Artifact-Resistant Motion Estimation for Motion-Compensated CT

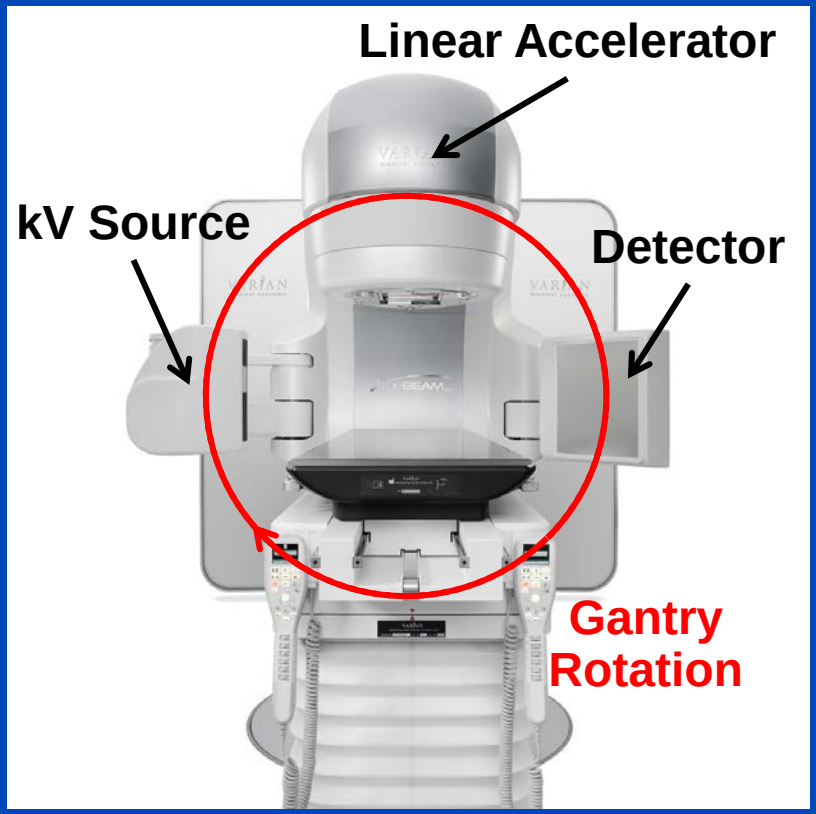
Marcus Brehm[1,2], Thorsten Heußer[1],
Pascal Paysan[3], Markus Oehlhafen[3], and Marc Kachelrieß[1,2]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]Friedrich-Alexander-University (FAU) Erlangen-Nürnberg, Germany
[3]Varian Medical Systems Imaging Laboratory, Baden-Dättwil, Switzerland

FAU VARIAN medical systems dkfz.

Slowly Rotating CBCT Devices

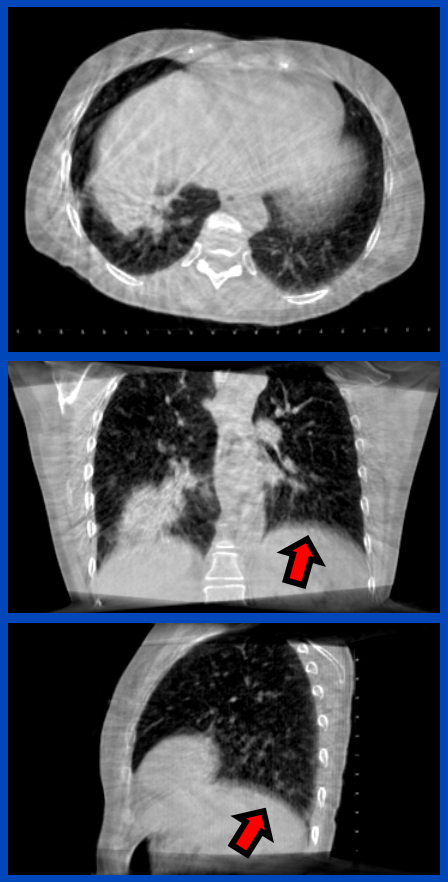
- **Image-guided radiation therapy (IGRT)**
  - CBCT imaging unit mounted on gantry of a LINAC treatment system
  - E.g. used for patient positioning
- **Maximum gantry rotation speed of 6° per second**
- **Breathing cycle about 2 to 5 seconds**
  - i.e. 12 to 30 respirations per minute (rpm) and thus per scan



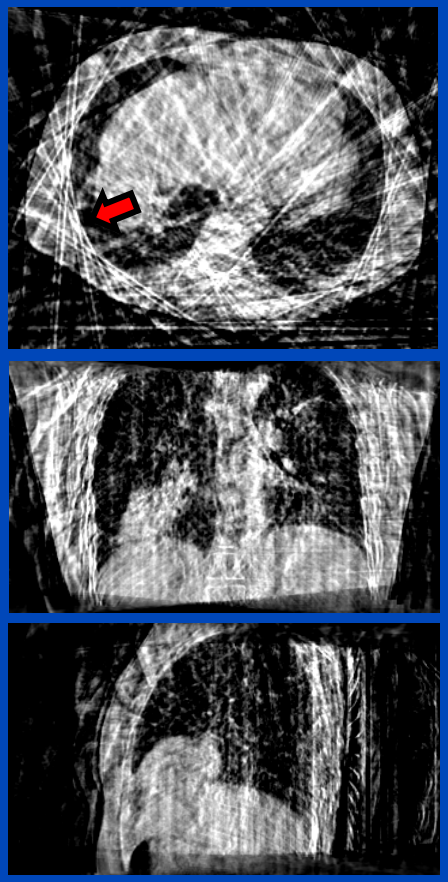
⇒ **Account for respiratory motion!**

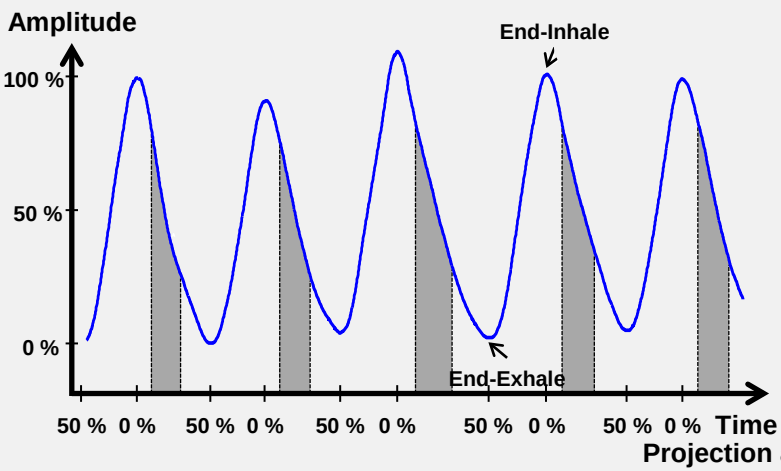
Retrospective Gating

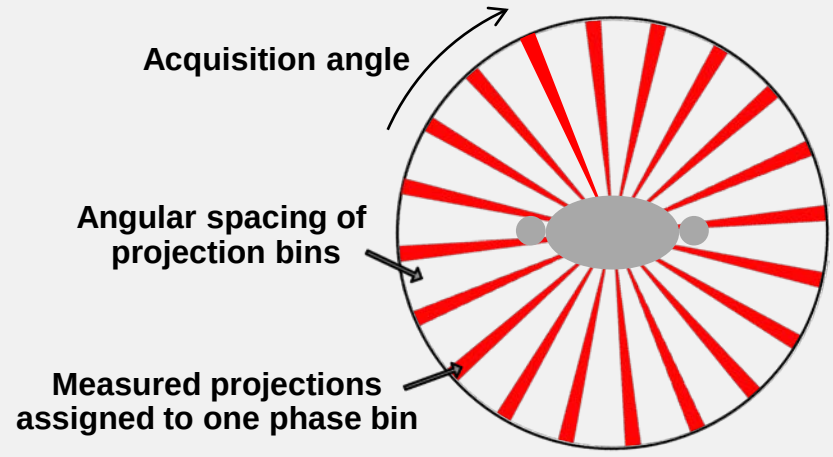
Without gating (3D): Motion artifacts



With gating (4D): Sparse-view artifacts







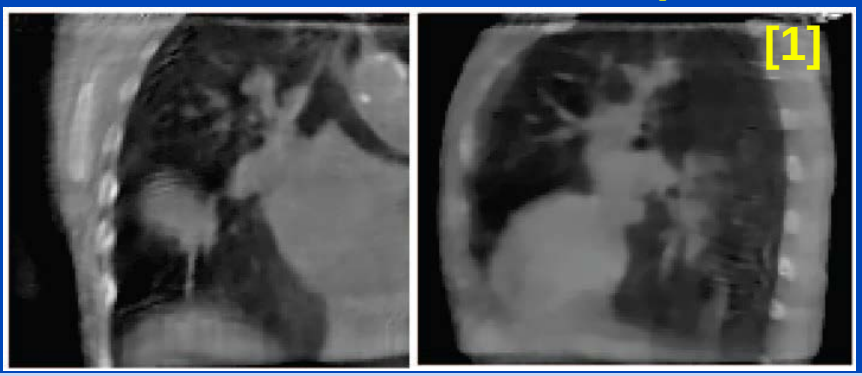
Prior Art in IGRT
(Respiratory-Correlated Reconstructions)

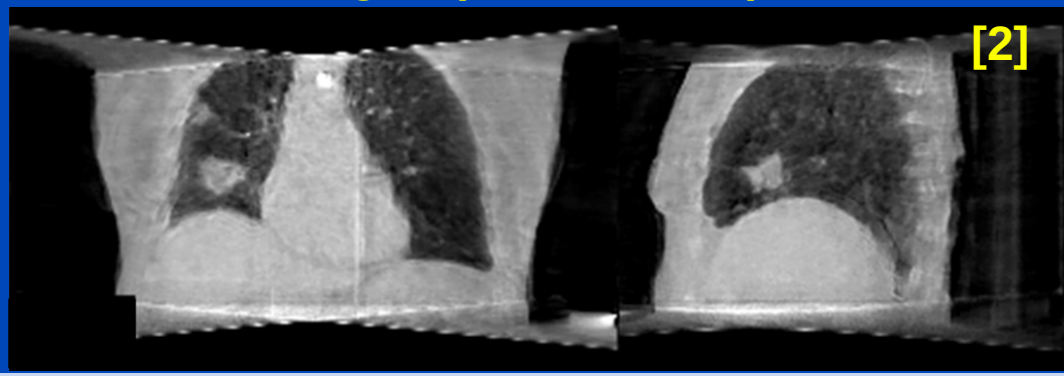
- **Respiratory gating and independent reconstruction**
  - **Sparse-view artifacts deteriorate image quality**
    - » **Streak artifacts and image noise**
  - **Increased patient dose required**
- **Dedicated acquisition techniques**
  - **These are not accepted in clinical routine, e.g., due to long acquisition times**
  - **Increased patient dose required**
- **Conventional motion-compensated reconstruction**
  - **Necessary motion estimation requires**
    - » **Increased patient dose**
    - » **Additional knowledge, e.g. 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. 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**

Results of recent publications from other groups on that topic



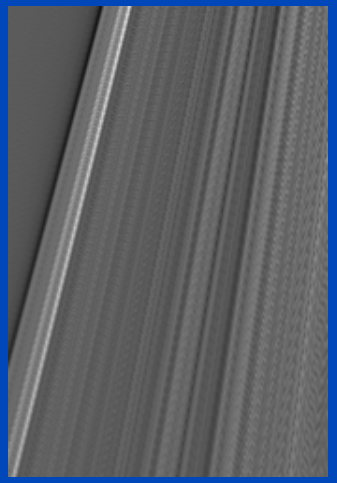


[1] Wang and Gu, *Simultaneous motion estimation and image reconstruction (SMEIR) for 4D cone-beam CT*, Medical Physics 40(10):101912 (2013).
[2] Christoffersen, Hansen, Poulsen, and Sørensen, *Registration-based reconstruction of four-dimensional cone beam computed tomography*, IEEE Transactions on Medical Imaging 32(11):2064-2077 (2013).

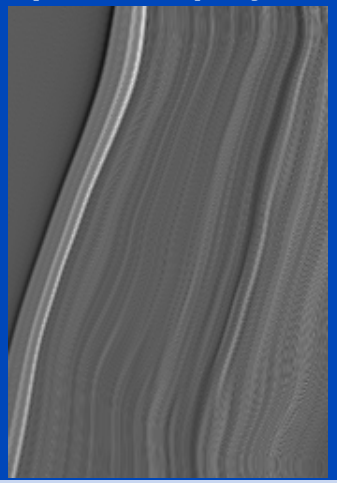
Motion Compensation (MoCo)

- **Use all projection data for each phase to be reconstructed**
  - **Even those of other phase bins (100 % dose usage)**
  - **Compensate for motion using motion vector fields (MVFs)**
  - **In our case MVFs are estimated from gated reconstructions**
- **Use MVFs during reconstruction**
  - **Backproject sparse data along straight lines, then warp with respect to the MVFs**

Straight backprojection

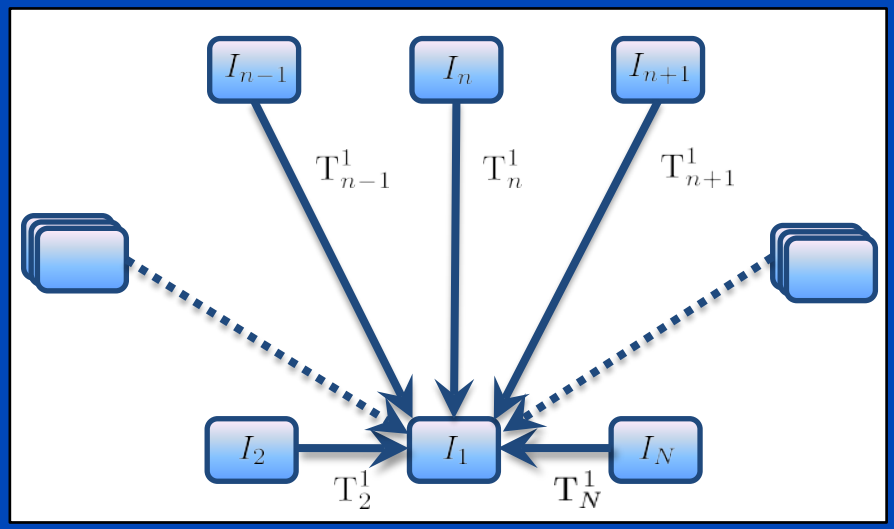


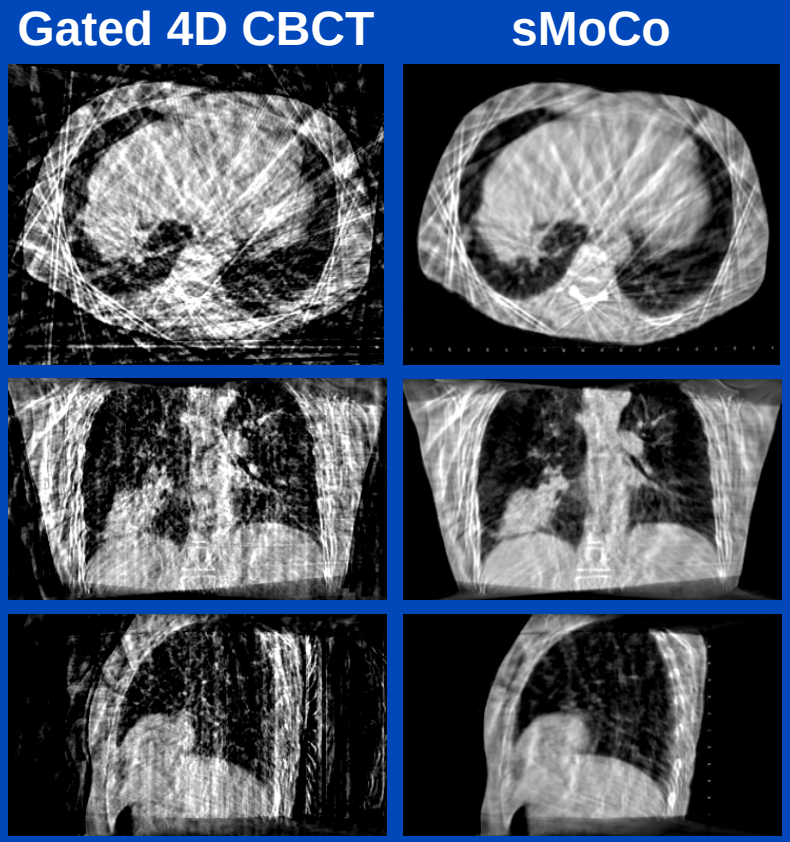
Warped backprojection



A Standard Motion Estimation and Compensation Approach (sMoCo)

- Motion estimation via standard 3D-3D registration



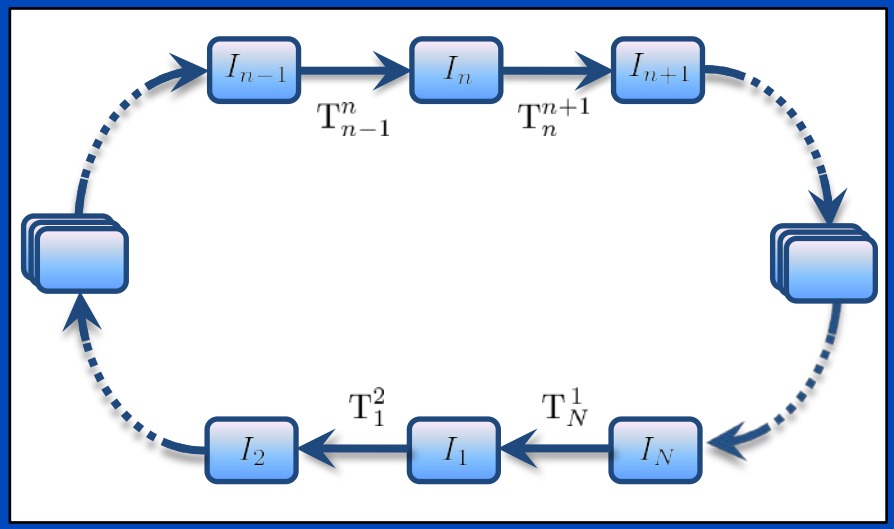


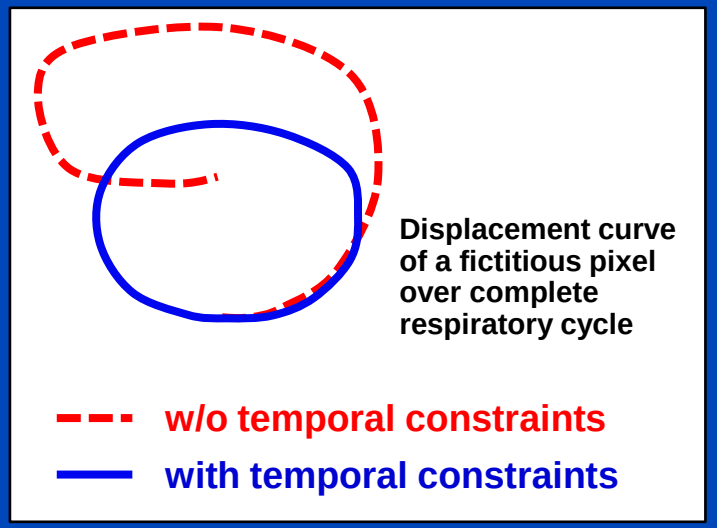
- Has to be repeated for each reconstructed phase
- Streak artifacts from gated reconstructions propagate into sMoCo results

Li et al., "*Enhanced 4D cone–beam CT with inter–phase motion model*," Med. Phys. 51(9), 3688–3695 (2007).

A Cyclic Motion Estimation and Compensation Approach (cMoCo)

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



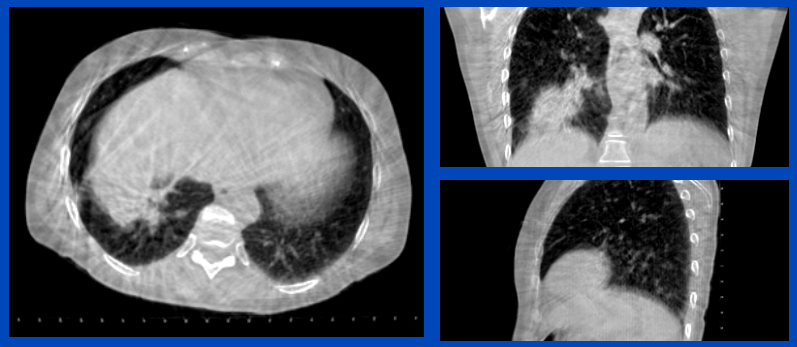


- **Incorporate additional knowledge**
  - **A priori knowledge of quasi periodic breathing pattern**
  - **Non-cyclic motion is penalized**
  - **Error propagation due to concatenation is reduced**

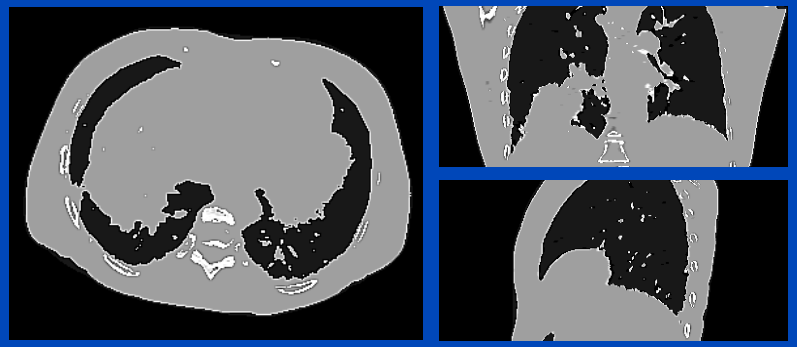
Brehm, Paysan, Oelhafen, Kunz, and Kachelrieß, "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12), 7603-7618 (2012).
Reported at CT-Meeting 2012, MIC 2012, RSNA 2012.

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



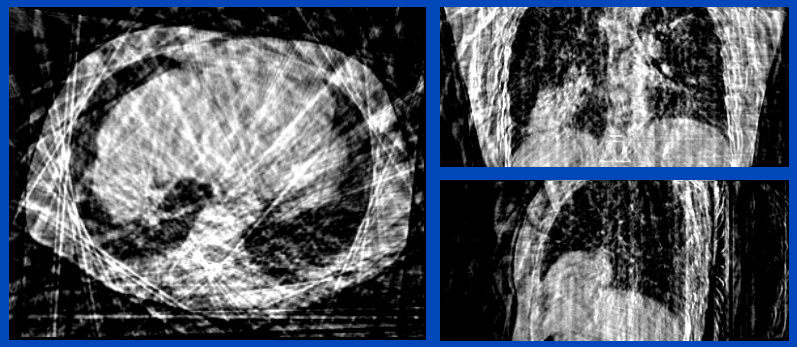
3D CBCT



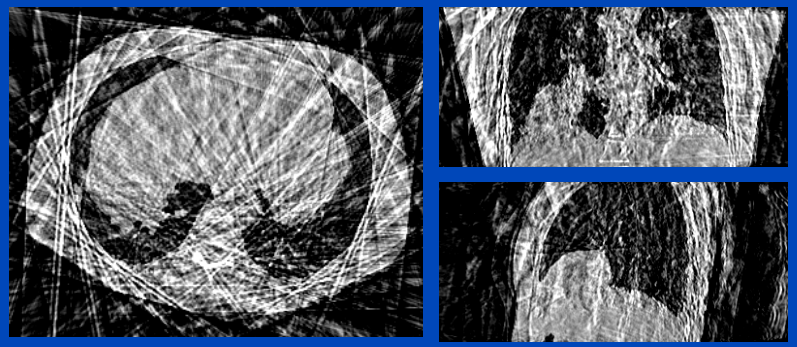
Segmented Image

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

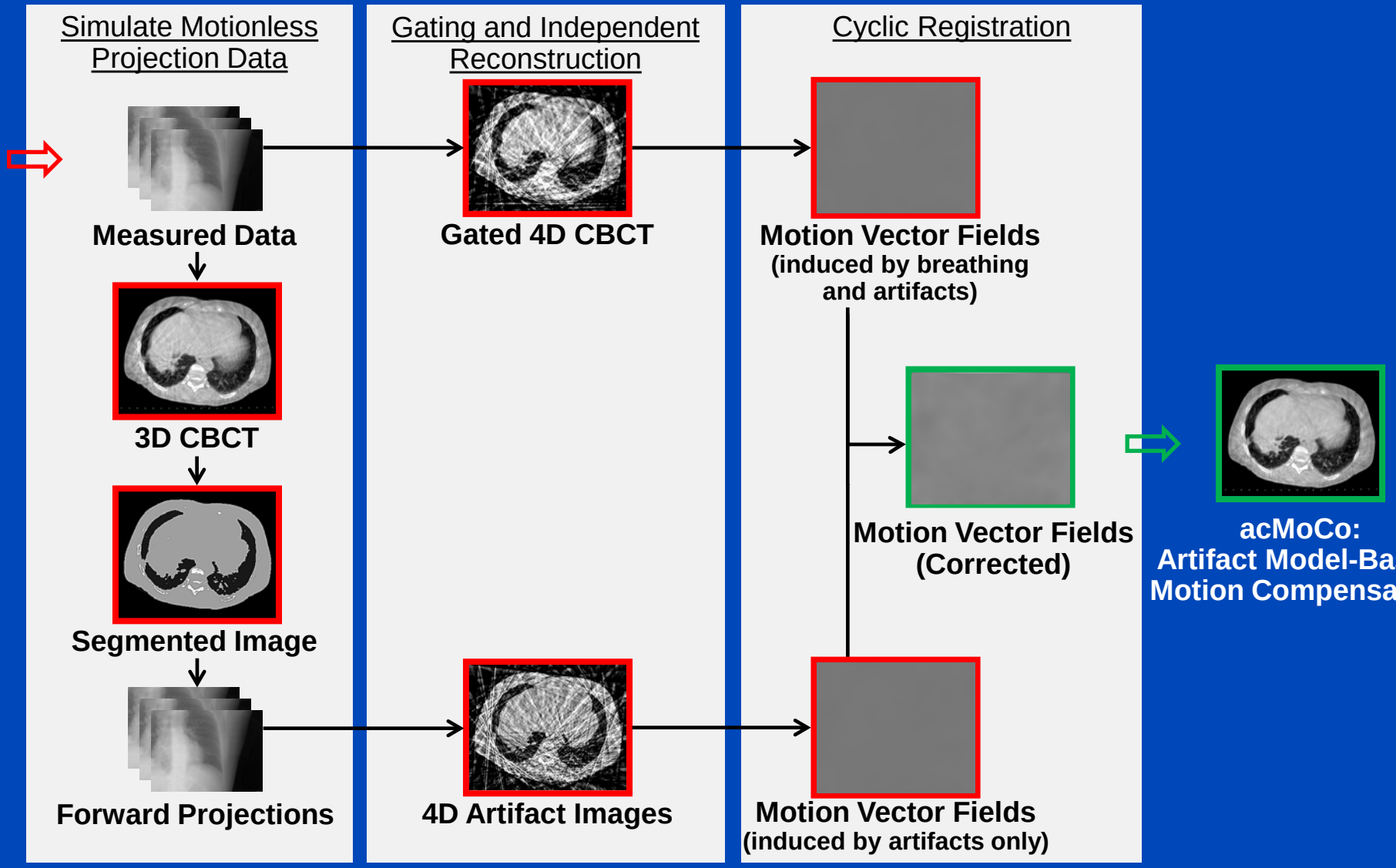


Gated 4D CBCT

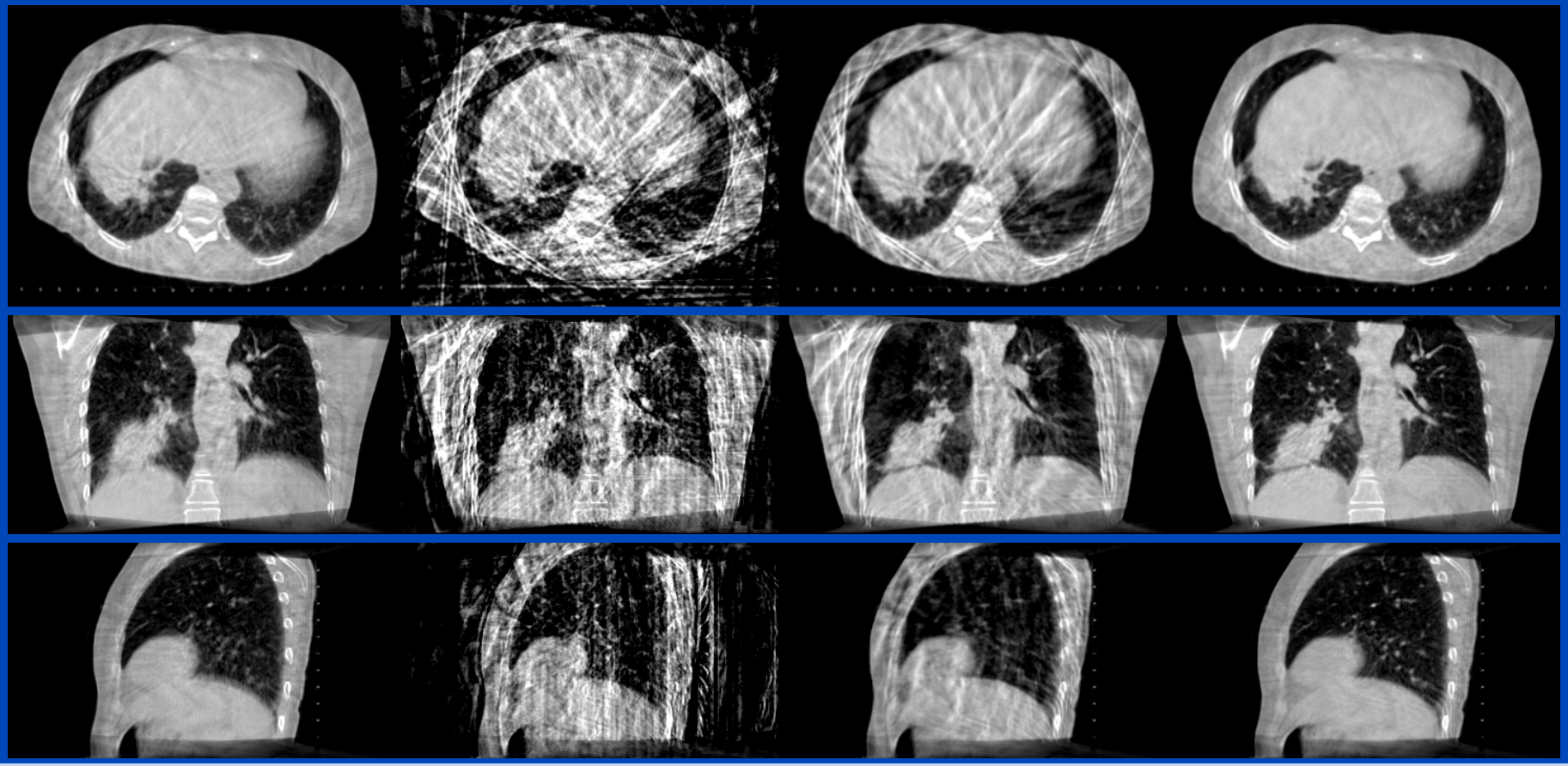


4D Artifact Images

Motion Estimation using an Patient-Specific Artifact Model



Patient Data – Results



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

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 appears to be suitable for application in IGRT.

Thank You!

This study was supported by a research grant from Varian Medical Systems, Palo Alto, CA.

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

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