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An „Expert Assistant“ for Chest X-rays Based on Anatomical Models

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Summary

A computer expert assistant has been designed, initially to apply to chest X-rays. A high-level symbolic model of the patient's anatomy is incorporated and refined as image segmentation proceeds. The system is currently limited to gross anatomical abnormalities, the features of primary interest being long edges. Symbolic model- and image-based edge descriptions are compared in a modality-dependent "feature space" implemented in a frame structure. The generic nature of the approach should allow extension to other imaging modalities and anatomical regions. The current system robustly identifies major features and abnormalities.

"Expert assistants" and Radiology

An appropriate role for "expert assistant" software for medical imaging workstations appears to be the provision of a "second opinion" in the context of high-throughput examinations, particularly screening [1]. More specifically, our work focuses on highlighting, with high sensitivity, possible abnormalities to reduce the risk of missing abnormalities. The underlying philosophy of our approach is that, to segment an image to the level of detail that can allow anatomical abnormalities to be detected, the system must incorporate anatomical knowledge in a form which facilitates high-level reasoning concerning the structures seen in the images [2,3]. Accordingly, it includes a frame-based anatomical description.

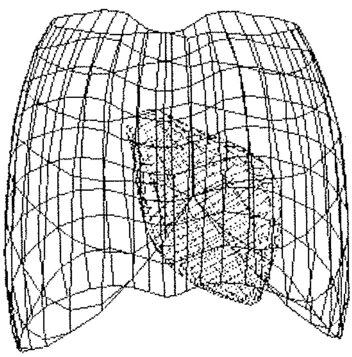
System overview

To incorporate a modality-independent anatomical model into the analysis of images from various imaging modalities, the analysis takes place in three closely related domains:

(1) Image space, consisting of arrays of pixels representing images obtained with (possibly) different modalities and views. The operations on this space are conventional image analysis operations such as edge detection, region identification etc.
(2) Anatomical space, consisting of the set of all possible configurations of human organs relating to the image(s). This model is independent of the modality which generated the images.
(3) Feature space, containing symbolic representations of features (such as edges or regions) derived from the images and from the model. Thus the feature space forms the intermediate link between image and model.

The initial system is based on chest X-rays, chosen because of their high throughput and the detailed anatomical knowledge required for their interpretation [4]. For chest X-rays, the principal features are edges rather than entire organs, and the feature space contains descriptions of edge character, shape, location and relationships, derived from both the image processing and the model. The model is progressively altered to better match, and hence "explain", the features derived from the image. Matching of image and model is done by matching relationship patterns in a network of frames organised as a "blackboard" [5]. Predicted feature positions are derived initially from a low-resolution *a priori* 2-D model, and, in later iterations, from the full 3-D model. Models fits are described using membership values in fuzzy sets, which return degrees of membership uncertainty of the "normal" set, translating into a report of the degree of abnormality. Detailed identification of structures in the image is aided by the fact that many features of interest in chest X-rays are described as long, smooth edges. Active contours ("snakes") are used to refine the positions of these edges, the energy of the snake being a sum of terms related to (a) internal elasticity, which biases the contour to relatively smooth curves, (b) image forces, essentially attracting the contour to high gradient regions, and (c) model forces, seeking a structure whose anatomical nature matches the model.

Using a symbolic anatomical model allows separation of the model from image processing [6]. The model makes extensive use of frames, with specific information about each organ being stored in "slots". Shape descriptions are based on medial axes and Fourier-based cross-sections (Fig. 1). The compactness of the description permits the model to be easily modified by manipulating a small number of parameters. Procedures are incorporated into the model descriptors to maintain anatomical invariances such as (a) adjacency, which describes the relative positions of organs, (b) connectedness, which describes the actual connections between organs, often related directly to growth patterns, and (c) space-filling constraints. This last requirement ensures that each internal voxel is associated with one organ only, and corresponds to a combination of the "collision resolution" concept in 3D computer graphics and the constraint that all internal space is filled. Vertex-based organ shape descriptions are easily generated, leading to visualisations either in realistic 3-D rendered form or as synthetic medical images for direct comparison with the original image [7].



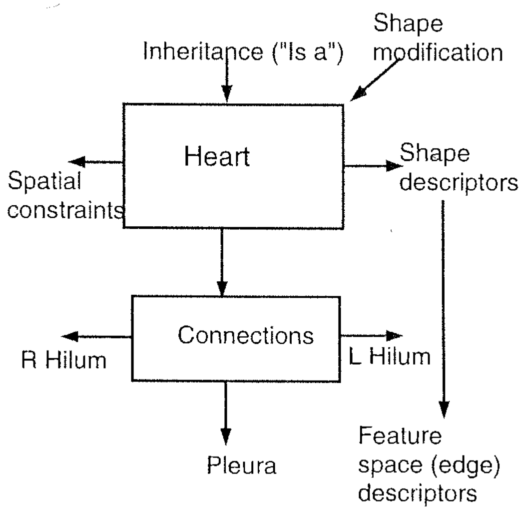


Figure 1: (Left) Medial-axis-based wire-frame model of the heart and costal pleurae. (Right) Knowledge organisation in the anatomical model permitting fitting to image and ensuring consistency with constraints such as space-filling, adjacency and connectedness.

Implementation

Implementation is on a Silicon Graphics Indigo workstation, using LISP for the frame structure, which handles both feature space and anatomical information. Image processing routines are written in C, while visualisation is through Open Inventor. A standard PACS-like user interface has been designed to test the efficacy of the expert assistant in a familiar environment. A block diagram of the complete system is shown in Fig. 2.

The current system identifies and reports on the positions, lengths and sharpness of the boundaries of the lung fields, using a 2-D model of the relationships and positions of these edges. A report is generated for each edge, with the fuzzy membership value of the "normal" set translating naturally into a linguistic value such as "normal", "slightly raised", "very indistinct", and so on. These reports have been well received by radiologists.

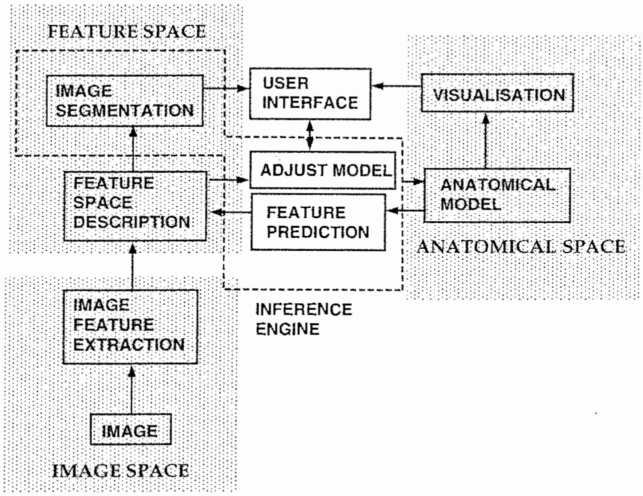


Figure 2. Symbolic block diagram of the system.

User interactivity may be provided in a number of ways. A degree of hypothesis testing is invoked when the system fails to find an edge, or misidentifies it, due to gross abnormalities. An edge may be manually entered by the operator, refined by a model-driven active contour [8], then all other edges updated based on the hypothesis of the new edge's labelling (Figs. 3 and 4).

However, the most powerful user interactivity will be the direct manipulation and hypothesis testing made possible through interactive access to the anatomical model, and the subsequent ability to test "anatomical hypotheses" directly.

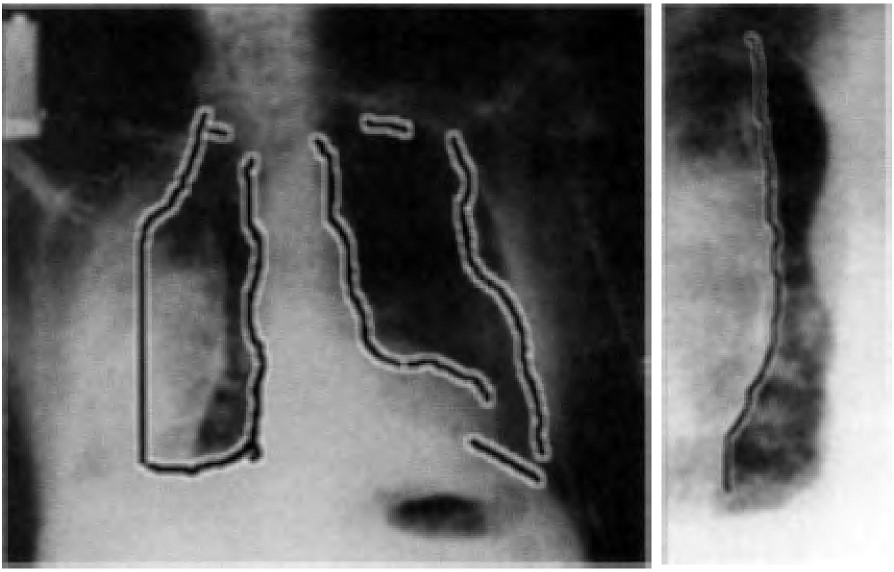


Figure 3: (Left) Automatic boundary identification in a chest X-ray in which the left lung is normal, but the right lung field is affected by calcification.
(Right) A new costal margin is entered as an approximation by the operator and refined automatically by active contour.

LEFT COSTAL SURFACE	LEFT COSTAL SURFACE
Silhouette is a bit unclear	Silhouette is a bit unclear
RIGHT COSTAL SURFACE	RIGHT COSTAL SURFACE
Silhouette is unclear	Shape appears abnormal
LEFT HEMIDIAPHRAGM	LEFT HEMIDIAPHRAGM
Shape appears abnormal Length appears abnormal	Shape appears abnormal Length appears abnormal
RIGHT HEMIDIAPHRAGM	RIGHT HEMIDIAPHRAGM
Shape appears abnormal	Shape appears abnormal
RIGHT MEDIASTINUM	RIGHT MEDIASTINUM
Normal	Normal

Figure 4: Extracts from computer-generated reports before (left) and after (right) the interactive intervention in Fig. 3. Note the changed report on the right costal margin.

Conclusion

This system has verified the usefulness of high level models in medical image segmentation. It successfully labels chest X-rays in a variety of patient types and with abnormalities which vary the relationships among features. Most importantly, it is highly sensitive to the presence of abnormalities. This preliminary version has been well received by radiologists. It is being enhanced to incorporate more detailed anatomical knowledge and, eventually, a variety of views and imaging modalities.

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