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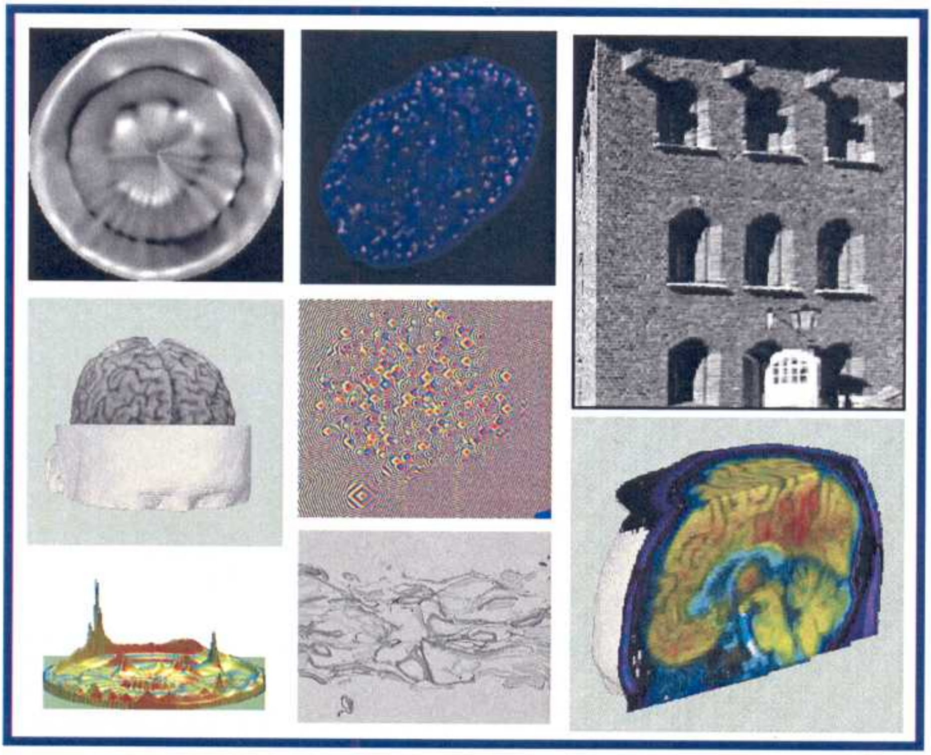

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7.2 PhD Thesis: "Towards Intelligent Deformable Models for Medical Image Analysis"

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The automated segmentation and labeling of anatomical structures in medical images is a persistent problem that continues to defy solution. There is a consensus within the medical image analysis research community that the development of general-purpose automatic segmentation algorithms will require not only powerful bottom-up, data-driven processes, but also equally powerful top-down, knowledge-driven processes capable of operating across multiple levels of abstraction. Ghassan Hamarneh's Thesis represents an attempt in this direction, including work on bottom-up as well as top-down image analysis procedures.

Ghassan's research concerns deformable models and their application to medical image analysis. These models, the most actively researched model-based segmentation techniques, stem from differential geometry, physics, and approximation theory. Geometry serves to represent object shape, physics imposes constraints on how the shape may vary over space and time, and optimal approximation theory including calculus of variation provides the formal underpinnings for fitting models to measured data.

The deformable model that has attracted the most attention to date is popularly known as *snakes*. Snakes or Active Contour Models (ACM) represent a special case of the multidimensional deformable model theory. They are planar deformable contours that are often used to approximate the locations and shapes of object boundaries in images based on the reasonable assumption that boundaries are piecewise continuous or smooth.

Active Shape Models (ASM) is a statistically based extension of ACM, based on Principal Component Analysis (PCA) that provides global shape constraints and takes advantage of a priori information about the shape under investigation. This means allowing the model to deform only in ways implied by a previously acquired training set.

Deformable organisms represent a new paradigm for medical image analysis that adopts modeling concepts from the field of artificial life. This type of intelligent deformable model possesses an *awareness* of the segmentation process, which emerges from a conflux of perceived sensory data, an internal mental state, memorized knowledge, and a pre-stored cognitive segmentation plan.

Ghassan's Thesis, authored as a monograph, is based on the following papers:

I. G. Hamarneh, A. Chodorowski, T. Gustavsson. "Active Contour Models: Application to Oral Lesion Detection in Color Images". IEEE Proceedings of the International Conference on Systems, Man, and

Cybernetics, vol. 4, pp. Nashville, Tennessee, USA, October 8-11, 2000.

II. G. Hamarneh, T. Gustavsson. "Combining Snakes and Active Shape Models for Segmenting the Human Left Ventricle in Echocardiographic Images". IEEE Proceedings of Computers in Cardiology, vol. 27, pp. 115-118, Cambridge, USA, September 24-27, 2000.

III. G. Hamarneh, T. Gustavsson. "Statistically Constrained Snake Deformations". IEEE Proceedings of the International Conference on Systems, Man, and Cybernetics, vol. 3, pp. 1610-1615, Nashville, Tennessee, USA, October 8-11, 2000.

IV. K. Althoff, G. Hamarneh, T. Gustavsson. "Tracking Contrast in Echocardiography by a Combined Snake and Optical Flow Technique". IEEE Proceedings on Computers in Cardiology, vol. 27, pp. 29-32, Cambridge, USA, September 24-27, 2000.

V. G. Hamarneh, T. Gustavsson. "Deformable Spatio-Temporal Shape Models: Extending ASM to 2D+Time". Proceedings of the British Machine Vision Conference, BMVC 2001, vol. 1, pp. 13-22, Manchester, UK, September 10-13, 2001. Received Best Conference Paper Award. A revised version will appear in Image and Vision Computing Journal.

VI. G. Hamarneh, T. McInerney. "Controlled Shape Deformations via Medial Profiles". Proceedings of Vision Interface, VI 2001, pp. 252-258, Ottawa, Canada, June 7-9, 2001.

VII. G. Hamarneh, T. McInerney. "Physics-Based Shape Deformations for Medical Image Analysis". Technical Report CSRG-436, Department of Computer Science, University of Toronto, 2001.

VIII. G. Hamarneh, T. McInerney, D. "Deformable Organisms for Automatic Medical Image Analysis". Proceedings of the Fourth International Conference on Medical Image Computing and Computer-Assisted Intervention. MICCAI 2001, Utrecht, The Netherlands, October 14-17, 2001. Received Best Conference Paper Award.

Papers I-II represent two applications of ACM and ASM to segmentation in ultrasonic heart images and digital color images of the oral cavity, respectively.

Paper III presents a PCA inspired method applied to a set of shape descriptors represented in the frequency domain. The method elegantly solves the difficult problem of identifying corresponding anatomical landmarks.

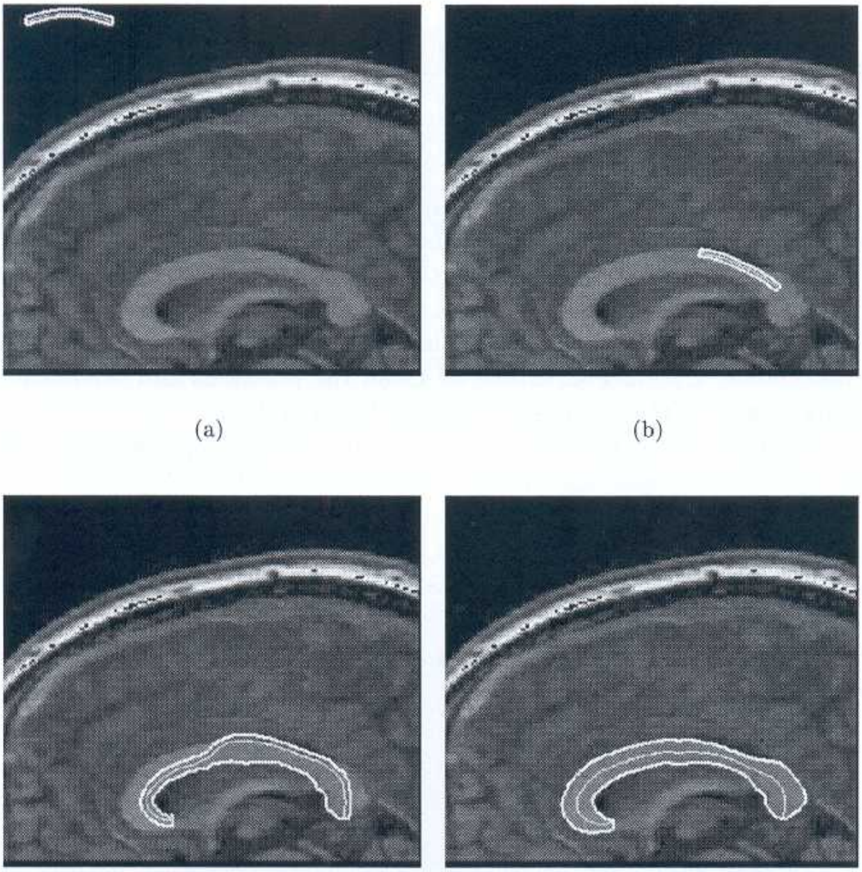
Paper IV deals with the well-known optical flow computational technique. When adding an energy term derived from the optical flow field, the conventional snake algorithm converged much more rapidly. The new technique was applied to left ventricular boundary tracking in contrast echocardiography.

Paper V describes an extension of two-dimensional (2D) ASM to the spatio-temporal case (2D + time). A 2D closed contour that moves dynamically in the plane (envision a 2D cross-section of a boundary in a pulsating heart) can be considered a 3D generalized cylinder. Segmenting the surface of this spatio-temporal cylinder is a much more powerful boundary detection approach than sequential segmentation of separate 2D contours. The paper presents results on successful segmentation of synthetic spatio-temporal shapes.

Papers VI-VII report on a new hierarchical and regional PCA methodology. It represents a multi-scale and self-learning approach to shape analysis. The ability to produce controlled deformations on a medial-based representation of a certain class of brain structures (corpus callosum) is demonstrated.

Paper VIII introduces a novel framework for medical image analysis referred to as Deformable Organisms. A higher-level cognitive layer is incorporated on top of the lower-level physics and geometry levels typical for traditional deformable models. It is demonstrated how deformable models can deal with noise, incomplete edges, anatomical variations, and occlusions in order to segment structures from medical images.

Figure 1 shows the performance of a deformable organism. The task is to find a brain structure (in this case corpus callosum).



(a) (b)

(c) (d)

Figure 7.1: The task is to find a brain structure. Given a start position and shape (a), the organism begins searching for the structure. This search goes via the skull and downwards. When a segment of the structure boundary is detected, the organism goes through a series of deformations (b and c) until there is a good fit between the deformed organism and the target (d). As indicated in (d), the organism is being represented by its medial axis.