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Hierarchical Uncertainty Estimation for Learning-based Registration in Neuroimaging

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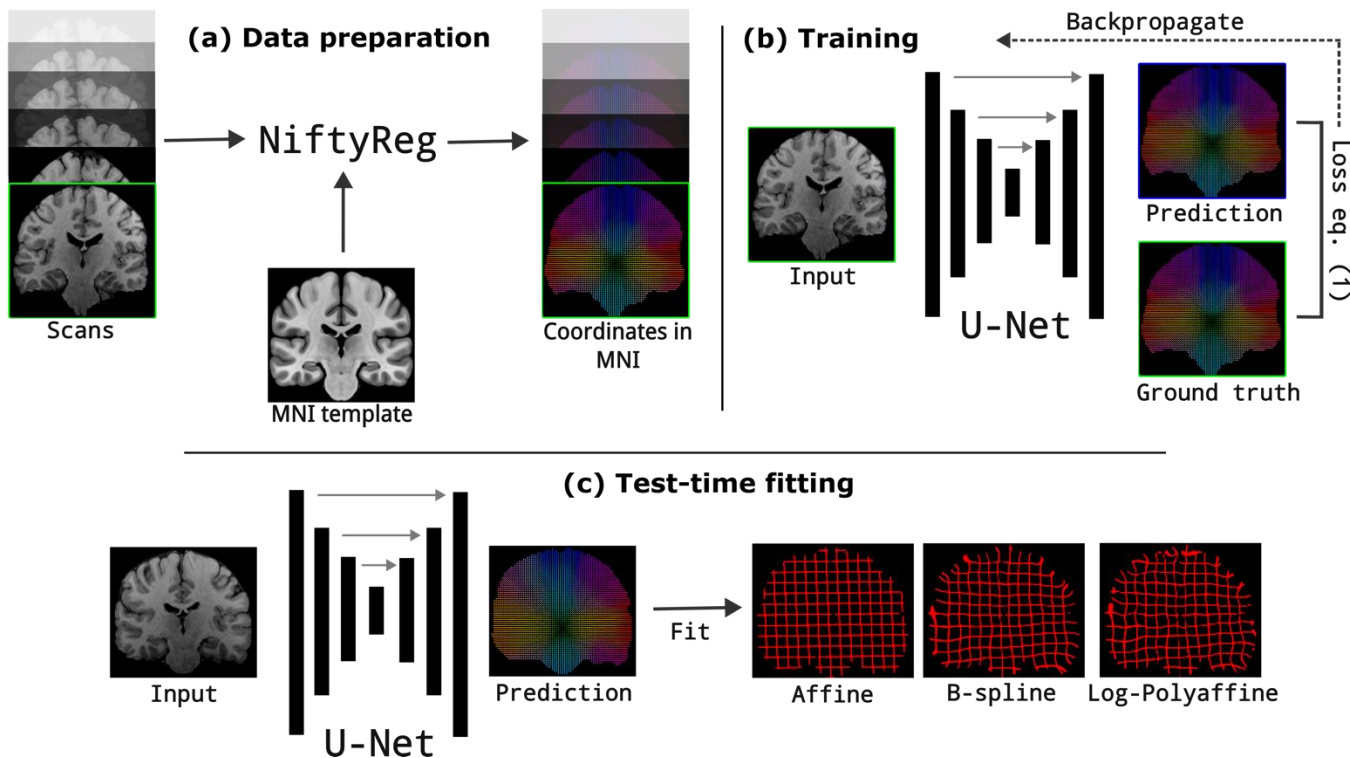
MGH/Harvard Medical School

<https://huxiaoling.github.io/>

Reg4Regis: Introduction

- **CNN to regress the coordinates**
 - Combination of regression loss of coordinates (l1 loss) and mask loss (dice loss)
- **CNN + registration network**
 - Efficiency and flexibility (fit whatever functions we want to use)
 - Every voxel is a key point

Reg4Regis: Introduction

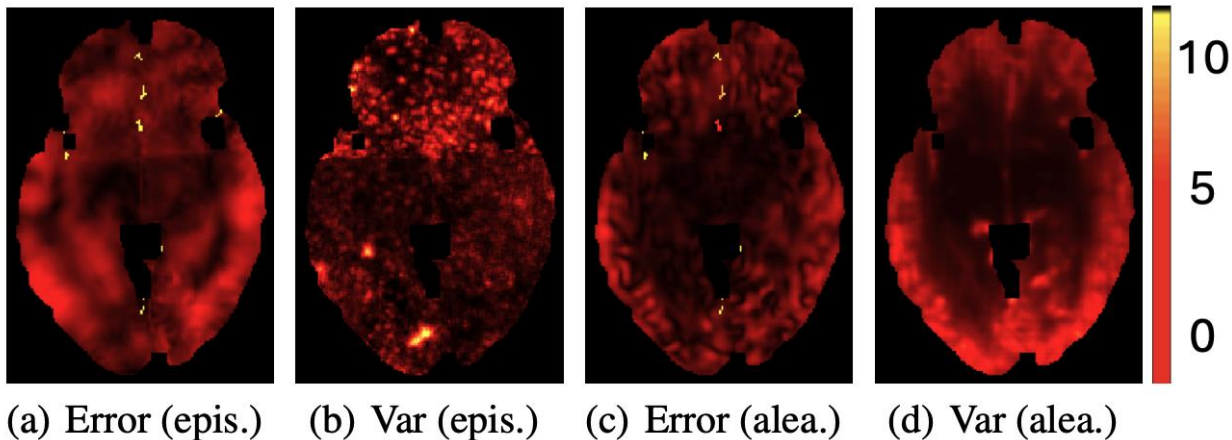


Registration Uncertainty

- **First level of uncertainty: target regression**

- Regress both mean + standard deviation instead of only mean

$$\mu = [\mu_1, \mu_2, \mu_3] \quad \sigma = [\sigma_1, \sigma_2, \sigma_3]$$



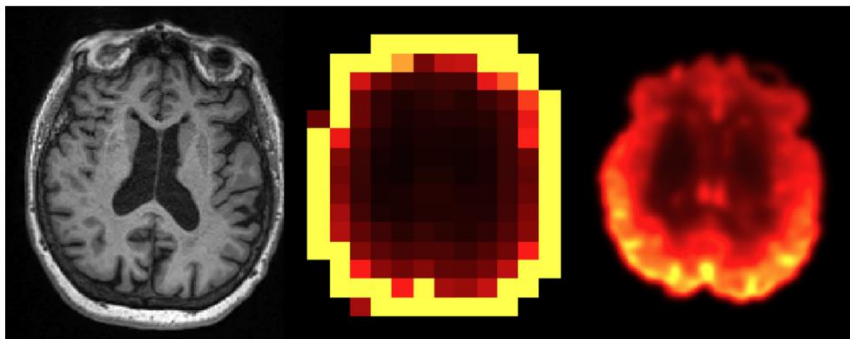
Registration Uncertainty

- **Second level of uncertainty: weighted fitting**

- Uncertainty-Aware Parametric Transformations

$$E_j = [\boldsymbol{\mu}_j - \boldsymbol{\phi}\mathbf{c}_j]^T \mathbf{W}_j [\boldsymbol{\mu}_j - \boldsymbol{\phi}\mathbf{c}_j]$$

- Uncertainty-Aware Non-Parametric Transformations



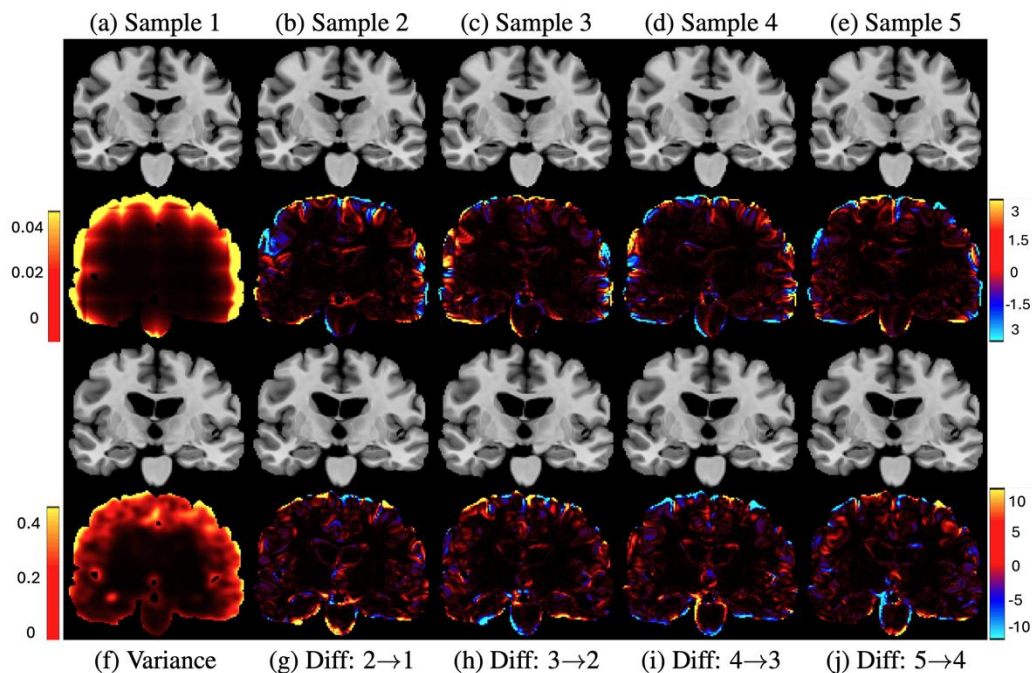
(a) Input

(b) B-spline

(c) Demons

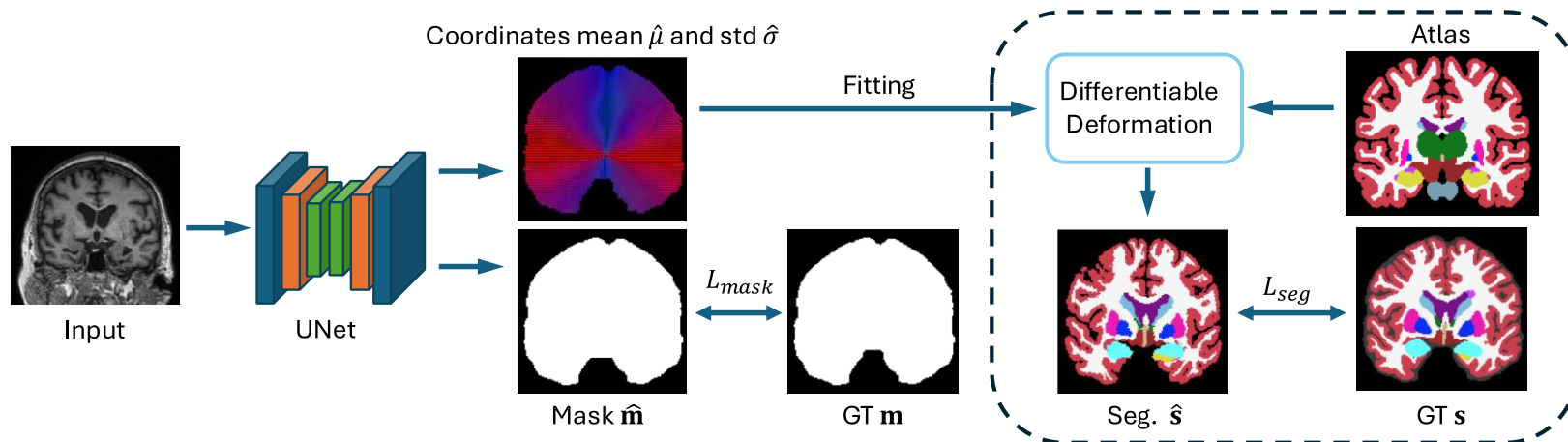
Registration Uncertainty

- Third level of uncertainty: downstream tasks



Registration Uncertainty

- Framework



$$L_{total} = L_{coord} + \lambda_{mask}L_{mask} + \lambda_{seg}L_{seg} + \lambda_{uncer}L_{uncer}.$$

Results

- Registration performance

Table 1: Registration performance for transformations with and without uncertainties.

Fitting Strategy	ABIDE	OASIS3
Affine	0.718 ± 0.038	0.673 ± 0.056
Affine with uncertainty	0.730 ± 0.033	0.682 ± 0.055
B-Spline 10 mm	0.782 ± 0.020	0.750 ± 0.034
B-Spline 10 mm with uncertainty	0.790 ± 0.019	0.772 ± 0.030
Demons 3	0.799 ± 0.020	0.783 ± 0.029
Demons 3 with uncertainty	0.799 ± 0.019	0.783 ± 0.028

Ablation studies

- Segmentation loss

Table 2: Comparison between RbR and proposed approach with segmentation loss (average Dice).

Method	ABIDE		OASIS3	
	RbR (Gopinath et al., 2024)	Proposed	RbR (Gopinath et al., 2024)	Proposed
Affine	0.712 ± 0.045	0.715 ± 0.040	0.667 ± 0.057	0.669 ± 0.058
Demons 1	0.734 ± 0.038	0.764 ± 0.025	0.730 ± 0.026	0.758 ± 0.025
Demons 3	0.739 ± 0.038	0.767 ± 0.024	0.728 ± 0.028	0.759 ± 0.030
Demons 5	0.743 ± 0.039	0.761 ± 0.026	0.722 ± 0.031	0.755 ± 0.026
B-Spline 2.5	0.733 ± 0.038	0.766 ± 0.024	0.728 ± 0.026	0.760 ± 0.032
B-Spline 5	0.735 ± 0.038	0.764 ± 0.027	0.725 ± 0.027	0.757 ± 0.034
B-Spline 10	0.738 ± 0.039	0.758 ± 0.023	0.713 ± 0.032	0.738 ± 0.029

Thank you for your attention!

Q&A

