DeepCSR: A 3D Deep Learning Approach For Cortical Surface Reconstruction

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WACV21 - January 5 - 9, 2021
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Cortical Surface Reconstruction From MRI (CSR)

“The diagnosis, prognosis, and study of neurodegenerative diseases, as well as many psychological disorders, rely on the analysis of in vivo measurements on the cerebral cortex using magnetic resonance imaging (MRI).”
Existing Methods & DeepCSR

Ex: FreeSurfer/FastSurfer

Voxel-wise Segmentation

Surface Fitting

DeepCSR

Implicit Surfaces
DeepCSR - Learning

Using a dataset of image and surface pairs:

DeepCSR learns to predict implicit surfaces:

\[ f_\theta : \mathcal{I} \times \Omega \rightarrow \mathbb{R} \]

Occupancy Field

\[ r^{occ}_S(p) = \mathbf{1}_{p \in S_{int}} \]

Signed Distance

\[ r^{stdf}_S(p) = (2 r^{occ}_S(p) - 1) \| p - \text{proj}_S(p) \|_2 \]
DeepCSR - Inference
NN Architecture & Hypercolumns Features

MRI
(182 x 218 x 182)

Hypercolumn $c(l, p)$

Layers:
- $\text{Conv3D} + \text{ReLU}$
- $\text{Max3D} + \text{Conv3D} + \text{ReLU}$
- $\text{Linear Interpolation}$
- $\text{Concatenation}$
- $\text{CBN} + \text{ReLU} + \text{FC}$
- $\text{Max3D} + \text{FC} + \text{ReLU}$
- $\text{Addition}$
- $\text{FC}$

For $i = 1, ..., 5$

$p$

3
Comparison to FreeSurfer And FastSurfer

**Precision:**
- **Test-Retest dataset (TRT):** 120 T1-weighted MRI scans from 3 subjects which are scanned twice in 20 sessions spanning 31 days.
- The goal is to evaluate the reproducibility of the algorithms.

**Accuracy:**
- **Multi-Atlas Labelling Challenge (MALC) dataset:** 30 brain volumes manually segmented by experts using the NeuroMorphometric labelling schema for the whole brain.
- We compare the algorithms on the **segmentation of the brain cortex** generated by the reconstructed surfaces.

**Reconstruction Time:**
- We report the average elapsed time to reconstruct the cortical surfaces of the MRI scans in the **MALC dataset**.
## Comparison to FreeSurfer

<table>
<thead>
<tr>
<th>Method</th>
<th>Precision on TRT</th>
<th>Accuracy on MALC</th>
<th>Runtime (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AD ((mm))</td>
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<td></td>
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<tr>
<td></td>
<td>% &gt; 1(mm)</td>
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<td>% &gt; 2(mm)</td>
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<tr>
<td>FreeSurfer</td>
<td>0.241 (±0.291)</td>
<td>0.841 (±0.020)</td>
<td>373.86 (±47.64)</td>
</tr>
<tr>
<td></td>
<td>2.472</td>
<td>0.953 (±0.027)</td>
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<tr>
<td></td>
<td>0.983</td>
<td></td>
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<tr>
<td>FastSurfer</td>
<td>0.204 (±0.028)</td>
<td>0.834 (±0.021)</td>
<td>28.943 (±13.281)</td>
</tr>
<tr>
<td></td>
<td>1.492</td>
<td>0.942 (±0.029)</td>
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<tr>
<td></td>
<td>0.374</td>
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<tr>
<td>DeepCSR</td>
<td>0.193 (±0.051)</td>
<td>0.846 (±0.019)</td>
<td>27.824 (±1.393)</td>
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<tr>
<td></td>
<td>1.266</td>
<td>0.958 (±0.024)</td>
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<td>0.263</td>
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- **DeepCSR has better reproducibility** which is critical for medical studies of neurodegenerative diseases.
- **DeepCSR provides brain cortex segmentation with greater overlap and more similar volume** to the manually annotated data.
- **DeepCSR is at least thirteen times faster** than FreeSurfer. It also presents less runtime variation across subjects than FastSurfer.
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