Instituto Universitario de Investigación
de Ingeniería de Aragón
Universidad Zaragoza

XIV Jornada de Jóvenes Investigadores/as del I3A

Descriptor-based Structural Similarity and Neural ODEs for Multimodal Diffeomorphic Registration

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MOTIVATION

Diffeomorphic registration is a task in medical image analysis whose goal is finding a dense non-rigid transformation that spatially aligns two given images, referred to as moving and fixed. Registration is parametrized by a quasi-time varying flow encoded by a **Neural ODE** [1]

$$\frac{\partial \Phi}{\partial t}(t,x) = v_\theta(\Phi(t,x)), \quad \text{such that} \quad \Phi(0,\cdot) = \mathrm{Id}_\Omega.$$

We address diffeomorphic registration on **a multimodal setting**. This setting is challenged by: (1) Poor generalization of gradient descent or second-order methods; (2) Intrinsic miscorrespondence in local features; (3) Matching sparseness due to gradient miscorrespondence. We compute dense descriptors by **spatial self-similarity** [3] in **gradient and texture**, and **robust to noise**.

METHOD

Neural ODE [1] encodes the flow field and is trained on **Euler solver on instance-specific optimization**

$$\mathcal{L}_{\mathrm{NODEO}} = \mathcal{S}(I_0 \circ \varphi^*, I_1) + \lambda_J \mathcal{L}_J + \lambda_{\mathrm{grad}} \mathcal{L}_{\mathrm{grad}} + \lambda_{\mathrm{mag}} \mathcal{L}_{\mathrm{mag}}$$

This parametrization exploits the benefits of numerical optimization methods with **fast function evaluations** of deep learning networks on GPUs.

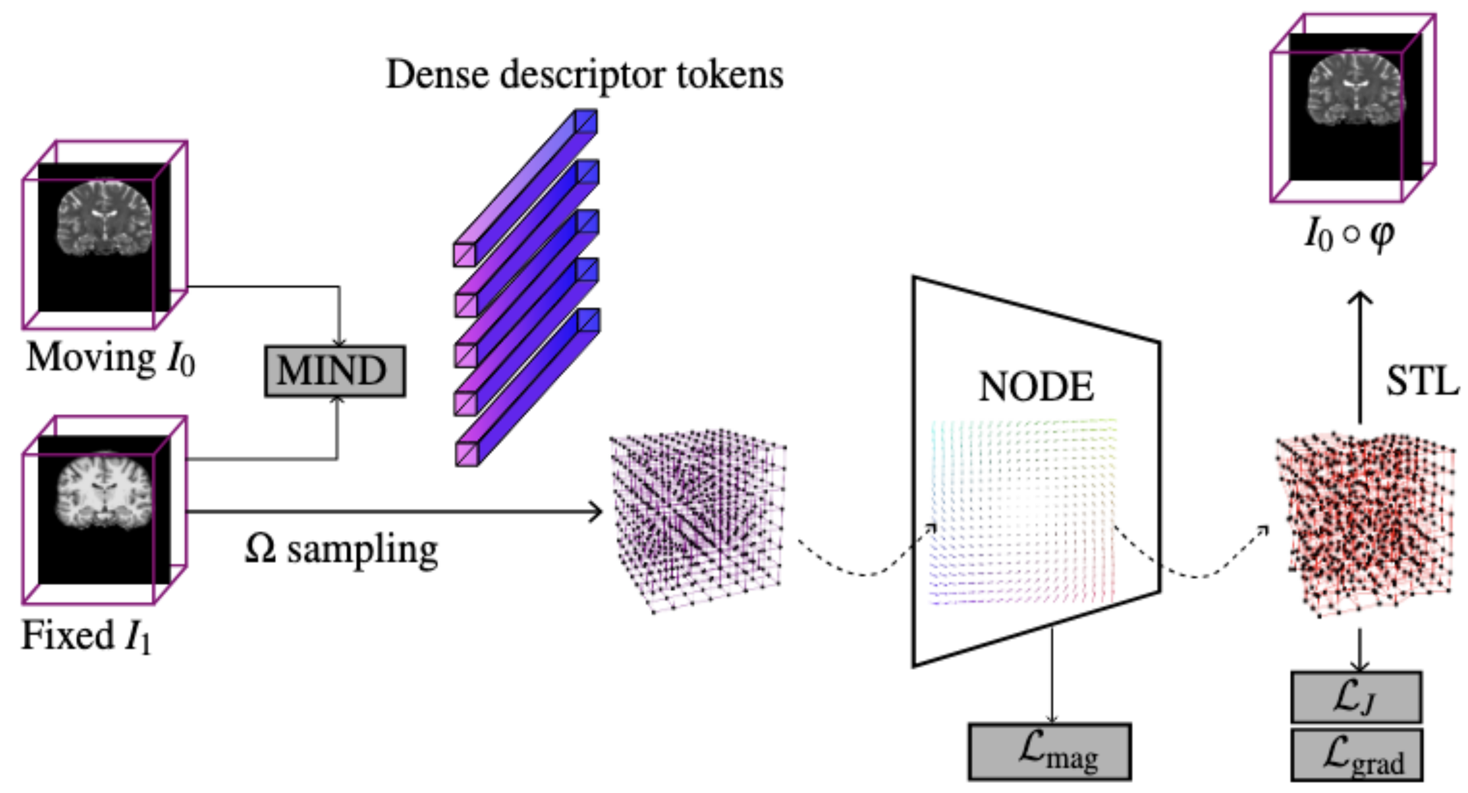

Figure 1. Multimodal registration by Neural ODEs. The pairwise method uses a differentiable sampler (Spatial Transformer, STL) to interpolate on the image domain.

RESULTS

We optimize the registration result by computing distances on the sum of square differences on descriptor tokens [3].

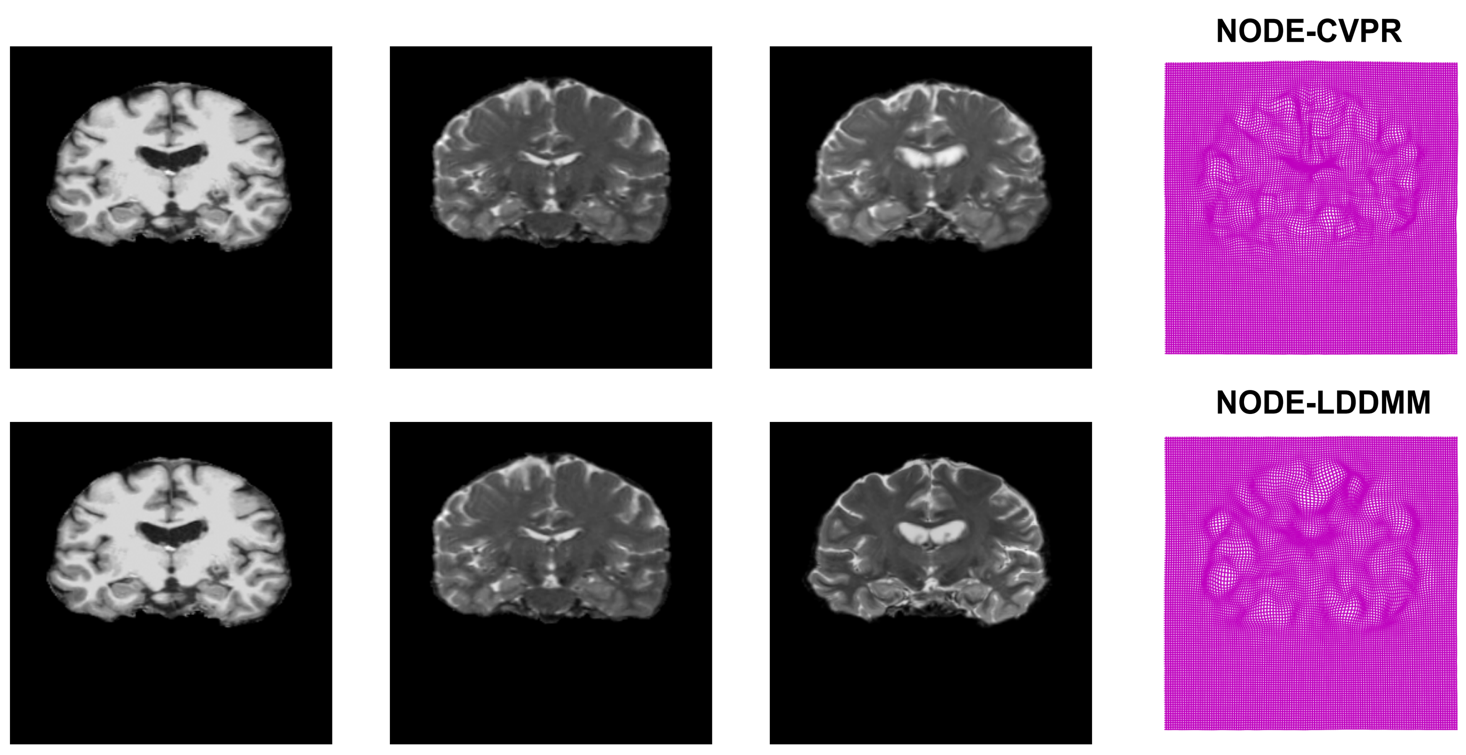

Figure 2. Qualitative registration results. Comparison on the same scan.

T1-T2 OASIS-3 Test Set			
Baseline	DSC (%) ↑	Sum $\lvert J_\varphi \rvert \leq 0 \downarrow$	% of $\lvert J_\varphi \rvert \leq 0 \downarrow$
ANTs-SyN	68.75 ± 2.55	0	0
NiftyReg [44]	70.93 ± 1.50	0	0
NODE + Similarity $\mathcal{S}(\cdot,\cdot)$	DSC (%) ↑	Sum $\lvert J_\varphi \rvert \leq 0 \downarrow$	% of $\lvert J_\varphi \rvert \leq 0 \downarrow$
NODE + MIND [21]	**75.64 ± 1.70**	0	0
NODE-LDDMM + MIND [23]	**75.10 ± 2.11**	0	0
NODE + Local MI [46]	70.49 ± 3.80	0	0
NODE + Global MI [46]	44.90 ± 14.40	$2.94 \cdot 10^{-3}$	$1.01 \cdot 10^{-6}$
NODE + NGF [19]	72.40 ± 4.12	0	0

Figure 3. Quantitative evaluation results. Comparison on the same scan with the NODE and PDE-constrained framework.

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AGENCIA ESTATAL DE INVESTIGACIÓN

ACKNOWLEDGEMENTS

This work has been supported with the funding from Ministerio de Ciencia, Innovación y Universidades Trust-BEyE **PID2022-138703OB-I00**, Gobierno de Aragón by **PROY-B50-24** from Orden ECU/1871/2023 and the Carlos III Health Institute **RD24/0007/022**. Salvador Rodriguez Sanz is supported by Gobierno de Aragón predoctoral grant (2024-2028) and is member of COS2MOS T64_23R.

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