

Quantifying Knee Cartilage Shape and Lesion: From Image to Metrics

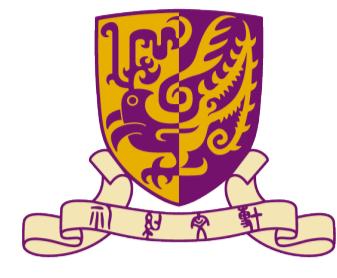
Yongcheng Yao ‡ Weitian Chen †

‡ The University of Edinburgh

† The Chinese University of Hong Kong



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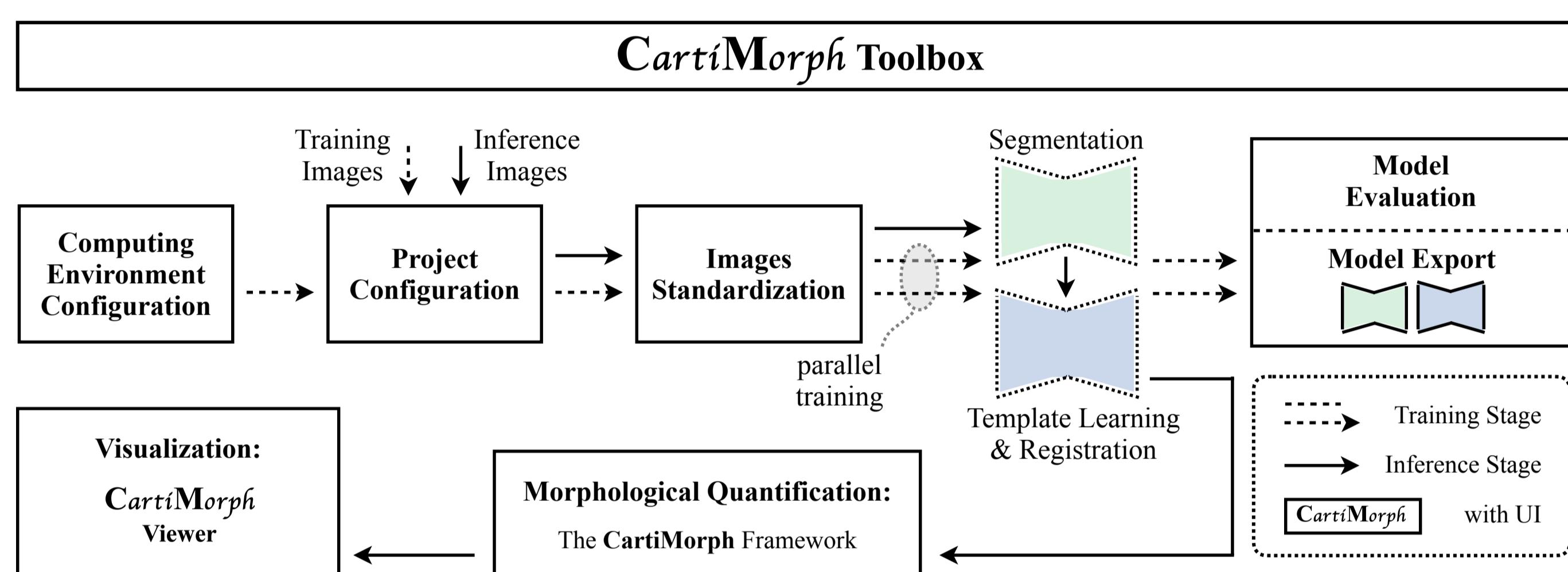
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1. Objective

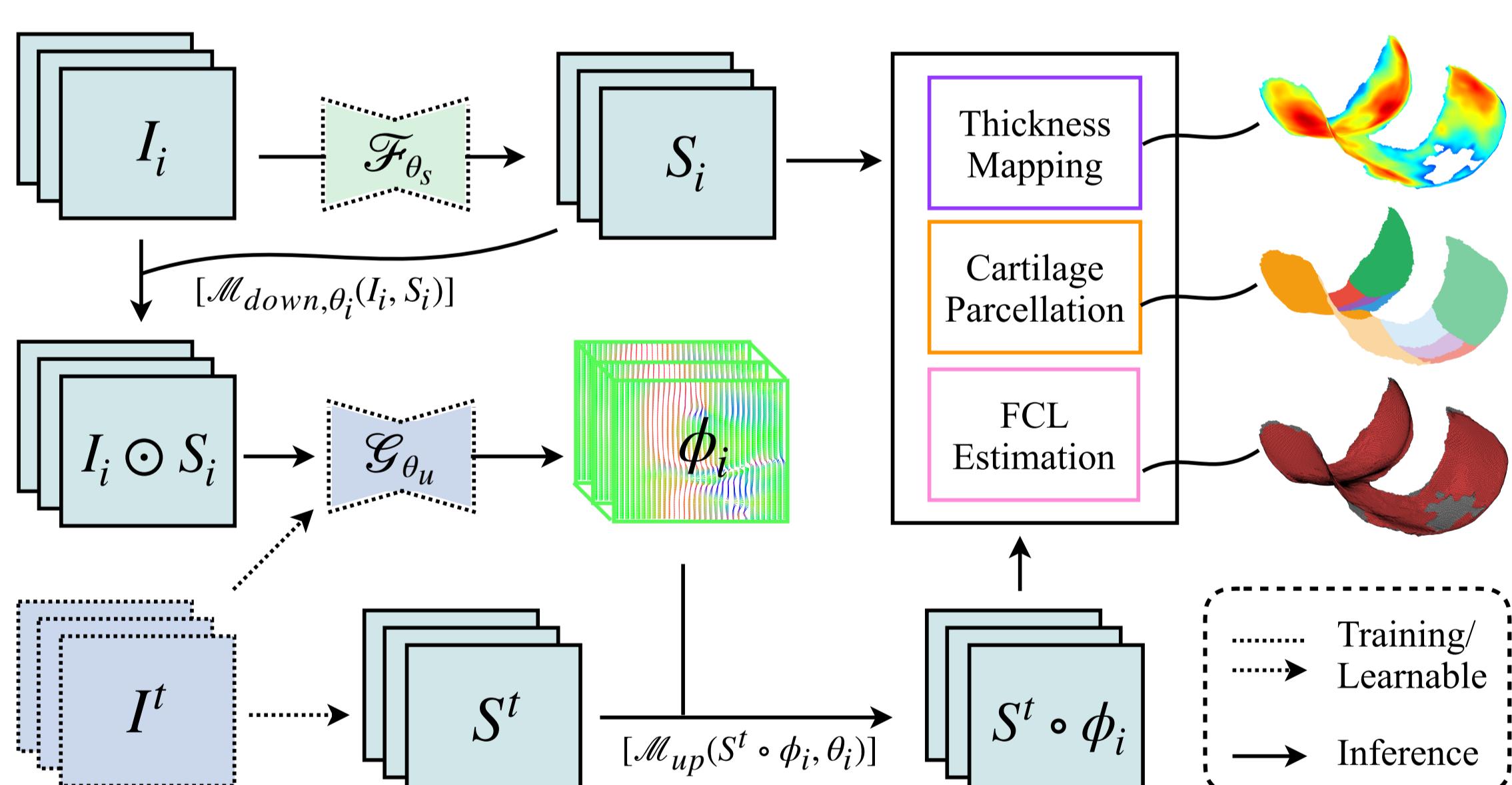
- ✓ AI tool for extracting imaging biomarkers (quantifying cartilage shape and lesion): MR image → quantitative metrics (surface area, volume, cartilage thickness, and full-thickness cartilage loss in 20 subregions)
- ✓ A joint template learning and registration model
- ✓ Q: Are SoTA registration models always preferable for all tasks?

2.1 Method: CartiMorph Toolbox (CMT) [1]

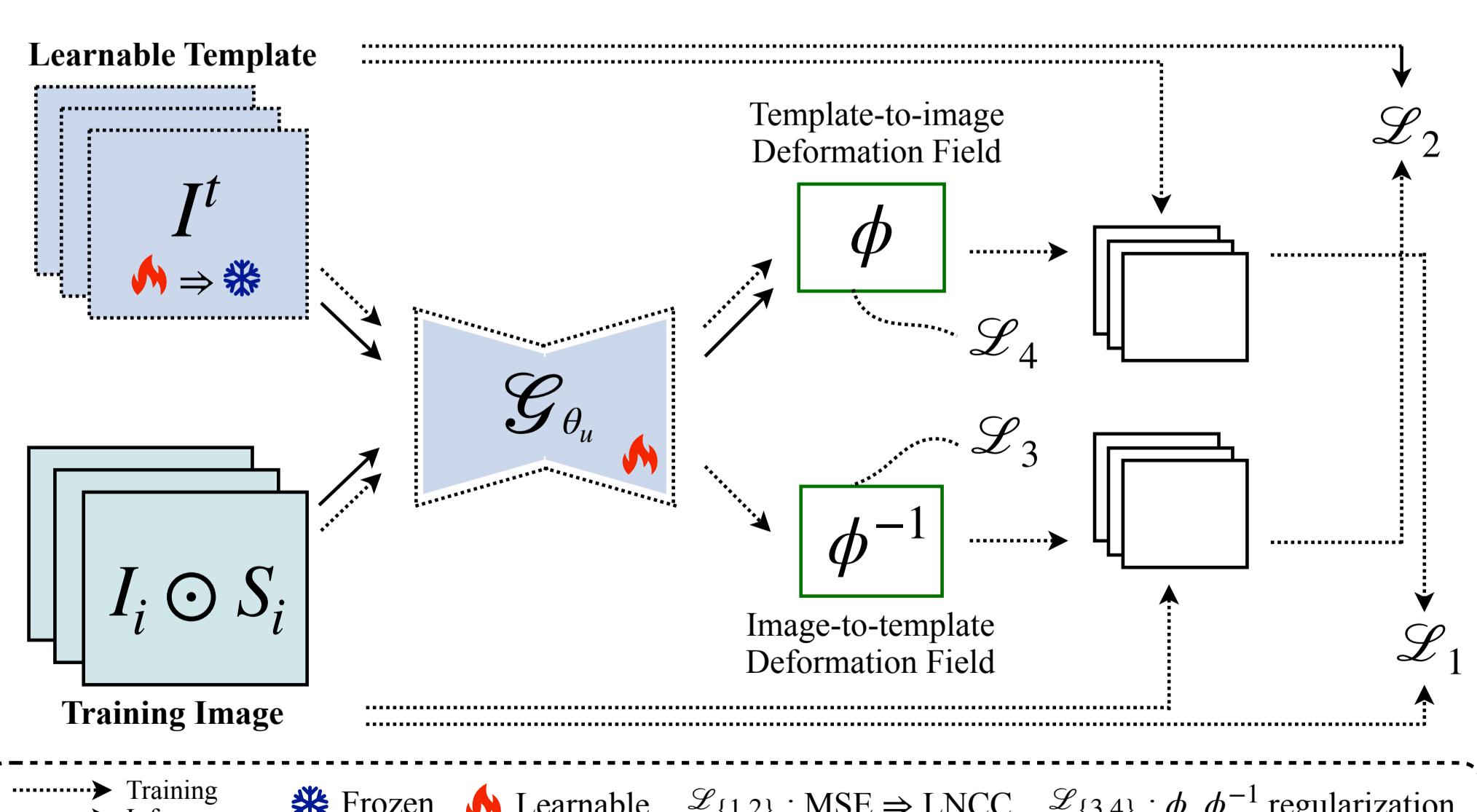


- Automatic medical image analysis with user interface (CMT)
- Models life-cycle management: training, fine-tuning, evaluation, inference, and sharing
- Framework: CartiMorph [2]
- Visualization: CartiMorph Viewer (CMV)

2.2 Method: Models



The segmentation model \mathcal{F}_{θ_s} (nnUNet), the proposed joint template-learning-and-registration model $\mathcal{G}_{\{\theta_u, I^t\}}$ (**CMT-reg**), and the quantification algorithms adopted from CartiMorph [2].

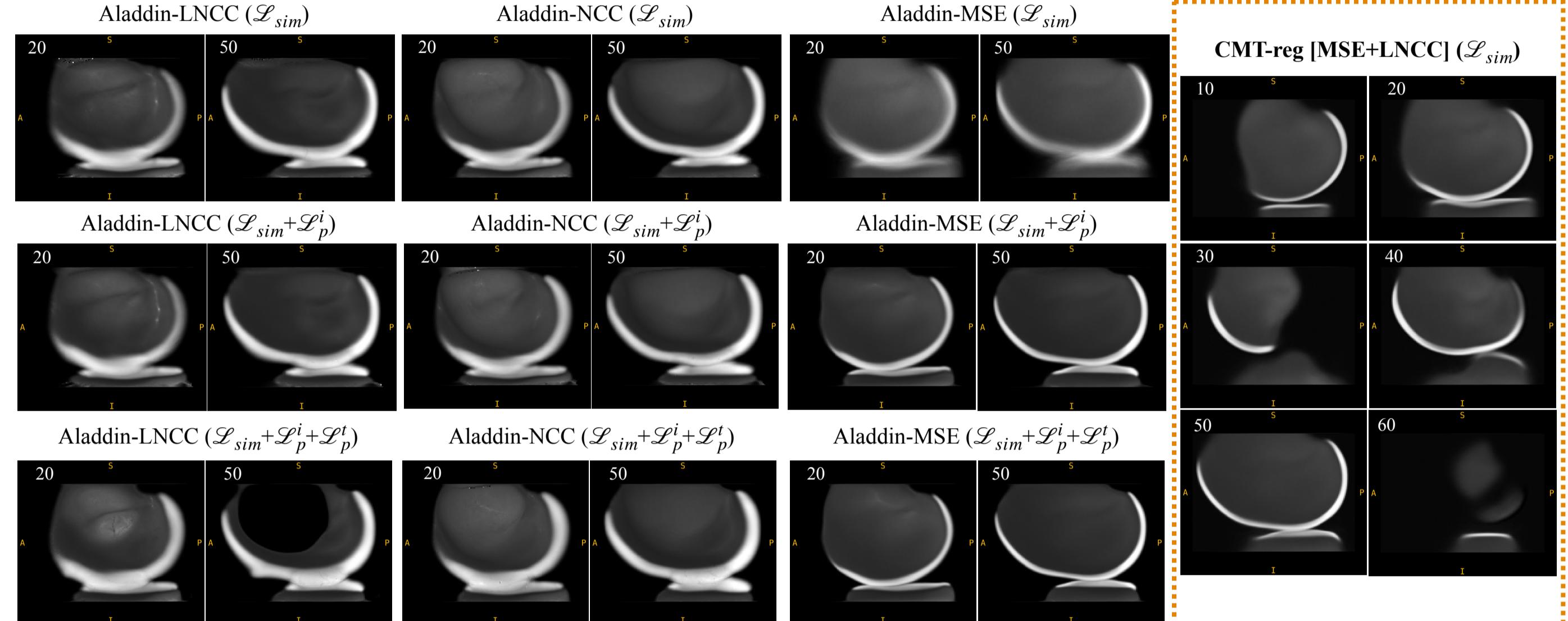


Training strategy of CMT-reg:

- Stage 1: update θ_u and I^t with $\mathcal{L}_{\{1,2\}}$ being mean square error (MSE) loss
Stage 2: update θ_u with $\mathcal{L}_{\{1,2\}}$ being local normalized cross-correlation (LNCC) loss

3. Experiments & Results

- ❖ Learn a representative template image from masked healthy and pathological MRIs



- ❖ Evaluate template-to-image registration accuracy (Table 2)

- ❖ Evaluate registration model behavior (Table 3)

- **Expected behavior:** the registered template mask covers as much pseudo-healthy bone-cartilage interface (BCI) as possible
- **Metric:** $(A_i - A_i^{\text{pseudo}})/A_i^{\text{pseudo}}$, where A_i is the area of BCI extracted from the registered template mask, and A_i^{pseudo} is the area of human-calibrated pseudo-healthy BCI

Table 2. Template-to-image registration accuracy.

Table 3. Registration models behavior analysis.

Model (Loss)	DSC ↑			HD95 ↓ (mm)			$(A_i - A_i^{\text{pseudo}})/A_i^{\text{pseudo}}$ ↓
	FC	mTC	ITC	FC	mTC	ITC	
Aladdin-LNCC (\mathcal{L}_{sim})	0.905	0.816	0.839	0.58	0.92	0.94	-0.035
Aladdin-LNCC ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i$)	0.905	0.817	0.839	0.59	0.92	0.92	-0.029
Aladdin-LNCC ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i + \mathcal{L}_p^t$)	0.904	0.809	0.831	0.64	1.09	1.16	-0.026
Aladdin-NCC (\mathcal{L}_{sim})	0.904	0.818	0.842	0.59	0.92	0.89	-0.031
Aladdin-NCC ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i$)	0.908	0.829	0.858	0.55	0.85	0.72	-0.029
Aladdin-NCC ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i + \mathcal{L}_p^t$)	0.904	0.819	0.840	0.62	0.99	1.03	-0.032
Aladdin-MSE (\mathcal{L}_{sim})	0.505	0.368	0.305	3.49	5.69	6.51	-0.203
Aladdin-MSE ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i$)	0.889	0.808	0.849	0.65	0.97	0.76	-0.021
Aladdin-MSE ($\mathcal{L}_{\text{sim}} + \mathcal{L}_p^i + \mathcal{L}_p^t$)	0.885	0.803	0.841	0.65	0.98	0.82	-0.002
LapIRN-diff (\mathcal{L}_{sim})	0.855	0.740	0.731	1.09	1.69	2.01	0.007
LapIRN-disp (\mathcal{L}_{sim})	0.898	0.806	0.850	0.81	1.38	1.28	0.040
CMT-reg (\mathcal{L}_{sim})	0.895	0.821	0.850	0.70	1.10	0.89	0.036



video

4. Conclusion

- ❖ CMT can benefit human knee cartilage morphometrics (watch the video)
- ❖ CMT-reg is suboptimal in terms of volume overlap (DSC) and surface alignment (HD95), yet prevails in pseudo-healthy BCI coverage which is crucial for accurate estimation of full-thickness cartilage loss (FCL). Therefore, CMT-reg is best suited for the CartiMorph framework.

Acknowledgement

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References & Resources

1. Yongcheng Yao and Weitian Chen. "Quantifying Knee Cartilage Shape and Lesion: From Image to Metrics." In: *International Workshop on Applications of Medical AI*, 2024
 2. Yongcheng Yao, et al. "CartiMorph: A framework for automated knee articular cartilage morphometrics." *Medical Image Analysis* 91 (2024): 103035.
- CMT: <https://github.com/YongchengYAO/CartiMorph-Toolbox>
CartiMorph: <https://github.com/YongchengYAO/CartiMorph>
Code: <https://github.com/YongchengYAO/CMT-AMAI24paper>