A Cross-Stitch Architecture for Joint Registration and Segmentation in Adaptive Radiotherapy

Laurens Beljaards[1], Mohamed S. Elmahdy[2], Fons Verbeek[1], Marius Staring[2,3]
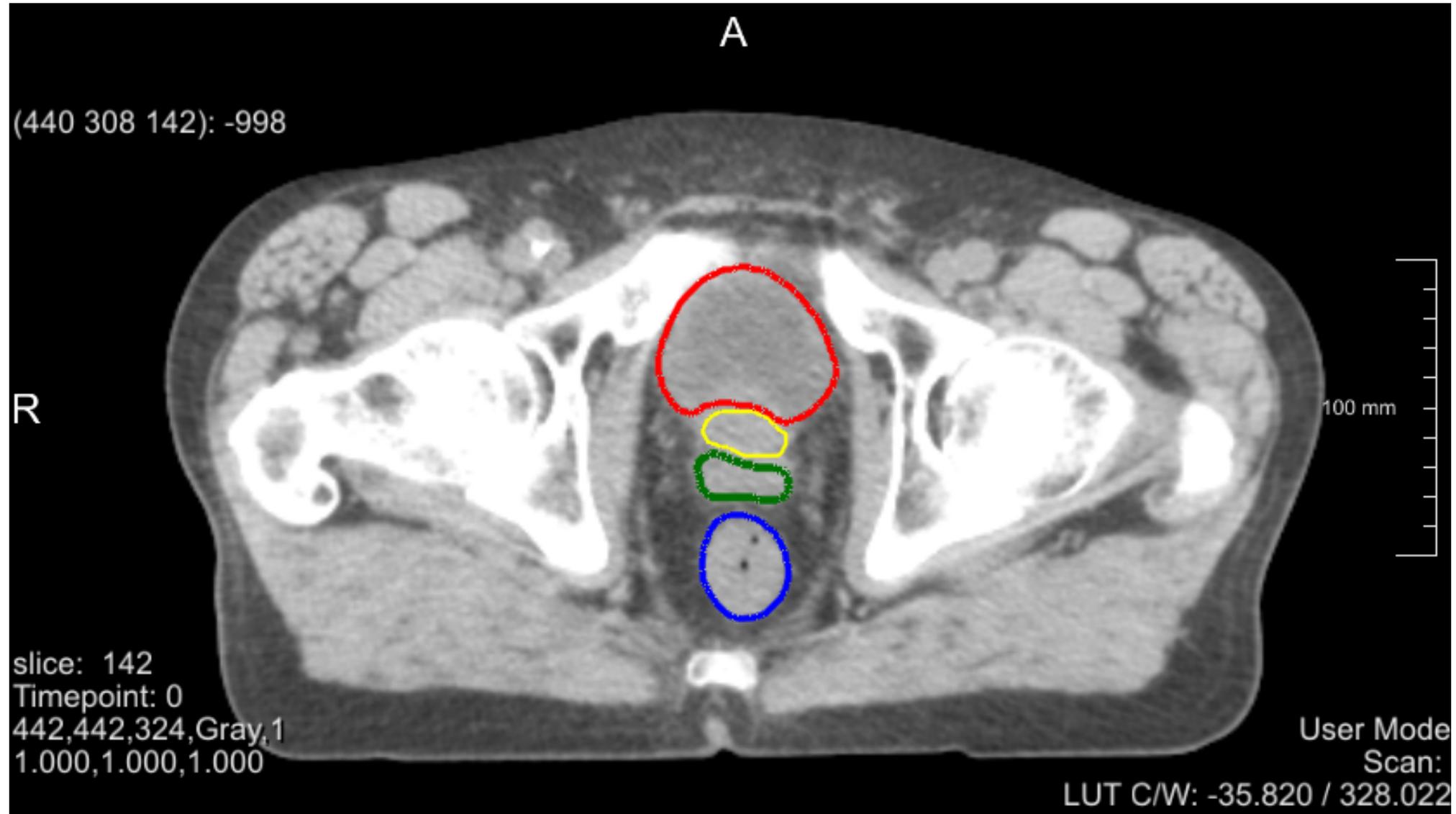
MIDL
Montréal 2020

[1] Leiden Institute of Advanced Computer Science
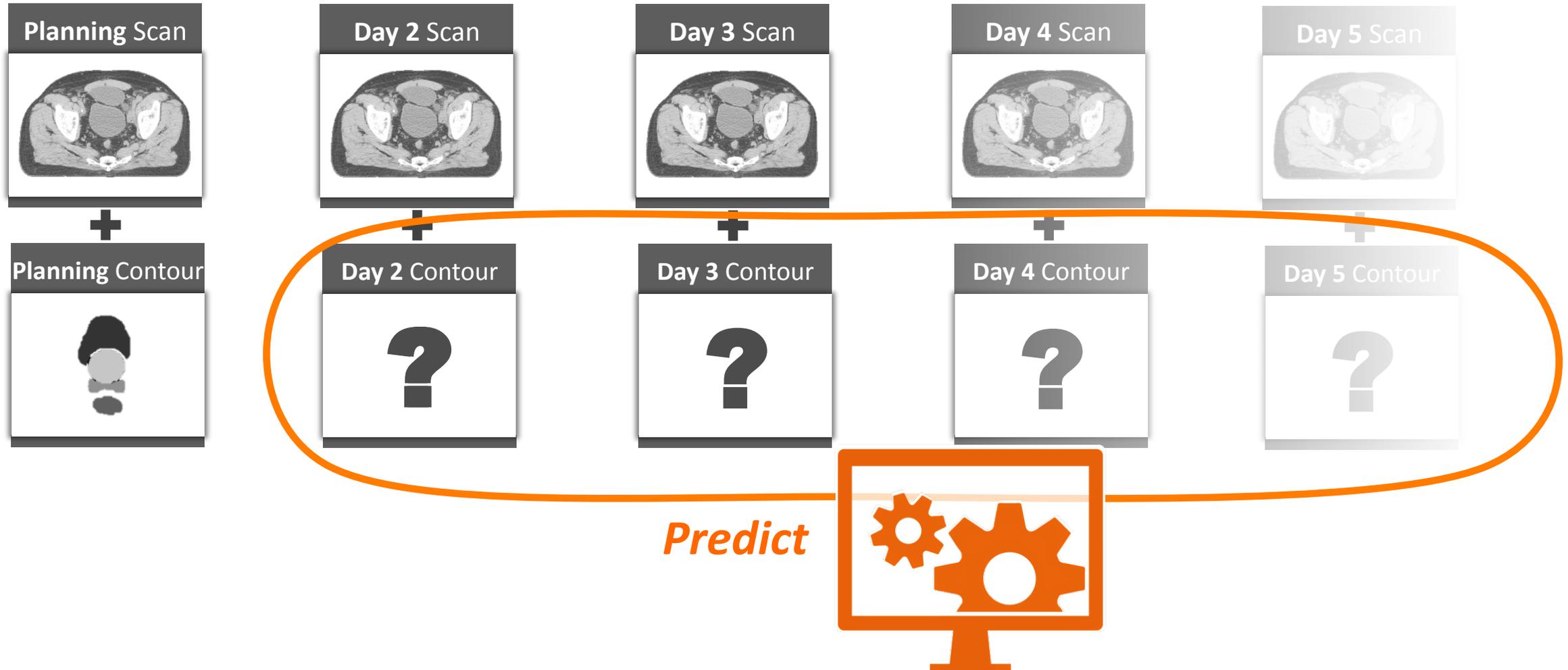[2] Division of Image Processing, Department of Radiology, Leiden University Medical Center
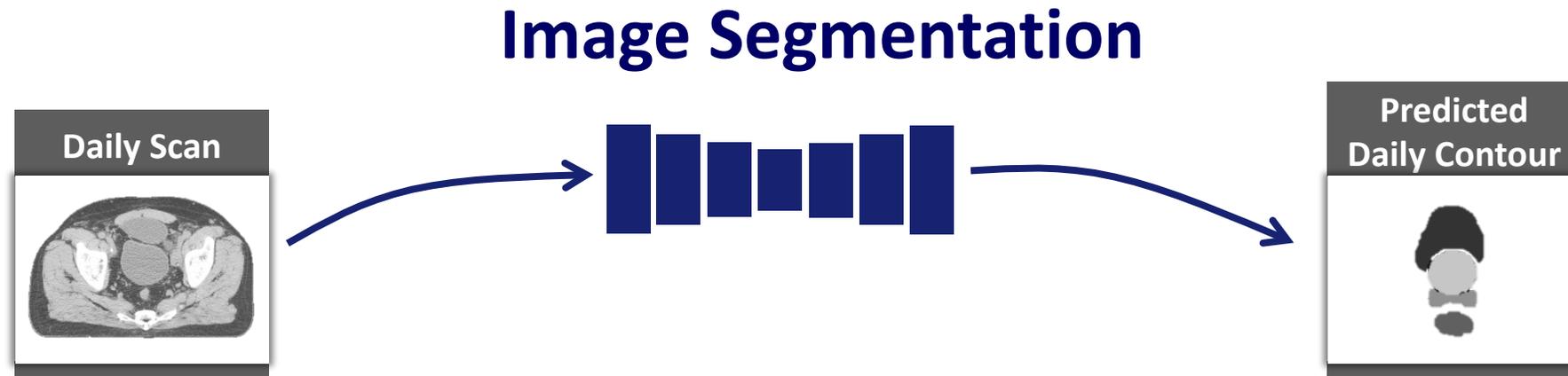[3] Department of Radiation Oncology, Leiden University Medical Center

- **Online Adaptive Radiotherapy: Time intensive**

Predict

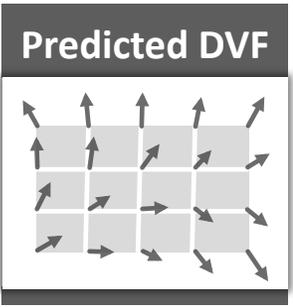# Generating Contours

Image Segmentation
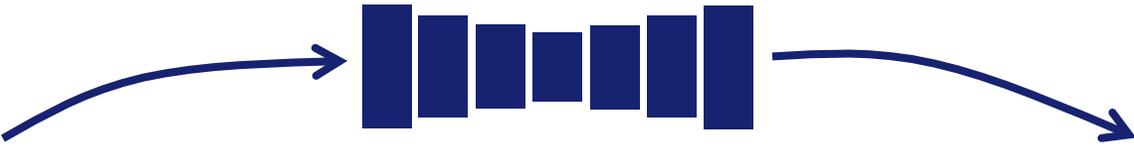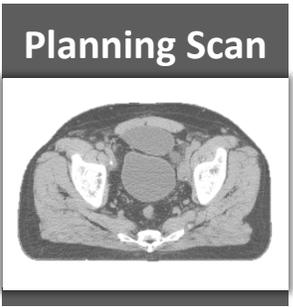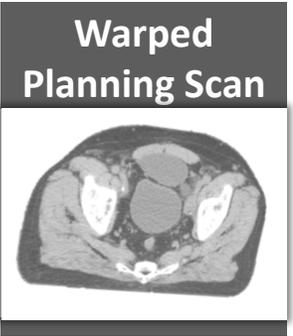
Daily Scan

Predicted Daily Contour

Image Registration

Planning Scan

Daily Scan

Predicted DVF

Warp planning scan

Warped Planning Scan ≈ Daily Scan
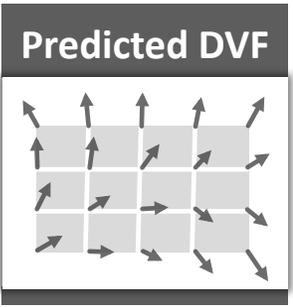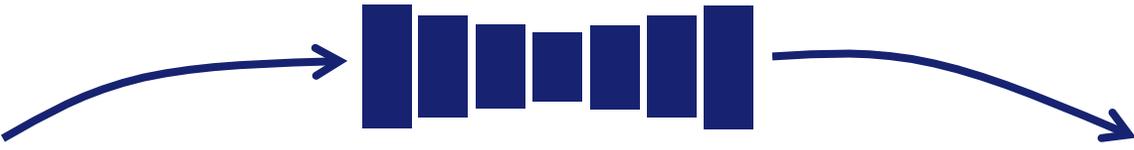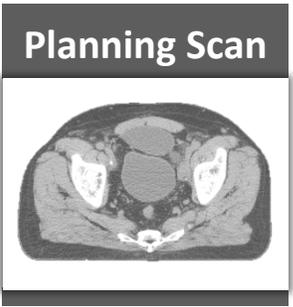
Overview

- **Registration** with contour propagation:
    Prior knowledge of the patient's anatomy (Planning scan & contour)

- **Segmentation**:
    Robust to organ **deformations**

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- Joining the two methods to exploit their strengths

- **A)** Joint-Registration-Segmentation (JRS) through **loss** for contour propagation

- **B)** We combine Segmentation and Registration in **one joint network**

Results in terms of MSD

	Prostate	Seminal vesicles	Rectum	Bladder
	$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$
Segmentation	1.49 ± 0.3	2.50 ± 2.6	3.39 ± 2.2	$\mathbf{1.60 \pm 1.1}$
Registration	$\mathbf{1.43 \pm 0.8}$	$\mathbf{1.71 \pm 1.4}$	$\mathbf{2.44 \pm 1.1}$	3.40 ± 2.3

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JRS-Registration	$\mathbf{1.20 \pm 0.4}$	$\mathbf{1.35 \pm 0.7}$	$\mathbf{2.08 \pm 1.0}$	2.63 ± 2.3

Results in terms of MSD

	Output Path	Prostate $\mu \pm \sigma$	Seminal vesicles $\mu \pm \sigma$	Rectum $\mu \pm \sigma$	Bladder $\mu \pm \sigma$
Segmentation		1.49 ± 0.3	2.50 ± 2.6	3.39 ± 2.2	1.60 ± 1.1
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JRS-Registration		1.20 ± 0.4	1.35 ± 0.7	2.08 ± 1.0	2.63 ± 2.3
Fully Hard Sharing	*Segmentation*	$\mathbf{1.14 \pm 0.4}$	1.73 ± 2.1	$\mathbf{1.91 \pm 0.9}$	$\mathbf{1.04 \pm 0.7}$
	Registration	1.20 ± 0.3	$\mathbf{1.33 \pm 0.7}$	2.16 ± 1.1	2.56 ± 1.9

Results in terms of MSD

- † denotes a significant difference (at p = 0.05) with the cross-stitch network

	Output Path	Prostate $\mu \pm \sigma$	Seminal vesicles $\mu \pm \sigma$	Rectum $\mu \pm \sigma$	Bladder $\mu \pm \sigma$
Segmentation		$1.49 \pm 0.3^{\dagger}$	$2.50 \pm 2.6^{\dagger}$	$3.39 \pm 2.2^{\dagger}$	$1.60 \pm 1.1^{\dagger}$
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	Registration	$1.20 \pm 0.3^{\dagger}$	1.33 ± 0.7	$2.16 \pm 1.1^{\dagger}$	$2.56 \pm 1.9^{\dagger}$
Cross-Stitch	*Segmentation*	$\mathbf{1.06 \pm 0.3}$	$\mathbf{1.27 \pm 0.4}$	$\mathbf{1.76 \pm 0.8}$	$\mathbf{0.91 \pm 0.4}$
	Registration	1.10 ± 0.3	1.30 ± 0.6	2.00 ± 1.0	2.45 ± 2.1

Comparison with State-of-the-Art Methods

- **"*Elastix*"**[1]: Conventional **iterative** method using Elastix software[1] with MI similarity measure

- **"*JRS-GAN*"**[2]: An **unsupervised GAN** to jointly perform deformable image registration and segmentation

- **"*Hybrid*"**[3]: A **hybrid learning and iterative** approach. It uses domain specific strategies to further improve the registration

[1] S. Klein, M. Staring, K. Murphy, M.A. Viergever, J.P.W. Pluim. elastix: a toolbox for intensity based medical image registration, IEEE Transactions on Medical Imaging, vol. 29, no. 1, pp. 196 - 205, January 2010

[2] Mohamed S. Elmahdy, Jelmer Wolterink, et al. Adversarial Optimization for Joint Registration and Segmentation in Prostate CT Radiotherapy. In Lecture Notes in Computer Science (pp. 366–374). Springer, 2019

[3] Mohamed S. Elmahdy, Thyrza Jagt, et al. Robust contour propagation using deep learning and image registration for online adaptive proton therapy of prostate cancer. Medical physics, 2019

Results – Validation Set (HMC Dataset)

- Results in terms of MSD on the validation set (HMC dataset)

- † denotes a significant difference (at p = 0.05) with the cross-stitch network

	Output Path	Prostate $\mu \pm \sigma$	Prostate Median	Seminal vesicles $\mu \pm \sigma$	Seminal vesicles Median	Rectum $\mu \pm \sigma$	Rectum Median	Bladder $\mu \pm \sigma$	Bladder Median
Cross-Stitch	*Segmentation*	**1.06 ± 0.3**	**0.99**	**1.27 ± 0.4**	1.15	**1.76 ± 0.8**	**1.47**	**0.91 ± 0.4**	**0.82**
	Registration	1.10 ± 0.3	1.06	1.30 ± 0.6	**1.13**	2.00 ± 1.0	1.75	2.45 ± 2.1	1.81
Elastix		1.73 ± 0.7†	1.59	2.71 ± 1.6†	2.45	3.69 ± 1.2†	3.50	5.26 ± 2.6†	4.72
JRS-GAN		1.14 ± 0.3†	1.04	1.75 ± 1.3†	1.44	2.17 ± 1.1†	1.89	2.25 ± 1.9†	1.54
Hybrid		1.27 ± 0.3†	1.25	1.47 ± 0.5†	1.32	2.03 ± 0.6†	1.85	1.75 ± 1.0†	1.26

Results – Independent Test Set (EMC Dataset)

- Results in terms of MSD on the **independent test set** (EMC dataset)

- The networks have **not been retrained** or fine-tuned on this dataset

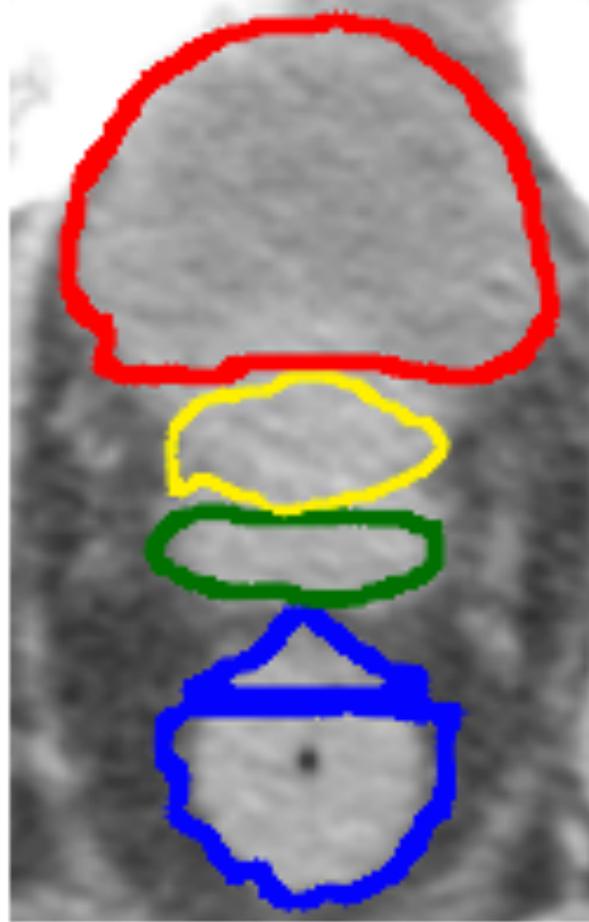|	Output Path	Prostate $\mu \pm \sigma$	Prostate Median	Seminal vesicles $\mu \pm \sigma$	Seminal vesicles Median	Rectum $\mu \pm \sigma$	Rectum Median	Bladder $\mu \pm \sigma$	Bladder Median
Segmentation		$3.18 \pm 1.8^{\dagger}$	2.57	$9.33 \pm 10.1^{\dagger}$	5.82	$5.79 \pm 3.4^{\dagger}$	5.18	$\mathbf{1.88 \pm 1.5}$	1.50
Registration		$2.01 \pm 2.5^{\dagger}$	1.18	$2.86 \pm 5.2^{\dagger}$	1.18	$2.89 \pm 2.5^{\dagger}$	2.23	$5.98 \pm 4.7^{\dagger}$	4.44
Cross-Stitch	*Segmentation*	1.88 ± 2.2	1.21	4.73 ± 8.0	1.42	3.61 ± 5.0	2.18	2.45 ± 2.4	$\mathbf{1.24}$
	Registration	1.82 ± 2.4	$\mathbf{1.09}$	2.45 ± 5.0	$\mathbf{1.02}$	$\mathbf{2.57 \pm 2.3}$	$\mathbf{2.10}$	4.93 ± 4.1	2.69
Elastix		$\mathbf{1.42 \pm 0.7}$	1.17	$2.07 \pm 2.6^{\dagger}$	1.24	$3.20 \pm 1.6^{\dagger}$	3.07	$5.30 \pm 5.1^{\dagger}$	3.27
Hybrid		$1.55 \pm 0.6^{\dagger}$	1.36	$\mathbf{1.65 \pm 1.3}$	1.22	2.65 ± 1.6	2.36	$3.81 \pm 3.6^{\dagger}$	2.26

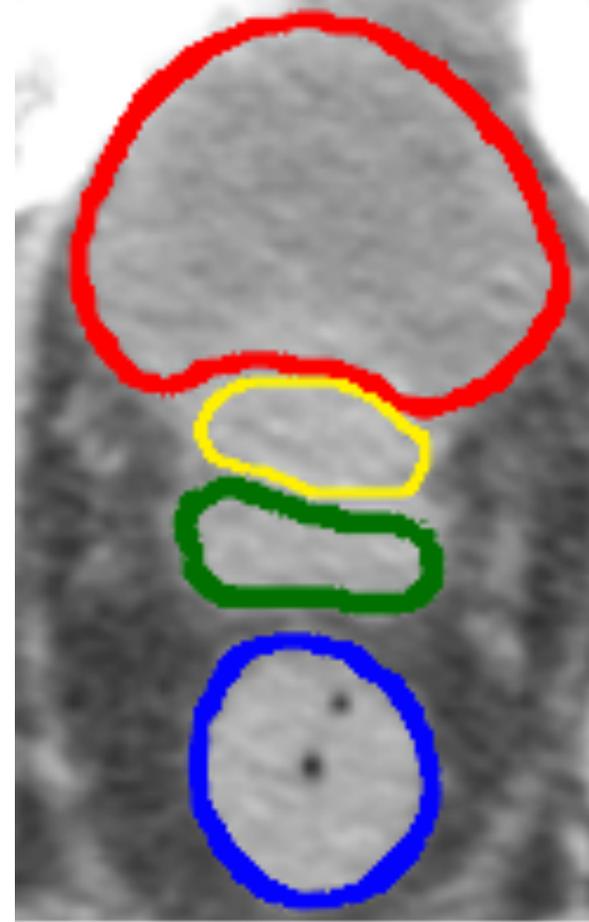Results for JRS-GAN not available for this dataset
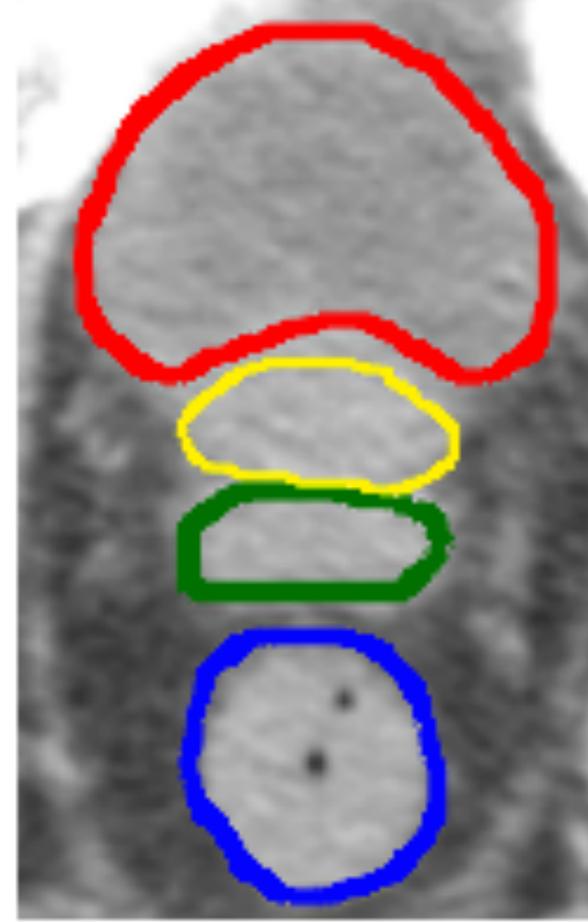
Visual Examples

Segmentation · Registration · Cross-Stitch (Segmentation Path) · Manual

Conclusion

- Combined segmentation and registration through **loss** and **architecture**

- Fully hard-sharing network and cross-stitch network

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- Good performance when compared to state-of-the-art methods

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- Future work:
    Generalization across datasets
    Third task, next to registration and segmentation tasks