

# Deep Learning-based 4D CT and 4D CBCT Motion Compensation of Periodic and Non-Periodic Patient Motion with Single-View Temporal Resolution

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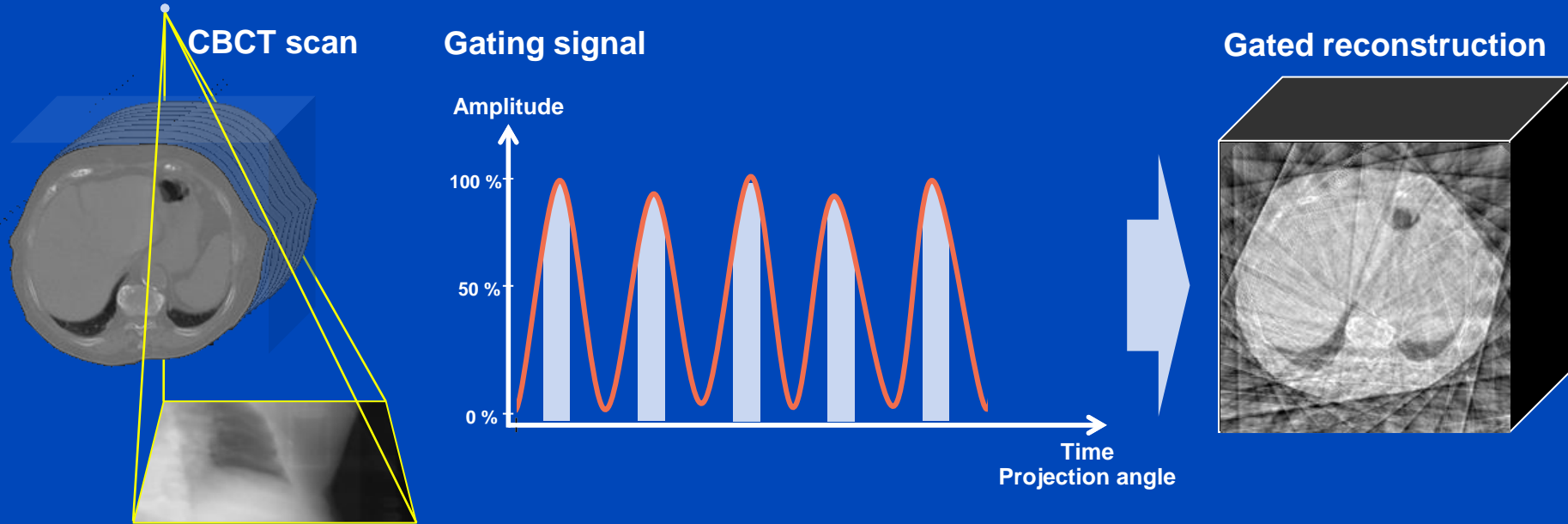
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# Motion in CT and CBCT

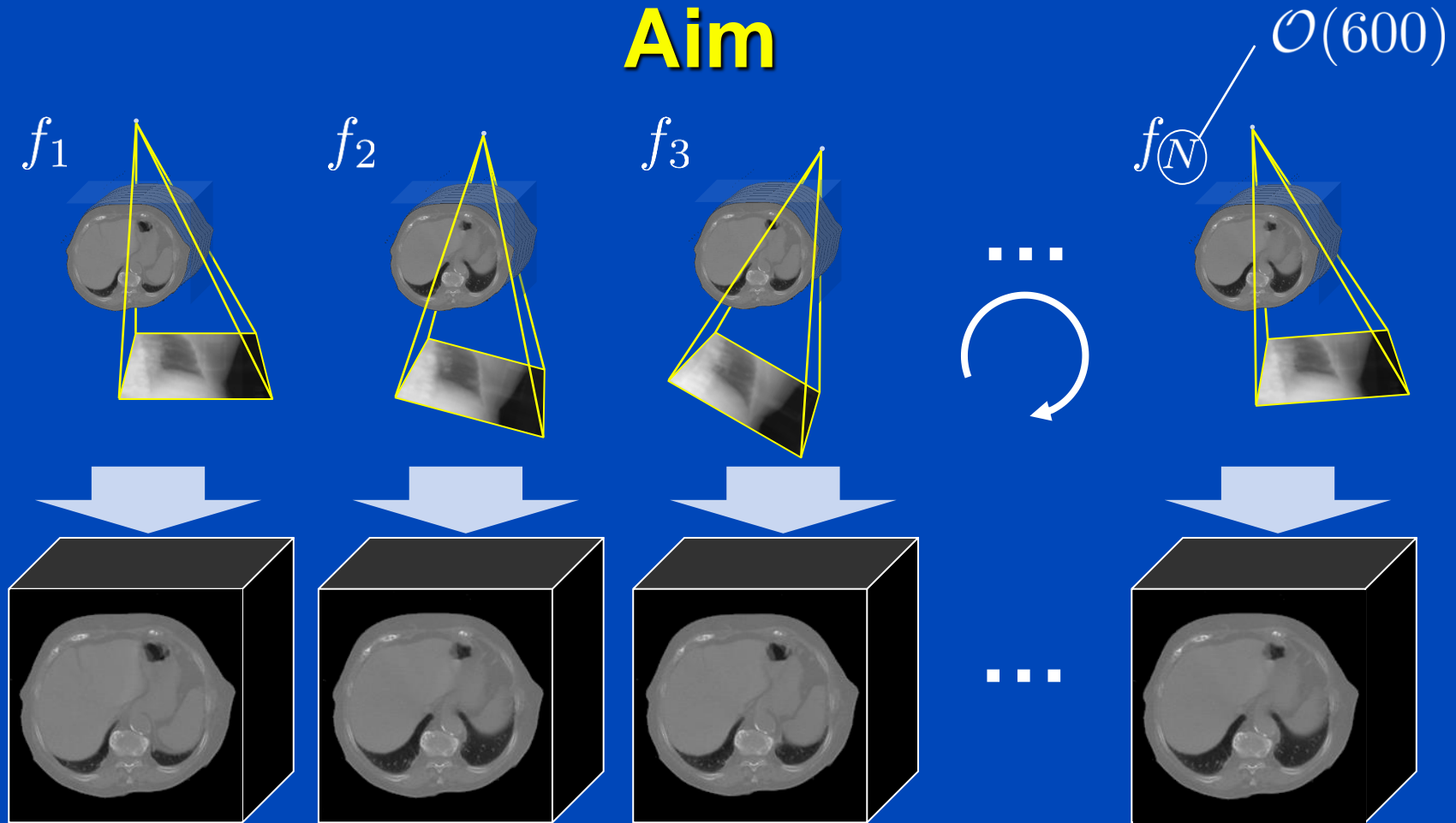
## Gating-based strategies



## Drawbacks:

- requires gating signal,
- assumes periodic motion,
- has low temporal resolution,
- fails on irregular breathing.

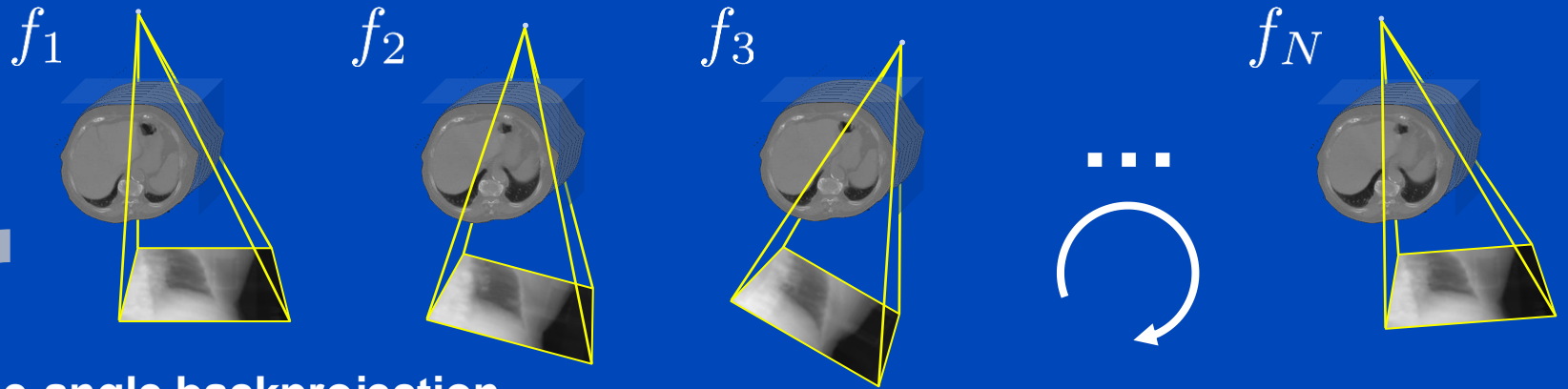
# Aim



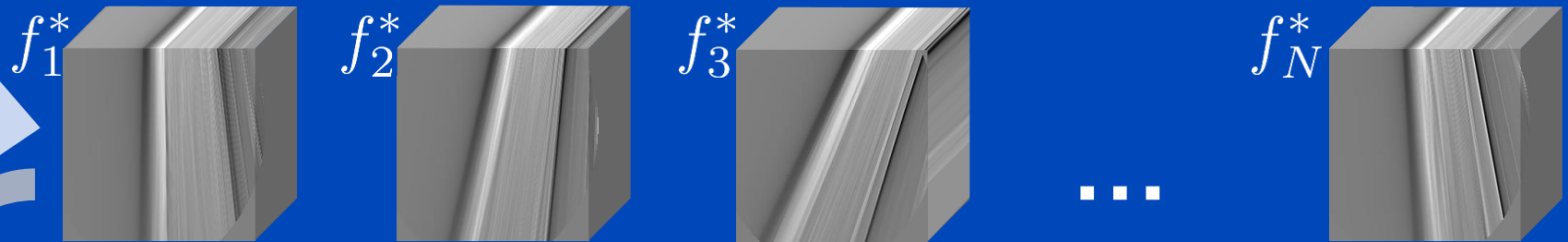
**Goal: Reconstruct any motion state that occurred during the CBCT scan, i.e. reconstruct a separate volume for every projection view, without the need for a gating signal.**

# Single-angle Motion Compensation (SAMoCo)

## Basic Principle



Single-angle backprojection



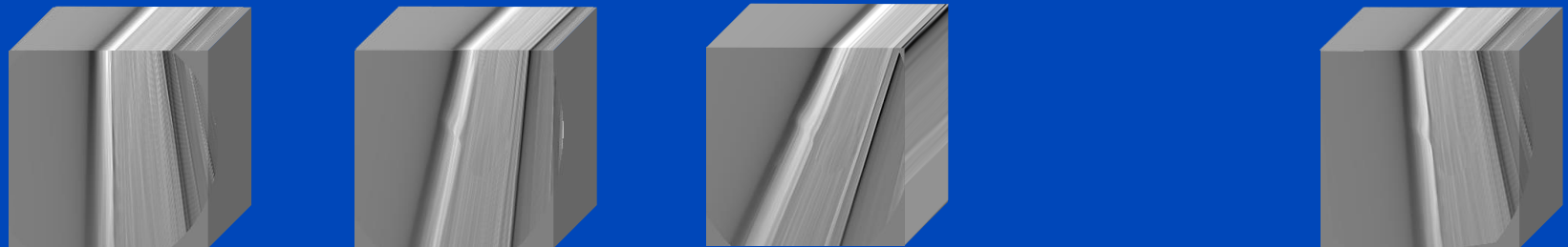
Warp

$$T_1^j \circ f_1^*$$

$$T_2^j \circ f_2^*$$

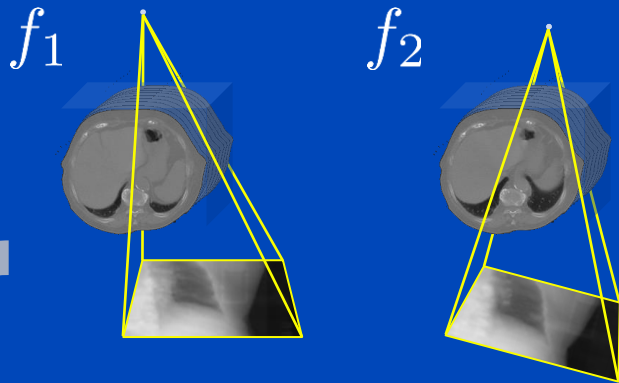
$$T_3^j \circ f_3^*$$

$$T_N^j \circ f_N^*$$

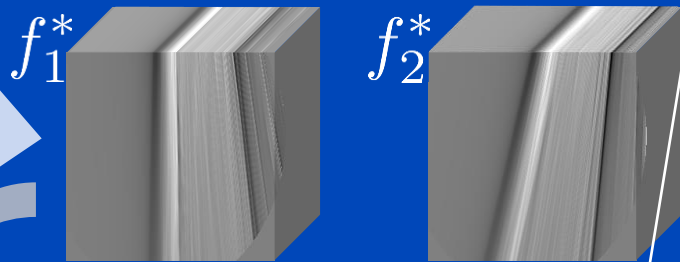


# Single-angle Motion Compensation (SAMoCo)

## Basic Principle



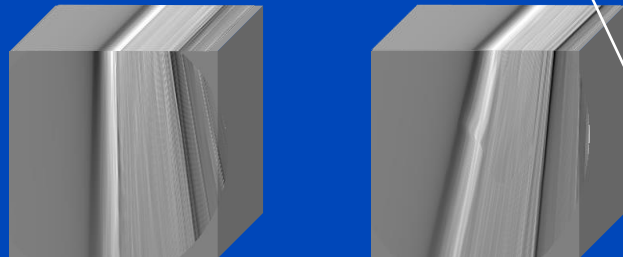
Single-angle backprojection



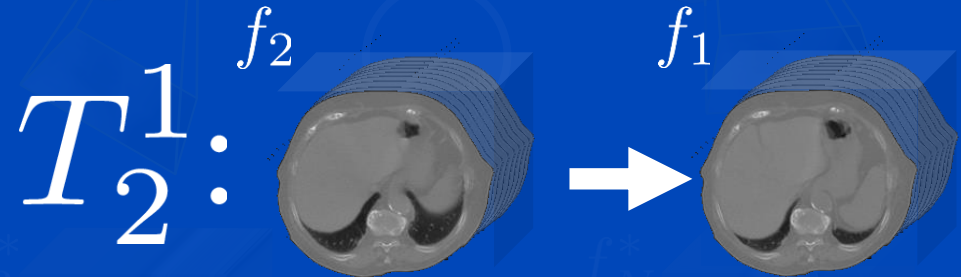
Warp

$$T_1^j \circ f_1^*$$

$$T_2^j \circ f_2^*$$



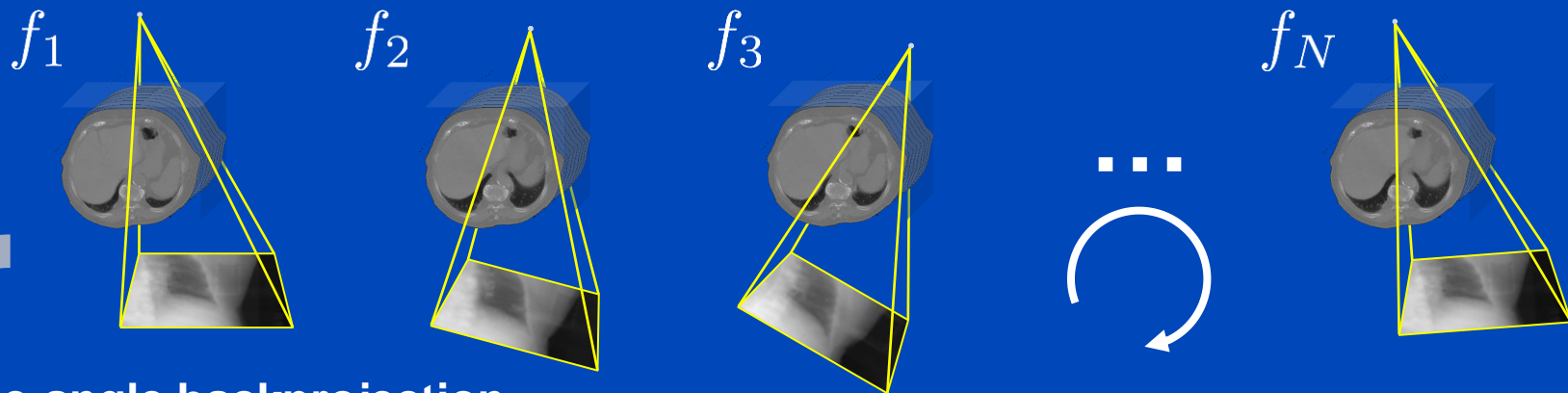
E.g. reconstruction of the 1<sup>st</sup> motion state  $j = 1$ :



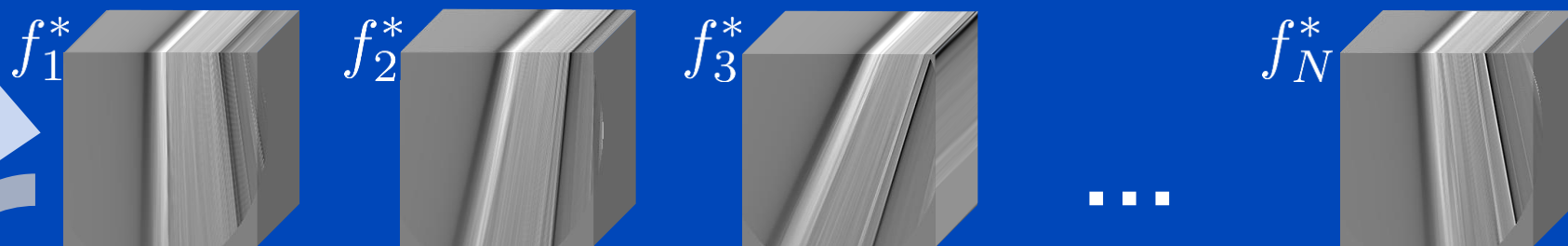
$$f_1 = T_2^1 \circ f_2$$

# Single-angle Motion Compensation (SAMoCo)

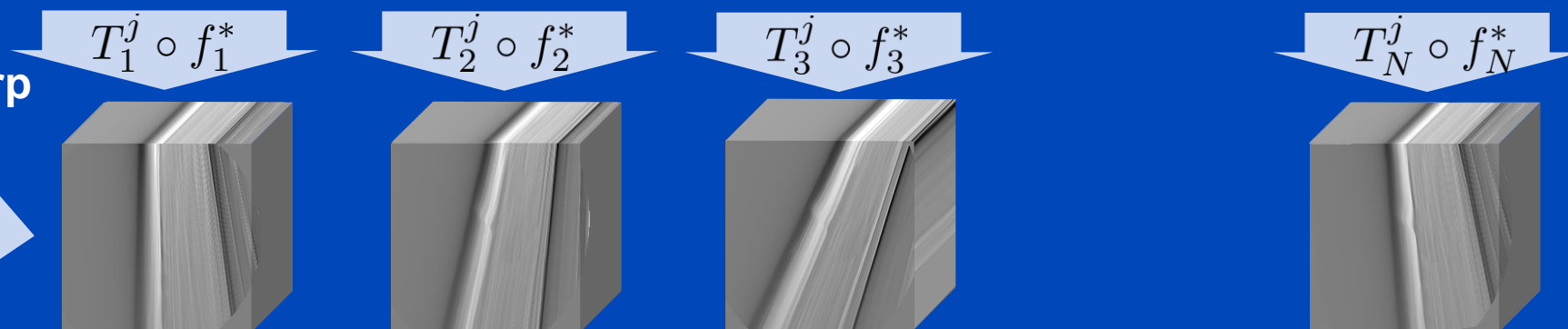
## Basic Principle



Single-angle backprojection



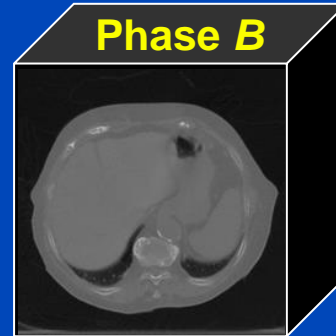
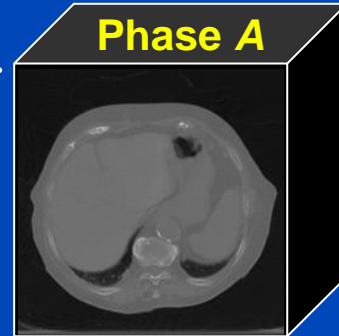
Warp



$$\text{SAMoCo: } f_{j,\text{MoCo}} = \sum_i T_i^j \circ f_i^*$$

# Learning to Predict Deformation Vector Fields

Randomly select  
- projection  $i$  from  $A$   
- projection  $j$  from  $B$   
and backproject.

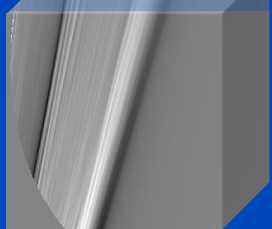


Random patient, random phase ( $A$  and  $B$ )  
from gated CT reconstruction

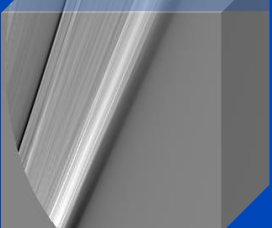
Calculate DVF from  
phase  $A$  to phase  $B$   
(Demons, Deeds,  
VoxelMorph, ...)

DVF deforming  
patient from  
time  $i$  to time  $j$

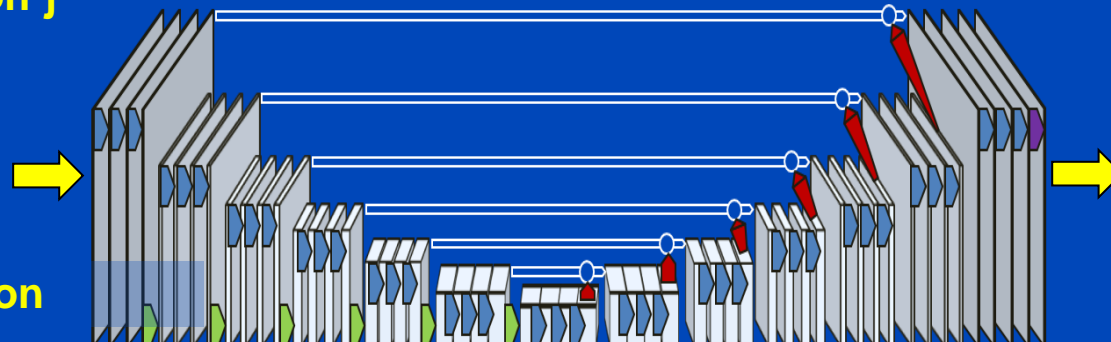
SAR of projection  $i$



SAR of projection  $j$



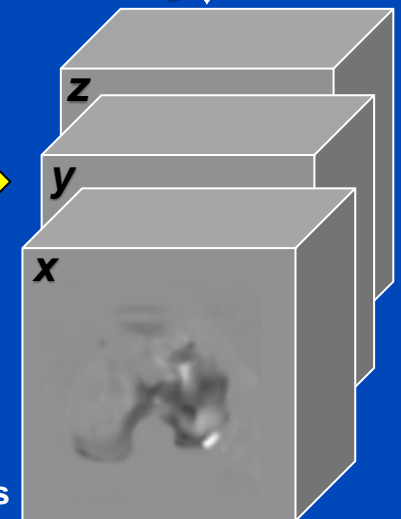
3D reconstruction



Network input

Network (modified U-Net)

Training labels



# Training and Testing Details

- **Training using gated CT reconstruction (high temporal resolution, no motion artifacts)**
  - Gated CT reconstructions of 84 patients.
  - Simulation of CBCT (shifted-detector) single-angle reconstructions with random motion state and random projection angle.
  - Training of the network for 500 epochs using the MSE between prediction and ground truth DVF as loss function.
- **Testing:**
  - Simulated shifted-detector CBCT scans (rotation time: 60 s, 657 views per rotation).
  - Real-measurements of a Varian TrueBeam CBCT system.



# Results: Simulation Study

Axial view

Coronal view

Ground truth (GT)

SAMoCo

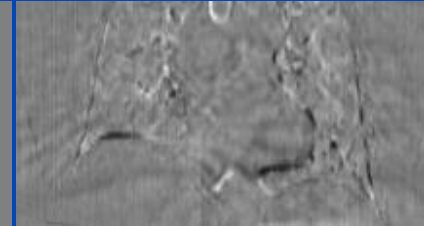
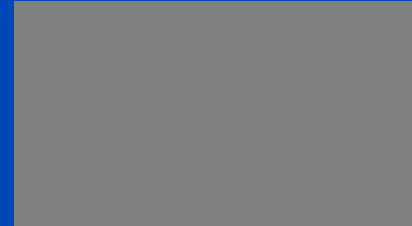
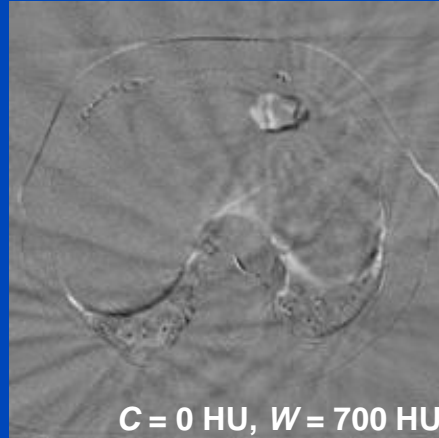
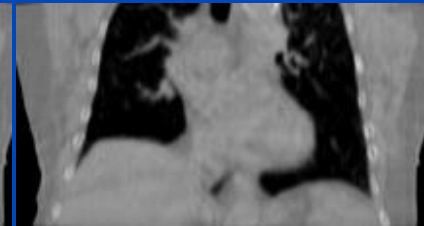
Reconstruction



Ground truth (GT)

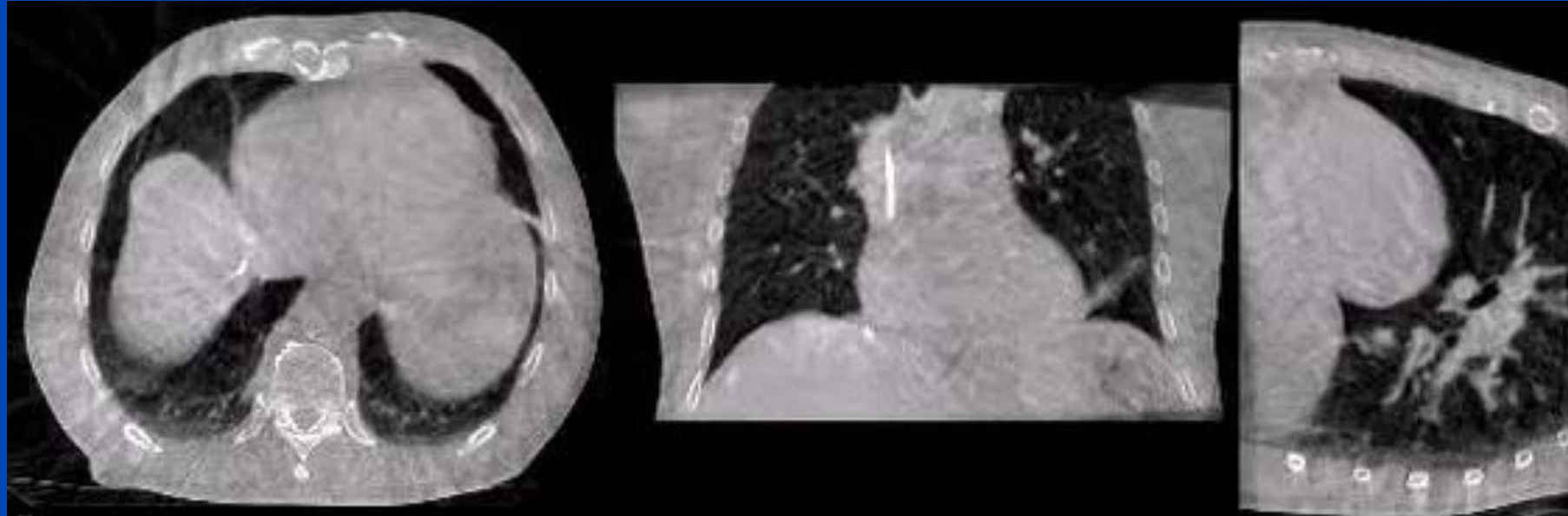
SAMoCo

Difference to GT



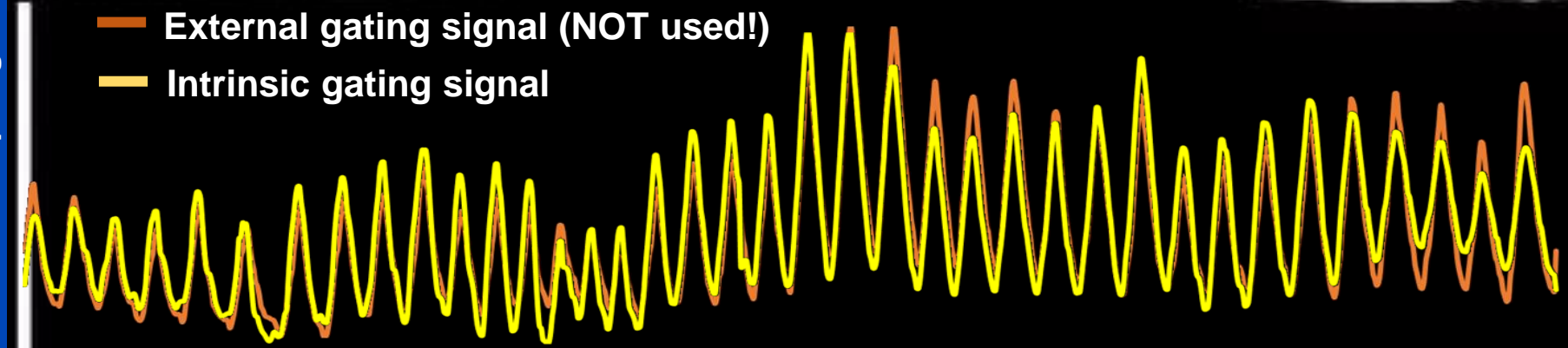
# Results: Varian CBCT Measurement

CT Reconstruction



External Resp. Signal

- External gating signal (NOT used!)
- Intrinsic gating signal



# Conclusions

- Deep SAMoCo is able to resolve cardiac and respiratory motion with single-view temporal resolution.
- High correlation between intrinsic respiration signal and Varian RPM marker block.
- Deep SAMoCo can potentially overcome limitations of gating-based motion compensation.
- Further efforts are needed to improve the quality of the reconstructions. In particular this issue will be addressed by incorporating the SAMoCo concept into an iterative reconstruction framework.

# Thank You!



## The 8<sup>th</sup> International Conference on Image Formation in X-Ray Computed Tomography

August 5 – August 9, 2024, Bamberg, Germany  
[www.ct-meeting.org](http://www.ct-meeting.org)



Conference Chair

**Marc Kachelrieß**, German Cancer Research Center (DKFZ), Heidelberg, Germany

This presentation will soon be available at [www.dkfz.de/ct](http://www.dkfz.de/ct).

Job opportunities through DKFZ's international PhD programs or through [marc.kachelriess@dkfz.de](mailto:marc.kachelriess@dkfz.de).

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