Statistical Shape Analysis of Anatomical Structures

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The Problem: In this work, we develop a computational framework for image-based statistical analysis of anatomical shape in different populations. Fig. 1 shows example of the hippocampus-amygdala complex from the comparative study of the structure in schizophrenia.

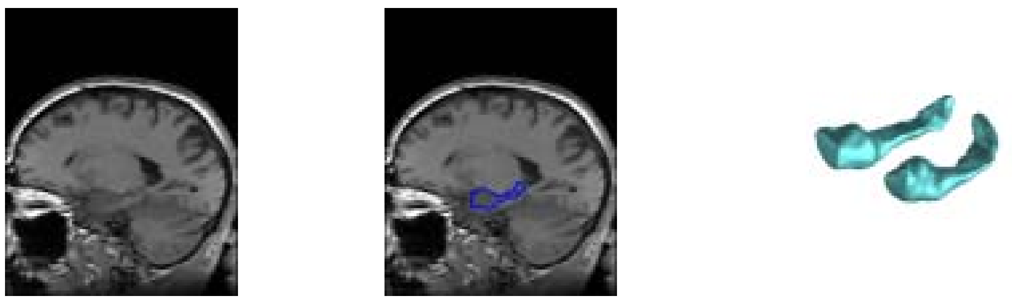

Figure 1: Example input data from the hippocampus-amygdala study in schizophrenia. The pictures show a single midsagittal slice of the volumetric MRI scan (left), the hippocampus segmentation (middle) and the 3D surface model reconstructed from the segmentation of the whole volume (right).

Motivation: Anatomical shape, and its variation, has always been an important topic of medical research, but only with the introduction of high resolution 3D imaging, such as MRI and CT, has it become possible to study morphology *in vivo*. Understanding morphological changes caused by a particular disorder can help to identify the time of onset of a disease, quantify its development and potentially lead to a better treatment. Other examples of morphological studies include investigating anatomical changes due to aging through a comparison of different age groups and identifying differences in anatomy between genders.

Previous Work: Most work in discriminative modeling [1, 2, 5] has been developed based on the existing techniques for generating shape priors for segmentation. Typically, generative models based on Principal Component Analysis are employed for detection and visualization of the shape variation within each group. Our approach is to construct an accurate model of the shape differences between the classes and analyze it in terms of the properties of the original feature vectors and their influence on the output of the classification function. The results can be represented in the image domain as deformations of the original input shape, yielding both a quantitative description of the morphological differences between the classes and an intuitive visualization mechanism.

Approach: Once a quantitative description of organ shape is extracted from input images, the problem of identifying differences between the two groups can be reduced to one of the classical questions in machine learning, namely constructing a classifier function for assigning new examples to one of the two groups while making as few mistakes as possible [3]. We propose a novel approach to interpretation of the resulting classifier in the original feature space [4]. For each example in the input space, we derive a discriminative direction that corresponds to the differences between the classes implicitly represented by the classifier function. For morphological studies, the discriminative direction can be conveniently represented by a deformation of the original shape that allows medical researchers to argue about the identified shape differences in anatomically meaningful terms of organ development and deformation.

(a) Schizophrenia patient

(b) Normal control

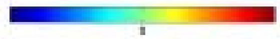

Figure 2: Discriminative direction for the right hippocampus shown as a deformation of one example shape from the schizophrenia group (top) and the normal control group (bottom). Four views of each shape are shown. The color coding is used to indicate the direction and the magnitude of the deformation, changing from blue (inwards) to green (no deformation) to red (outwards).

Impact: We demonstrate the method on both artificial examples that illustrate the approach and the real medical studies in which the resulting deformations describe shape changes due to diseases and can be helpful in advancing the medical research towards explaining the mechanisms by which the organs are affected. To the best of our knowledge, this is one of the first few attempts to automatically detect and interpret shape differences between populations, and the first work that takes advantage of the discriminative modeling. Since the discriminative models require significantly fewer data than the generative models to reliably estimate the differences between the classes, a discriminative approach has better chances of succeeding in small training sets. Anatomical studies have always been challenging exactly because the images are difficult to collect and process and therefore the available training sets are typically very small. Thus, we believe that the proposed framework can allow the medical researches to efficiently utilize the available data in order to study various diseases.

Future Work: Experimental studies suggested several directions of future work, from refining the analysis technique for interpretation of shape differences to collecting more data for strengthening the statistical confidence indicators. We would like to mention two promising directions of research in statistical shape analysis that are enabled by our approach. First, we note that the training algorithm and the discriminative direction analysis can be used as a very effective tool for investigating the power of different shape descriptors for representing morphological variability. The other interesting observation is concerned with the medical implications of the experimental results produced by our method. Once we start working with non-linear classifiers, we accept a possibility of the differences between the normal subjects and the patients varying over the shape space. Thus, the results of the analysis could be used for partitioning the region of the feature space occupied by the examples of pathology into sub-regions characterized by the nature of the deformation that separates the pathology from the normal cases. This partition, especially if supported by other evidence, such as symptoms, functional data, etc., can be used as an initial indication that the disease in question is really a collection of several different disorders.

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References:

[1] J. G. Csernansky *et al.* Hippocampal morphometry in schizophrenia by high dimensional brain mapping. *Proceedings of National Academy of Science*, 95(19):11406–11411, 1998.

[2] G. Gerig and M. Styner. Shape versus size: Improved understanding of the morphology of brain structure. In *Proceedings of MICCAI'01: Medical Image Computing and Computer-Assisted Intervention*, 2001. To Appear.

[3] P. Golland, W. E. L. Grimson, M. E. Shenton, and R. Kikinis. Small sample size learning for shape analysis of anatomical structures. In *Proceedings of MICCAI'2000: Medical Image Computing and Computer-Assisted Intervention*, pages 72–82. LNCS 1935, Springer-Verlag, 2000.

[4] P. Golland, W. E. L. Grimson, M. E. Shenton, and R. Kikinis. Deformation analysis for shaped based classification. In *Proceedings of IPMI'01: Information Processing in Medical Imaging*, pages 517–530. LNCS 2082, Springer-Verlag, 2001.

[5] J. Martin, A. Pentland, and R. Kikinis. Shape analysis of brain structures using physical and experimental modes. In *Proceedings of CVPR'94: Computer Vision and Pattern Recognition*, pages 752–755, 1994.