# 4D Anatomical Constrained Motion-Compensated Reconstruction of On-Board 4D CBCT Scans

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# **Problem Statement**

remaining sparseness one minute CBCT artifacts **DIR** artifacts  $\approx$  20 breathings  $\Rightarrow$  20 scan angles sliding interface motion acMoCo<sup>1,2</sup> 4D FDK spine motion 0.8 0.6 0.4 back motion 0.2

### **Problems solvable with anatomical 4D regularisation ⇒ acacMoCo**

<sup>1</sup> Brehm, Kachelrieß et al., "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12) 7603, 2012. <sup>2</sup> Brehm, Kachelrieß et al., "Artifact-resistant motion estimation with a patient-specific artifact model for motion-compensated cone-beam CT," Med. Phys. 40(10) 101913, 2013. varian



# cMoCo<sup>1</sup> and acMoCo<sup>2</sup>



<sup>1</sup> Brehm, Kachelrieß et al., "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12) 7603, 2012. <sup>2</sup> Brehm, Kachelrieß et al., "Artifact–resistant motion estimation with a patient–specific artifact model for motion–compensated cone–beam CT," Med. Phys. 40(10) 101913, 2013.

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# **Materials and Methods**

### **Reconstruction:**

- 512×512×210 mm<sup>3</sup>
- 8×1 min scans and 2×2 min scans
- 20 phase-gated 4D FDK images, width = 10%, increment = 5%
- Methods: 4D FDK, acMoCo, acacMoCo

### **Motion Estimation:**

- Demons Algorithm
- Cyclic constraints<sup>1</sup>
- Artifact model<sup>2</sup>
- Anatomical constraints
  - Sliding Organ Motion<sup>3</sup>
  - Couch handling
  - Stationarity rules
  - Patient outline registration
- Multi-resolutions
- <sup>1</sup> Brehm, Kachelrieß et al., "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12) 7603, 2012.
- <sup>2</sup> Brehm, Kachelrieß et al., "Artifact–resistant motion estimation with a patient–specific artifact model for motion–compensated cone–beam CT," Med. Phys. 40(10) 101913, 2013.
- <sup>3</sup> Sauppe, Kachelrieß et al., "Sliding organ motion regularisation for motion– compensated cone–beam CT (CBCT) in image–guided radiation therapy (IGRT)," ECR 2018, B–1432.





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# **Anatomical Constrained Motion Estimation**

### acMoCo | anatomical-constrained acMoCo = acacMoCo

Demons driven motion vector field *u* estimation:

Calculate update field Δu.

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- Smooth  $\Delta u$  with Gaussian (FWHM = 17.7 mm).
- Smooth Δu with guided bilateral filter on sliding interface borders (FWHM = 17.7 mm) to prevent perpendicular cross interface motion transfer.
- Apply 4D weights:  $\Delta u_{4D} = W_{4D} \cdot \Delta u$ .
- Diffeomorphic composition  $u \rightarrow u \circ \Delta u$ .
- Smooth u with Gaussian (FWHM = 4.4 mm)



# end of inhale mid of exhale end of exhale mid of inhale Image: Imag



# guided bilateral filter at sliding organ border

### zero weights on spine

<sup>1</sup>Thirion, "Image matching as a diffusion process: an analogy with Maxwell's demons," Medical Image Analysis 2(3) 243-260, 1998. <sup>2</sup>Tom Vercauteren et al., "Diffeomorphic demons: Efficient non-parametric image registration", NeuroImage 45(1) S1 S61-S72, 2009.



### **Motion Vector Field Differences:**



C = 0 mm, W = 3 mm



gated FDK

**3D FDK** 3D FDK acMoCo acacMoCo acMoCo acacMoCo

**mMKB** 

acMoCo



B00

B01

B02

B03

BT2

H02

M00

M01

M03

V01

3%

2%

1%

0%

<sup>1</sup>Kingston et al., "Reliable automatic alignment of tomographic projection data by passive auto-focus". Med. Phys. 38(9), 4934, 2011.

**3D FDK** 



acacMoCo

# Conclusions

- Anatomical boundary conditions are an useful addition for physiologically better registration results in MoCo 4D CBCT reconstruction.
- The sharpness and stationarity of the spine can be enforced.
- The motion at the lung boundary can be decoupled.
- Artifacts related to the couch are reduced.



