CortexMorph: fast cortical thickness estimation via diffeomorphic registration using VoxelMorph

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Abstract

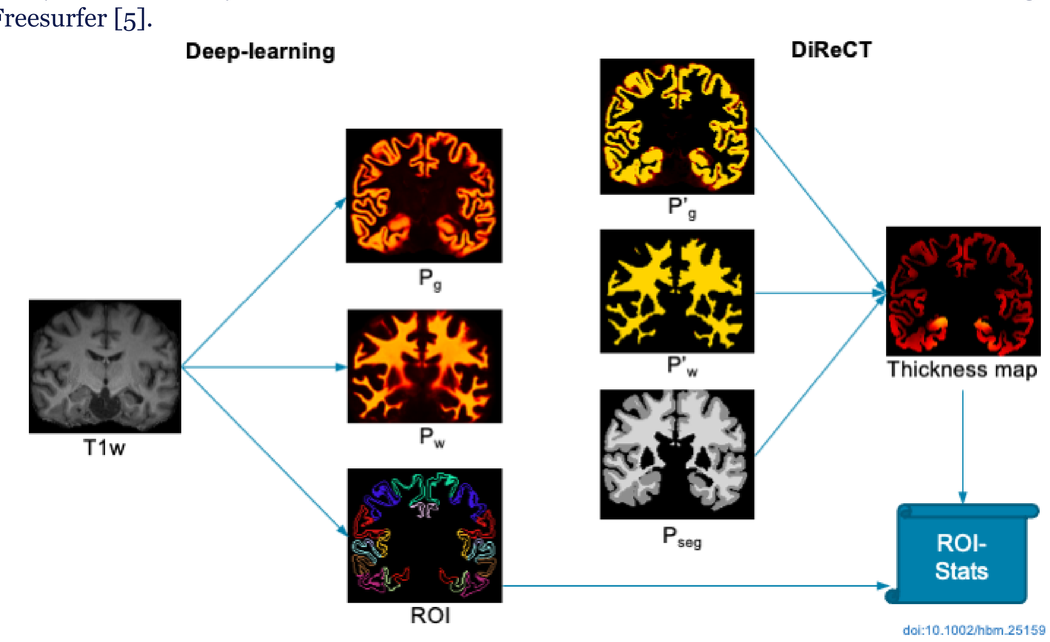
The thickness of the cortical band is linked to various neurological and psychiatric conditions, and is often estimated through surface-based methods such as Freesurfer in MRI studies. This paper proposes CortexMorph, a new method that employs Voxelmorph-style unsupervised deep learning to directly regress a deformation field for the estimation of region-wise thickness in seconds from WM and GM segmentations, obtaining cortical thickness estimates from the DiReCT method.

DiReCT cortical thickness estimation

The DiReCT method [2] offers an alternative to surface-based morphometry methods, calculating CTh via a diffeomorphic deformation of the gray-white matter interface (GWI) towards the pial surface (the outer edge of the cortical band). ANTs provides an implementation of DiReCT via the function `KellyKapowski`. The ANTs cortical thickness pipeline uses a three-class segmentation (grey matter, white matter, cerebrospinal fluid).

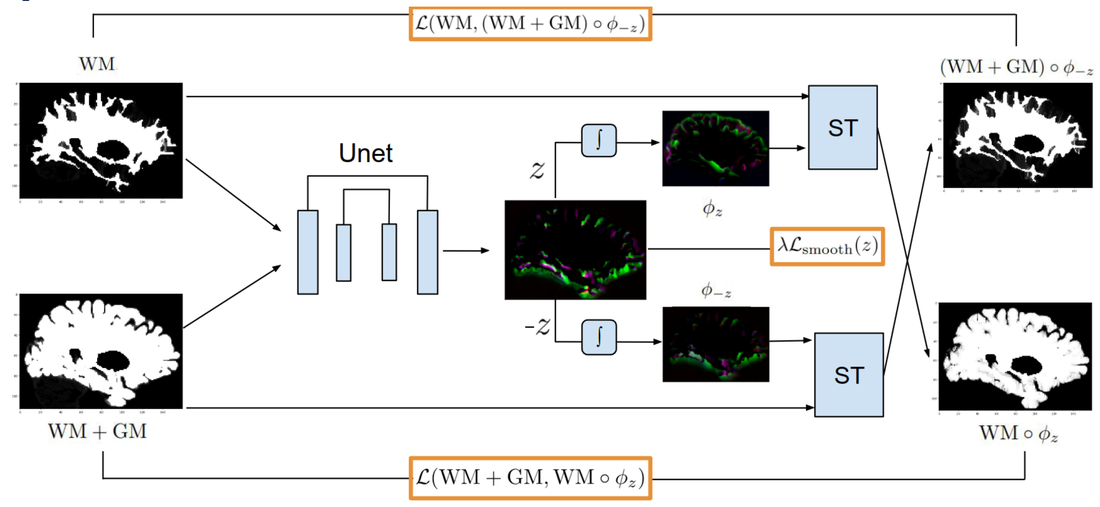
DL+DiReCT

DL+DiReCT [3] is a freely available package for calculating cortical thickness from T1 weighted imaging, which combines a CNN-based segmentation of neuroanatomy and cortical areas with the DiReCT algorithm (as implemented in ANTs) to provide regional CTh measures. The method agrees strongly with Freesurfer-derived measures, while having improved repeatability on repeated scans. A digital phantom built using GAN-generated scans with simulated cortical atrophy was recently used in a study which showed that DL+DiReCT is more sensitive to cortical thinning than Freesurfer [5].



CortexMorph

Since diffeomorphic registration is required in the DiReCT method, we adapt the variant of Voxelmorph in which the Unet performs regression of a stationary *velocity field*, with the subsequent deformation field being calculated via an integration layer [1]. The loss function $\mathcal{L}$ producing best results (in terms of agreement with the DL+DiReCT definition of Cortical Thickness) was mean squared error.



Model Training and Testing

Images from 200 randomly selected elderly individuals from the ADNI dataset and images from 200 randomly selected healthy adults from the IXI dataset. From each of these datasets, 160 images were randomly chosen to serve as training data, yielding in total 320 training cases and 80 validation cases. For testing, we use two sources different from the training/validation data: the OASIS-3 dataset (2,643 scans of 1,038 subjects, acquired over > 10 years on three different Siemens scanners), and the CTh phantom of Rusak et al. [5, 4]

For WM/GM segmentation, we employed the DeepSCAN model, which is available as part of DL+DiReCT, since this is already known to give high-quality CTh results when combined with DiReCT.

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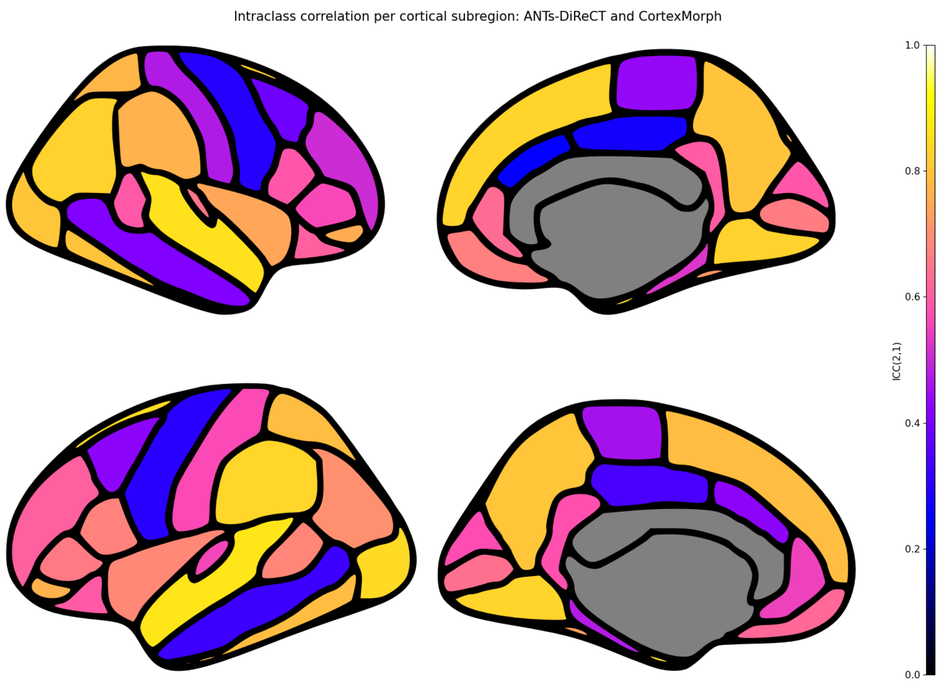
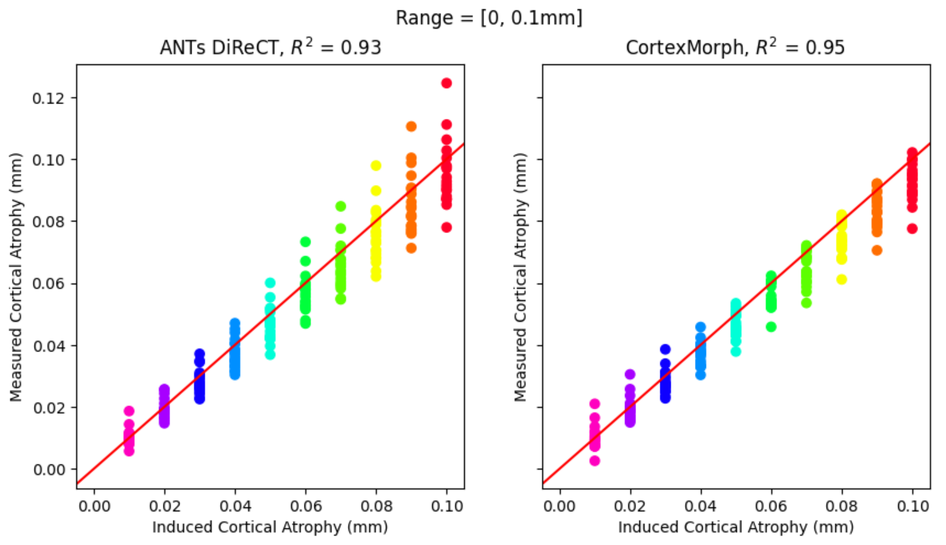
- https://github.com/SCAN-NRAD/DL-DiReCT
- https://github.com/SCAN-NRAD/CortexMorph

Comparison with DL+DiReCT on OASIS3 (ICC(2,1))

Global cortical thickness: ICC(2,1) of 0.91 (95% confidence interval [0.9, 0.92]) versus DL+DiReCT with ANTs-DiReCT. For comparison, on the same dataset the ICC between Freesurfer and DL+DiReCT with ANTs-DiReCT is 0.50 ([95% confidence interval -0.08, 0.8]).



Performance on the Rusak et al. CTh phantom



Conclusions

- Cortical thickness measurements with CortexMorph show excellent agreement (measured by ICC(2,1)) with the ANTs implementation of DiReCT globally, and good agreement locally.
- Correlation of regional cortical thickness values is excellent between CortexMorph and both Freesurfer and DL+DiReCT
- On a GPU, calculation of the deformation field (given a WM/GM segmentation) takes < 1s: total time to output regional CTh values is ~ 4s
- Like Voxelmorph, CortexMorph is *unsupervised*: the deformation field model is not trained on surfaces/deformation fields/cortical thickness measures of any existing morphometry tool.
- While CortexMorph was trained on the outputs of a fixed model, we expect it to give reasonable results from any high-performing model segmenting the grey and white matter.
- Model selection criterion for the final model was based on agreement with `KellyKapowski` on a small validation set (80 cases). Are there better mosdel selection criteria which yield better CTh measures?

References

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