Vox2Cortex: Fast Explicit Reconstruction of Cortical Surfaces from 3D MRI Scans with Geometric Deep Neural Networks

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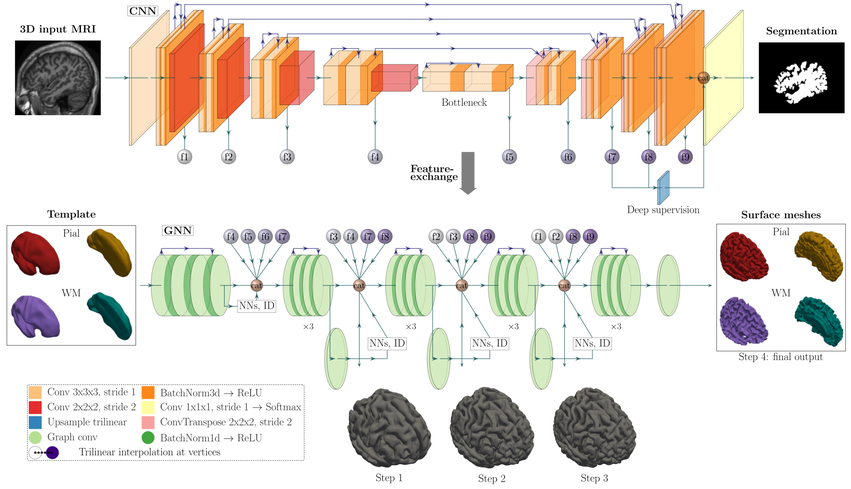
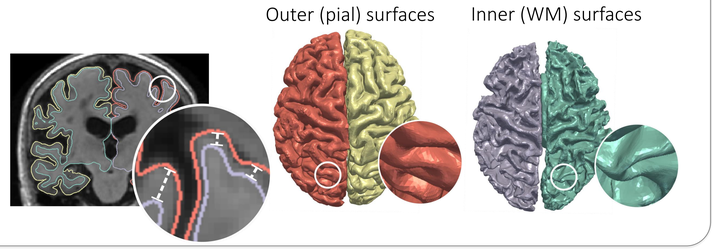
Combination of CNN and graph neural network yields meticulous brain surfaces within seconds



Contributions

- ✓ First combination of CNN + GNN for cortical surface reconstruction
- ✓ Guaranteed spherical topology
- ✓ Modeled interdependency between inner and outer brain surfaces
- ✓ Novel curvature-weighted Chamfer loss function
- ✓ State-of-the-art brain surfaces with 168,000 vertices per mesh

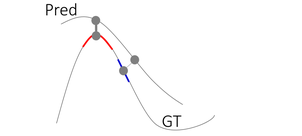


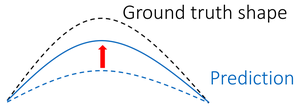
Loss function

Curvature-weighted Chamfer loss:

$$\mathcal{L}_{\mathrm{C}}(\mathcal{M}_{s,c}^{\mathrm{p}}, \mathcal{M}_{c}^{\mathrm{gt}}) = \frac{1}{|\mathcal{P}_{c}^{\mathrm{gt}}|} \sum_{\mathbf{u} \in \mathcal{P}_{c}^{\mathrm{gt}}} \kappa(\mathbf{u}) \min_{\mathbf{v} \in \mathcal{P}_{s,c}^{\mathrm{p}}} \|\mathbf{u} - \mathbf{v}\|^2 + \frac{1}{|\mathcal{P}_{s,c}^{\mathrm{p}}|} \sum_{\mathbf{v} \in \mathcal{P}_{s,c}^{\mathrm{p}}} \kappa(\tilde{\mathbf{u}}) \min_{\mathbf{u} \in \mathcal{P}_{c}^{\mathrm{gt}}} \|\mathbf{v} - \mathbf{u}\|^2$$

$\mathcal{M}_{c}^{\mathrm{gt}}$: Ground truth mesh
$\mathcal{M}_{s,c}^{\mathrm{p}}$: Predicted mesh
κ : Curvature weight from ground truth
$\mathcal{P}_{s,c}^{\mathrm{p}}$: Predicted points
$\mathcal{P}_{c}^{\mathrm{gt}}$: Ground truth points





Total loss function:

$$\mathcal{L}(y^{\mathrm{p}}, y^{\mathrm{gt}}) = \mathcal{L}_{\mathrm{vox}}(y^{\mathrm{p}}, y^{\mathrm{gt}}) + \mathcal{L}_{\mathrm{mesh}}(y^{\mathrm{p}}, y^{\mathrm{gt}})$$

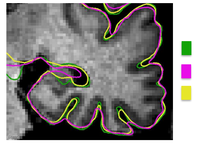
$$\mathcal{L}_{\mathrm{vox}}(y^{\mathrm{p}}, y^{\mathrm{gt}}) = \sum_{l=1}^{L} \mathcal{L}_{\mathrm{BCE}}(B_l^{\mathrm{p}}, B^{\mathrm{gt}})$$

$$\mathcal{L}_{\mathrm{mesh}}(y^{\mathrm{p}}, y^{\mathrm{gt}}) = \mathcal{L}_{\mathrm{mesh},cons}(y^{\mathrm{p}}, y^{\mathrm{gt}}) + \mathcal{L}_{\mathrm{mesh},reg}(y^{\mathrm{p}})$$

y^{p}: Predicted mesh & binary segmentation
y^{gt}: Ground-truth mesh & binary segmentation

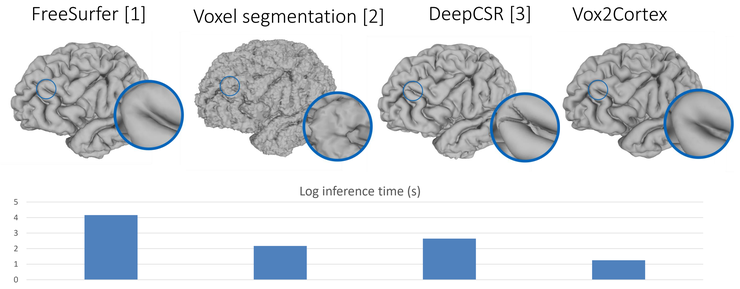
Chamfer (point) + normal loss

Surface regularity

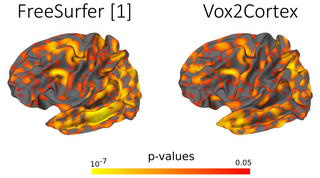


Results

Data	Method	Left WM Surface ASSD (mm)	Left WM Surface HD (mm)	Right WM Surface ASSD (mm)	Right WM Surface HD (mm)	Left Pial Surface ASSD (mm)	Left Pial Surface HD (mm)	Right Pial Surface ASSD (mm)	Right Pial Surface HD (mm)
ADNI large	Vox2Cortex	**0.345** ±0.056	**0.720** ±0.125	**0.347** ±0.046	**0.720** ±0.087	**0.327** ±0.031	**0.755** ±0.102	**0.318** ±0.029	**0.781** ±0.102
	DeepCSR [3]	0.422 ±0.058	0.852 ±0.134	0.420 ±0.058	0.880 ±0.156	0.454 ±0.059	0.927 ±0.243	0.422 ±0.053	0.890 ±0.197
	nnUNet [2]	1.176 ±0.345	1.801 ±2.835	1.159 ±0.242	1.739 ±1.880	1.310 ±0.292	3.152 ±2.374	1.317 ±0.312	3.295 ±2.387
OASIS	Vox2Cortex	**0.315** ±0.039	**0.680** ±0.137	**0.318** ±0.048	0.682 ±0.151	**0.362** ±0.036	**0.894** ±0.141	**0.373** ±0.041	**0.916** ±0.137
	DeepCSR [3]	0.360 ±0.042	0.731 ±0.104	0.335 ±0.050	**0.670** ±0.195	0.458 ±0.056	1.044 ±0.290	0.442 ±0.058	1.037 ±0.294



- ✓ Topologically correct
- ✓ No staircase artifacts
- ✓ No geometric artifacts
- ✓ Fastest



Group comparison of cortical thickness between patients with Alzheimer's disease and healthy controls

[1] B. Fischl. "FreeSurfer". In: Neuroimage 62.2 (2012), pp. 774–781
[2] F. Isensee, P. F. Jaeger, S. A. A. Kohl, J. Petersen, and K. Maier-Hein. "nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation." In: Nature methods (2020)
[3] R. S. Cruz, L. Lebrat, P. Bourgeat, C. Fookes, J. Fripp, and O. Salvado. "DeepCSR: A 3D Deep Learning Approach for Cortical Surface Reconstruction". WACV 2021