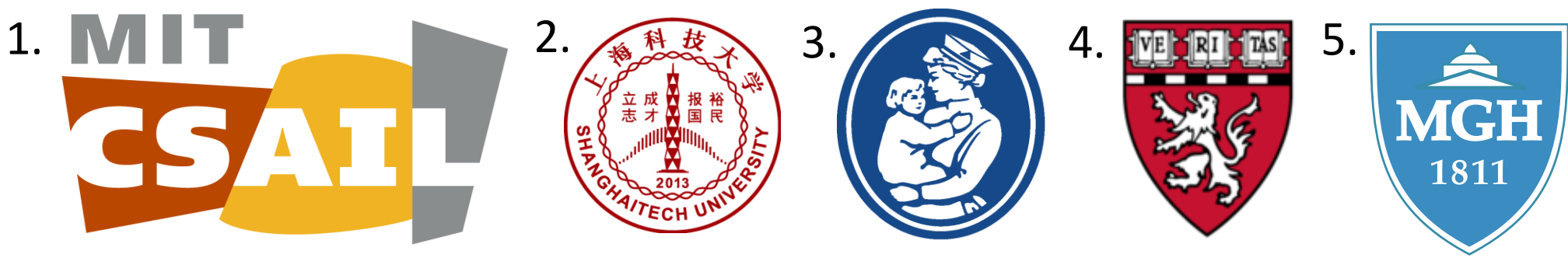


# Dynamic Neural Fields for Learning Atlases of 4D Fetal MRI Time-series



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## Spatiotemporal Fetal MRI Analysis Setup

### Fetal BOLD MRI time-series

Track nutrient transfer from mother to fetus

### Strong fetal motion

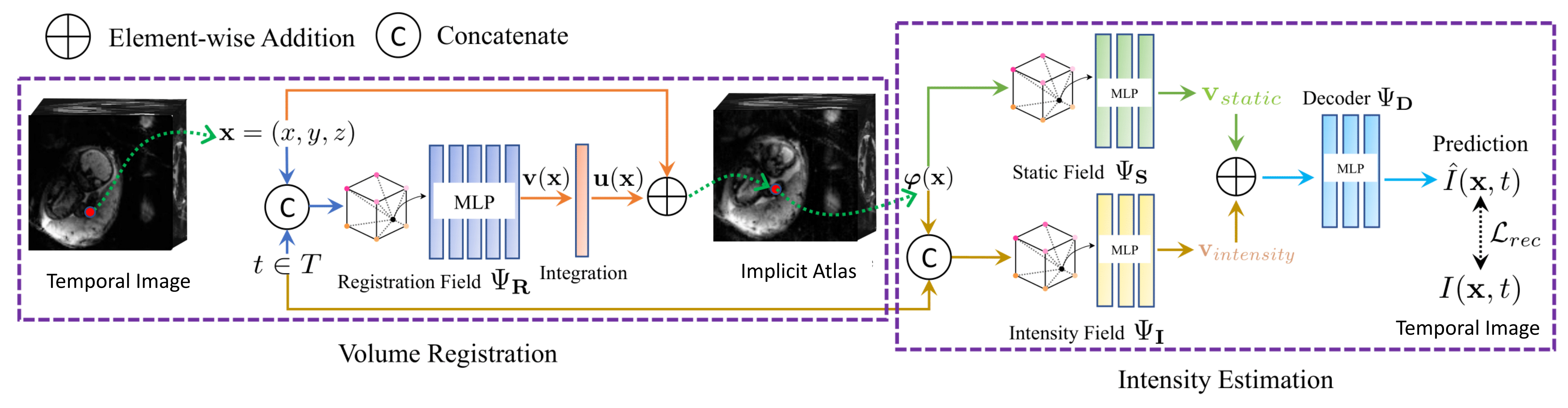
Deformable registration required

### Group-wise registration does not scale

- Need standardized coordinates
- Hrs—days per subject
- 100s of subjects
- Infeasible computation
- Incorrect deformation model assumption

Image: S. Joshi, 2002

## Dynamic neural fields with hash encoding for fast spatiotemporal atlasing



**Method**

- Jointly learn *subject-specific* registration network and atlas
- Estimate warps and atlas intensities using HashMLPs
- Estimate locally rigid and diffeomorphic warps
- Trained with regularized registration loss

**Losses**

$$|I(\mathbf{x}, t) - \hat{I}(\mathbf{x}, t)| + \lambda_1 \|\mathbf{u}(\mathbf{x})\|_2 + \lambda_2 \|\bar{\mathbf{u}}(\mathbf{x})\|_2^2 + \lambda_3 \|\text{div}(\mathbf{u}(\mathbf{x}))\|^2 + \lambda_4 \text{TV}(\mathbf{v}_{\text{intensity/static}})$$

registration      small & central displacements      locally rigid warps      sharp appearance

## Experiments

**Data**

- 112 x 112 x 80 (3 mm<sup>3</sup>)
- 2 subj. for development
- 9 for held-out testing
- 78—146 time points/subj.

**Baselines**

- ANTs SyGN (Avants, '10) *Iterative Optimization*
- AtlasMorph (Dalca, '19) *Unsupervised DL*

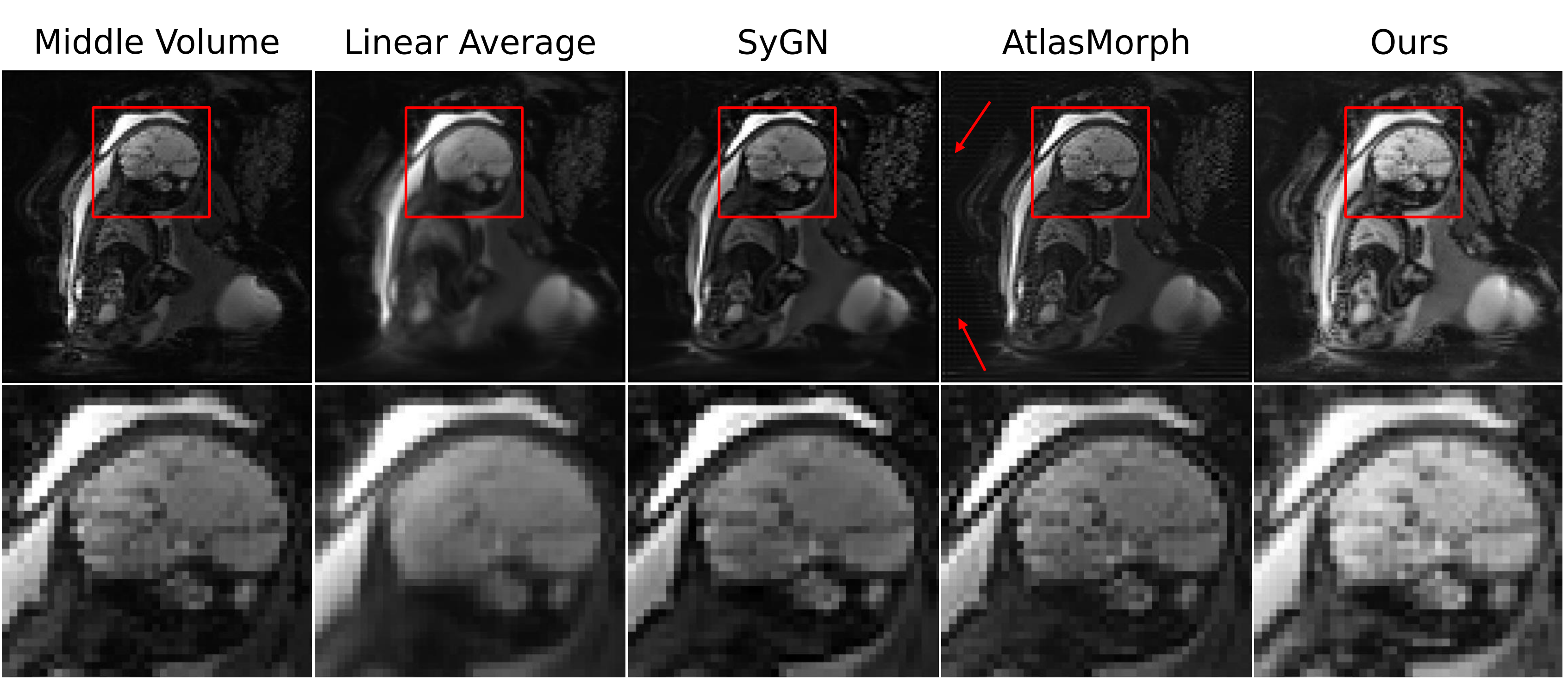
**Results**

- 5.5-7.4X faster convergence
- Comparable atlas and registration quality
- Enables processing hundreds of subjects

**Limitations**

- Lower accuracy when baselines trained fully.
- Sparse temporal sampling unaccounted currently.

	Registration accuracy		Deformation Characteristics			Speed
	LNCC (↑)	Wt. Dice (↑)	$\ \mathbf{u}(\mathbf{x})\ _2$ (↓)	$ J_\varphi $	% folds (↓)	Runtime (↓)
Unaligned	0.392(0.073)	0.80(0.05)	-	-	-	-
SyGN [7]	0.528(0.075)	<b>0.91</b> (0.02)	0.0227(0.0035)	1.000(0.000)	<b>0</b>	12hrs / 96-core CPU
AtlasMorph [10]	0.531(0.079)	0.90(0.02)	<b>0.0083</b> (0.0014)	1.004(0.003)	<b>0</b>	16hrs / A6000 GPU
Ours	<b>0.579</b> (0.081)	0.88(0.02)	0.0183(0.0067)	1.004(0.013)	0.01(0.01)	<b>2.2hrs</b> / A6000 GPU
(- SVF)	0.503(0.081)	0.85(0.04)	0.0096(0.0021)	1.006(0.010)	0.04(0.02)	1.1hrs / A6000 GPU
(- Divergence)	0.579(0.078)	0.87(0.02)	0.0200(0.0063)	1.013(0.012)	0.06(0.04)	1.5hrs / A6000 GPU
(- Intensity field)	0.578(0.083)	0.88(0.02)	0.0209(0.0086)	1.000(0.018)	0.01(0.01)	2.2hrs / A6000 GPU



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