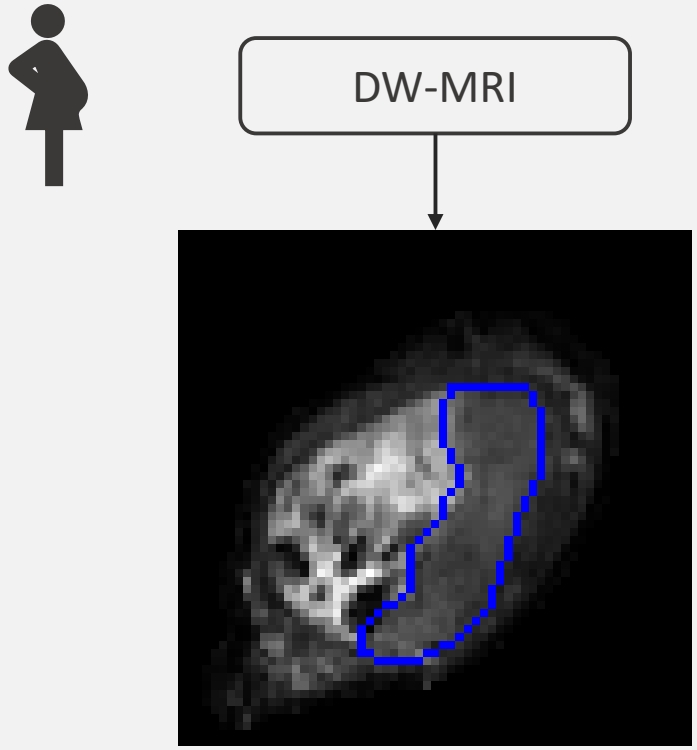
Plug-and-Play Priors for Reconstruction-based Placental Image Registration (PnP-RR)

Jiarui Xing, Ulugbek Kamilov,
Wenjie Wu, Yong Wang,
and Miaomiao Zhang

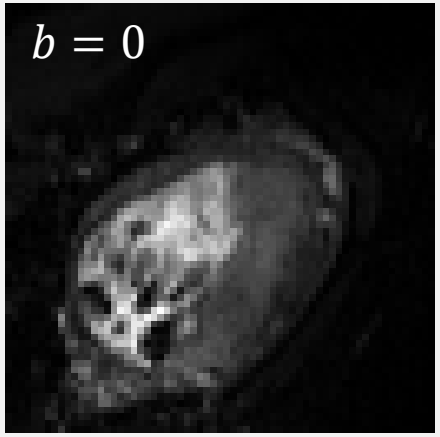


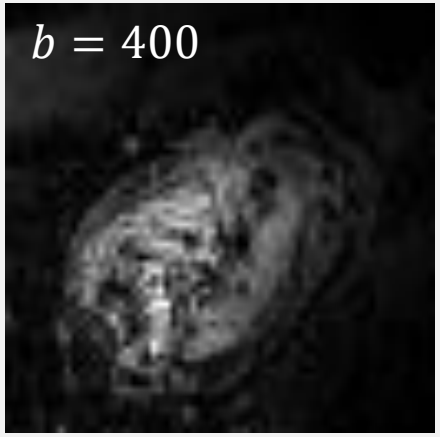


Monitoring Pregnancy Health through Diffusion-weighted MRI (DW-MRI)



Motion Correction for DW-MRI





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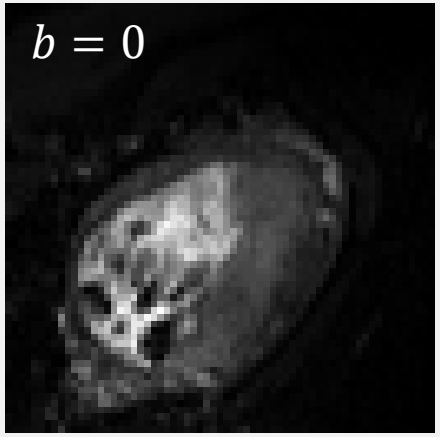

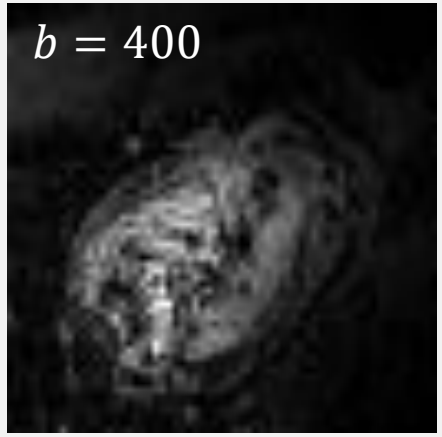

Motion Correction

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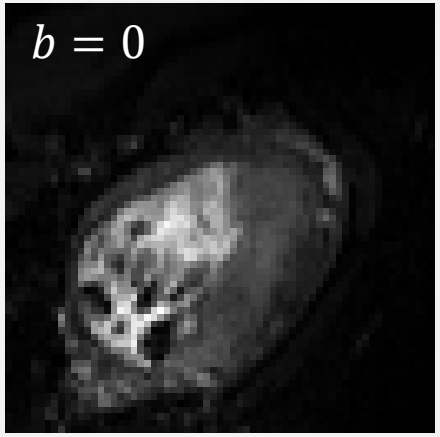

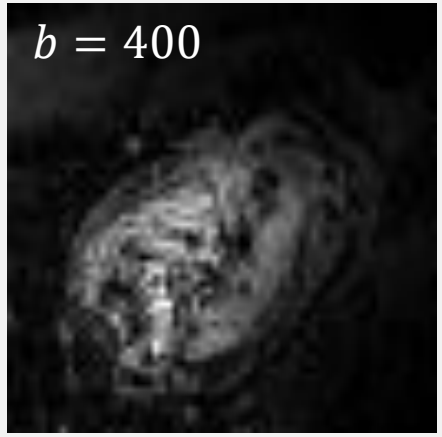

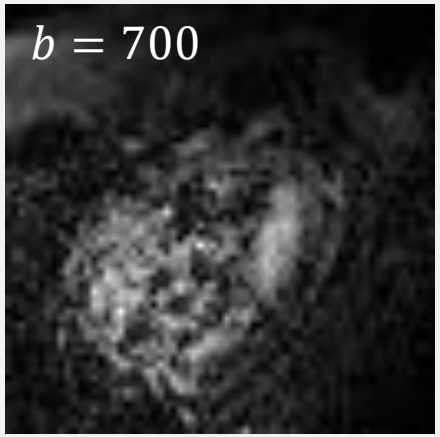

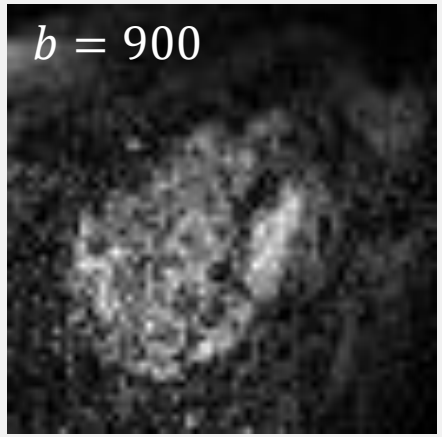

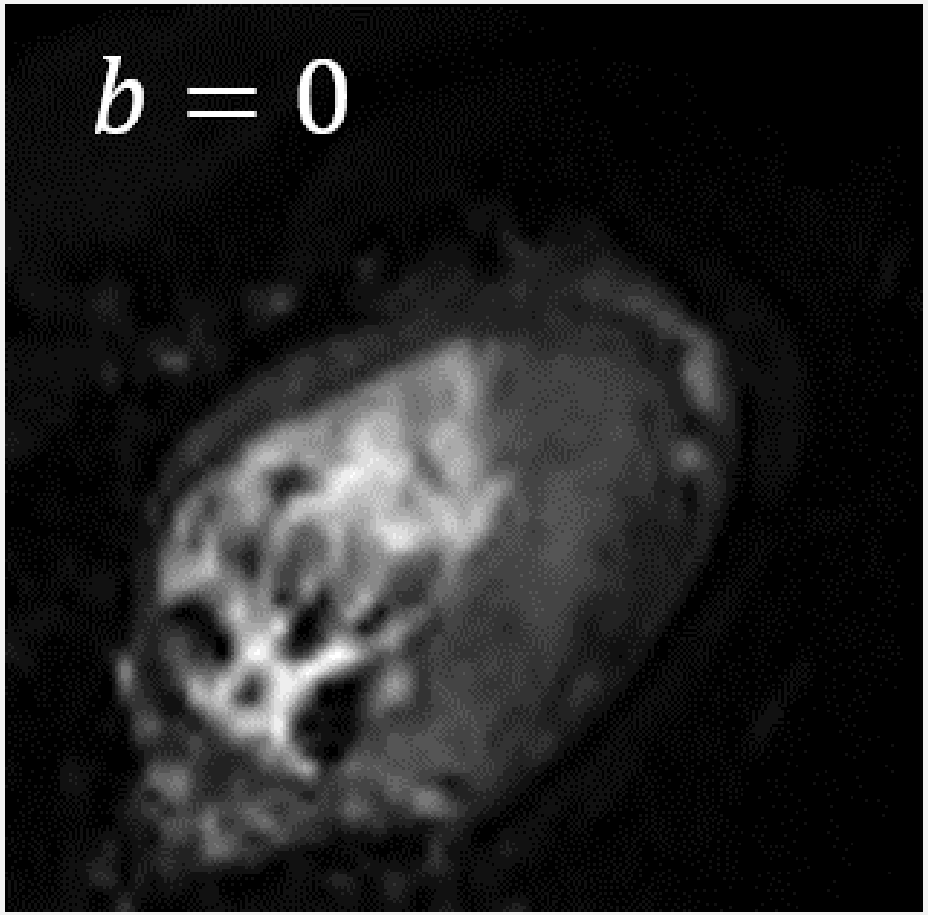

Higher b-value -> stronger noise

Goal

- Motion Correction for placental DW-MR images containing severe noise

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- Motion Correction for placental DW-MR images containing severe noise
- Develop a noise-robust registration framework

Challenges

- Traditional registration methods fail due to severe noises

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- Traditional registration methods fail due to severe noises
- Explicit objective function for optimization is unclear

Outline

- Background: Image registration
- Related Work
- Proposed Method: Plug-and-play Reconstruction-registration (PnP-RR)
- Experiments and results
- Conclusion

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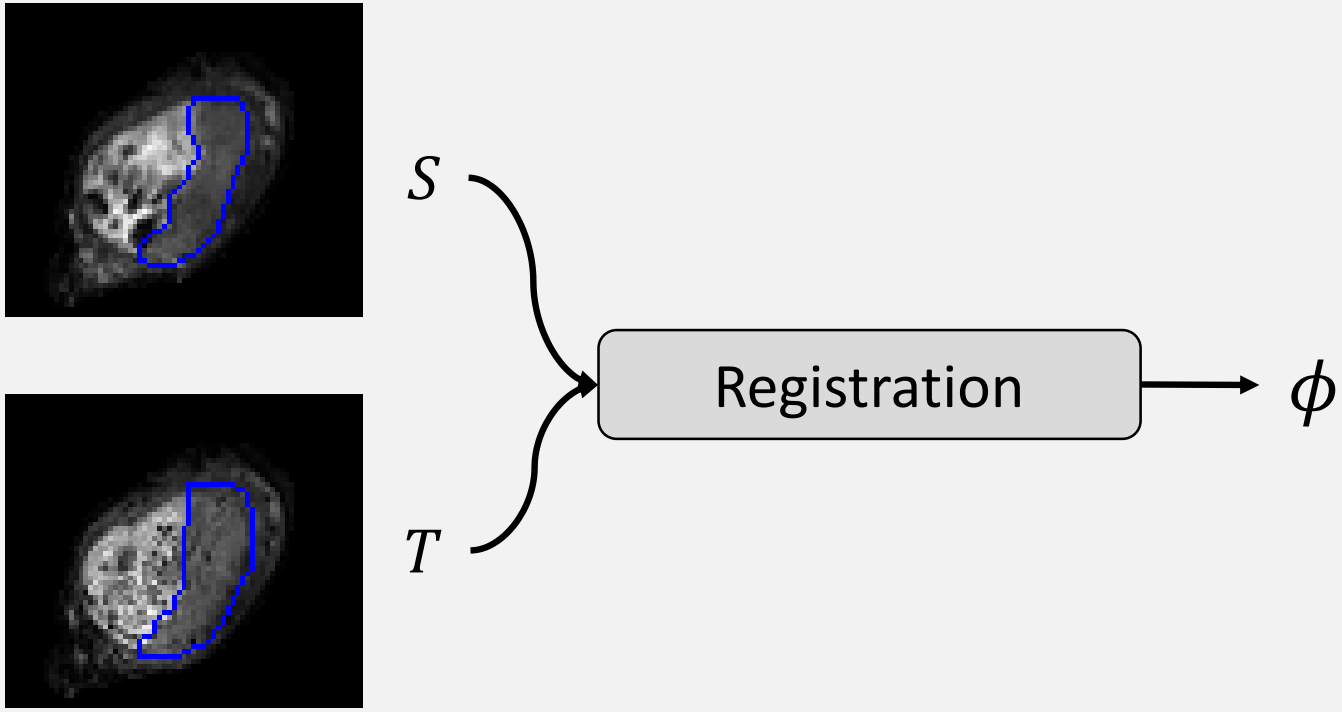
Background: Image registration

- Task: find the deformation ϕ between a source Image S and a target image T



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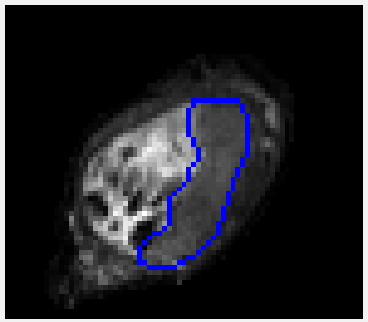

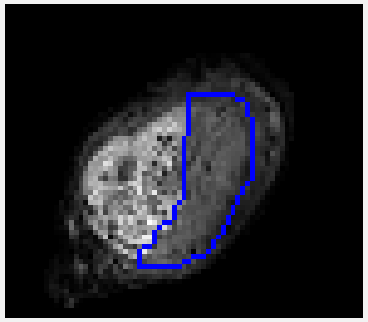

S

T

Registration

ϕ

$$\underset{\phi}{\operatorname{argmin}} \frac{1}{\sigma^2} \operatorname{dist}\left(S \circ \phi^{-1}, T\right) + \mathcal{R}(\phi)$$

Noise variance

Image dissimilarity

Regularization for smooth transformation

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- Discussion and conclusion

Related Work

- Traditional Image Registration

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- Traditional Image Registration

Low b-value; clean

High b-value; noisy

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- Traditional Image Registration

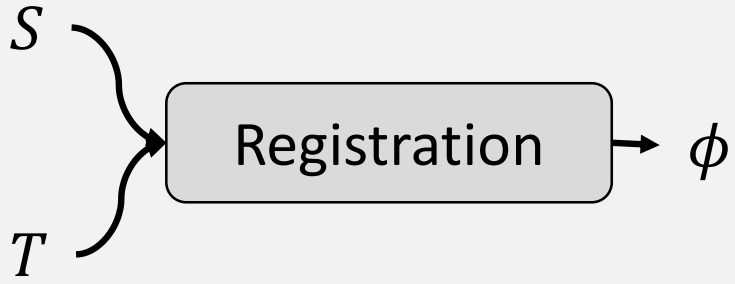
Low b-value; clean

High b-value; noisy

$\rightarrow$ FAIL for SEVERE NOISE-CORRUPTED images

Related Work

- Traditional Image Registration

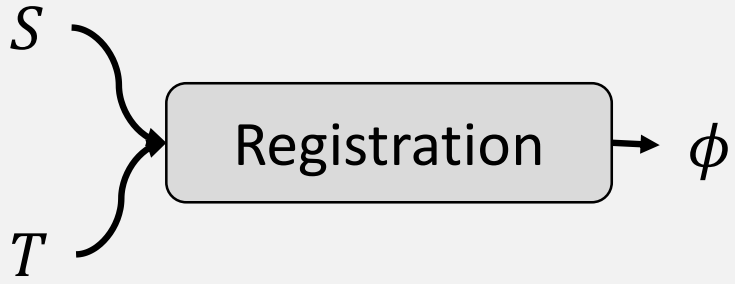


→ FAIL for
SEVERE NOISE-CORRUPTED images

- Idea: Denoising + Registration

Related Work

- Traditional Image Registration



→ FAIL for
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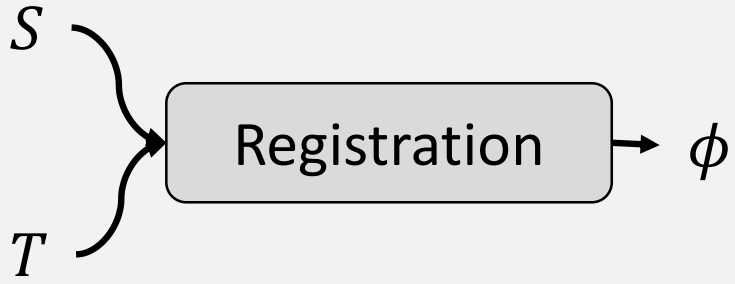
- Idea: Denoising + Registration
- Question: “+”?

Related Work

- Traditional Image Registration



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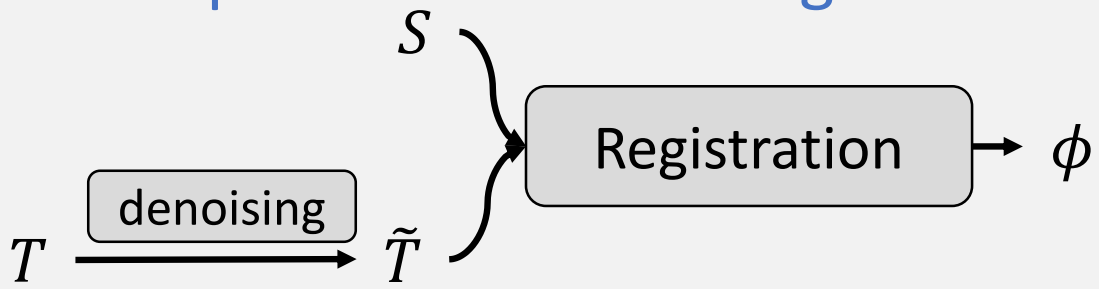
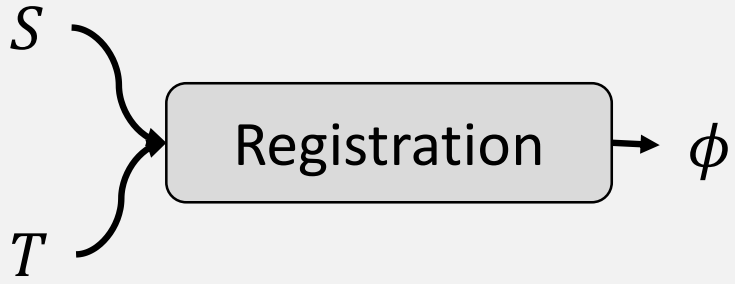
- Two-step Method: denoising before registration



Related Work

- Traditional Image Registration



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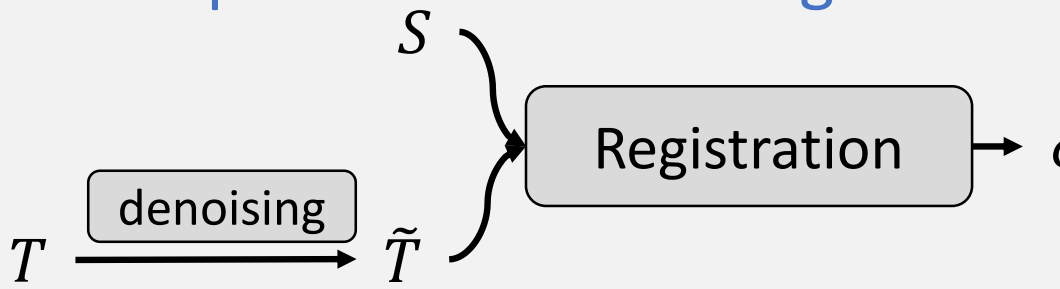
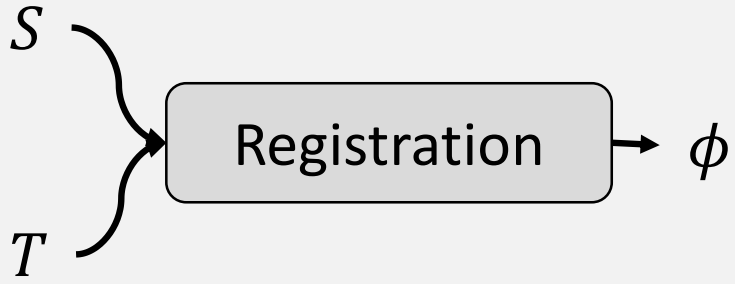


→ May NOT converge to OPTIMAL solution

Related Work

- Traditional Image Registration



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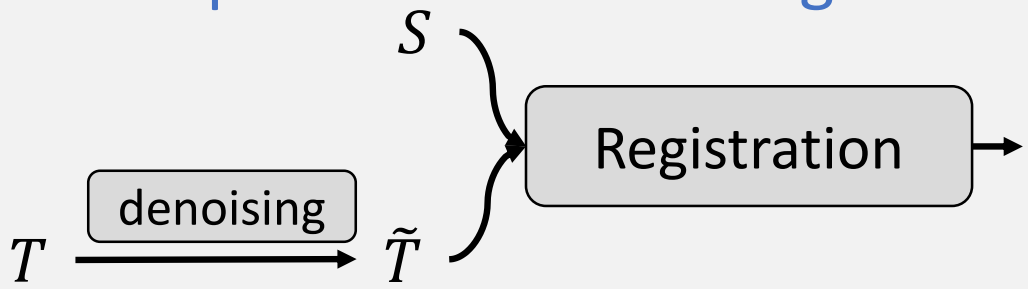
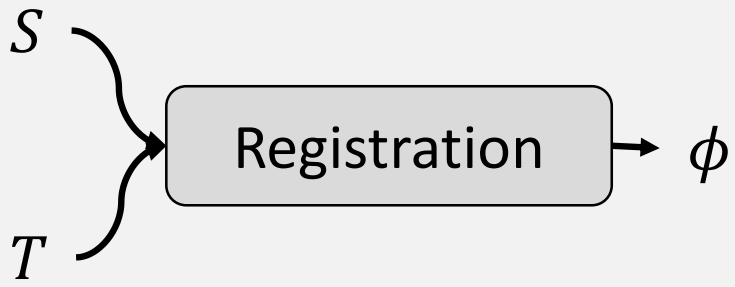


→ May NOT converge to OPTIMAL solution

- Joint Optimization Method

Related Work

- Traditional Image Registration



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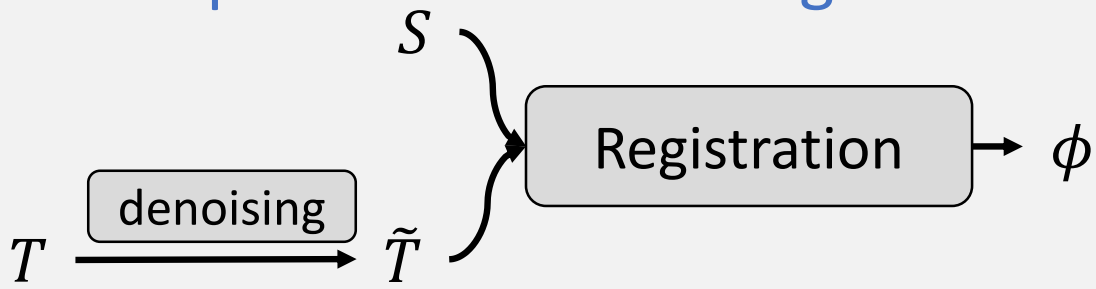

→ May NOT converge to OPTIMAL solution

- Joint Optimization Method

→ Requires explicit objective function
-> LIMITED CHOICES for denoisers

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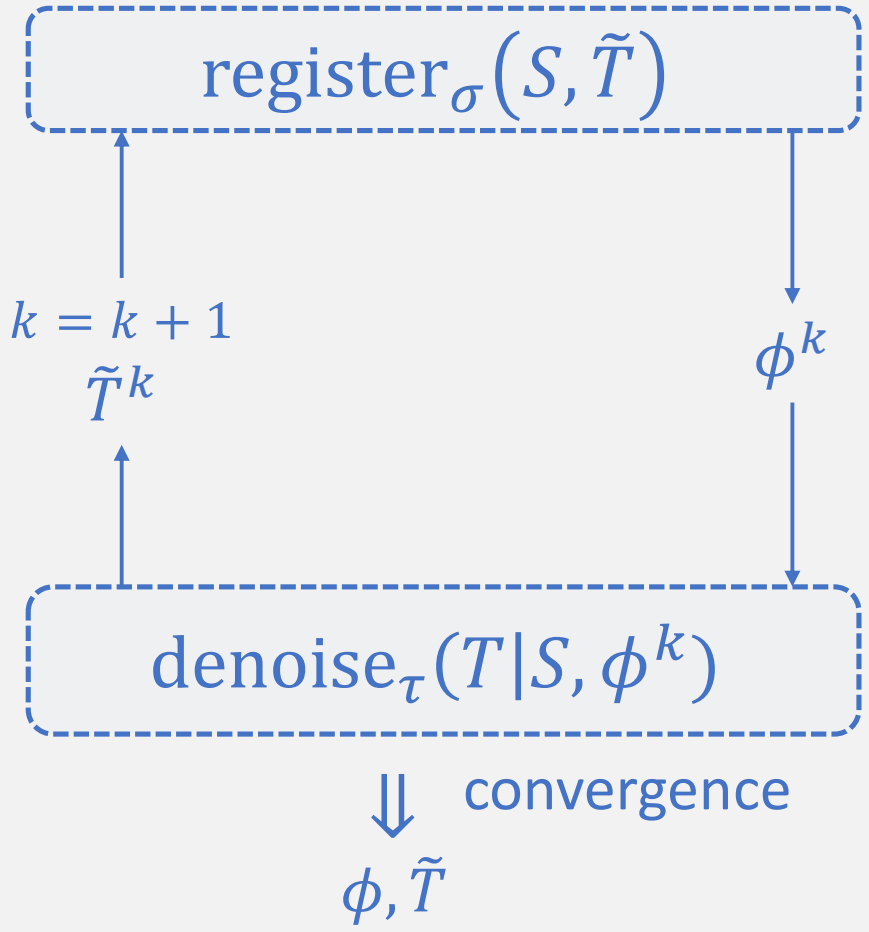
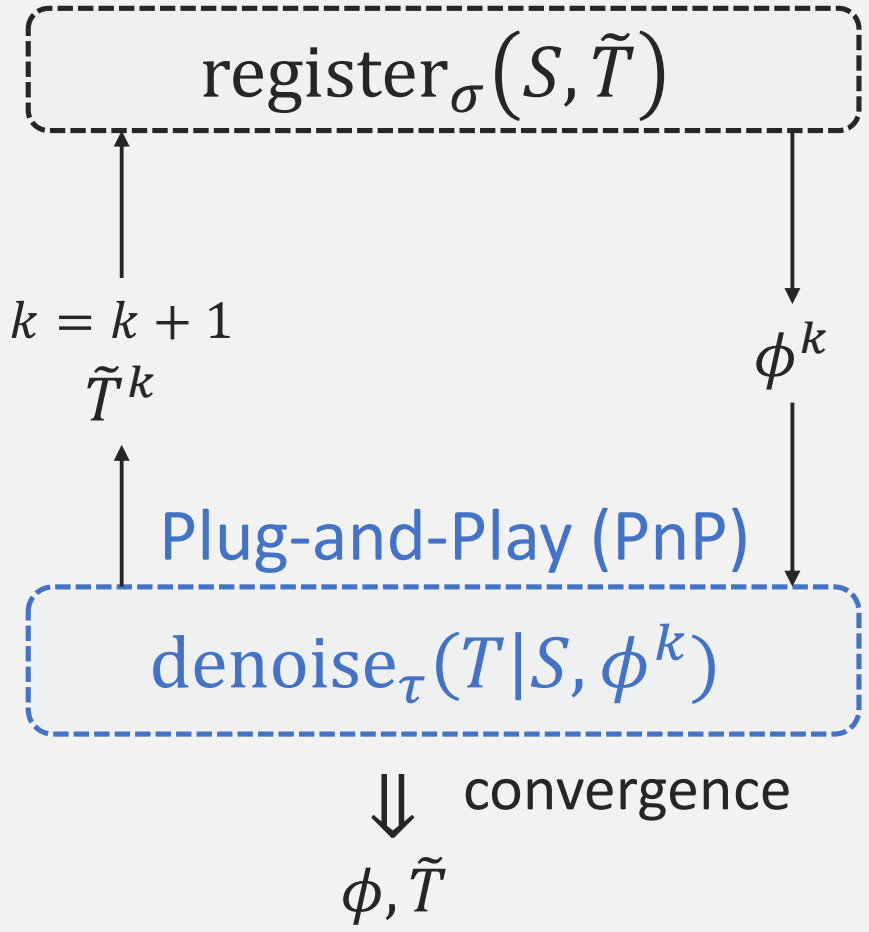
Proposed method: PnP-RR



S: Source image T: Target image
$\tilde{T}$: denoised target images
ϕ: deformation

Proposed method: PnP-RR



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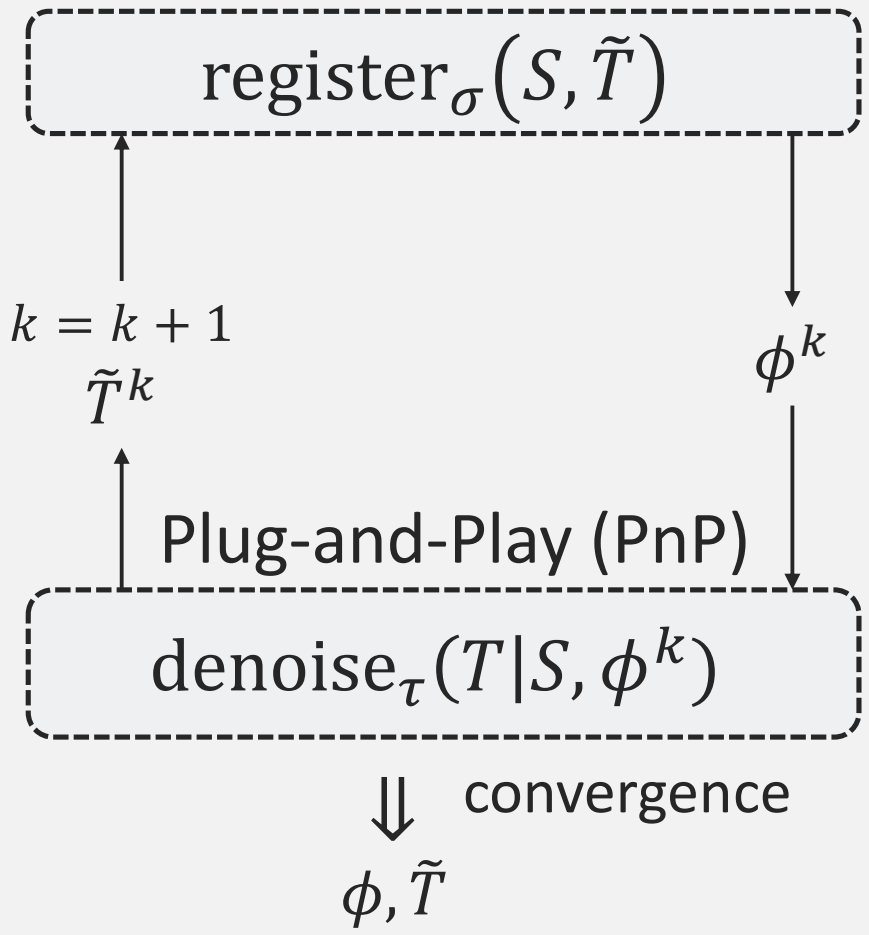

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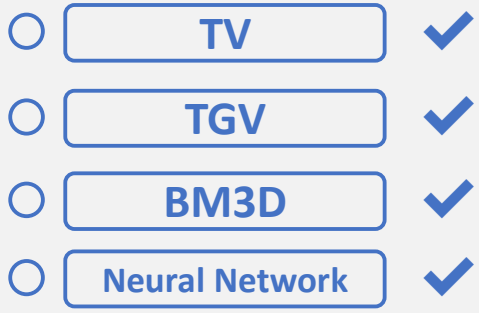
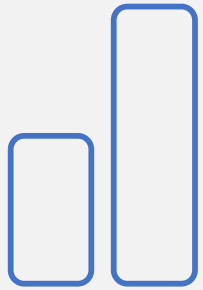
- Advantages

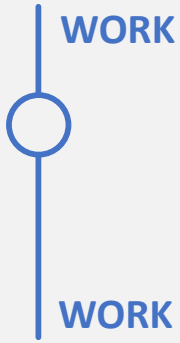


Flexible to CHOOSE DENOISER



Better PERFORMANCE

Simple to IMPLEMENT



Easy to TUNE

Proposed method: PnP-RR

- Mathematical View

- **JOINT**
  denoising-registration
  objective function

$$\underset{\phi,\tilde{T}}{\operatorname{argmin}} \frac{1}{\sigma^2}\left\|S \circ \phi^{-1} - \tilde{T}\right\|_{L2}^2 + \mathcal{R}_{\text{reg}}(\phi)$$

$$+\lambda_1 \mathcal{R}_{\text{denoising}}(\tilde{T}) + \lambda_2\left\|T - \tilde{T}\right\|_{L2}^2$$

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Registration

Denoising

Proposed method: PnP-RR

- Mathematical View

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- **SPLIT**
  Formulated as proximal algorithm

$$\text{register}_{\sigma}\left(S, \tilde{T}^k\right) \rightarrow \phi^k$$

$$\text{denoise}_{\tau}\left(\tilde{T}^k \middle| S, \phi^k\right) \rightarrow \tilde{T}^{k+1}$$

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Iteratively repeat until convergence

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register_σ

denoise_τ

- **REPLACE**
  Formulated as PnP algorithm

register_σ

$\text{denoise}'_\tau$

Replace with arbitrary denoiser

Proposed method: PnP-RR

- Mathematical View

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denoise_{τ}

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Specifying an image prior

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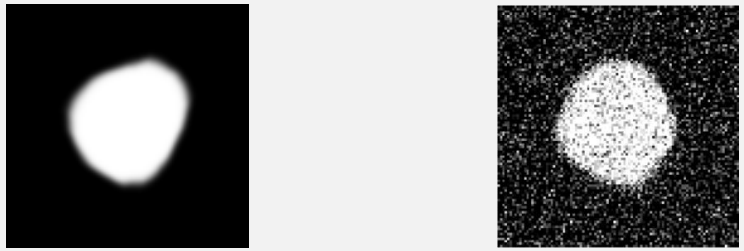
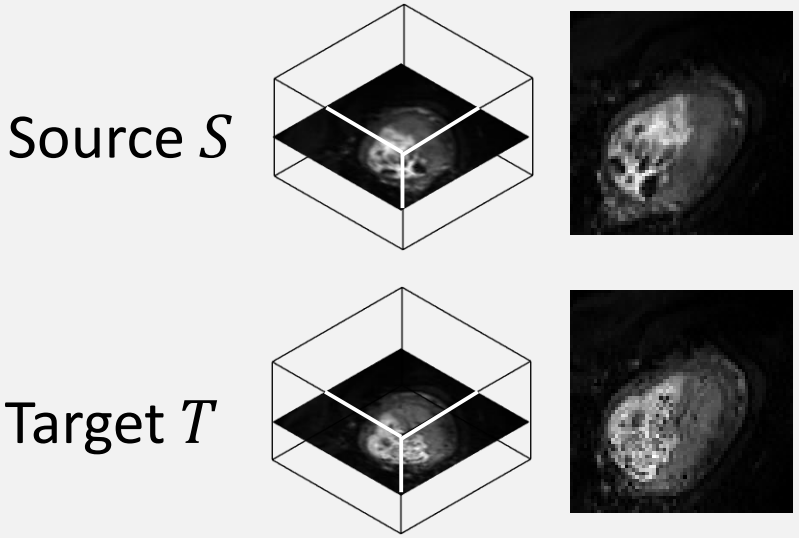
Experiments

- Data
  - 2D synthetic images



Source S Target T

  - 3D placental DW-MR images



Source S

Target T

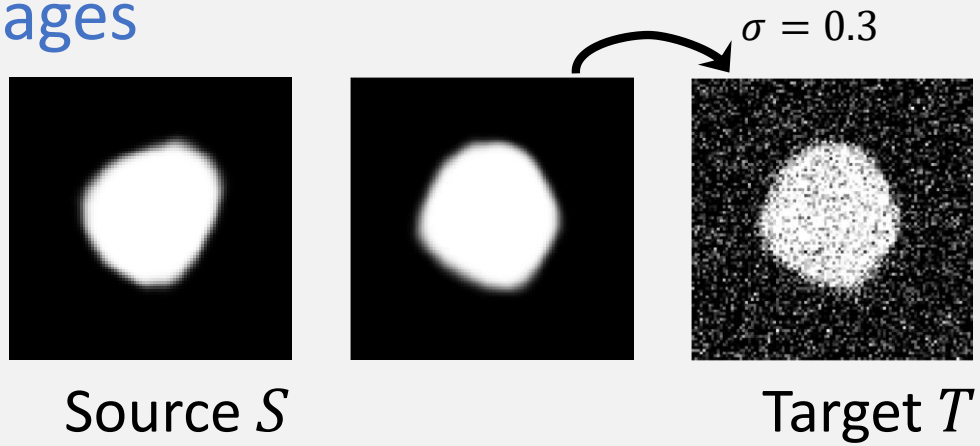
- Algorithm Setting
  - Registration
    - Fourier-approximated Lie Algebras for Shooting (FLASH)[1]
  - Denoising
    - Total variation (TV)[2]
    - Total generalized variation (TGV)[3]
    - Block-matching and 3D filtering (BM3D)[4]

[1] Zhang, et al., IPMI, 2017
[2] Rudin, Leonid I. et al., Physica D: nonlinear phenomena 60.1-4 (1992)
[3] Bredies et al., SIAM Journal on Imaging Sciences 3.3 (2010)
[4] Dabov et al. Image Processing: Algorithms and Systems, Neural Networks, and Machine Learning. Vol. 6064. (2006)

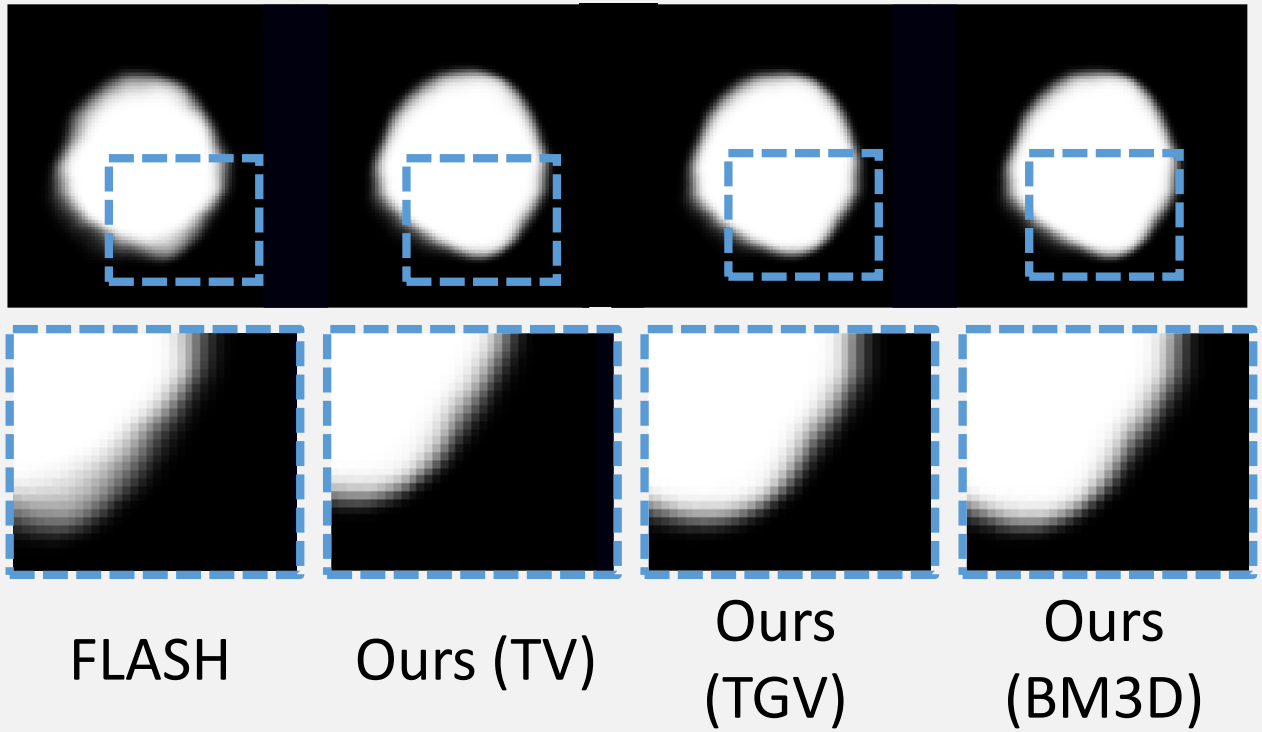
Results

- 2D synthetic images

Source and Target

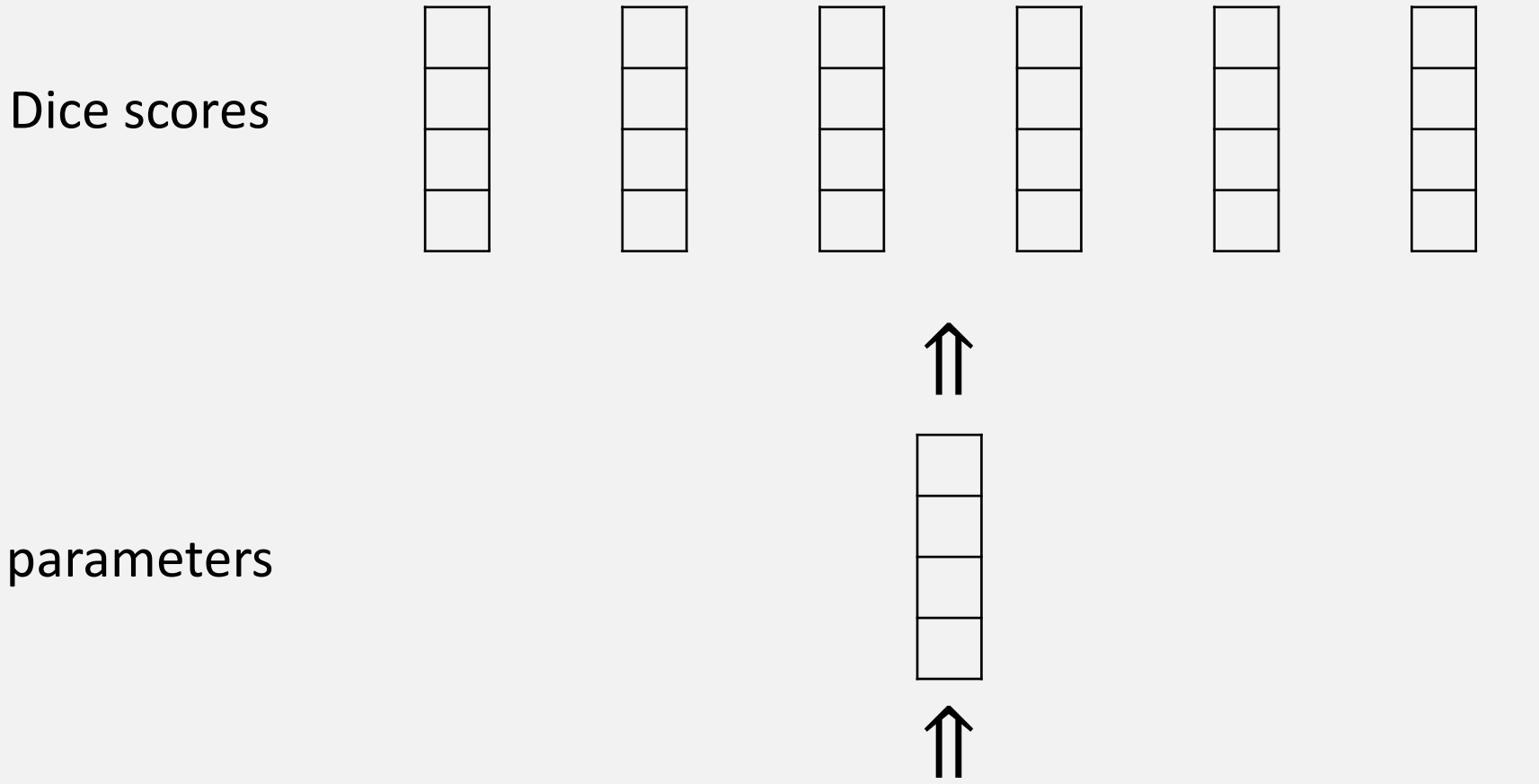


Result (deformed source)



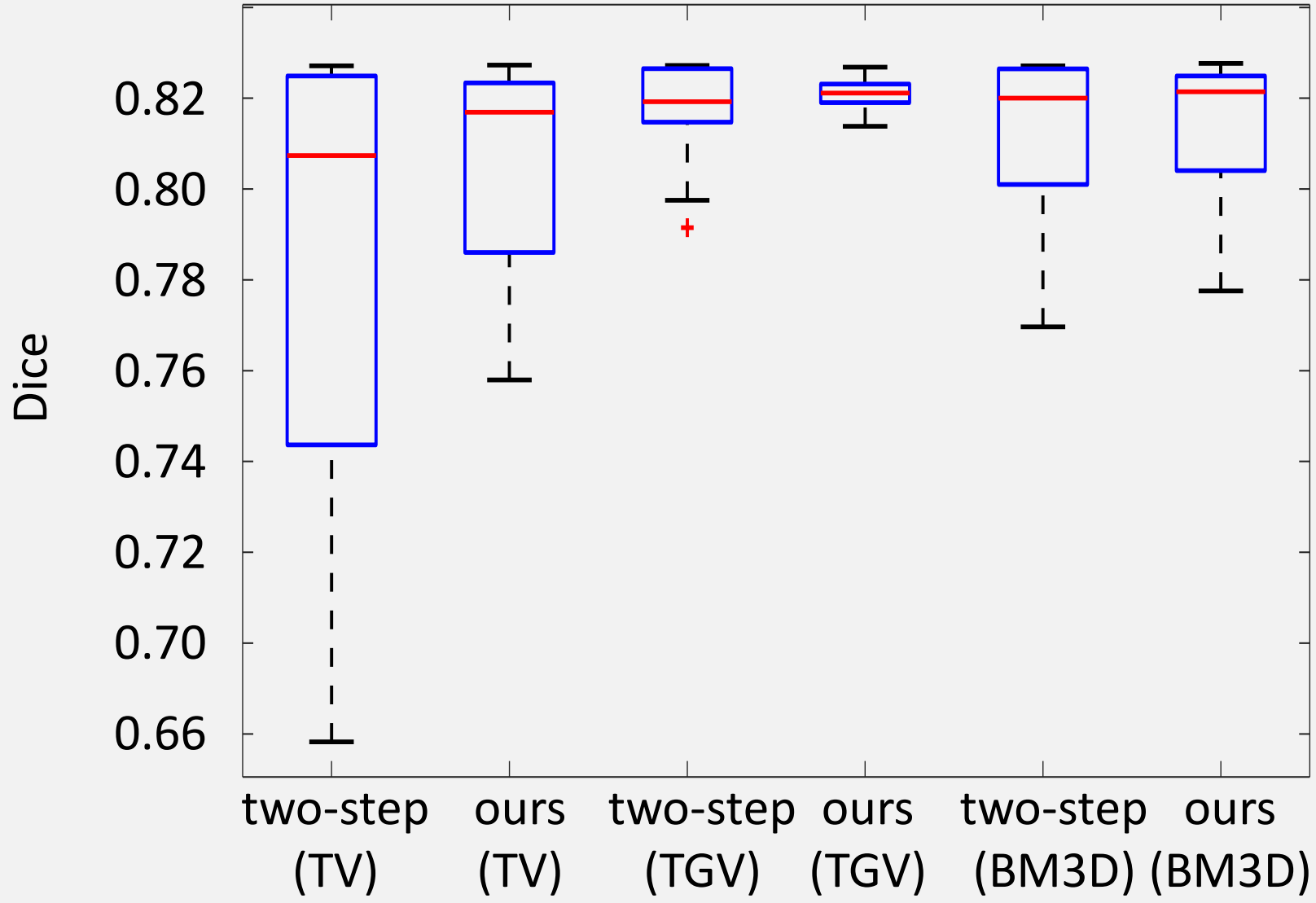
Results

- 2D synthetic images: Dice Evaluation



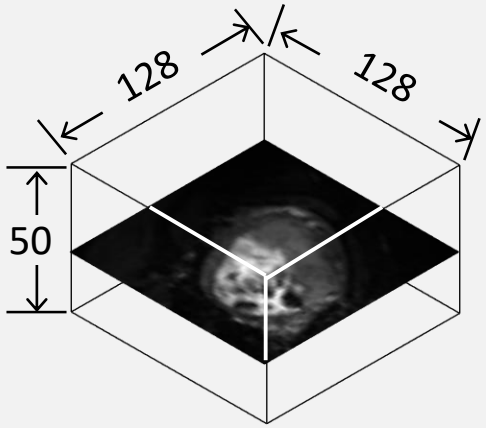
Results

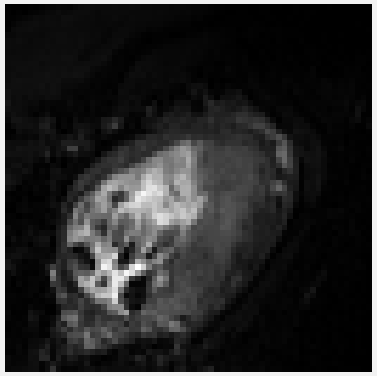
- 2D synthetic images: Dice Evaluation



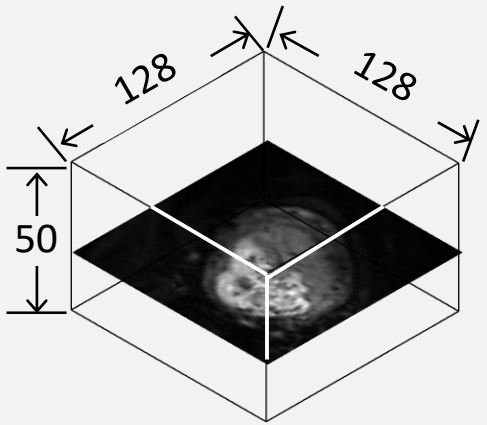
Results

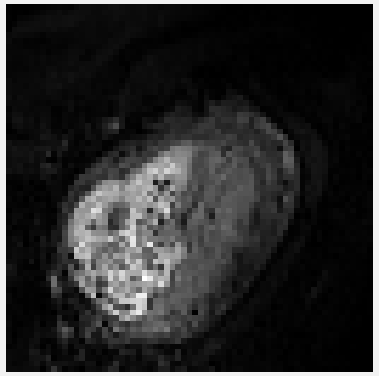
- 3D placental DW-MR images





Source S

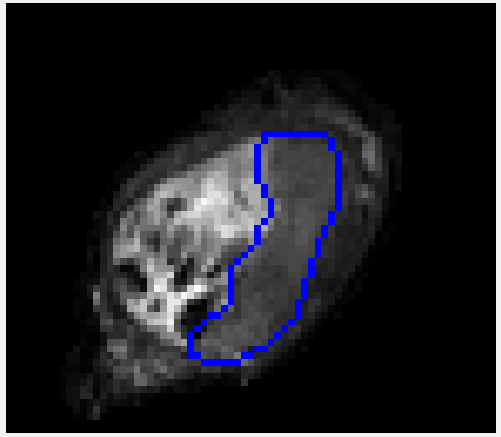




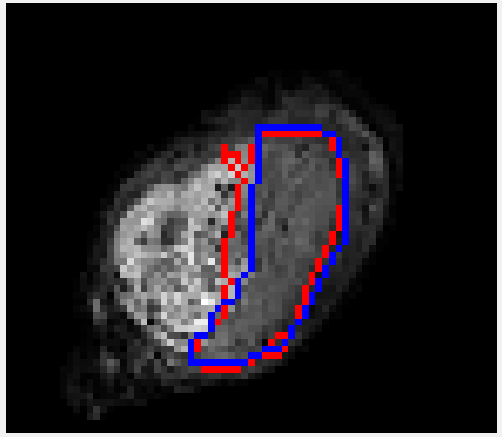
Target T

Results

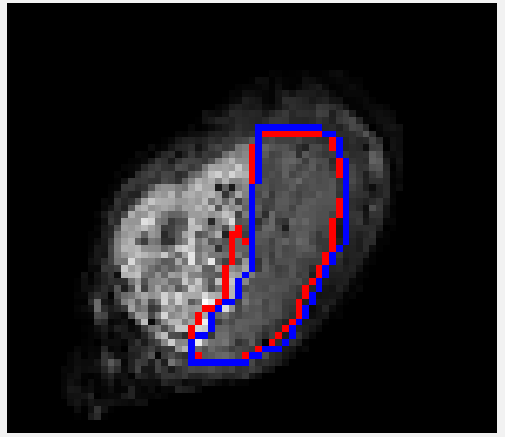
- Propagated placental segments



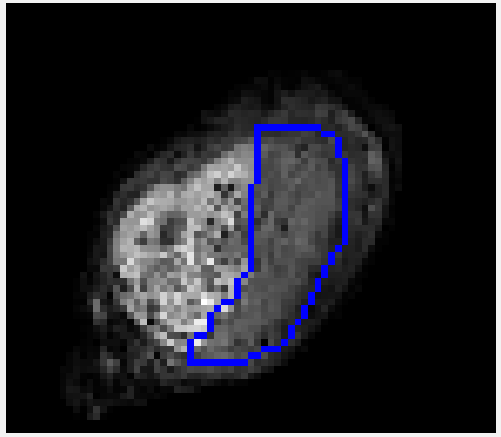
Source



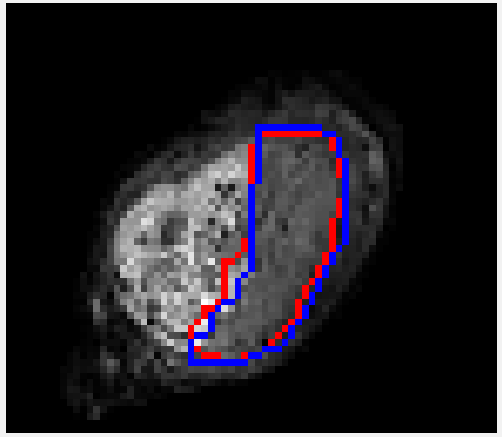
FLASH



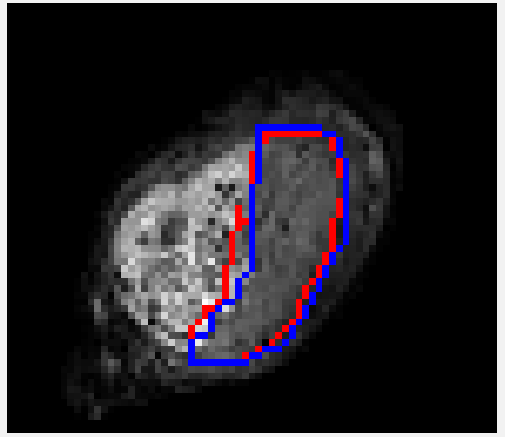
Ours (TGV)



Target



Ours (TV)



Ours (BM3D)

Outline

- Background: Image registration
- Related Work
- Proposed Method: Plug-and-play Reconstruction-registration (PnP-RR)
- Experiments and results
- Conclusion

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- Develop a robust registration framework, PnP-RR, that corrects motion for severely noise-corrupted images

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- Develop a robust registration framework, PnP-RR, that corrects motion for severely noise-corrupted images
- Model has more flexibility to allow arbitrary denoising algorithm integrated with the registration task
- Easy to implement and robust to parameter tuning

Paper

Slides