WHY REGISTRATION QUALITY MATTERS: ENHANCING SCT SYNTHESIS WITH IMPACT-BASED REGISTRATION

🥉 3rd place – SynthRAD2025 Challenge

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OBJECTIVES

🎯 Generate **synthetic CT** (sCT) from **unpaired** MRI (578 scans, Task 1) and CBCT (955 scans, Task 2) from the SynthRAD 2025 challenge

🔍 Assess how **registration quality** influences supervised sCT synthesis

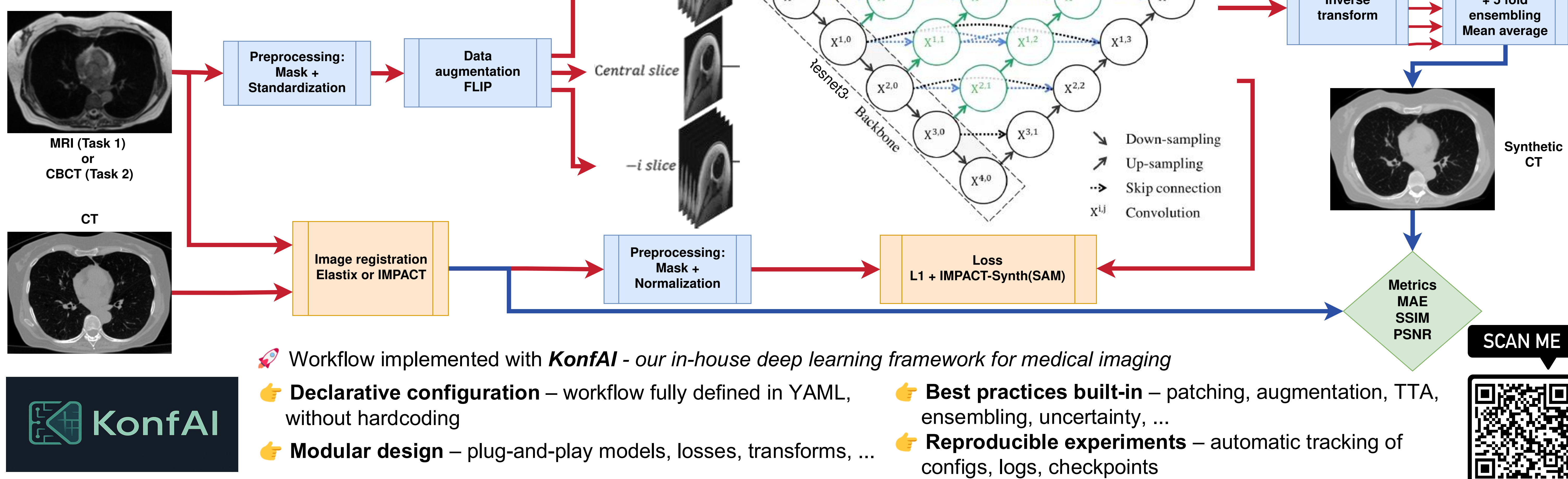📊 Evaluate whether supervised models learn registration bias, compromising evaluation metrics

OUR CONTRIBUTIONS

🛠 Designed a **supervised** workflow for Tasks 1 & 2 using the **KonfAI**[2] framework

📈 Demonstrate the benefit of **IMPACT**[3] **metric** for registration over the challenge organizers' baseline (Elastix with Mutual Information)

🔬 Introduced **IMPACT-Synth**, a perceptual loss leveraging pretrained segmentation features (SAM[4], TotalSegmentator)
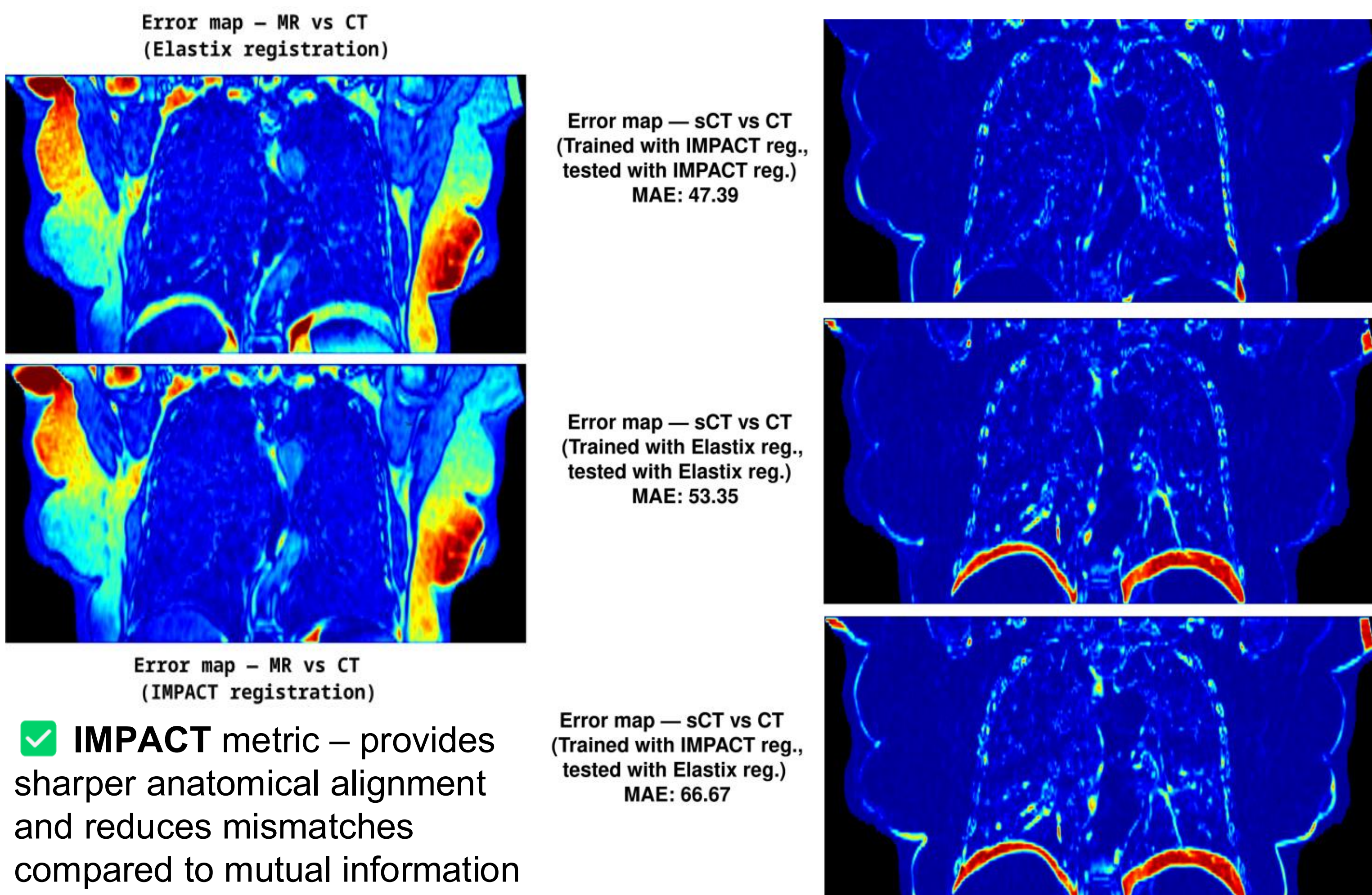
SUPERVISED SYNTHESIS WORKFLOW

Workflow **(Tasks 1 & 2):**
MRI/CBCT and CT are **registered** with Elastix (baseline) or IMPACT, preprocessed, then used to train a **2.5D U-Net++**[1] **(ResNet–34)** in two stages (global pretraining → region fine-tuning) with **L1 + IMPACT-Synth**. At inference, **TTA** and **5-fold ensembling** improve robustness.

2 steps: Global model (all regions) → Fine-tuning (AB+TH / HN)

🚀 Workflow implemented with **KonfAI** - *our in-house deep learning framework for medical imaging*

👉 **Declarative configuration** – workflow fully defined in YAML, without hardcoding

👉 **Modular design** – plug-and-play models, losses, transforms, ...

👉 **Best practices built-in** – patching, augmentation, TTA, ensembling, uncertainty, ...

👉 **Reproducible experiments** – automatic tracking of configs, logs, checkpoints

SCAN ME

RESULTS

Error map – MR vs CT (Elastix registration)

Error map – MR vs CT (IMPACT registration)

✅ **IMPACT** metric – provides sharper anatomical alignment and reduces mismatches compared to mutual information

Error map — sCT vs CT (Trained with IMPACT reg., tested with IMPACT reg.) MAE: 47.39

Error map — sCT vs CT (Trained with Elastix reg., tested with Elastix reg.) MAE: 53.35

Error map — sCT vs CT (Trained with IMPACT reg., tested with Elastix reg.) MAE: 66.67

✅ **Lowest error** – trained on well-aligned pairs ⇒ faithful correspondence and preserved anatomy

⚠️ **Higher error** – model learns bias from misaligned pairs ⇒ blur and anatomical deformations

❌ **Worst error** – inconsistent train/test registration ⇒ large errors

Local validation: 75 patients (Task 1 & 2). IMPACT improved pixel-wise similarity metrics.

Metric	Task 1		Task 2	
	Baseline	IMPACT	Baseline	IMPACT
MAE	63.37	**60.28**	56.61	**48.57**
PSNR	30.02	**30.53**	31.16	**31.82**
SSIM	0.93	**0.94**	0.92	**0.94**

Public validation: 148 patients (Task 1) and 89 patients (Task 2). The baseline performs higher scores across all metrics, due to evaluation bias.

Metric	Task 1		Task 2	
	Baseline	IMPACT	Baseline	IMPACT
MAE	**68.20**	75.82	**52.87**	56.05
PSNR	**29.81**	28.70	**32.36**	31.65
SSIM	**0.92**	0.91	**0.96**	0.95
Dice	**0.72**	0.70	**0.83**	0.82
HD95	**8.42**	8.89	**5.40**	5.41

IMPACT-SYNTH

IMPACT-Synth is an extension of IMPACT for image synthesis. It uses an L1 loss on feature maps extracted from pretrained segmentation networks (SAM, TotalSegmentator). This perceptual supervision sharpens anatomical boundaries in the generated CT, yielding clearer structures than VGG-based perceptual loss, while complementing pixel-wise losses.

1. Zhou, Z., Rahman Siddiquee, M.M., Tajbakhsh, N., Liang, J.: Unet++: A nested u-net architecture for medical image analysis. pp. 3–11. Springer (2018)
2. Boussot, V., Dillenseger, J.L.: Konfai: A modular and fully configurable framework for deep learning in medical imaging. arXiv–2508.09823 (2025)
3. Boussot, V., Hémon, C., Nunes, J.C., Downling, J., Rouzé, S., Lafond, C., Barateau, A., Dillenseger, J.L.: Impact: A generic semantic loss for multimodal medical image registration. arXiv–2503.24121 (2025)
4. Kirillov, A., Mintun, E., Ravi, N., Mao, H., Rolland, C., Gustafson, L., Xiao, T., Whitehead, S., Berg, A.C., Lo, W.Y., et al.: Segment anything. In: Proceedings of the IEEE/CVF international conference on computer vision. pp. 4015–4026 (2023)

SCAN ME

👉 **IMPACT B-spline registrations available**

REGISTRATION QUALITY IN SCT

⚙️ **Assumption**: supervised sCT expects voxel-wise alignment, rarely true in practice ⇒ registration is essential but imperfect.

⚠️ **Pitfall**: Supervised CNNs may exploit misregistration artifacts ⇒ strong pixel-wise metrics but poor anatomical realism.

✅ **IMPACT**: outperforms MI with better alignment ⇒ higher scores and more realistic structures.

🔬 **IMPACT-Synth**: adds perceptual supervision (SAM/TotalSegmentator) ⇒ sharper and more anatomically faithful CT synthesis.

🔑 **Key message**: Registration quality is critical for reliable synthesis and evaluation, and our results suggest that IMPACT offers a promising solution to address this limitation.

FUTURE WORK

🔄 Compare supervised and unsupervised pipelines under fair conditions, limiting the influence of registration bias.

📊 Systematically benchmark different pretrained segmentation models as perceptual feature extractors, against the VGG baseline.