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

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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
\[ \hat{t} = \bar{y} - RSU^T \bar{x} \]
\[ \hat{C}(R, S) = \sum_i \| y'_i - RS \bar{x}_i \|^2 \]
\[ y'_i = y_i - \bar{y}, \bar{x} = U^T (x_i - \bar{x}) \]
\[ \hat{C}(q, S) = \sum_i \| y'_i - q \xi_i - \bar{q} \|^2 \]
\[ \xi_i = S \bar{x}_i \] [3]

Matricial quaternions: \( y'_i * q = Q y'_i q \) and \(-q * \xi_i = -P_{\xi_i} q = P_{\xi_i} q \)
\[ \hat{C}(q, S) = -q^T \left( -\sum_i (Q y'_i + P_{\xi_i})^2 \right) q \]
\( A_i = (Q y'_i + P_{\xi_i})^2 \) and \( A = \sum_i A_i \),
Alternate optimization each having an analytical solution:
- For fixed \( S \), \( \hat{q} \) eigenvector with smallest eigenvalue of \( A \)
- For fixed \( q \), \( \hat{S}_{jj} = \frac{1}{\sum_i \bar{x}_{ji}^2} q^T \left( \sum_i Q y'_i \frac{\partial P_{\xi_i}}{\partial s_j} \right) q \)

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)

Conclusion

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


[c] cmind database: cmind.research.cchmc.org
[a] Developing human connectome project (dHCP) database: http://www.developingconnectome.org