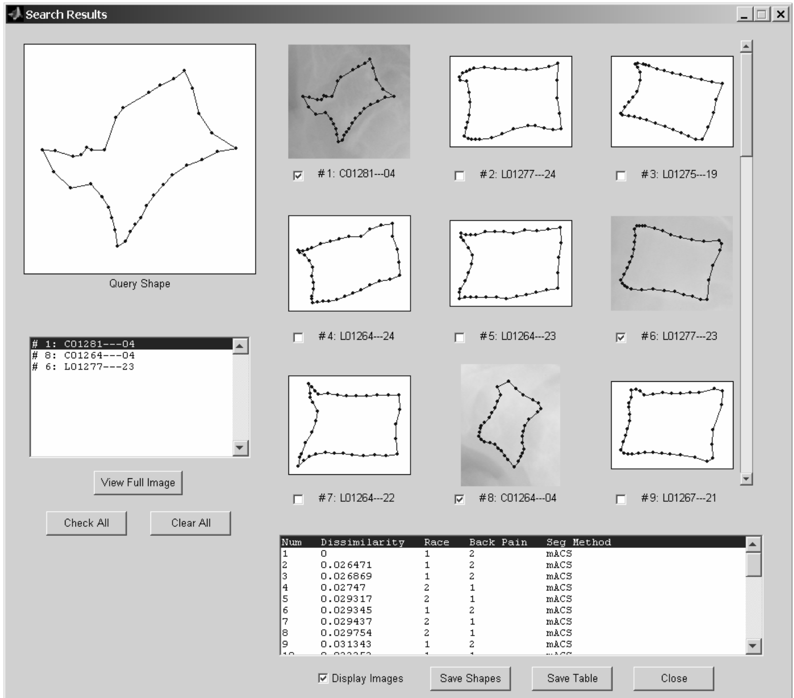

Fig 10. Sample result from a hybrid text-shape query. Note capability to view vertebra image crops, full image and save results as XML.

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