Distribution-Aware Replay for Continual MRI Segmentation

TECHNISCHE UNIVERSITÄT DARMSTADT

MEC Lab

OWL

hessian.AI

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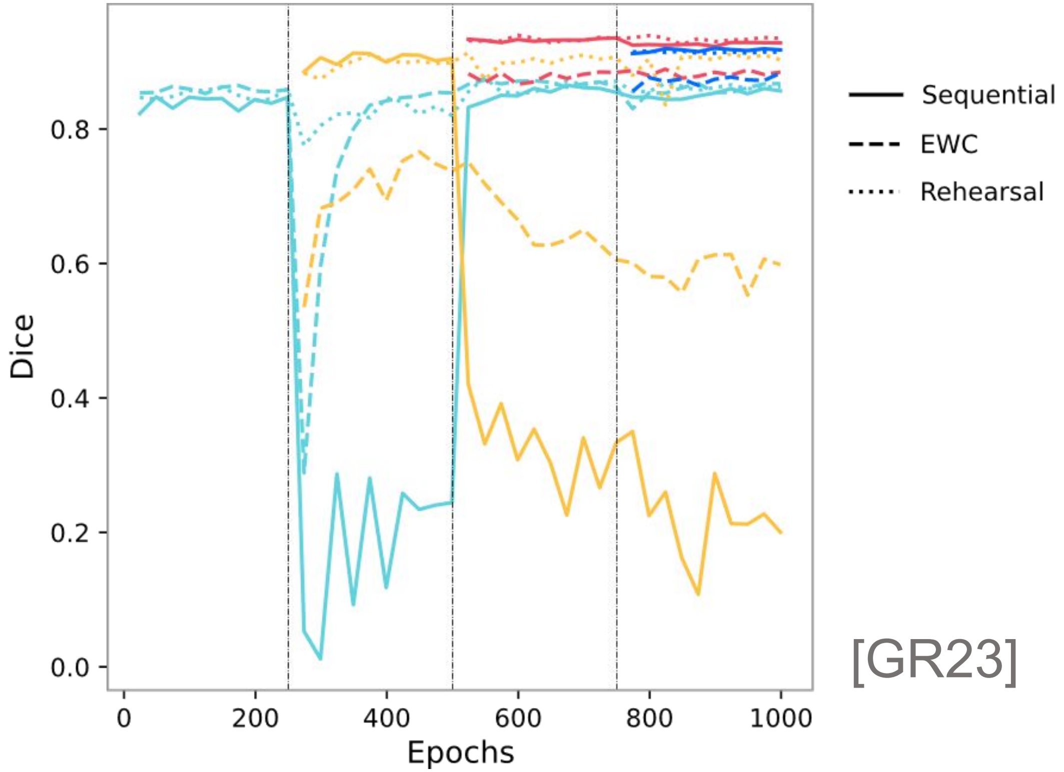
Why Pseudo-Rehearsal?

- ***Regularisation / Distillation:*** Do not perform well enough [GL20]
- ***Expansion:*** Model size grows
- ***Rehearsal:*** Performs well, but suffers from **privacy breach** [GL20]
- ***Solution:*** Pseudo-Rehearsal



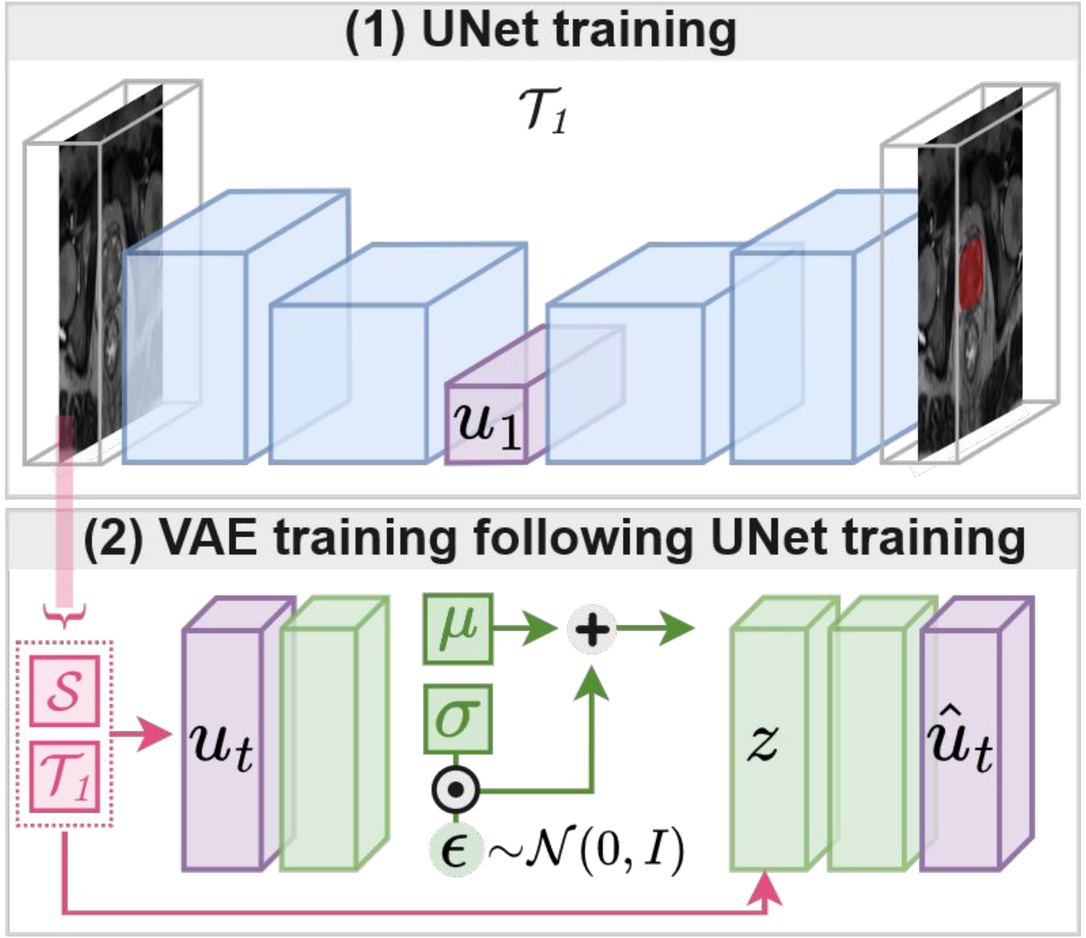
[GR23]

[GL20] González, C., Lemke, N., Sakas, G., Mukhopadhyay, A.: What is wrong with continual learning in medical image segmentation? arXiv:2010.11008 (2020)
[GR23] González, C., Ranem, A., Pinto dos Santos, D., Othman, A., & Mukhopadhyay, A.: Lifelong nnU-Net: a framework for standardized medical continual learning. Scientific Reports, 13(1), 9381 (2023)

Second-Stage Modeling

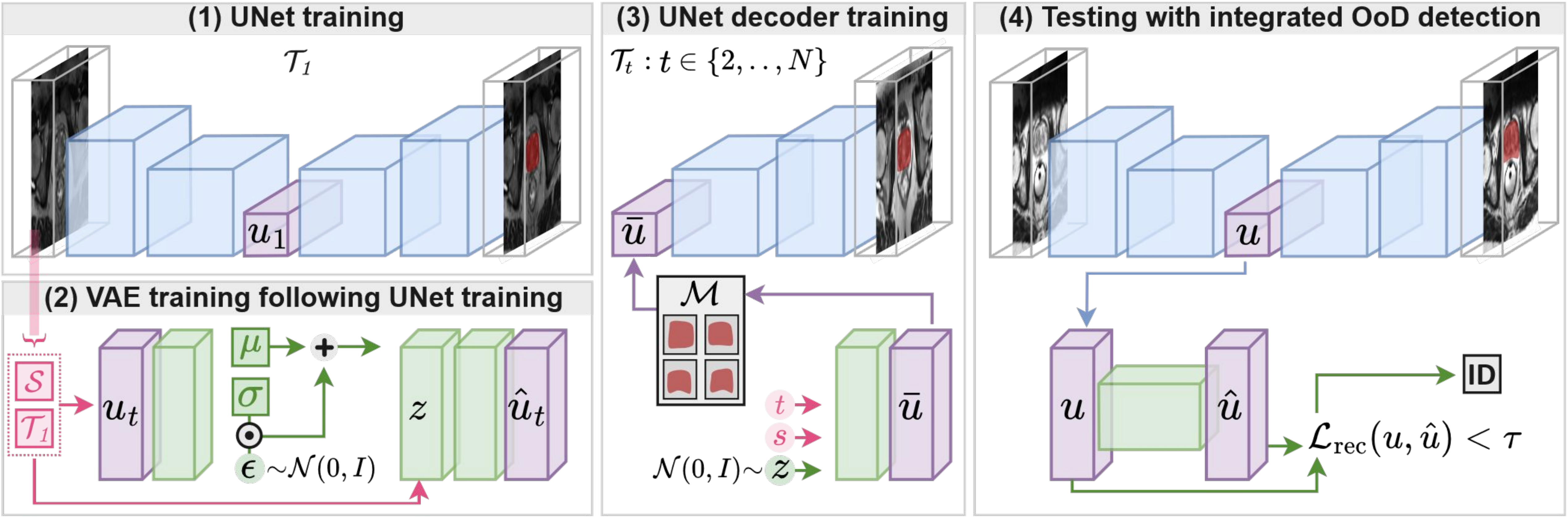
- Mathematically grounded [DW18, HM22]
- Additional privacy preservation
- Resource-efficient
- **Built-in** OoD detection

$$\log p(u) \geq \underbrace{\mathbb{E}_{z\sim q(z|u)}\left[\log p(u|z)\right]}_{\text{Reconstruction loss}} - \underbrace{\mathrm{KL}\left[q(z|u)||p(z)\right]}_{\text{KL divergence}}$$



[DW18] Dai, B., Wipf, D.: Diagnosing and enhancing vae models. International Conference on Learning Representations (2018)
[HM22] Hong, Y., Mundt, M., Park, S., Uh, Y., Byun, H.: Return of the normal distribution: Flexible deep continual learning with variational auto-encoders. Neural Networks 154, 397–412 (2022)

Distribution-Aware Replay via ccVAE



Experimental Setup

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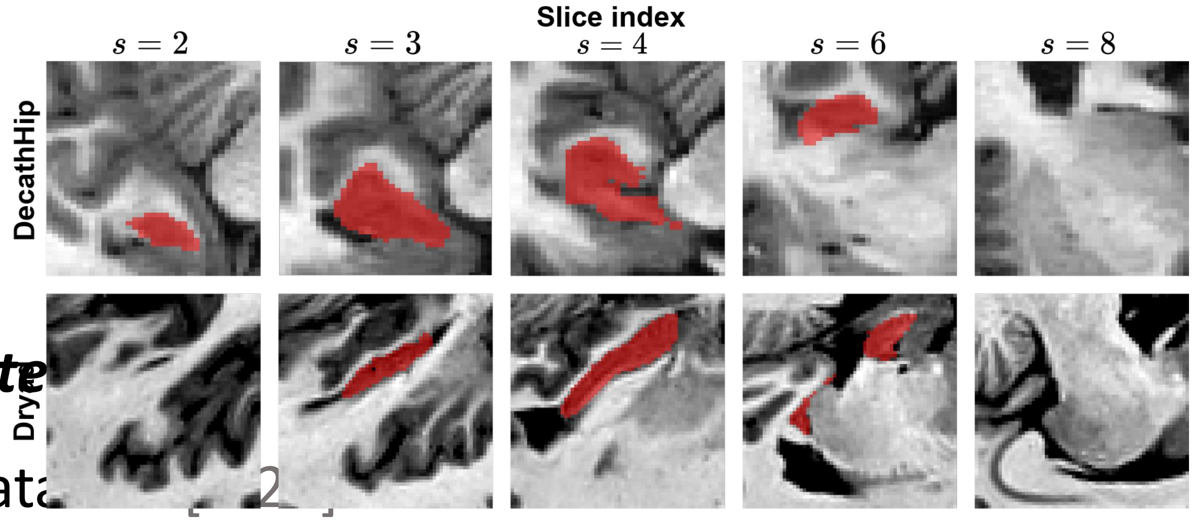
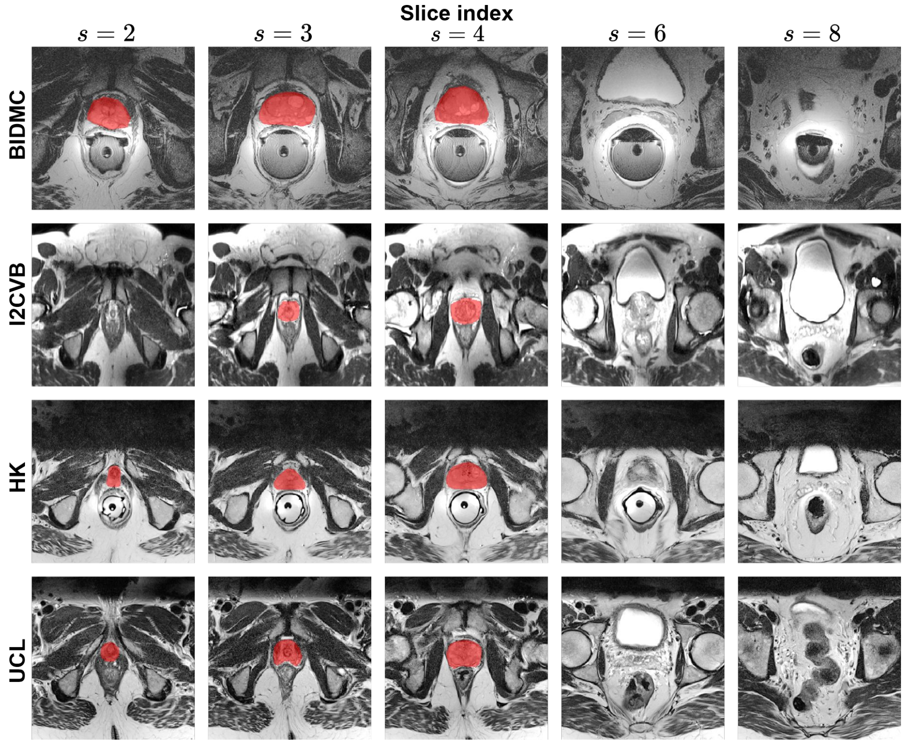
Hippocampus:

- 2 Datasets [AR22, KB15]
- 50 to 260 samples
- Median res.: [48, 64, 64]





Prostate

- 4 Data
- 12 to 30 samples
- Median res.: [20, 384, 384]

[AR22] Michela Antonelli, Annika Reinke, Spyridon Bakas, Keyvan Farahani, Annette Kopp-Schneider, Bennett A Landman, Geert Litjens, Bjoern Menze, Olaf Ronneberger, Ronald M Summers, et al. The medical segmentation decathlon. Nature communications, 13(1):4128, 2022

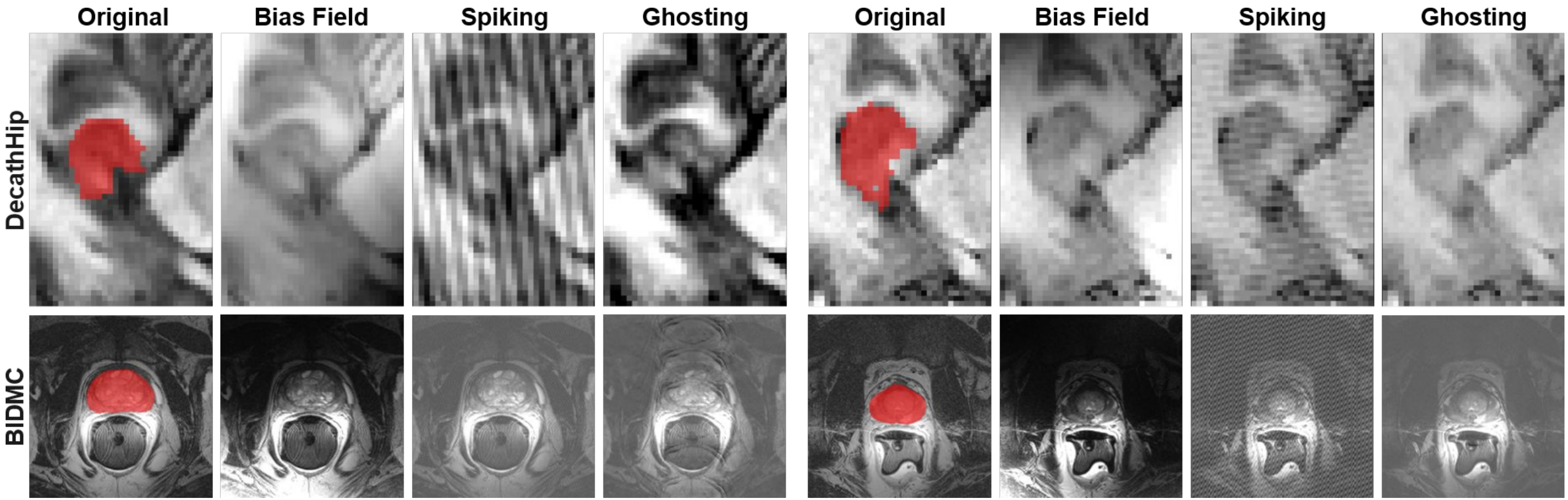
[KB15] Jessie Kulaga-Yoskovitz, Boris C Bernhardt, Seok-Jun Hong, Tommaso Mansi, Kevin E Liang, Andre JW Van Der Kouwe, Jonathan Smallwood, Andrea Bernasconi, and Neda Bernasconi. Multi-contrast submillimetric 3 tesla hippocampal subfield segmentation protocol and dataset. Scientific data, 2(1):1–9, 2015

[LY20] Quande Liu, Qi Dou, Lequan Yu, and Pheng Ann Heng. Ms-net: multi-site network for improving prostate segmentation with heterogeneous mri data. IEEE transactions on medical imaging, 39(9):2713–2724, 2020

Experimental Setup

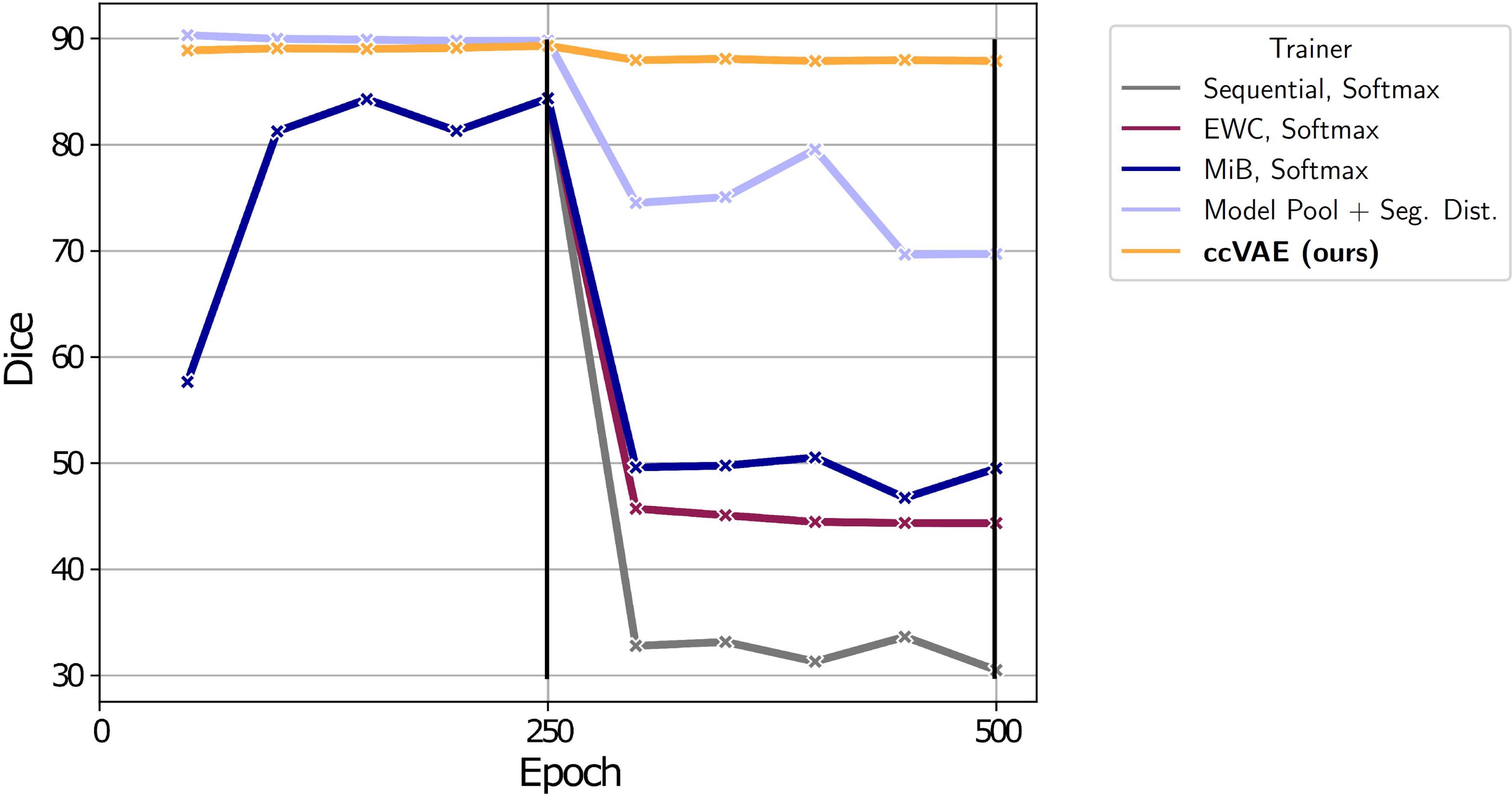
OoD detection:

- One additional dataset per anatomy [WD17, LY20]
- Artificial data augmentations

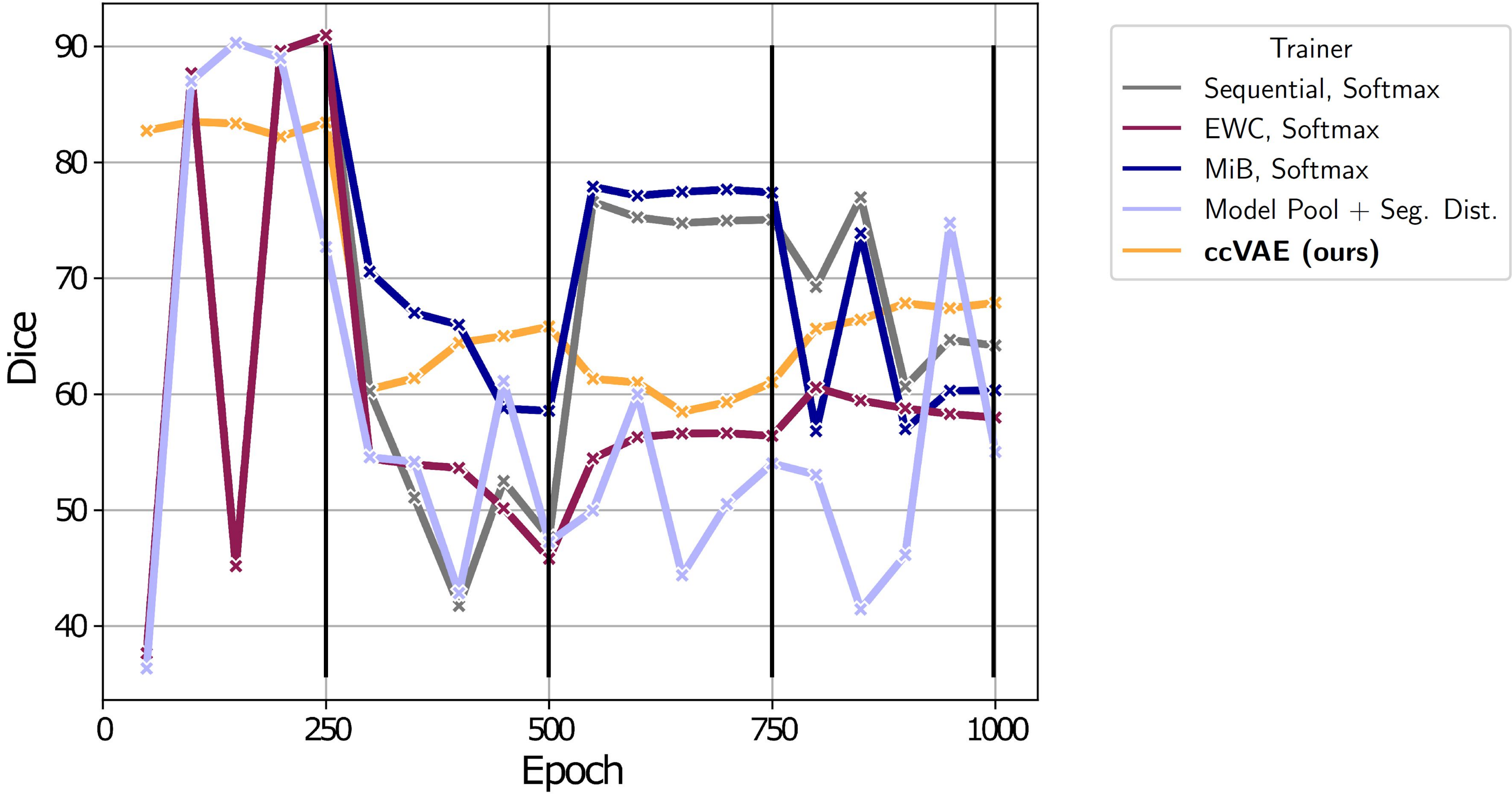


[LY20] Quande Liu, Qi Dou, Lequan Yu, and Pheng Ann Heng. Ms-net: multi-site network for improving prostate segmentation with heterogeneous mri data. IEEE transactions on medical imaging, 39(9):2713–2724, 2020
[WD17] Laura EM Wisse, Ana M Daugherty, Rosanna K Olsen, David Berron, Valerie A Carr, Craig EL Stark, Robert SC Amaral, Katrin Amunts, Jean C Augustinack, Andrew R Bender, et al. A harmonized segmentation protocol for hippocampal and parahippocampal subregions: Why do we need one and what are the key goals? Hippocampus, 27(1):3–11, 2017.

Results: Hippocampus



Results: Prostate



Data Shift and Image Artifacts

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- ccVAE demonstrates superior stable performance

Training stage/ Method	*DecathHip* Dice ↑	**E** ↓	*Dryad* Dice ↑	**E** ↓	*BIDMC* Dice ↑	**E** ↓	*I2CVB* Dice ↑	**E** ↓	*HK* Dice ↑	**E** ↓	*UCL* Dice ↑	**E** ↓
Seq., SM [HG17]	63.4±39	51.1	19.4±31	48.3	50.5±40	39.8	38.8±36	40.3	71.0±16	26.7	58.9±28	16.7
EWC [KP17], SM [HG17]	63.4±39	51.1	32.6±38	49.6	50.5±40	39.8	37.3±32	34.2	46.2±27	30.2	48.2±26	25.3
MiB [CM20], SM [HG17]	63.4±39	51.1	26.5±31	45.3	50.5±40	39.8	44.3±30	20.6	70.7±16	21.8	48.5±33	31.8
MPool [GR22], SD [LS23]	82.4±24	48.3	47.8±40	42.4	47.2±42	37.2	37.6±34	43.4	46.4±34	37.2	41.4±36	34.4
ccVAE (ours)	89.3±3	7.8	83.2±14	4.7	75.6±11	14.8	56.7±17	21.5	49.4±21	27.8	58.8±15	32.3

[CM20] Cermelli, F., Mancini, M., Bulo, S.R., Ricci, E., Caputo, B.: Modeling the back-ground for incremental learning in semantic segmentation. Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (2020)
[GR22] González, C., Ranem, A., Othman, A., Mukhopadhyay, A.: Task-agnostic continual hippocampus segmentation for smooth population shifts. MICCAI Workshop on Domain Adaptation and Representation Transfer pp. 108–118 (2022)
[HG17] Hendrycks, D., Gimpel, K.: A baseline for detecting misclassified and out-of-distribution examples in neural networks. International Conference on Learning Representations (2017)
[KP17] Kirkpatrick, J., Pascanu, R., Rabinowitz, N., Veness, J., Desjardins, G., Rusu, A.A., Milan, K., Quan, J., Ramalho, T., Grabska-Barwinska, A., et al.: Overcoming catastrophic forgetting in neural networks. Proceedings of the National Academy of Sciences 114(13), 3521–3526 (2017)
[LS23] Lennartz, J., Schultz, T.: Segmentation distortion: Quantifying segmentation uncertainty under domain shift via the effects of anomalous activations. International Conference on Medical Image Computing and Computer-Assisted Intervention pp. 316–325 (2023)

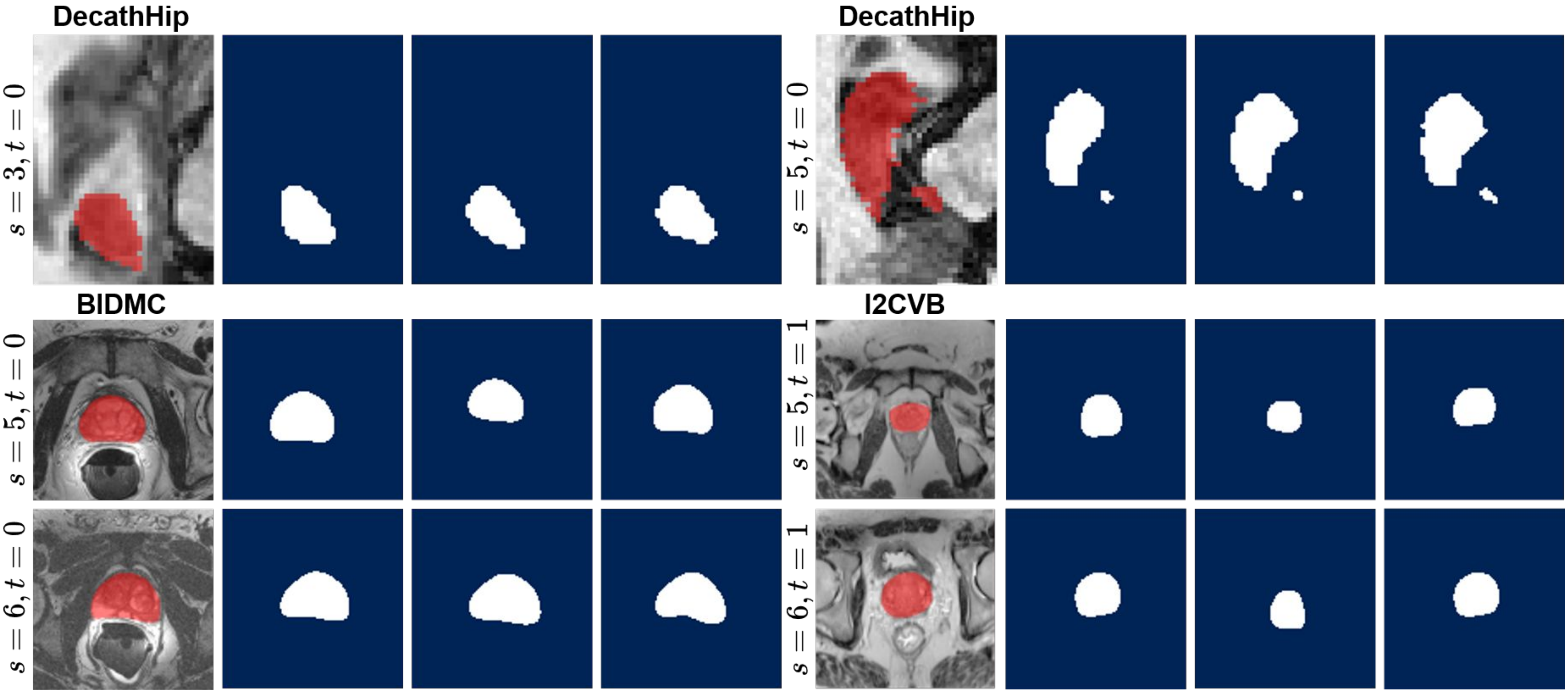
Ablation Study

- Both conditioning and OoD detection using reconstruction contribute to performance

Training stage/ Method	DecathHip Dice ↑	DecathHip E ↓	Dryad Dice ↑	Dryad E ↓	BIDMC Dice ↑	BIDMC E ↓	I2CVB Dice ↑	I2CVB E ↓	HK Dice ↑	HK E ↓	UCL Dice ↑	UCL E ↓
MPool [GR22], SD [LS23]	89.8±3	33.4	69.7±35	20.1	72.3±34	30.3	48.6±34	35.1	55.1±31	31.8	55.9±34	30.2
ccVAE, Mah. [GG22]	89.0±3	13.2	61.2±33	24.4	39.1±30	29.0	60.5±13	34.7	60.4±18	34.2	67.9±10	22.6
cVAE, Rec.	89.3±3	3.8	87.6±4	16.8	83.4±2	24.4	64.7±9	19.4	65.4±12	17.3	65.4±10	28.6
ccVAE	89.4±3	4.7	87.9±5	14.5	83.4±2	25.5	66.2±9	27.2	60.0±19	35.5	67.9±10	37.8

[GG22] González, C., Gotkowski, K., Fuchs, M., Bucher, A., Dadras, A., Fischbach, R., Kaltenborn, I.J., Mukhopadhyay, A.: Distance-based detection of out-of-distribution silent failures for covid-19 lung lesion segmentation. Medical image analysis 82, 102596 (2022)
[GR22] González, C., Ranem, A., Othman, A., Mukhopadhyay, A.: Task-agnostic continual hippocampus segmentation for smooth population shifts. MICCAI Workshop on Domain Adaptation and Representation Transfer pp. 108–118 (2022)
[LS23] Lennartz, J., Schultz, T.: Segmentation distortion: Quantifying segmentation uncertainty under domain shift via the effects of anomalous activations. International Conference on Medical Image Computing and Computer-Assisted Intervention pp. 316–325 (2023)

Generated Features



Conclusion

- No modification of segmentation model
- ccVAE models data distributions
- Pseudo-rehearsal tackles catastrophic forgetting
- Distribution-awareness detects OoD subjects

Publication

Code

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