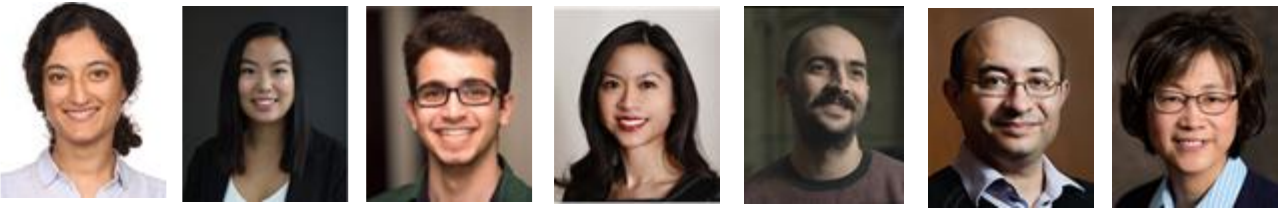
Technical University
of Denmark

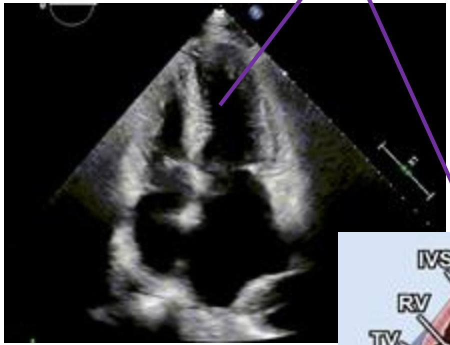
ProtoEFNet: Dynamic Prototype Learning for Inherently Interpretable Ejection Fraction Estimation in Echocardiography

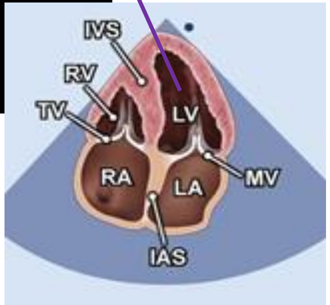


University of British Columbia (UBC) and Technical University of Denmark (DTU)

Left Ventricle Ejection Fraction (EF)

Left Ventricle (LV)





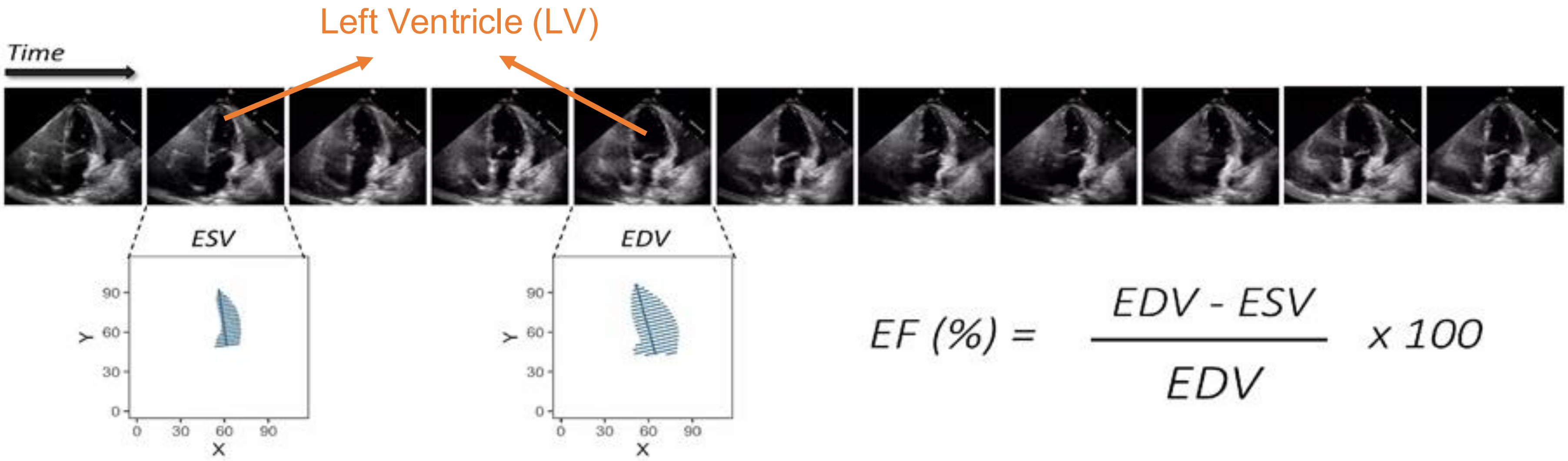
23 Million worldwide with heart failure of which

50%

Reduced Ejection Fraction[1]

[1] Murphy SP, Ibrahim NE, Januzzi JL Jr. Heart Failure With Reduced Ejection Fraction: A Review. JAMA. 2020 Aug 4;324(5):488-504. doi: 10.1001/jama.2020.10262. Erratum in: JAMA. 2020 Nov 24;324(20):2107. doi: 10.1001/jama.2020.21736. PMID: 32749493.
Figures from https://cardvasc.org/cvd-atlas-case/figure-12-apical-four-chamber-view-a4c/ and https://www.showmethepocus.com/ejection-fraction-left-ventricle and https://www.wikiwand.com/en/articles/Heart_failure_with_preserved_ejection_fraction

Left Ventricle Ejection Fraction (LVEF)



$$EF\ (\%) = \frac{EDV - ESV}{EDV} \times 100$$

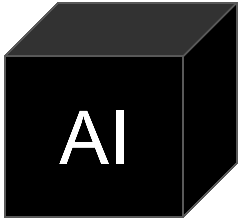
EDV: End Diastole Volume

ESV: End Systole Volume

Figures from Echonet-Dynamic

Goal

Automatic EF estimation using affordable, real-time ultrasound (Echo)



EF Prediction

Illustration: https://www.echocardiographer.org

Existing AI Based EF Estimation

Existing works show promise for AI-assisted prediction

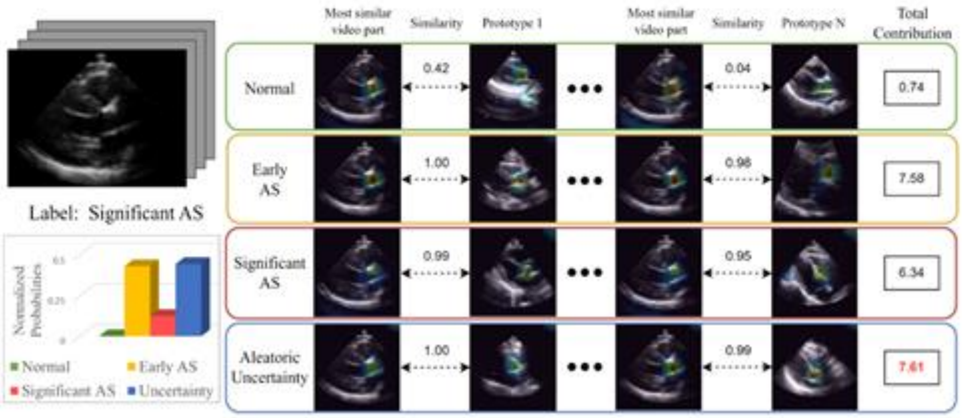
- Fadillah Adamsyah Maani et al. “CoReEcho: Continuous Representation Learning for 2D+ Time Echocardiography Analysis.” **MICCAI 2024**
- Masoud Mokhtari et al. “EchoGNN: explainable ejection fraction estimation with graph neural networks.” **MICCAI 2022**
- Rand Muhtaseb and Mohammad Yaqub. “Echocotr: Estimation of the left ventricular ejection fraction from spatiotemporal. **MICCAI 2022**
- Hadrien Reynaud et al. “Ultrasound video transformers for cardiac ejection fraction estimation.” **MICCAI 2021**
- Mohammad Mahdi Kazemi Esfeh et al. “A deep Bayesian video analysis framework: towards a more robust estimation of ejection fraction.” **MICCAI 2020**
- *David Ouyang et al. “Video-based AI for beat-to-beat assessment of cardiac function.”* **Nature 2020**

Existing Works Limitations

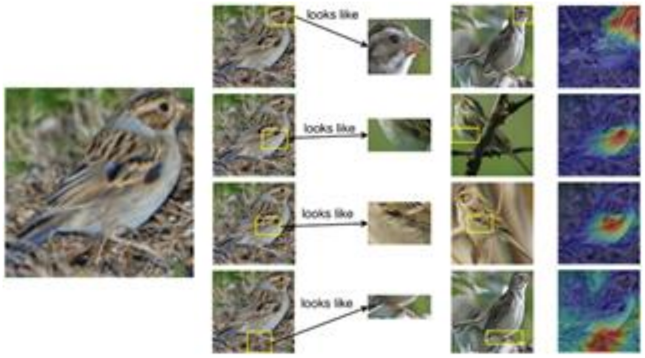
Black-box Model

Post-hoc Explainable Models

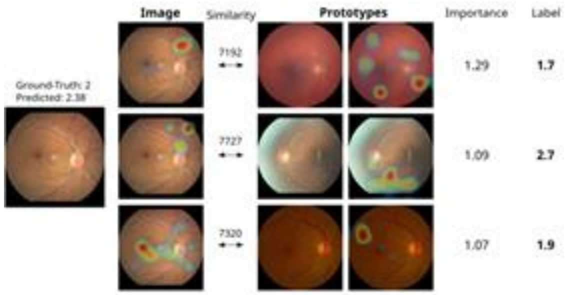
Existing Prototypical Neural Network



ProtoASNet
Vaseli et al. [MICCAI 2023]



ProtoPNet
Chen et al. [Neurips 2019]

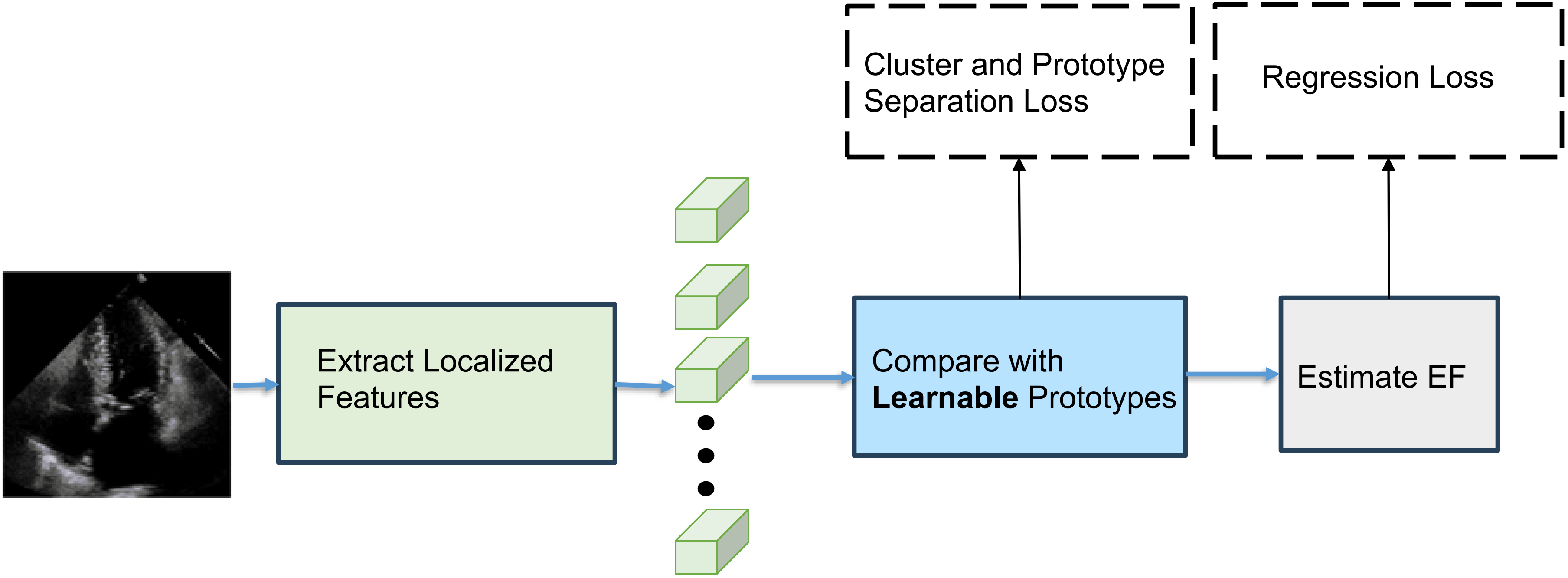


INSightR-Net
Hesse and Namburete [MICCAI 2022]

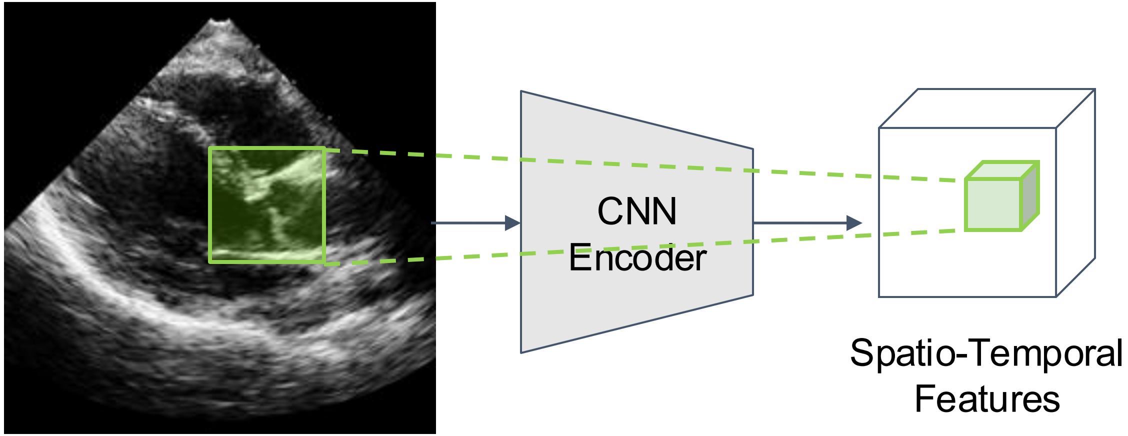
Key Contributions

- **ProtoEFNet**: The first **video-based** prototype learning approach for regression tasks.
- A novel inherently interpretable model for LVEF estimation.
- Proposed a **prototype angular separation loss (PAS)** to improve regression performance and the quality of the explanations.

ProtoEFNet Overview



Feature Extractor: ResNet(2+1)D Embeddings



Where and when to crop?

Figure borrowed from ProtoASNet

Feature Extractor: Localization with ROI

$$f_{p_k}(x) = \frac{1}{HWT} \sum_{H,W,T} M_{p_k}(x) \circ F(x)$$

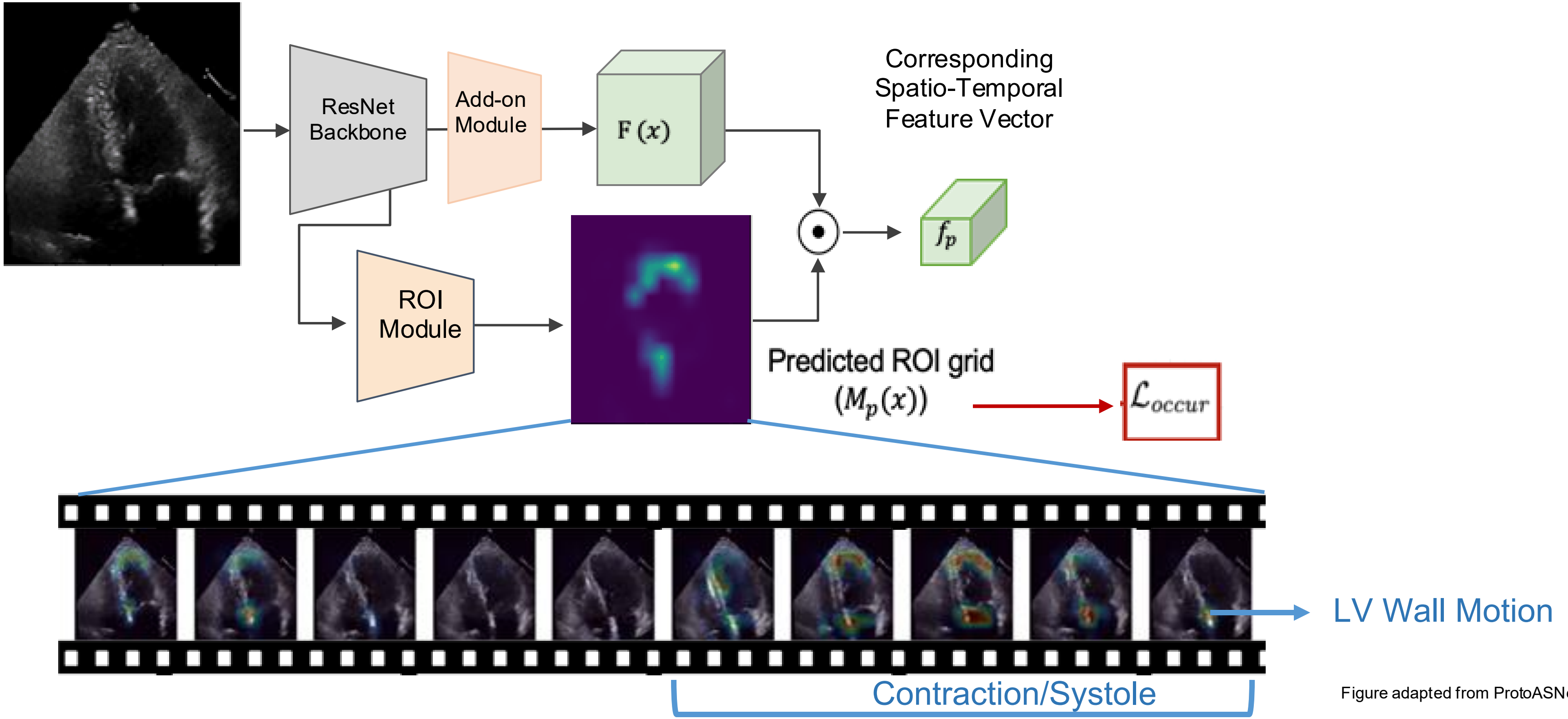
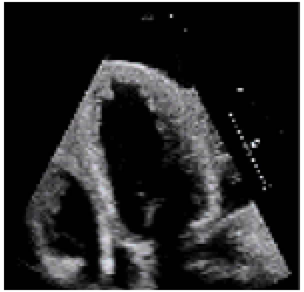
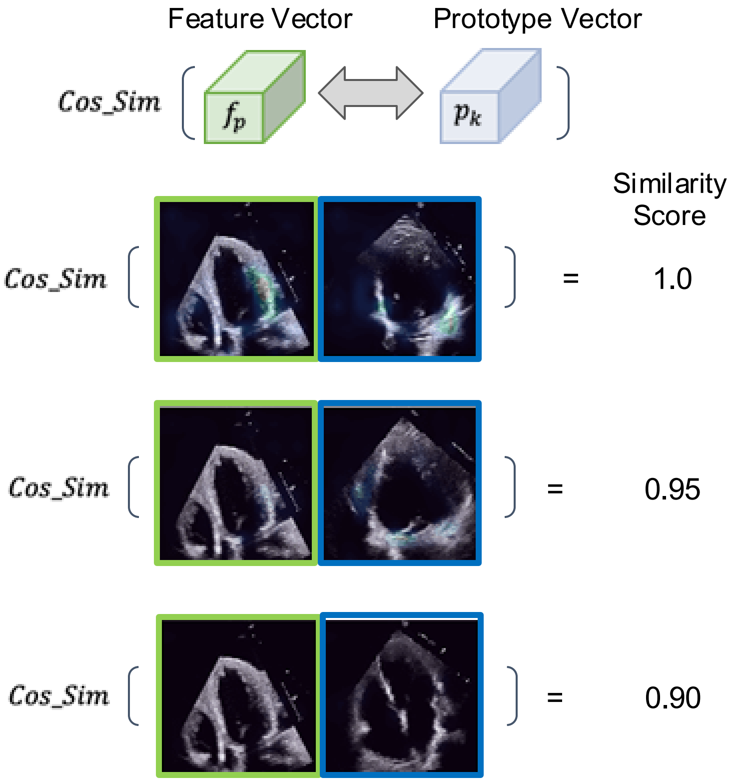


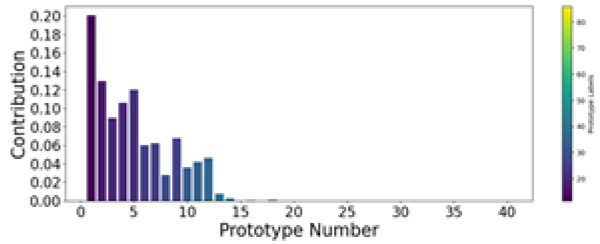
Figure adapted from ProtoASNet

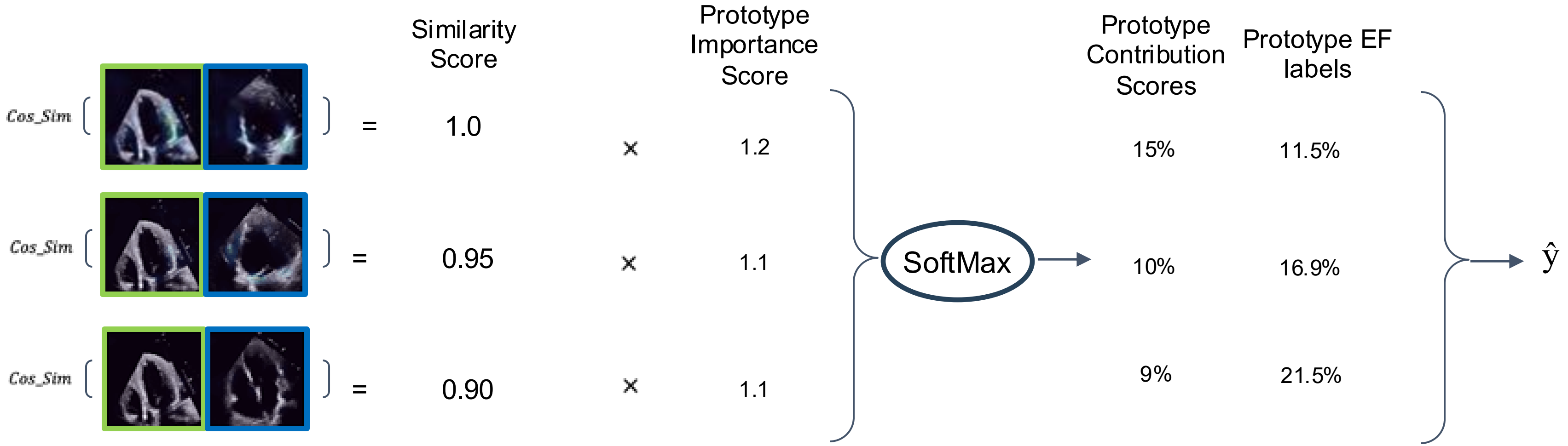
Prototype Layer



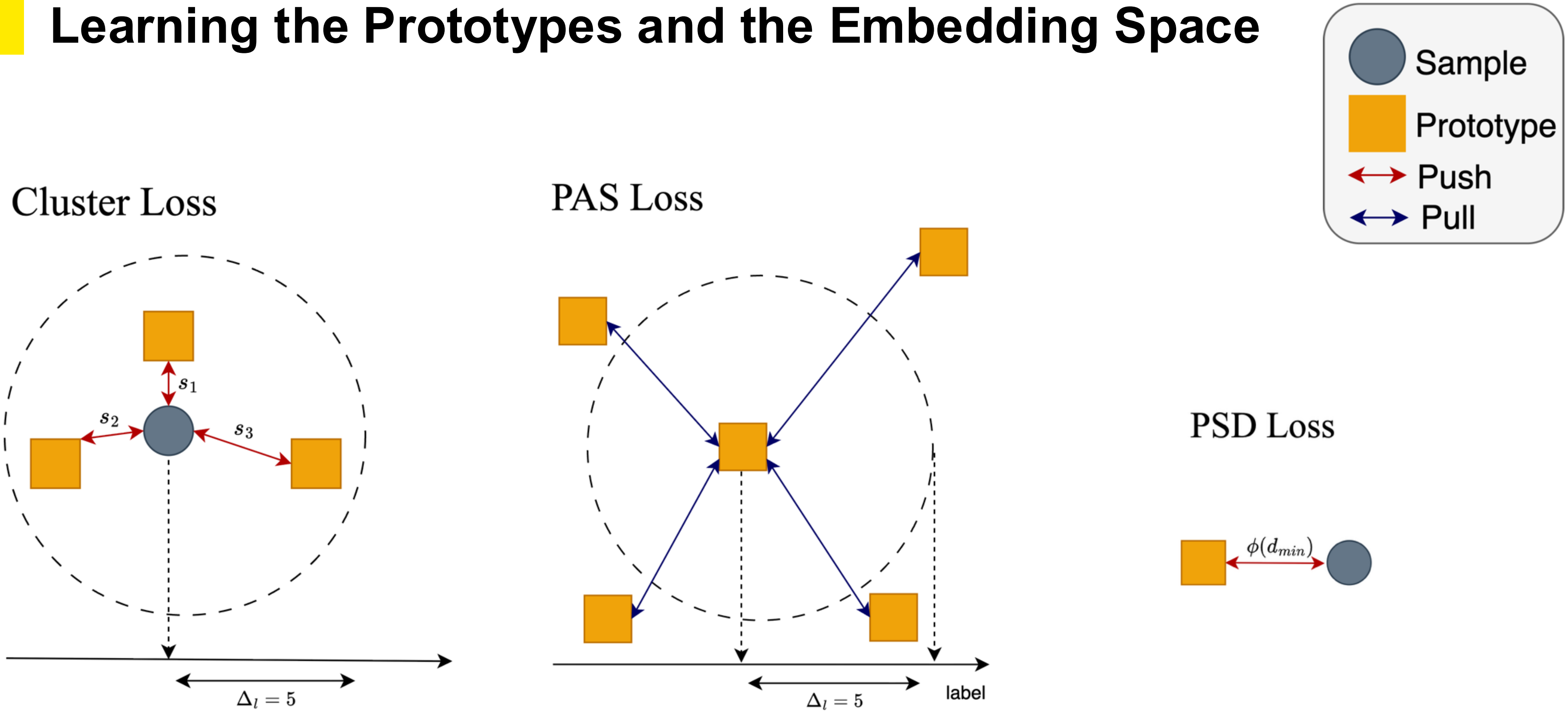


Regression Layer

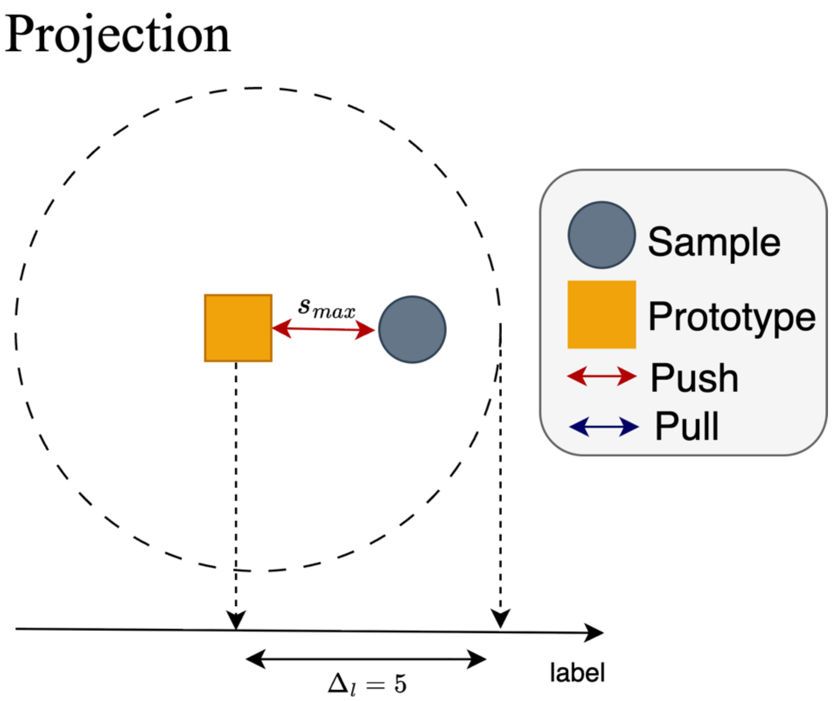




Learning the Prototypes and the Embedding Space



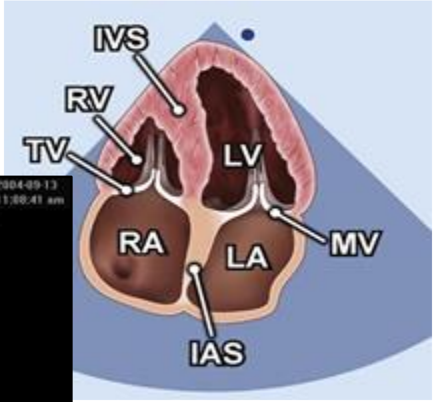
Prototype Projection



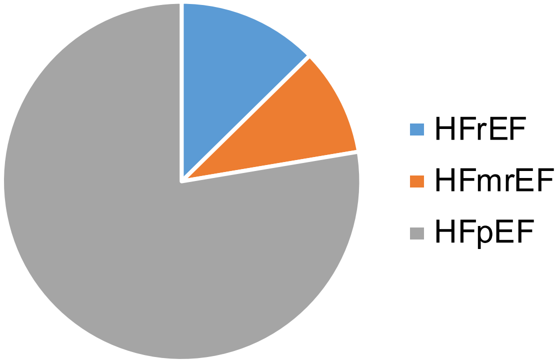
Dataset: EchoNet-Dynamic

- ~10,000 videos from unique patients

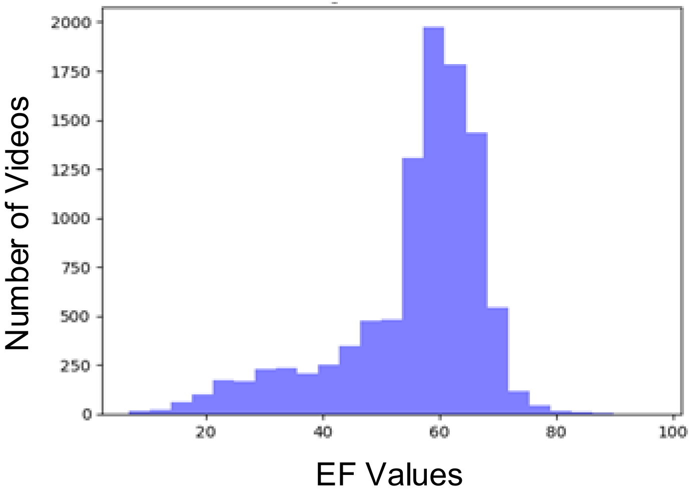
Apical 4 Chamber



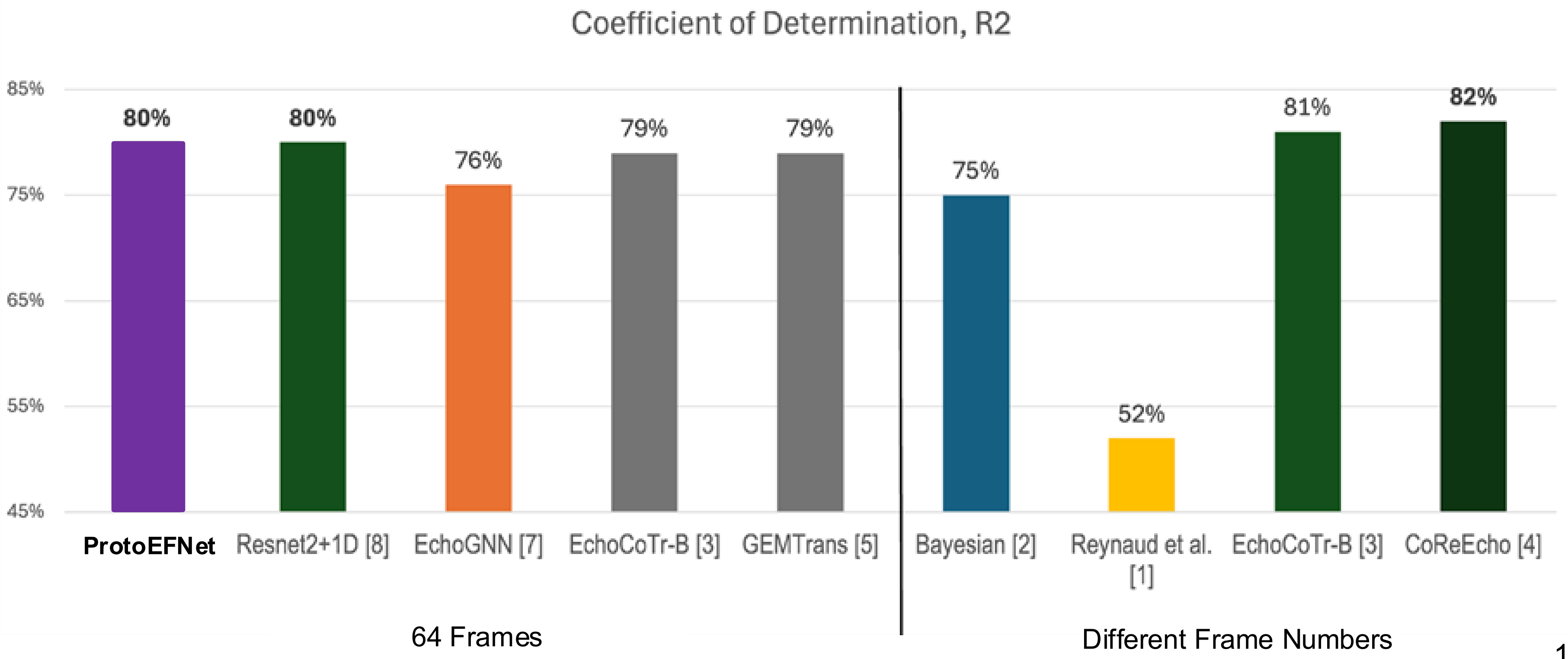
Number of Patients



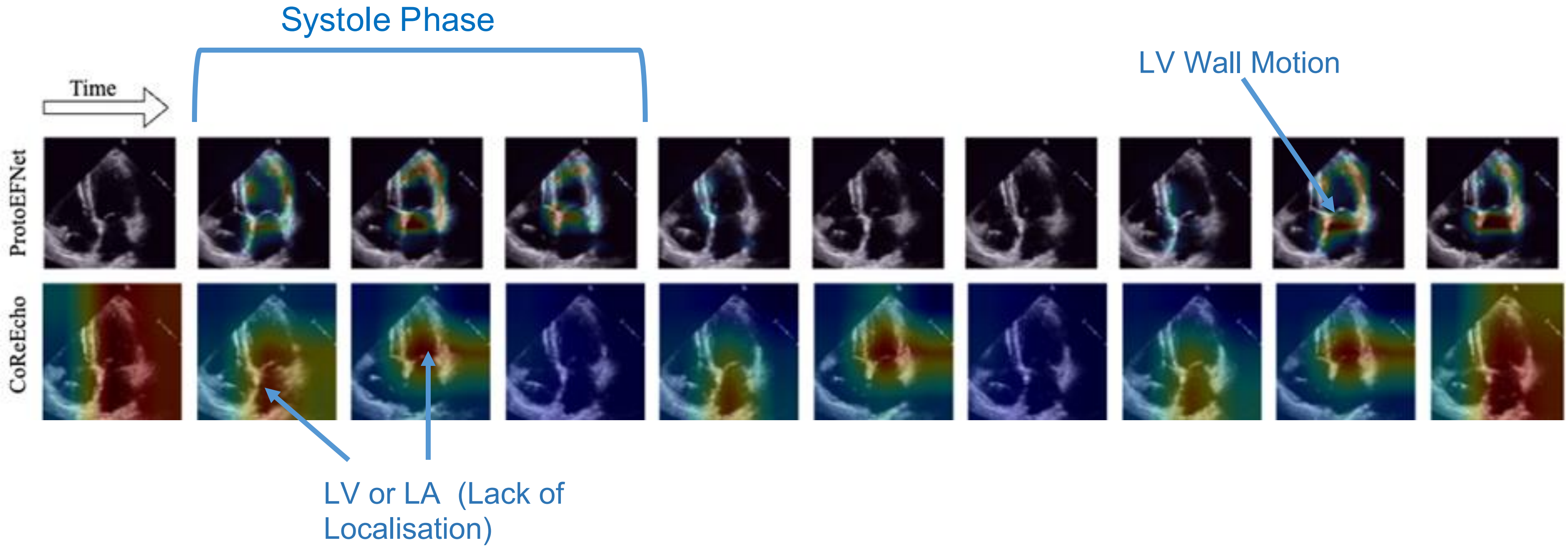
Histogram of EF Values



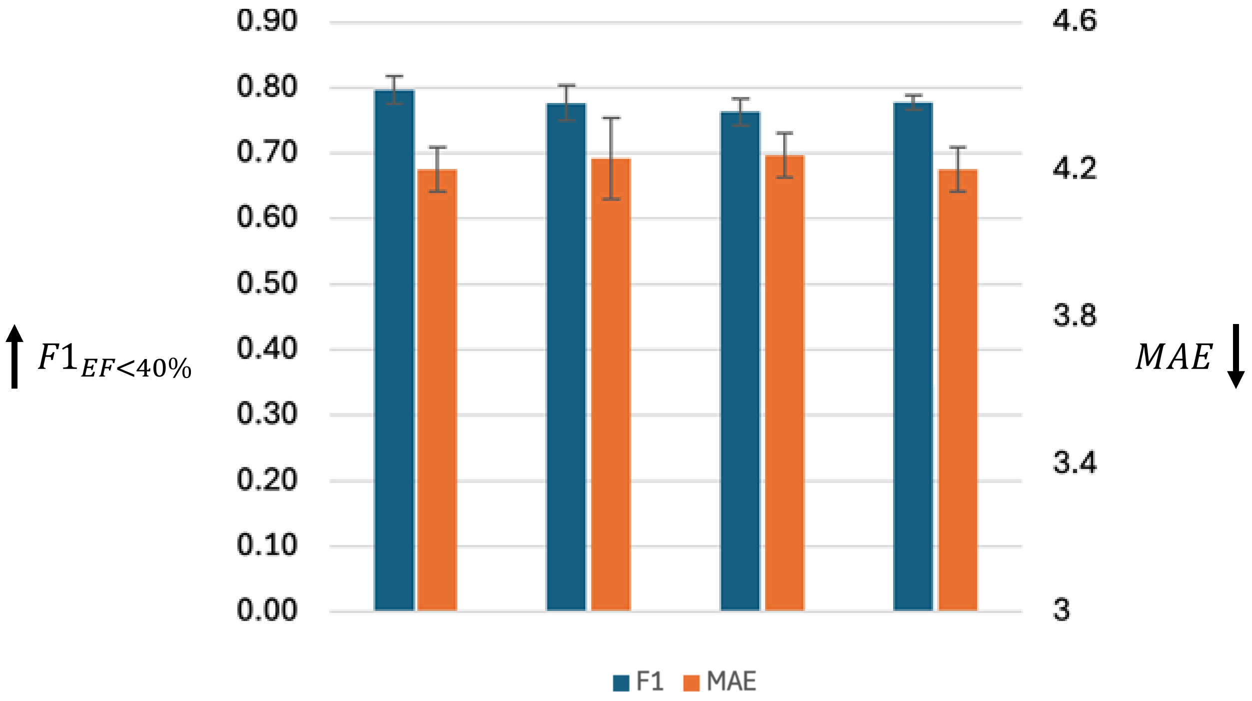
Comparison with SOTA: Quantitative Results



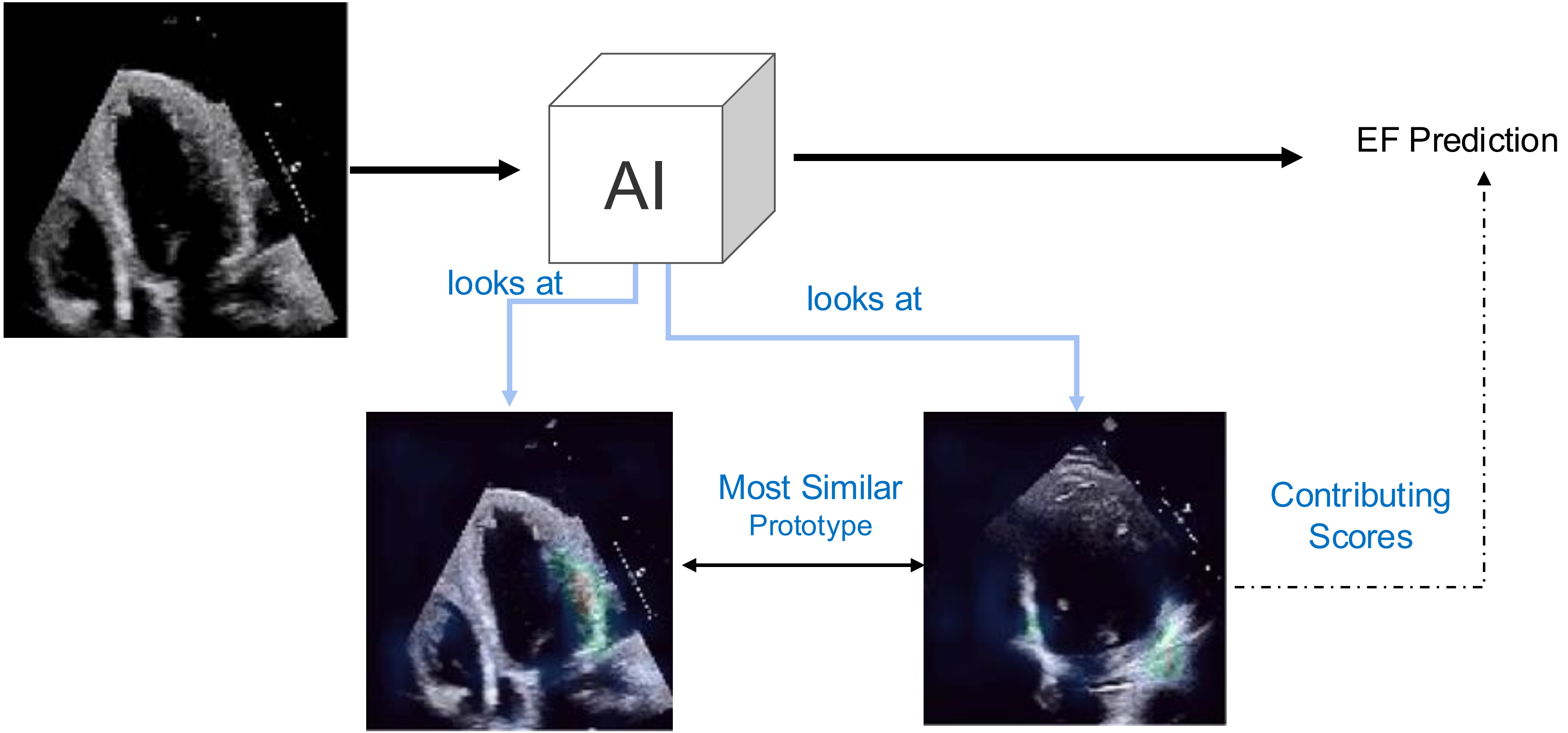
Comparison with SOTA: ProtoEFNet has localized attention



Ablation Study



ProtoEFNet in a Nutshell



Acknowledgement

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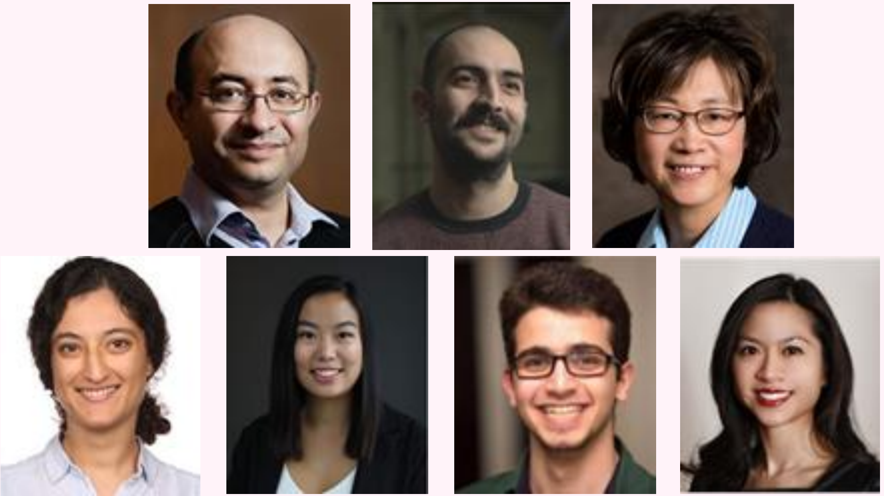
UBC VGH AI ECHO CORE LAB

Robotics and Control Lab

THE UNIVERSITY OF BRITISH COLUMBIA

DTU Technical University of Denmark

GitHub



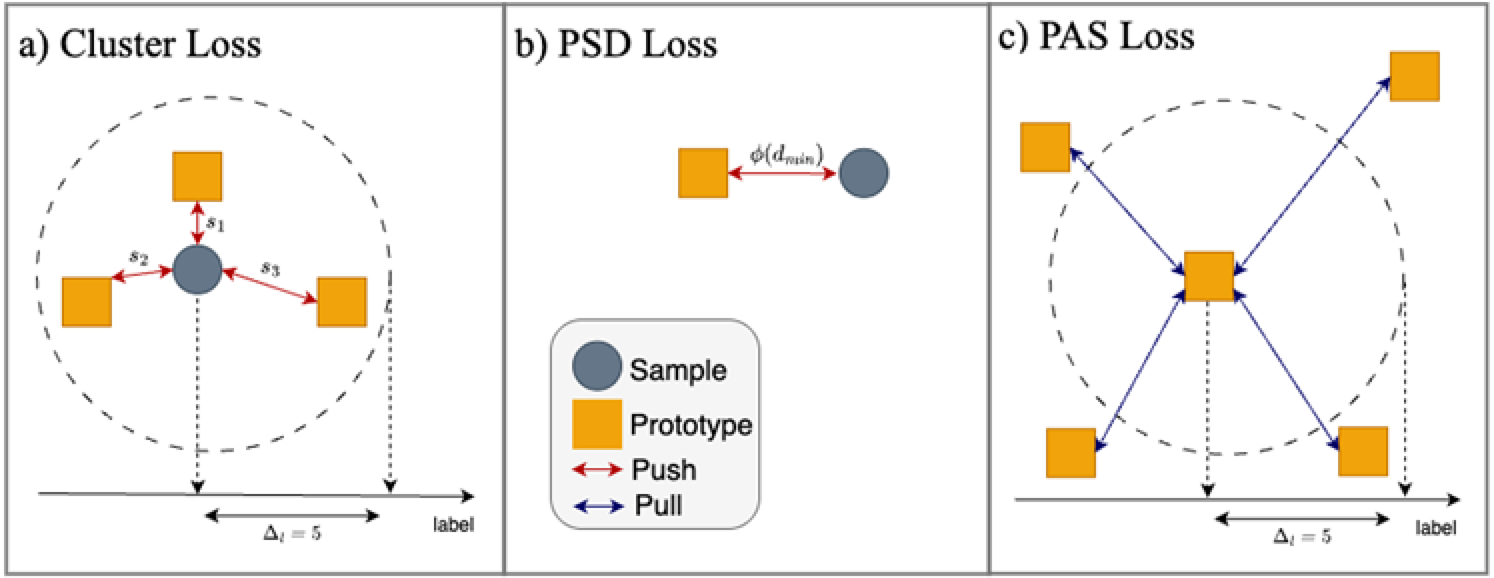
27

Q & A

GitHub

Appendix: Objective Functions

Loss Term	Goal	Type	Weight
$\mathcal{L}_{MSE}$	Regression Performance	MSE	0.1
$\mathcal{L}_{Clst}$	Cluster samples around prototypes	Agg	10
$\mathcal{L}_{PSD}$	Keep prototypes close to a sample	log-loss	30
$\mathcal{L}_{PAS}$	Separate prototypes based on their EF values	log-loss	0.1
$\mathcal{L}_{Occur}$	Focus activation map on LV region	L1	0.0001



$$\mathcal{L} = \underbrace{\lambda_{MSE}\mathcal{L}_{MSE}}_{\text{reg}} + \underbrace{\lambda_{Clst}\mathcal{L}_{Clst} + \lambda_{PSD}\mathcal{L}_{PSD} + \lambda_{PAS}\mathcal{L}_{PAS}}_{\text{Learning Embedding Space + Prototypes}} + \underbrace{\lambda_{occur}\mathcal{L}_{L_1}}_{\text{Optimize ROI}}$$