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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

$$\hat{t} = \bar{y} - \hat{R}\hat{S}U^T \bar{x}$$

$$\tilde{C}(R, S) = \sum_i \|y'_i - RS\tilde{x}_i\|^2 \quad y'_i = y_i - \bar{y}, \tilde{x}_i = U^T(x_i - \bar{x})$$

$$\tilde{C}(q, S) = \sum_i \|y'_i - q * \xi_i * \bar{q}\|^2 \quad \xi_i = S\tilde{x}_i \quad [3]$$

Matricial quaternions: $y'_i * q = Q_{y'_i} q$ and $-q * \xi_i = -P_{\xi_i}^T q = P_{\xi_i} q$

$$\tilde{C}(q, S) = -q^T \left(-\sum_i (Q_{y'_i} + P_{\xi_i})^2 \right) q$$

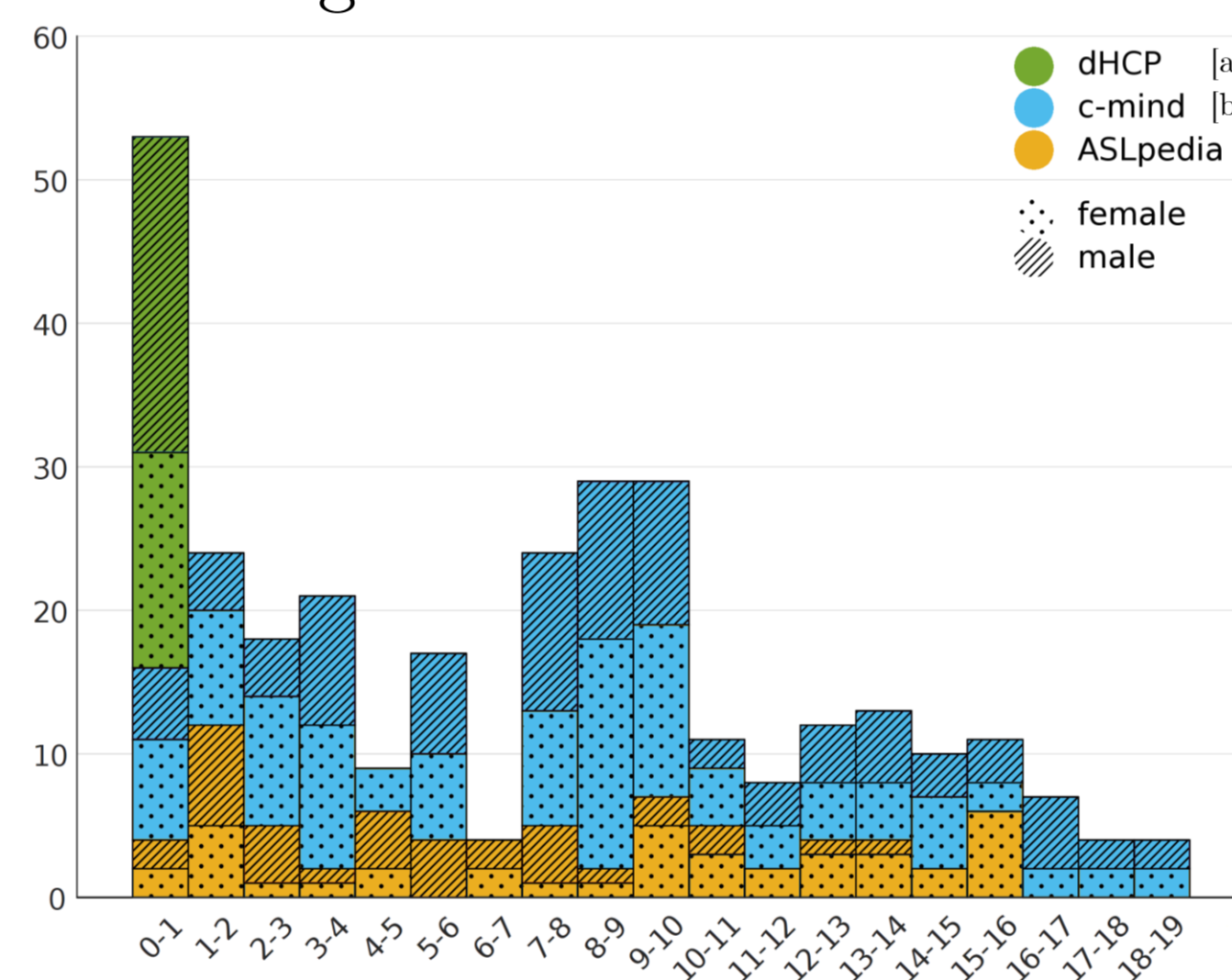
$A_i = (Q_{y'_i} + P_{\xi_i})^2$ and $A = \sum_i A_i$.

Alternate optimization each having an analytical solution:

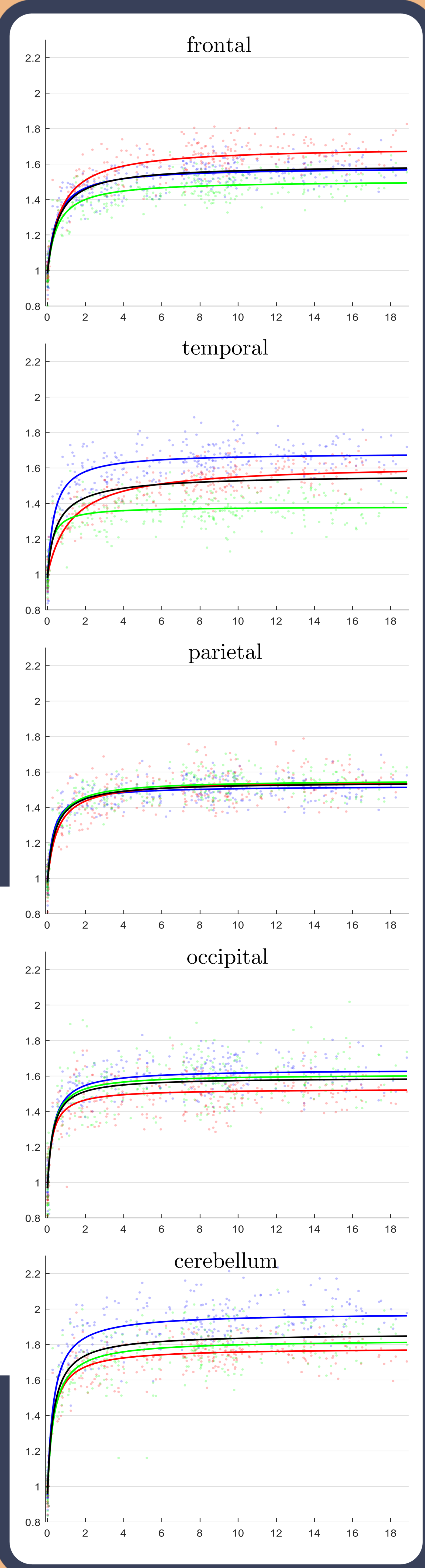
- For fixed S , \hat{q} eigenvector with smallest eigenvalue of A

- For fixed q , $\hat{S}_{jj} = \frac{1}{\sum_i \tilde{x}_{ji}^2} q^T \left(\sum_i Q_{y'_i} \frac{\partial P_{\xi_i}}{\partial s_j} \right) q$

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.

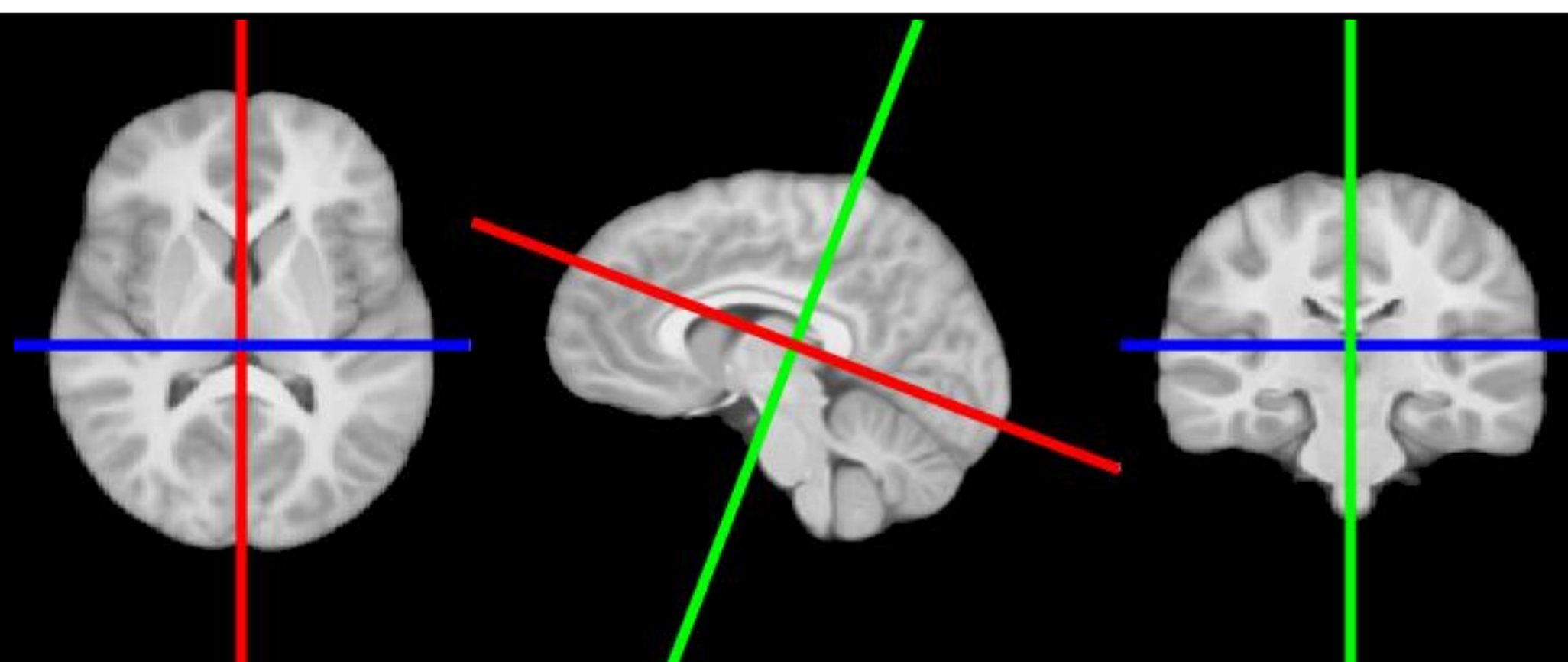


Results

Scaling factors along chosen directions

Black curve represents average model

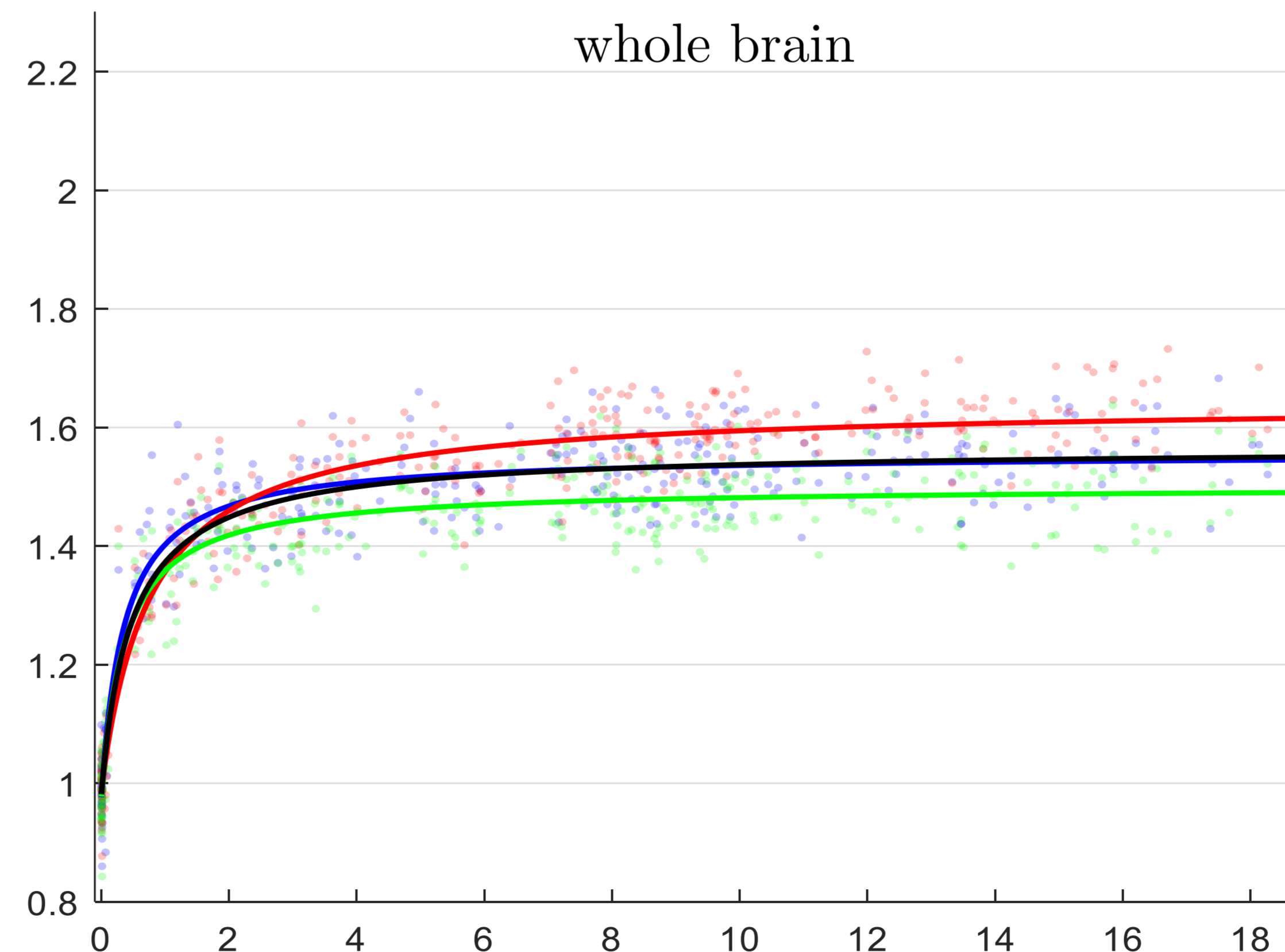
Fitted using first order rational regression: $y = \frac{ax + b}{x + c}$



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)

Scaling factors over age in years



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.

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