Artefakt-resistente Bewegungsschätzung für die bewegungskompensierte CT

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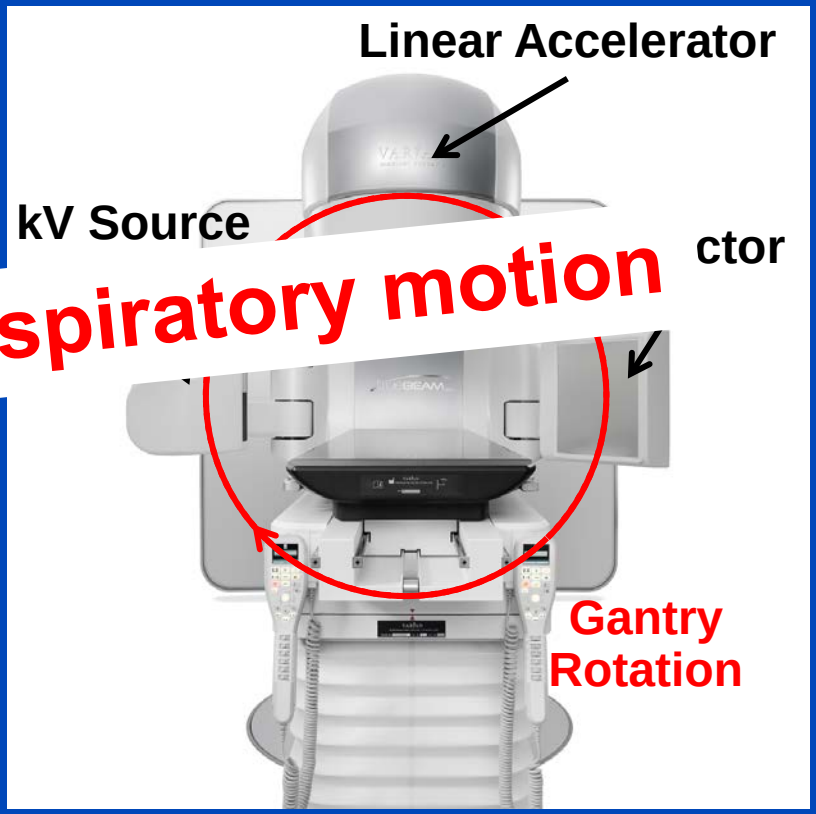
FAU VARIAN medical systems dkfz.

Slowly Rotating CBCT Devices

- **Image-guided radiation therapy (IGRT)**
  - CBCT imaging unit mounted on gantry of a LINAC treatment system
  - E.g. used for patient positioni
- **M**
  s **per second**
  - Much slower than clinical CT devices (60 s and more vs. about 0.28 s per rotation)
- **Breathing cycle about 2 to 5 seconds**
  - i.e. 12 to 30 respirations per minute (rpm) and thus per scan

Task: Account for respiratory motion



Prior Art in IGRT
(Respiratory-Correlated Reconstructions)

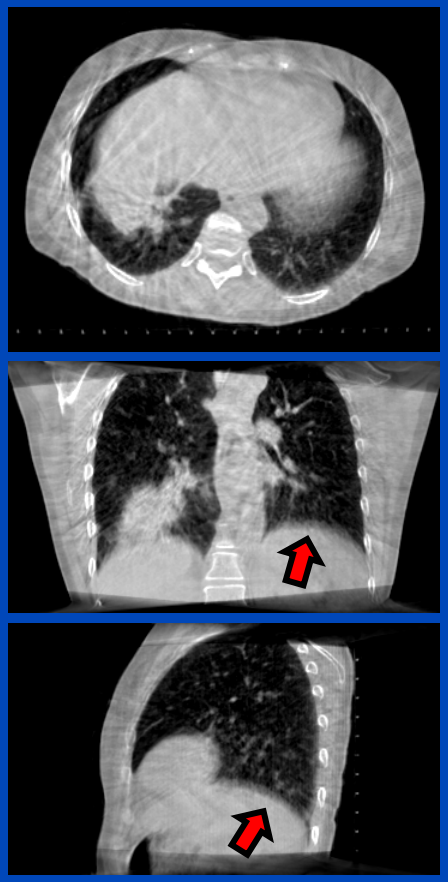
- **Respiratory gating and phase-correlated reconstruction**
  - **Sparse-view artifacts deteriorate image quality**
    - » **Streak artifacts and image noise**
- **Dedicated acquisition techniques**
  - **These are not accepted in clinical routine, e.g., due to long acquisition times**
- **Motion-compensated reconstruction**
  - **Required motion estimation leads to**
    - » **increased patient dose required,**
    - » **or detour over planning CT**

Aim

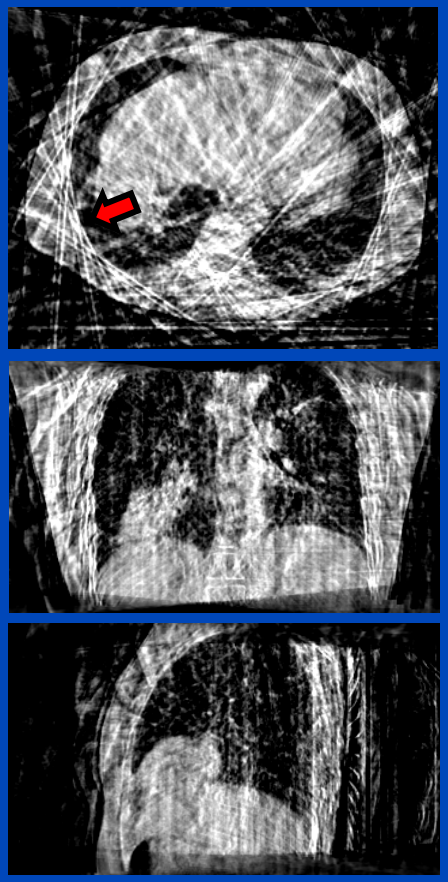
- **Provide high quality respiratory-correlated 4D volumes from on-board CBCT scans**
  - **Image quality comparable to that of motionless regions (e.g. head, neck, …)**
- **Do this with a standard acquisition protocol**
- **Do this without other prior information of higher temporal sampling such as a 4D planning CT**
  - **Account for inter-fractional variations in breathing motion**

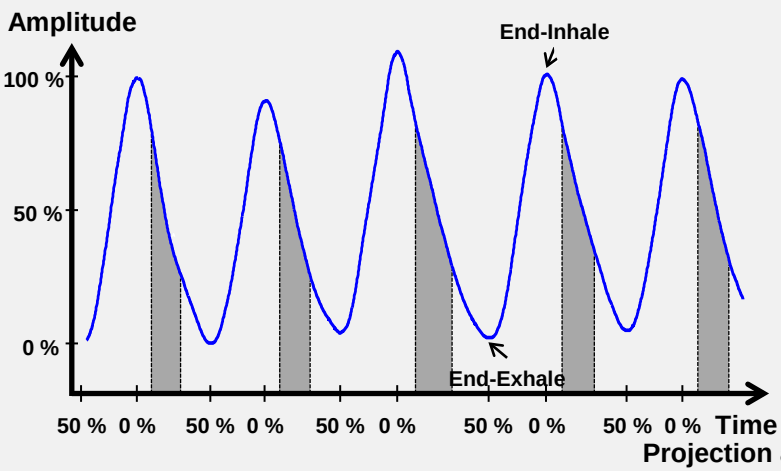
Retrospective Gating

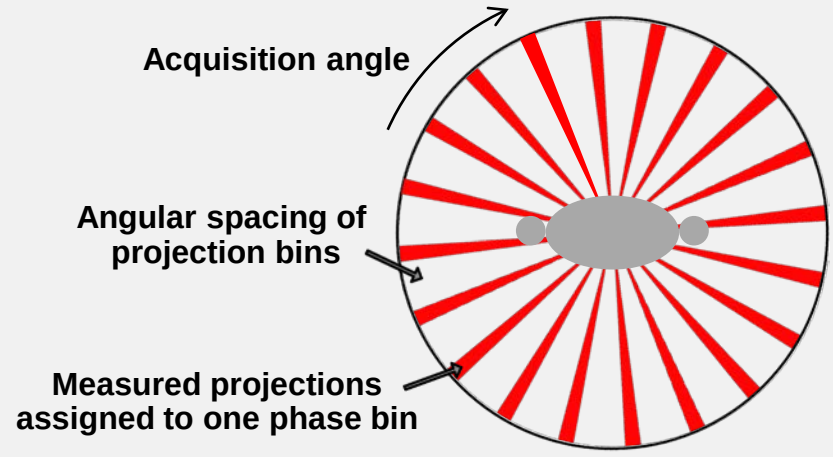
Without gating (3D): Motion artifacts



With gating (4D): Sparse-view artifacts





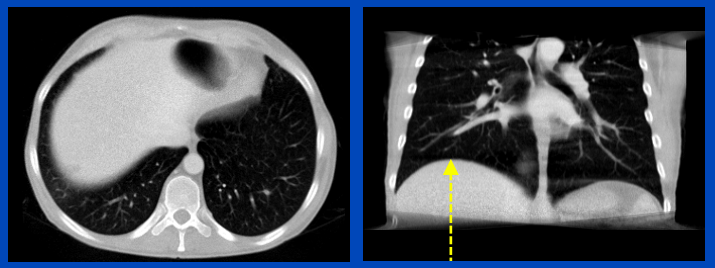


Motion Compensation (MoCo)

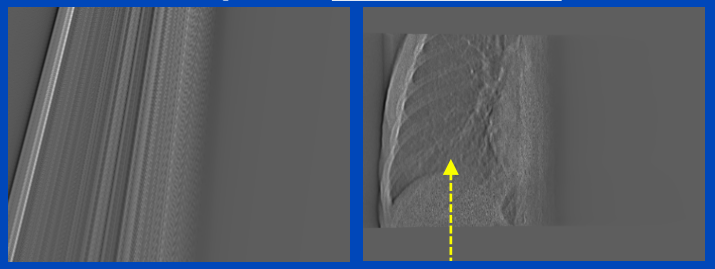
- **Use all projection data for each phase to be reconstructed**
  - Even those of other phase bins
  - Compensate for motion using motion vector fields (MVFs)
  - In our case MVFs are estimated from gated reconstructions
- **Backproject-then-warp**
  - Backproject sparse data along straight lines, warp with respect to the MVFs, and superimpose warped backprojections of all sparse data
  - Projection data p, phase-correlated reconstruction operator $\mathrm{X}_{\mathrm{PCF}}^{-1}$, MVF T_j^i from phase bin j to phase bin i

$$f_{\mathrm{MoCo}(i)} := \sum_j \left(\mathrm{X}_{\mathrm{PCF}(j)}^{-1} \, p \right) \circ \mathrm{T}_j^i$$

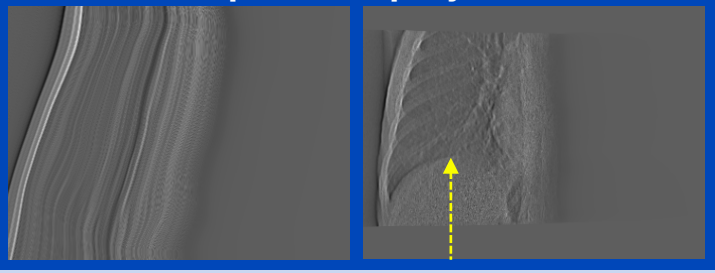
Ground truth in end-exhale



Backprojection on (straight) acquisition lines of a projection acquired in end-inhale

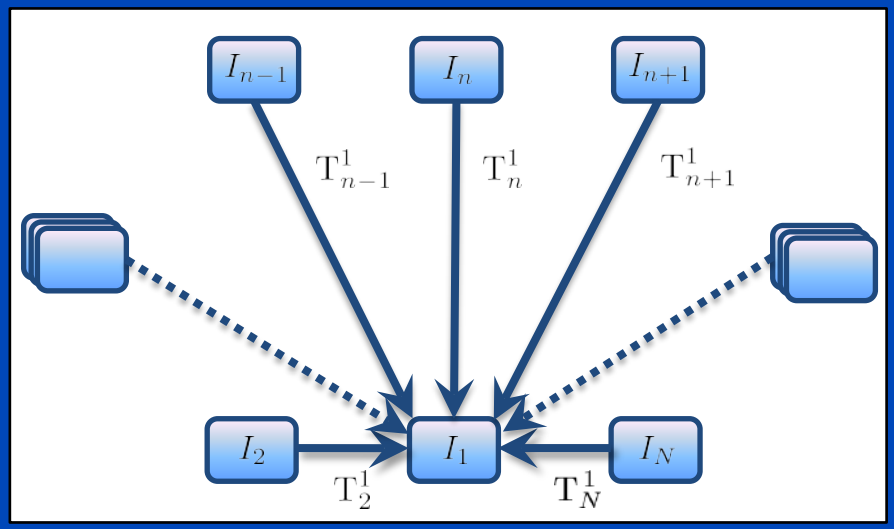


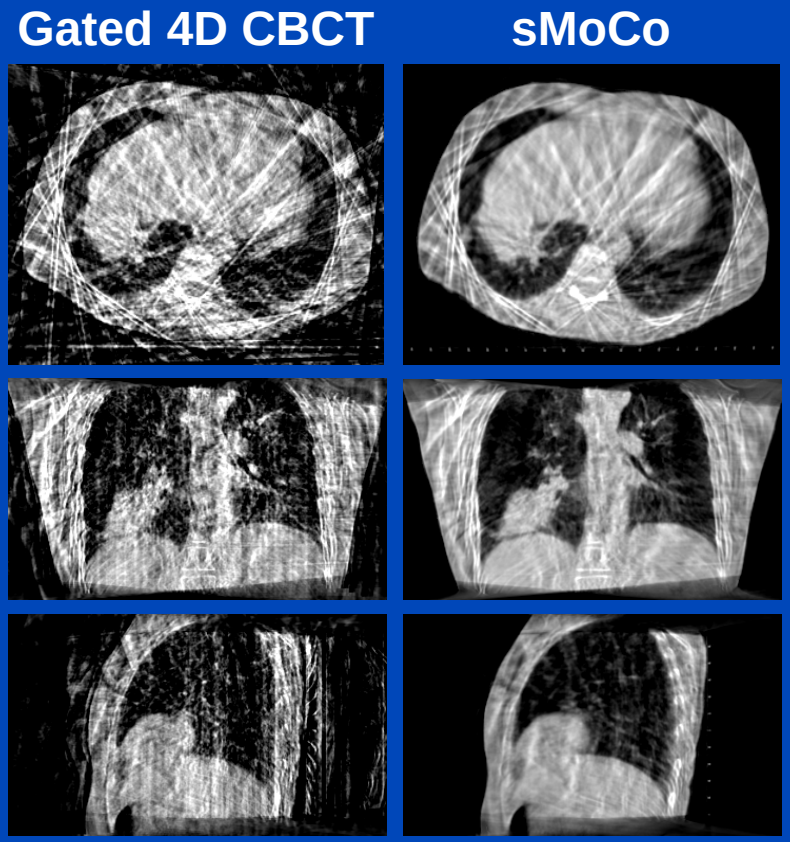
Warped backprojection



A Standard Motion Estimation and Compensation Approach (sMoCo)

- **Motion estimation via standard 3D-3D registration**

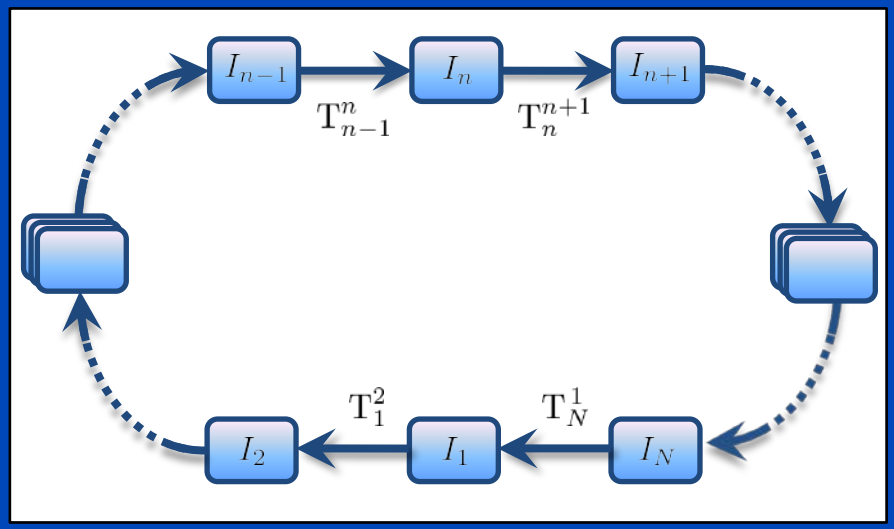


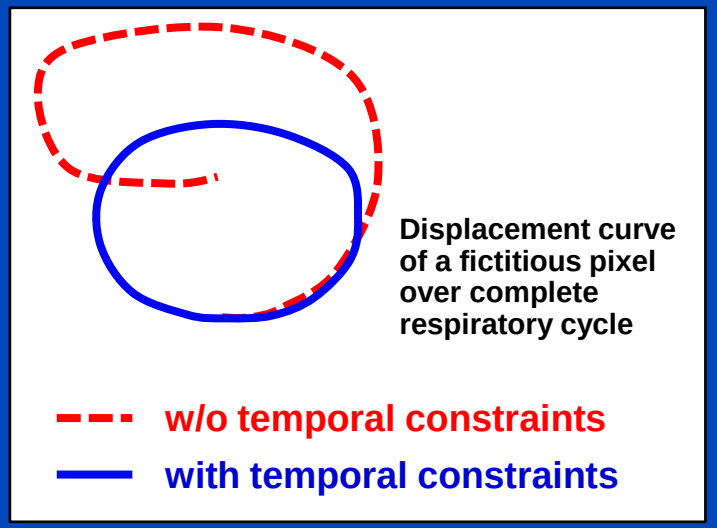


- **Has to be repeated for each reconstructed phase**
- **Streak artifacts from gated reconstructions propagate into sMoCo results**

A Cyclic Motion Estimation and Compensation Approach (cMoCo)

- **Motion estimation only between adjacent phases**
  - **All other MVFs given by concatenation**

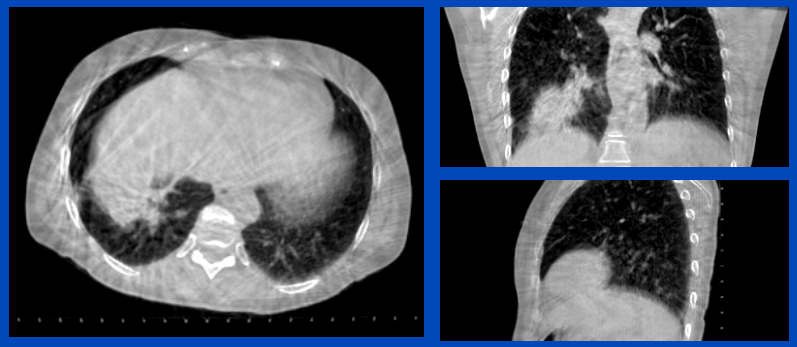




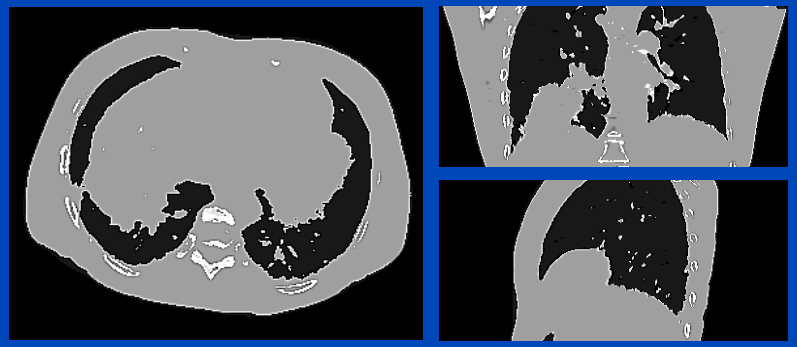
- **Incorporate additional knowledge**
  - **A priori knowledge of quasi periodic breathing pattern**
  - **Non-cyclic motion is penalized**
  - **Error propagation due to concatenation is reduced**

Angular Sampling Artifact Model

- Create second series of images with sparse-view artifacts but without breathing motion
- Eliminate breathing motion information
  - Threshold-based segmentation of 3D CBCT
- Simulate measurement and reconstruction process
  - Forward projection of segmented image
  - Backprojection at same angles as for gated 4D CBCT



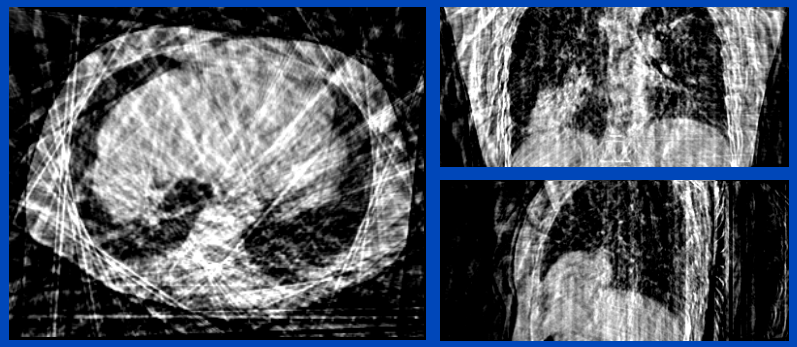
3D CBCT



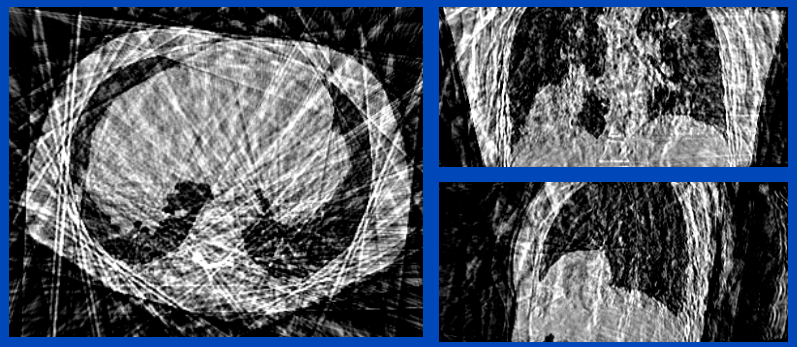
Segmented Image

Angular Sampling Artifact Model

- Create second series of images with sparse-view artifacts but without breathing motion
- Eliminate breathing motion information
  - Threshold-based segmentation of 3D CBCT
- Simulate measurement and reconstruction process
  - Forward projection of segmented image
  - Backprojection at same angles as for gated 4D CBCT

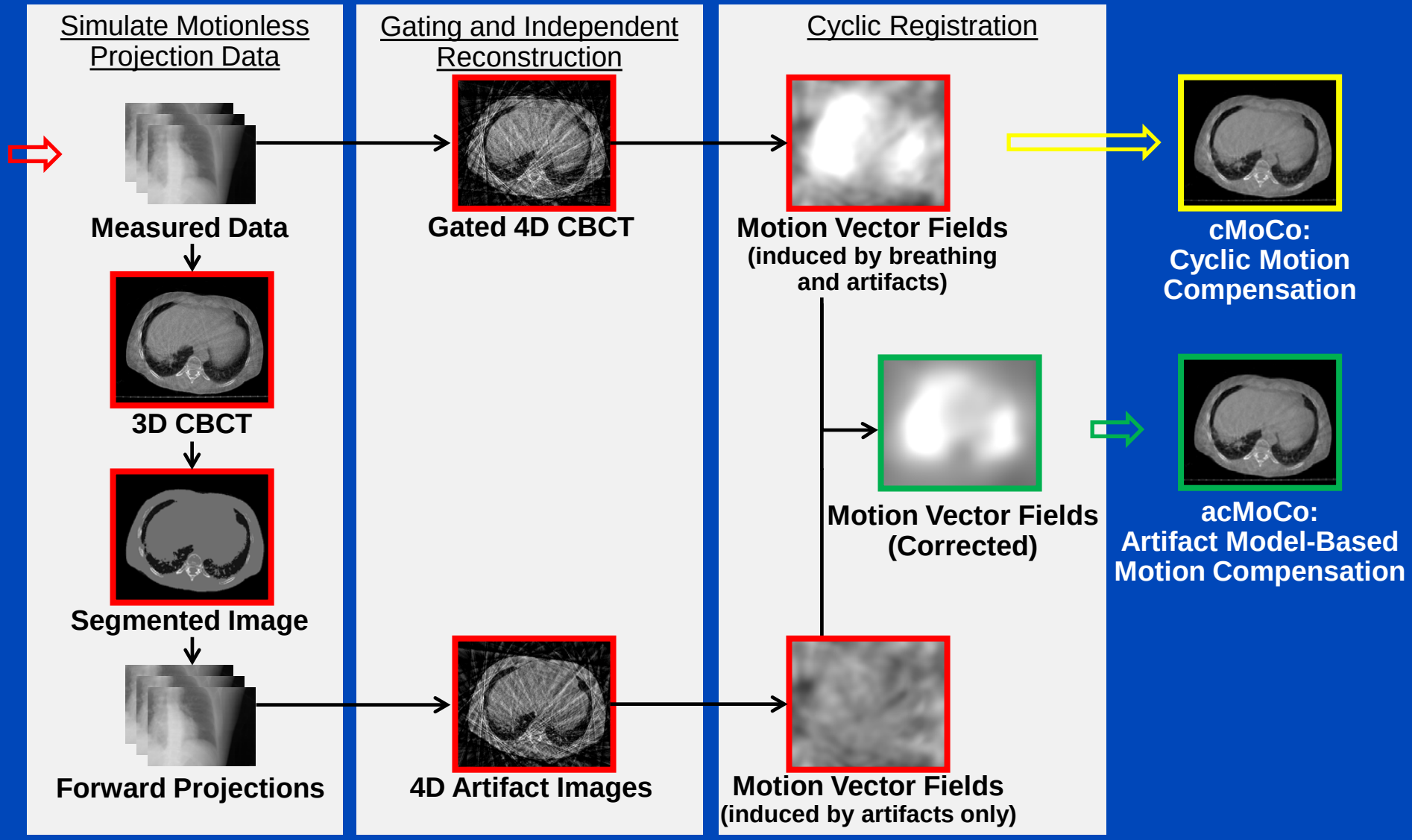


Gated 4D CBCT

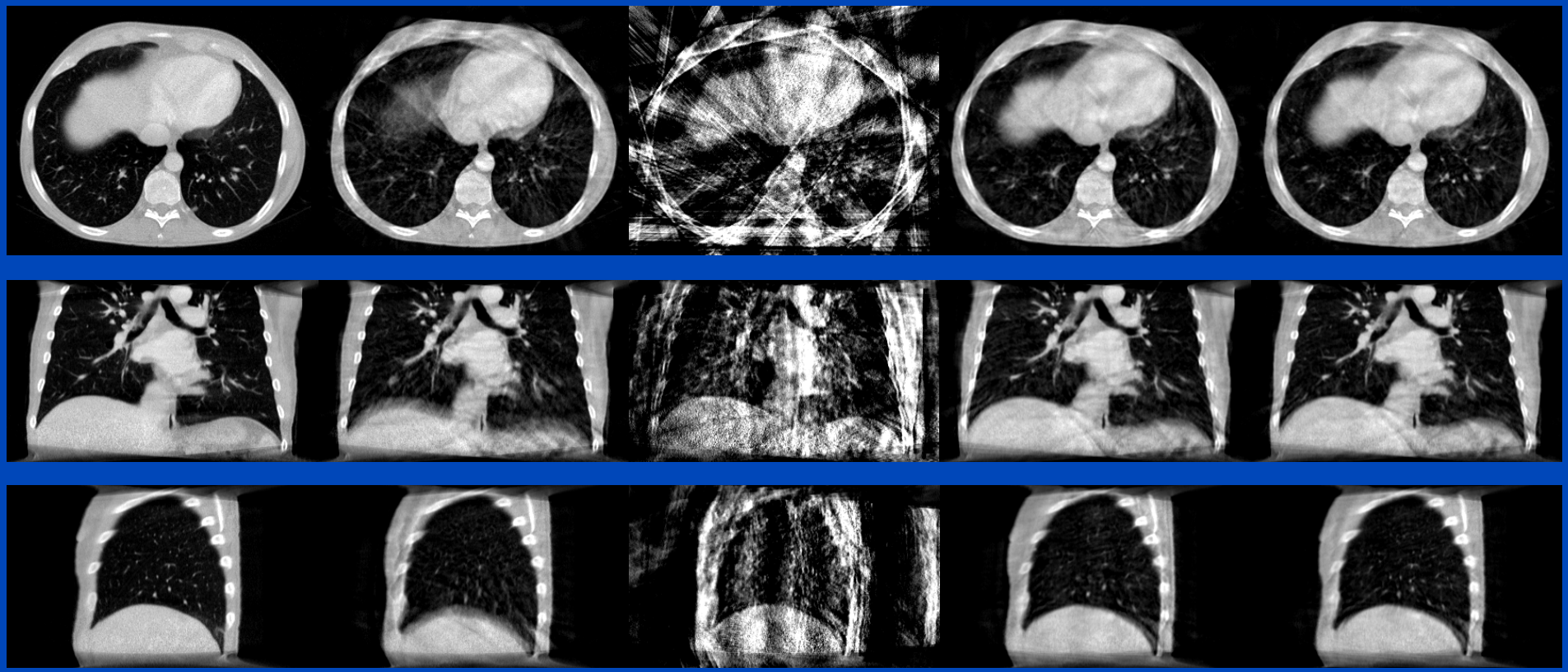


4D Artifact Images

Motion Estimation using an Angular Sampling Artifact Model

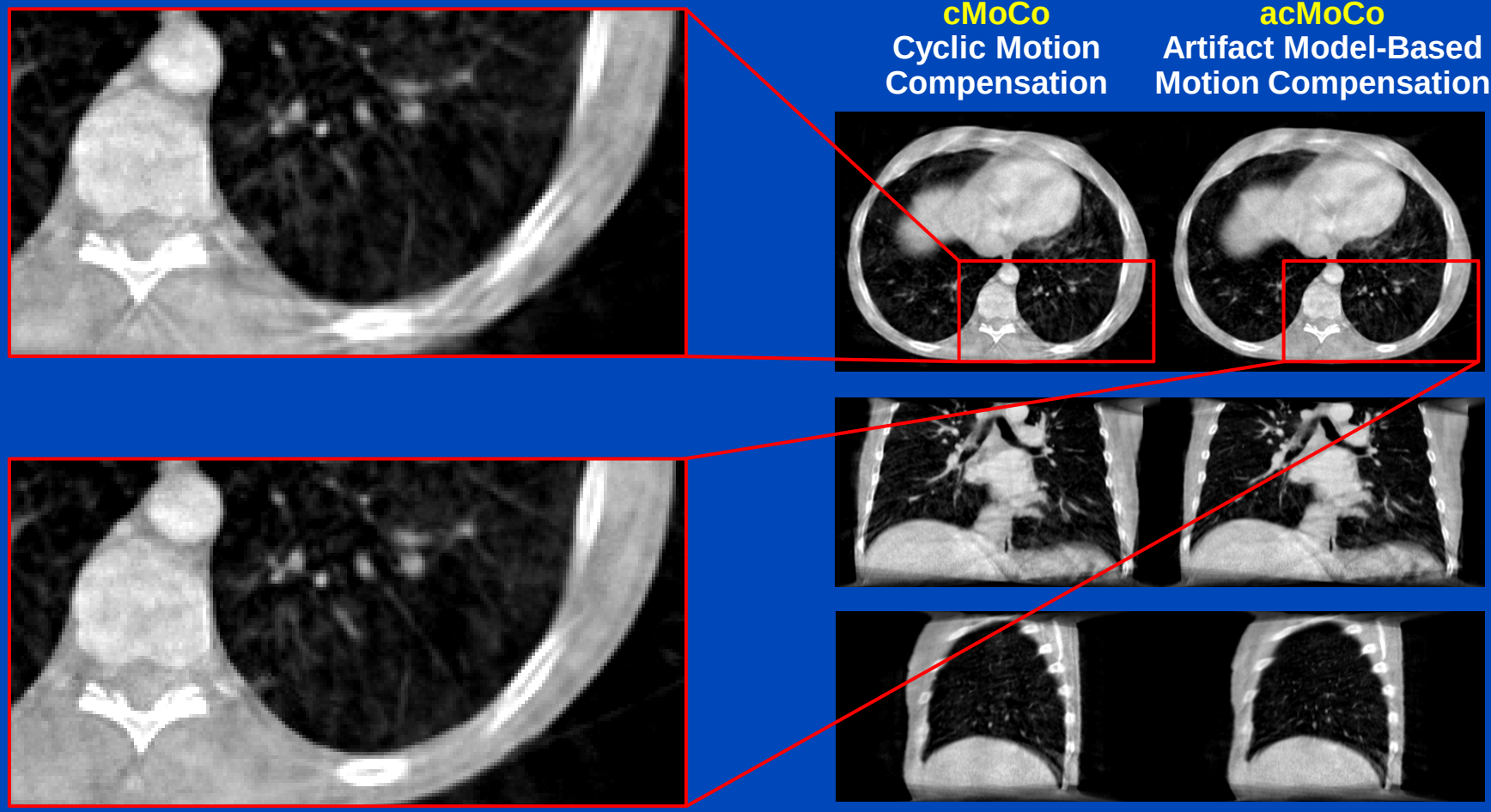


Simulated Data – Results



C = -200 HU, *W* = 1400 HU

Simulated Data – Results



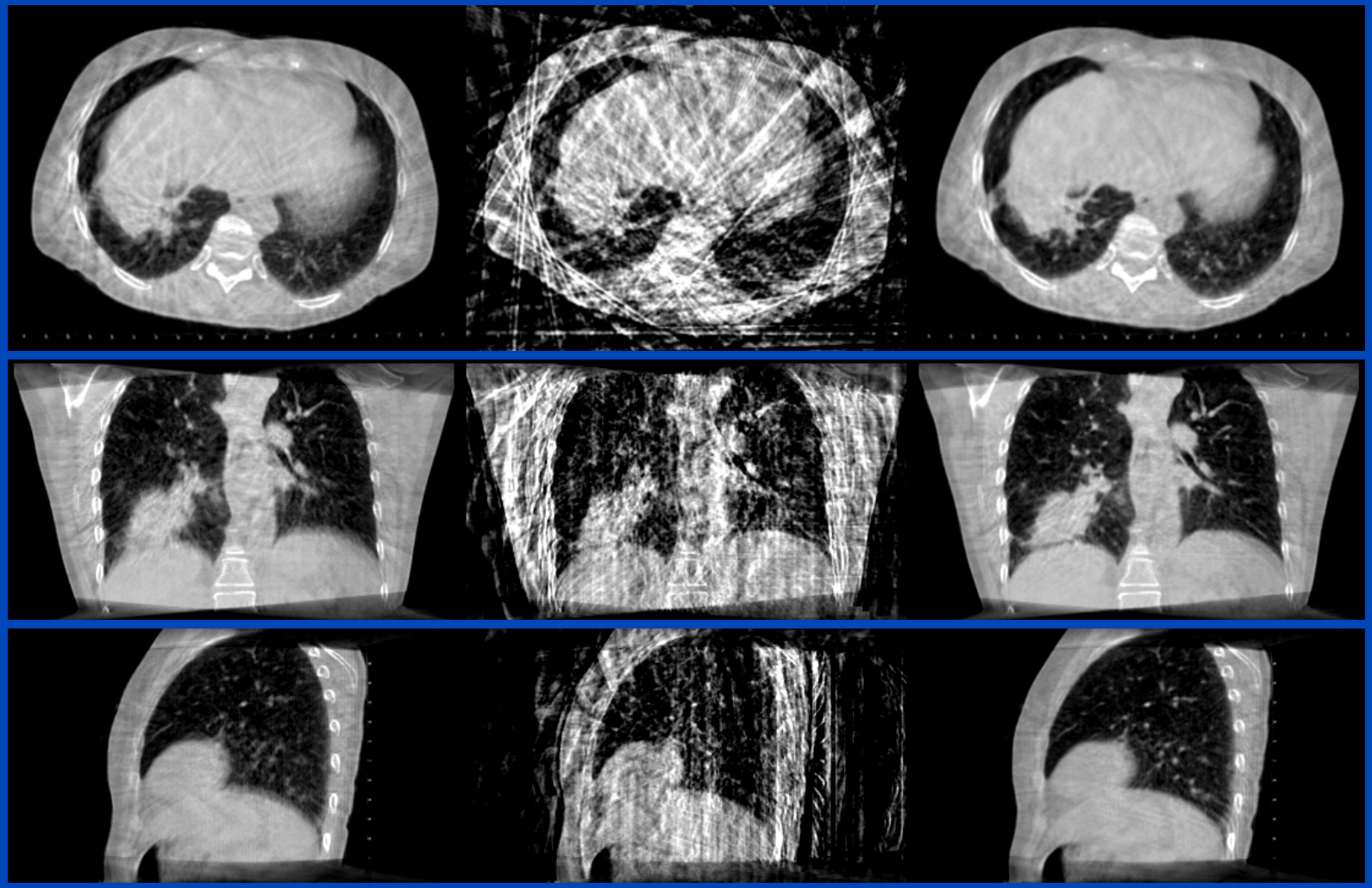
C = -200 HU, *W* = 1400 HU

Patient Data – Results

3D CBCT
Standard

Gated 4D CBCT
Conventional
Phase-Correlated

acMoCo
Artifact Model-Based
Motion Compensation



Summary

- Severe sparse-view artifacts deteriorate image quality of conventional phase-correlated images
- Standard deformable 3D-3D registration is sensitive to these artifacts
- Highly decreased sensitivity to sparse-view artifacts by combination of cyclic registration and artifact model
- Motion-compensated image reconstruction using MVFs obtained by combination of cyclic registration and artifact model is suitable for application in IGRT

Thank You!

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This presentation will soon be available at www.dkfz.de/ct.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.