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Anisotropic similarity, a constrained affine transformation: Application to brain development analysis

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Introduction

Objective: quantify regional brain growth in 3 orthogonal directions by linearly registering subjects on a common basis.

Approach: introduce an affine transformation with constrained scaling directions (9 degrees of freedom).

Material and Methods

Affine transformation: \( y = Lx + t \)

- \( L = RSU^T \)
  - \( U \) is a rotation matrix that determines scaling directions
  - \( S \) is an anisotropic scaling (diagonal matrix)
  - \( R \) is a rotation matrix

Anisotropic similarity: affine transformation with fixed \( U \)

Block-matching registration [1][2]:
1. Matching: find homologous blocks in both images best satisfying a similarity criterion
2. Aggregation into a global transformation by minimizing the distance between the sets of blocks

For an anisotropic similarity:

Minimize: \( C(R, S, t) = \sum_i \| y_i - (RSU^T x_i + t) \|^2 \), \( U \) fixed

\( i = g - RSU^T \)

\( \tilde{C}(R, S) = \sum_i \| y_i - RS\tilde{z}_i \|^2 \)

\( y_i = y_i - \bar{g}, \bar{x} = U^T (x_i - \bar{x}) \)

\( \tilde{C}(q, S) = \sum_i \| y_i - q \xi_i + \bar{q} \|^2 \)

\( \xi_i = S\tilde{z}_i \) [3]

Matricial quaternions: \( y_i^* = q \xi_i^* q \) and \(-q \xi_i = -P_\xi^T q = P_\xi^T q\)

\( \tilde{C}(q, S) = -q^T \left( -\sum_i (Q_{\xi_i} + P_\xi)^2 \right) q \)

\( A_i = (Q_{\xi_i} + P_\xi)^2 \) and \( A = \sum_i A_i \)

Alternate optimization each having an analytical solution:
- For fixed \( S \), \( \bar{q} \) eigenvector with smallest eigenvalue of \( A \)
- For fixed \( q \), \( \tilde{S}_{jj} = \frac{1}{\sum_i \tilde{z}_{ji}^2} q^T \left( \sum_i Q_{\xi_i} \frac{\partial P_\xi}{\partial \xi_j} \right) q \)

We registered whole brain and lobes from 308 subjects onto an atlas based on this population using anisotropic similarity with chosen \( U \).
Then we extracted the associated scaling factors describing brain growth.

Results

Scaling factors along chosen directions
Black curve represents average model
Fitted using first order rational regression: \( y = \frac{ax + b}{x + c} \)

Chosen scaling directions fixed on the reference image:
1. Orthogonal to the mid-sagittal plane (blue) [4]
2. and 3. Principal directions of voxel coordinates projected on mid-sagittal plane (red and green)

We developed a method to quantify regional brain growth in 3 orthogonal directions through anisotropic similarity registration.
An interesting continuation is to compare the results among groups of population.

References