PROBABILISTIC MODELING OF BRAIN SULCI BASED ON STATISTICAL ANALYSIS OF 3D SURFACES

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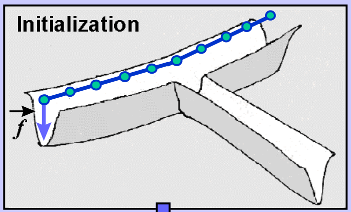
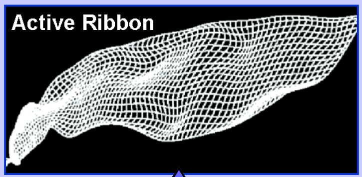
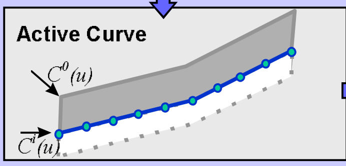
Goal and Rationale

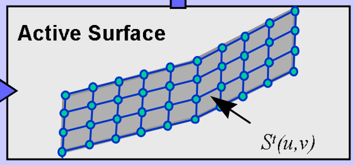
One of the major problems in functional neuroimaging is to match anatomical and functional data from different subjects. Usually this task is performed on morphological basis coming from MRI. This work intends to tackle this problem by computing statistical models of cortical sulci from analytical representations of these sulci obtained automatically from 3D MRI using the « active ribbon » method [1]. Our goal is to use these « local » statistical anatomical models as a substrate to compare functional recordings coming from different subjects (e.g. MEG or fMRI). This statistical modeling of cortical sulci will allows the description of their shapes and their variability and can be used as constraints to assist non-linear registration of human brains by inter-individual matching of anatomy following similar ideas than those proposed in [2, 3]. In this work, we propose to apply to neuro-anatomy a general statistical framework defined for modeling deformable objects [4, 5]. The model proposed here is devoted to be used for digital brain atlases.

Cortical Sulci Modeling: «Active Ribbon» Method(*)

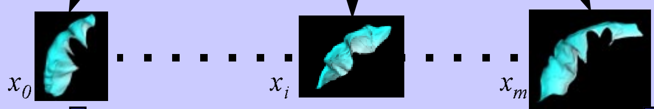




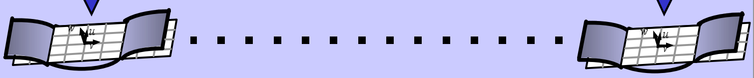




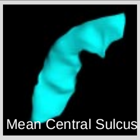
*: see [1] and posters # 796 , #731 and #177 for more details



Local Referential Definition



Modal Analysis



$$\overline{X} = \frac{1}{m}\sum_{i=1}^{m} x_i$$

$$C = \frac{1}{m}\sum_{i=1}^{m} \tilde{x}_i \tilde{x}_i^T \,;\; \tilde{x}_i = x_i - \overline{X}$$

$$C = \Phi \Lambda \Phi^T \,;\; \Lambda = \begin{bmatrix} \lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \lambda_m \end{bmatrix}$$

Analysis

$$x = \overline{X} + \Phi b$$

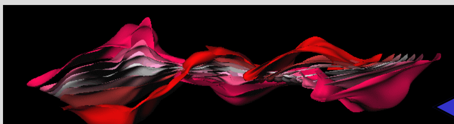
Mean Sulcus Shape — Reconstructed Sulcus Shape — Modal Amplitudes — Modes Matrix

Synthesis

$$x \approx \overline{X} + \sum_{i=1}^{m} \phi_i b_i$$

$$x = \overline{X} + \phi_1 b_1$$

$$b_1 \in \left[-2\sqrt{\lambda_1}, +2\sqrt{\lambda_1}\right]$$

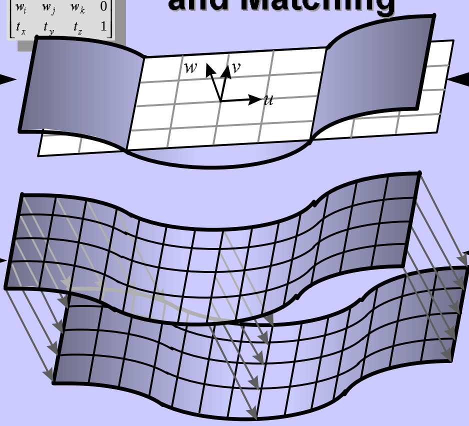


Principal Mode of Deformation of the Right Central Sulcus(*)

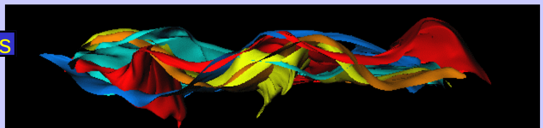
*: preliminary results from 6 items

Registration and Matching

$$\begin{bmatrix} u_i & u_j & u_k & 0 \\ v_i & v_j & v_k & 0 \\ w_i & w_j & w_k & 0 \\ t_x & t_y & t_z & 1 \end{bmatrix}$$



Modal Analysis



Matching of 6 Right Central Sulci

References

[1] G. Le Goualher, C. Barillot, Y. Bizais, *Int. J. of Pattern Recognition and Artificial Intelligence*, 1997, 11:8.

[2] Collins D.L., Le Goualher G., Venugopal R., Caramanos A., Evans A.C., Barillot C, In: *LNCS: Visualization in Biomedical Computing*, 1996, 1131:307-316.

[3] Thompson P.M., Toga A.W., *Medical Image Analysis*, 4(1):271-294.

[4] Cootes T., Cooper D., Taylor C., Graham J., *Image and Vision Computing*, 1992, Vol.10(5):289-294.

[5] Kervrann C., Heitz F, *Proc. of IEEE Computer Vision & Pattern Recognition*, 1994, pp.724-728

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Probabilistic Modeling of Brain Sulci based on Statistical Analysis of 3D Surfaces

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Material and Methods

The principle of this method takes advantage of a learning set built from analytical models representing the same class of sulci (e.g. the right central sulcus) among a population of individuals. A common referential is automatically computed from this set of individual sulci in order to define a « local » referential best adapted for the study of the local variations of this particular class of sulci. Each element of the learning set is aligned to the local referential using linear registrations. From this basis, the statistical analysis of the different shapes based on *an inter-individual local referential* can be performed using a Principal Component Analysis (PCA) procedure. A *mean* model is first computed which represents the mean location of the sulcus according to the computed referential (but not specially the most probable shape). For the shape analysis, deformation modes are estimated from PCA which allows the reconstruction of 99% of probable shapes typically with as little as 6 to 9 modes (depending of the size of the learning set). Deformations from one individual to the mean shape or another individual becomes straightforward to compute ; either by computing the deformation vectors between the different models or by using the eigenmodes of each individual which characterize the typical shape variation of one sulcus arround the mean model. These modes can also be used to characterize the probability for a sulcus to belong to a given class of sulci. In extension, the deformations computed for each sulcus can be applied to functional recordings or any kind of structures assigned (and close enough) to these cortical landmarks. Preliminary results from this work will be presented at the time of the conference.

Illustrations

Preliminary results showing the learning set after registration of 6 right central sulci (left), and the first deformation mode around the mean model (right).

References

1. G. Le Goualher, C. Barillot, Y. Bizais, Int. J. of Pattern Recognition and Artificial Intelligence, 1997, 11:8.
2. Collins D.L., Le Goualher G., Venugopal R., Caramanos A., Evans A.C., Barillot C, Lecture Notes in Computer Sciences: Visualization in Biomedical Computing, 1996, Vol.1131:307-316.
3. Thompson P.M., Toga A.W., Medical Image Analysis, 4(1):271-294.
4. Cootes T., Cooper D., Taylor C., Graham J., Image and Vision Computing, 1992, Vol.10(5):289-294.
5. Kervrann C., Heitz F, Proc. of IEEE Computer Vision & Pattern Recognition, 1994, pp.724-728