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

Rodrigo Santa Cruz, Leo Lebrat, Pierrick Bourgeat, Clinton Fookes, Jurgen Fripp, and Olivier Salvado

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rodrigo.santacruz@csiro.au
www.rfsantacruz.com

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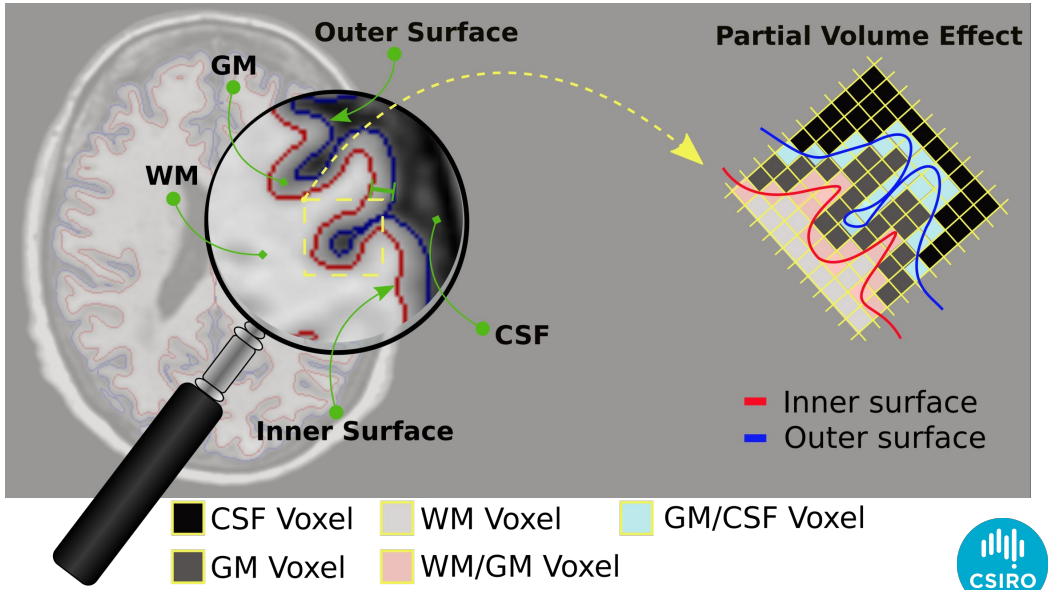
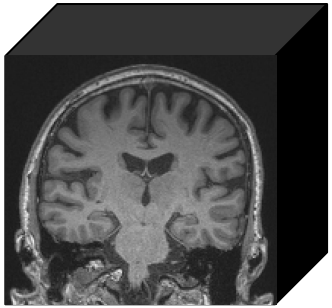
Cortical **S**urface **R**econstruction From MRI (CSR)

"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)."

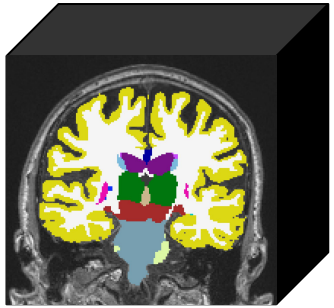


Existing Methods & DeepCSR

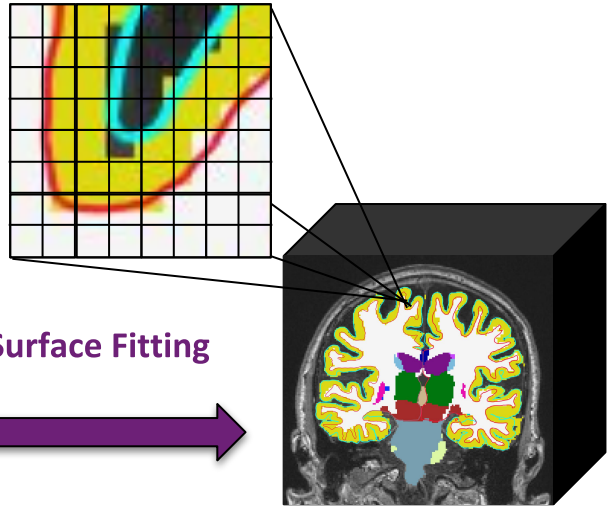
Ex: FreeSurfer/FastSurfer

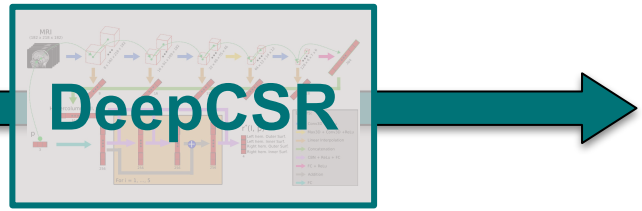


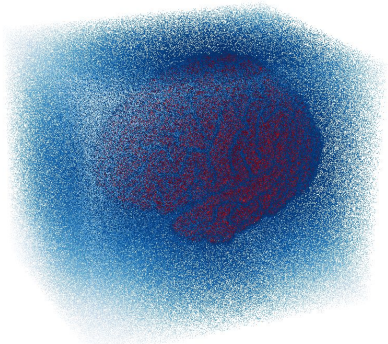
Voxel-wise Segmentation



Surface Fitting



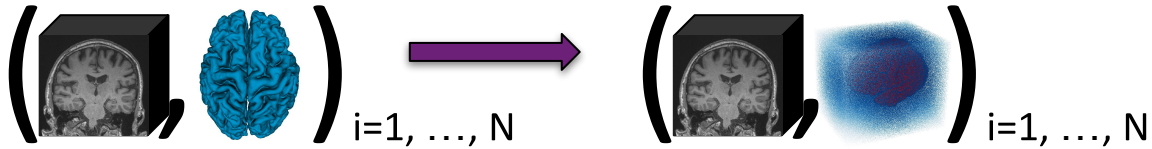




Implicit Surfaces

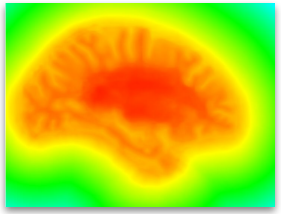
DeepCSR - Learning

Using a dataset of image and surface pairs:



Occupancy Field

$$r_S^{occ}(p) = \mathbf{1}_{p \in S_{int}}$$

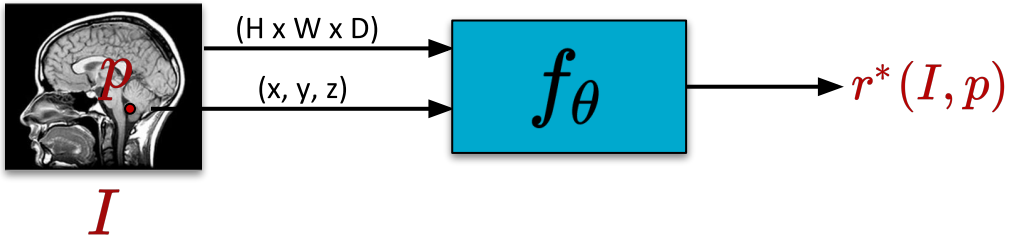


Signed Distance

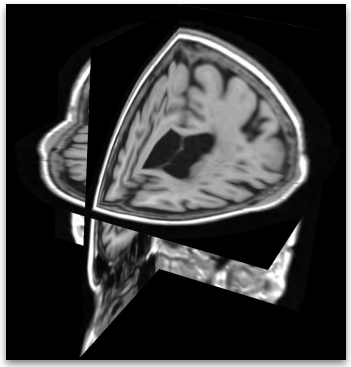
$$r_S^{sdf}(p) = (2\, r_S^{occ}(p) - 1)\left\| p - \text{proj}_S(p) \right\|_2$$

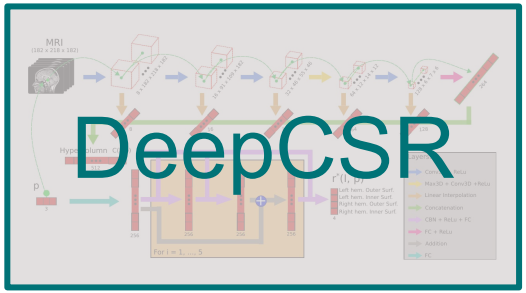
DeepCSR learns to predict implicit surfaces:

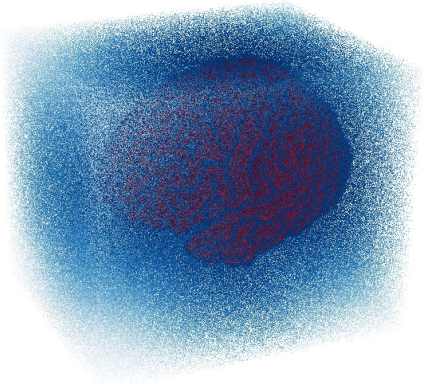
$$f_\theta : \mathcal{I} \times \Omega \mapsto \mathbb{R}$$

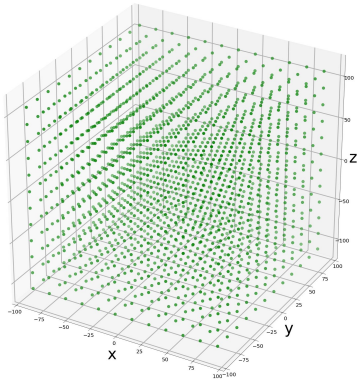


DeepCSR - Inference

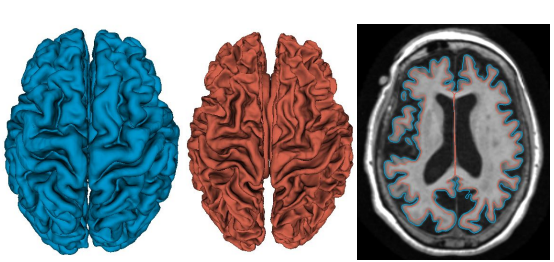




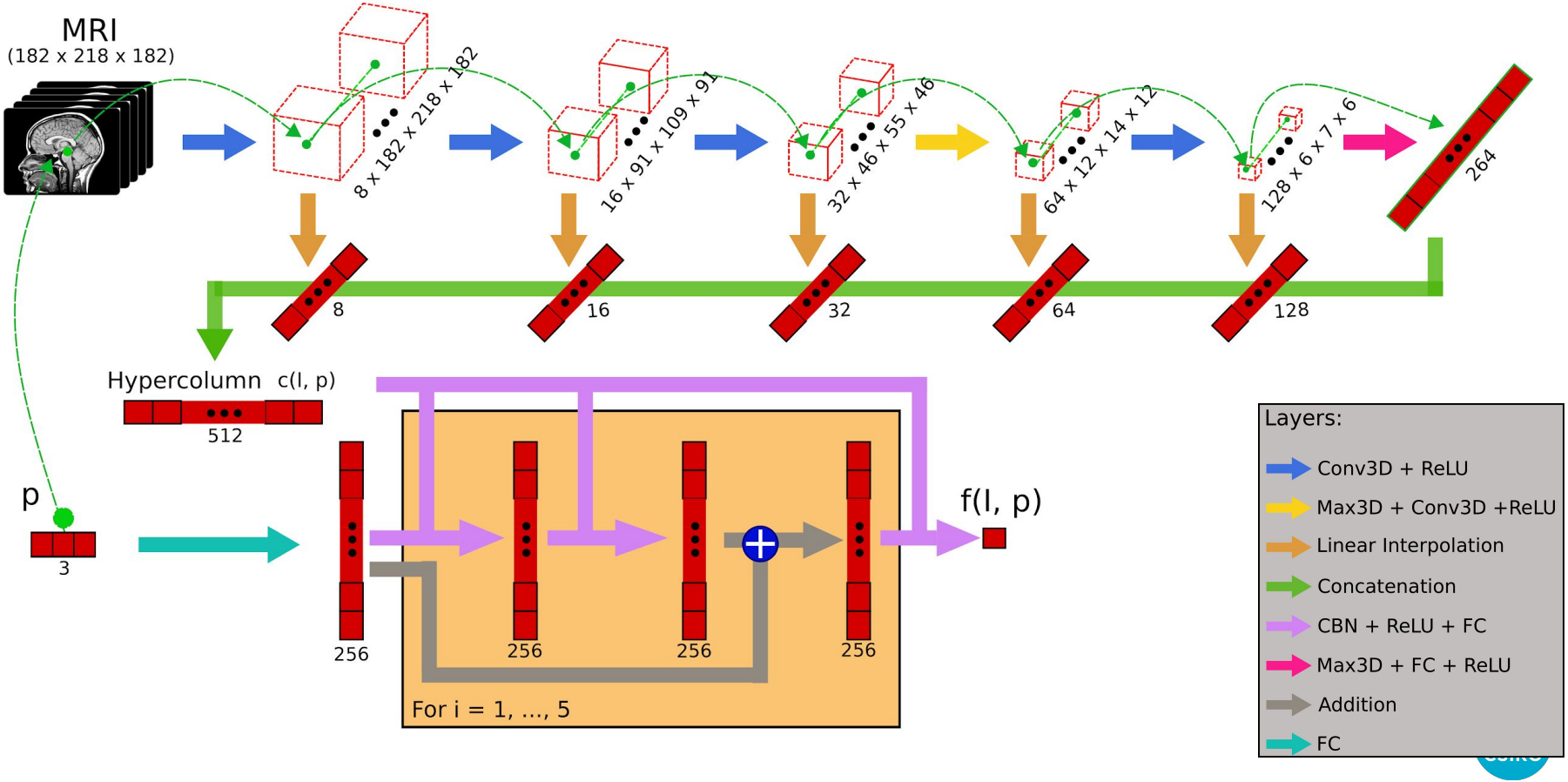




x_0	y_0	z_0
x_1	y_1	z_1
⋮	⋮	⋮
x_n	y_n	z_n



NN Architecture & Hypercolumns Features



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.

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Comparison to FreeSurfer

Method	*Precision on TRT*			*Accuracy on MALC*		*Runtime*
	AD (mm)	$\% > 1\,mm$	$\% > 2mm$	Dice	VS	$(minutes)$
FreeSurfer	0.241 (± 0.291)	2.472	0.983	0.841 (± 0.020)	0.953 (± 0.027)	373.86 (± 47.64)
FastSurfer	0.204 (± 0.028)	1.492	0.374	0.834 (± 0.021)	0.942 (± 0.029)	28.943 (± 13.281)
DeepCSR	0.193 (± 0.051)	1.266	0.263	0.846 (± 0.019)	0.958 (± 0.024)	27.824 (± 1.393)

- **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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