AI for a New Interventional X-Ray Imaging Application

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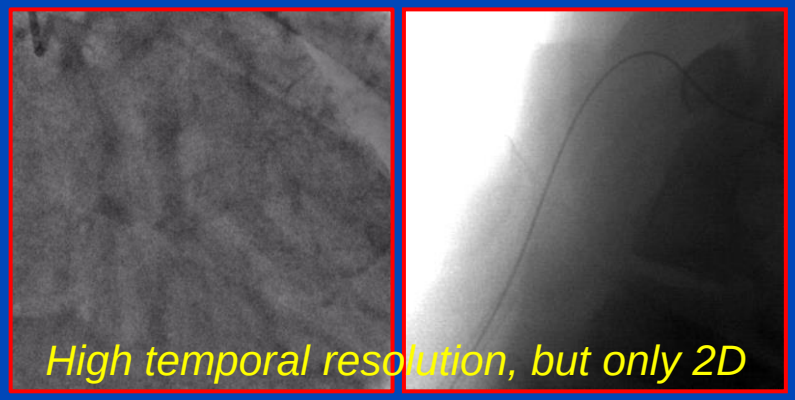
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Aim

To provide tomographic fluoroscopy at the same dose levels as today‘s projective fluoroscopy.

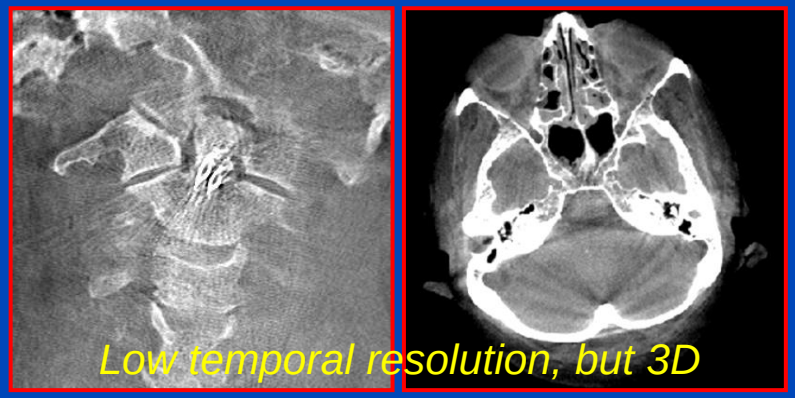
Deep 3D+T Tomographic Fluoroscopy

either 2D+T fluoroscopy



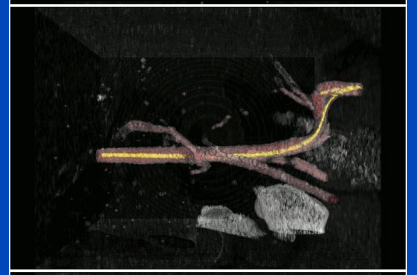
High temporal resolution, but only 2D

or 3D tomography



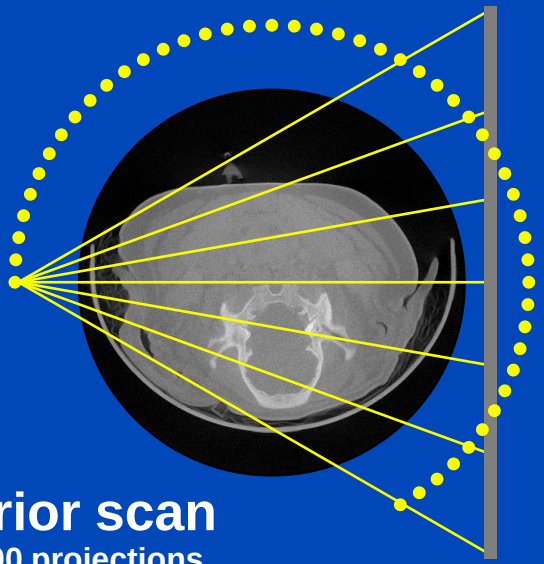
Low temporal resolution, but 3D

3D+T tomographic fluoroscopy? At low dose? How???

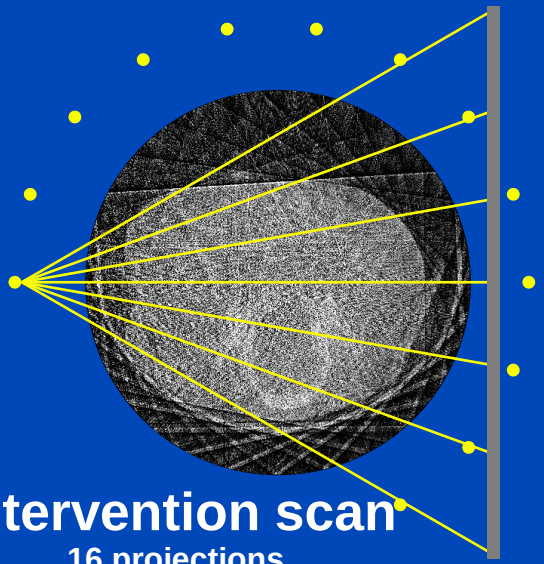


How to Realize 3D+T Fluoroscopy

- **Low dose by:**
  - Low tube current
  - Very few projections (pulsed mode)
- **Advantages of intervention guidance:**
  - Repetitive scanning of the same body region: changes are sparse.
  - Interventional materials are fine structures (few voxels) of high contrast (metal).



Prior scan
400 projections



Intervention scan
16 projections

Experimental setup

B. Flach, J. Kuntz, M. Brehm, R. Kueres, S. Bartling, and M. Kachelrieß. "Low dose tomographic fluoroscopy: 4D intervention guidance with running prior.", Med. Phys. 40:101909, 11 pages, October 2013.

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3D+T Fluoroscopy at 2D+T Dose

Guide Wire in the Carotis of a Pig with Angio Roadmap Overlay

10 years ago:
Dose of the approach: 20 to 50 µGy/s.
Obviously, 16 projections are still too much.

→ Wait until deep learning becomes available.

This work was awarded the intervention award 2013 of the German Society of Neuroradiology (DGNR).
This work was further selected as the Editor's Pick for the Medical Physics Scitation site.

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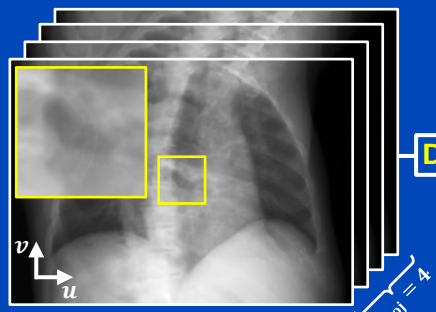
DTE + DTR

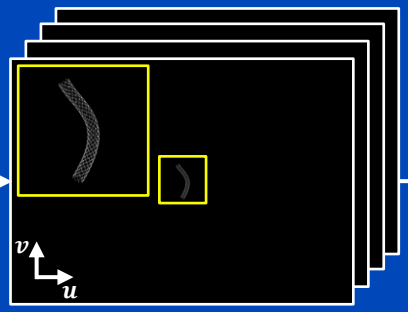
Deep Learning-Based 3D+T Fluoroscopy

Deep Tool Extraction (DTE) + Feldkamp Recon (FDK) + Deep Tool Reconstruction (DTR)



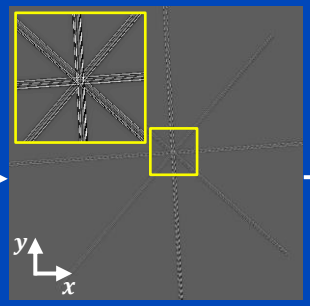
Input projections at current time step

DTE



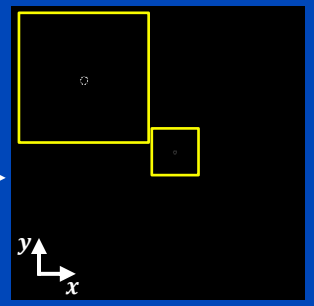
Tool-only projections at current time step

FDK



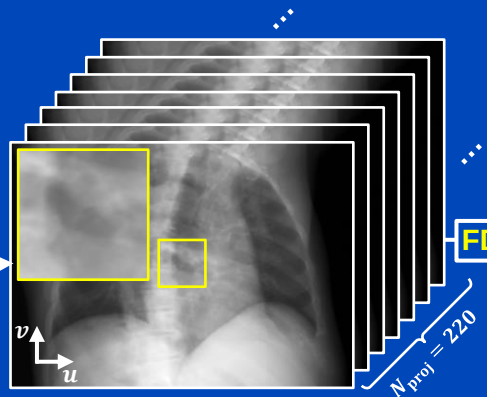
Sparse reconstruction of interventional tools

DTR



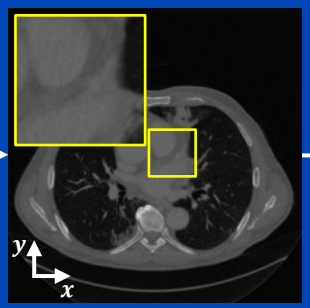
Segmentation of interventional tools

+



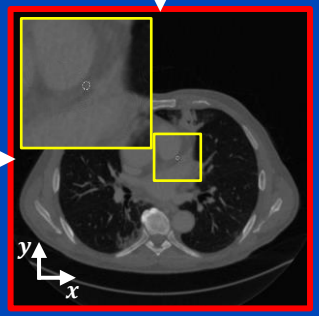
Patient-only projections accumulated over past timesteps

FDK



Patient-only reconstruction

+



Combined reconstruction, final image

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Congratulations

This paper received the Sylvia&Moses Greenfield Award for the best scientific paper on imaging in Medical Physics in 2021.

E. Eulig, J. Maier, M. Knaup, R. Bennett, K. Hörndler, A. Wang, and M. Kachelrieß. Deep learning-based reconstruction of interventional tools and devices from four x-ray projections for tomographic interventional guidance. Med. Phys. 48(10):5837-5850, October, 2021.

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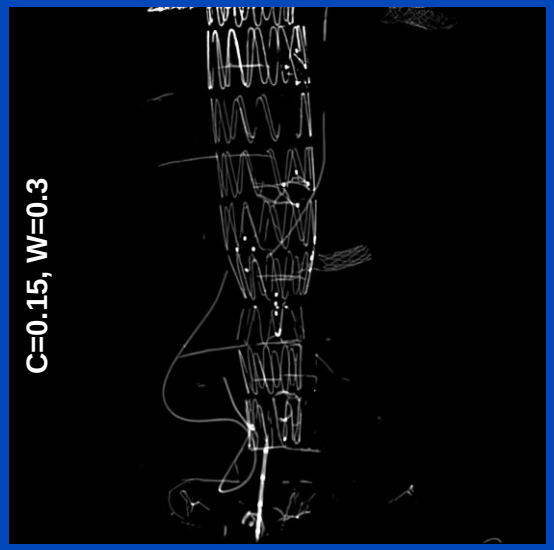
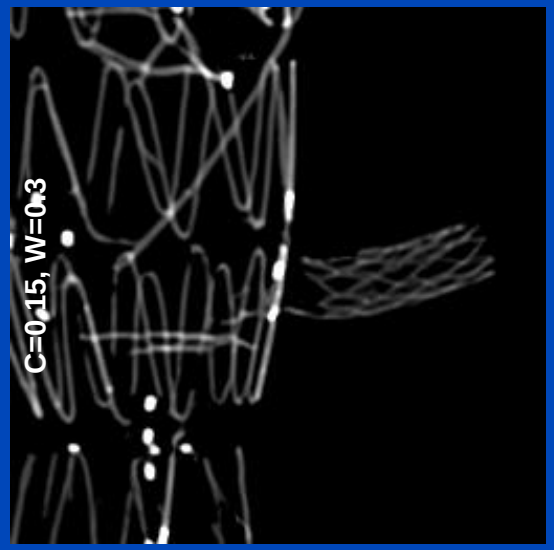
DTE Example 1

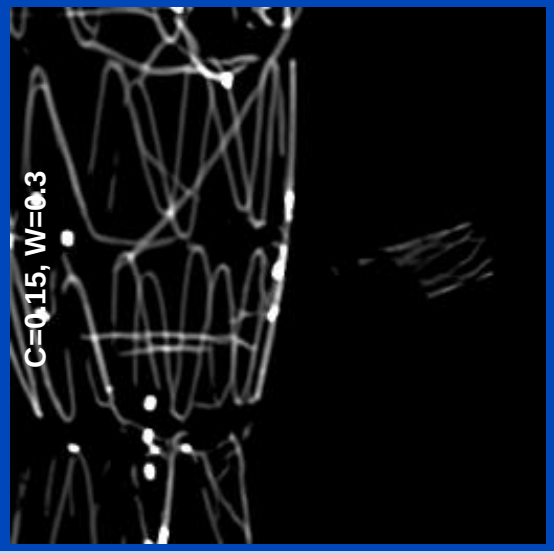
Input

Attention U-net





U-net



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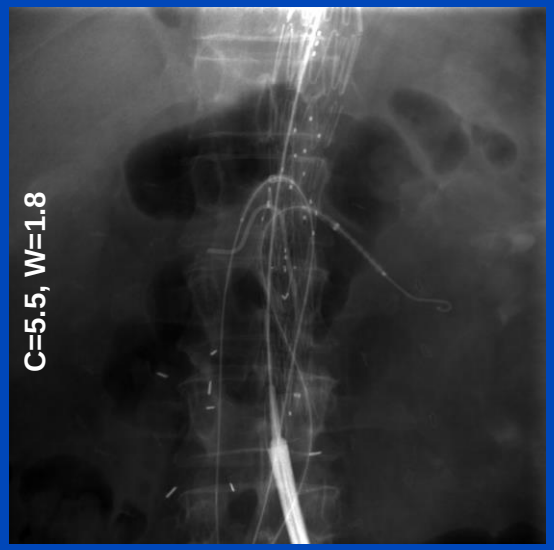
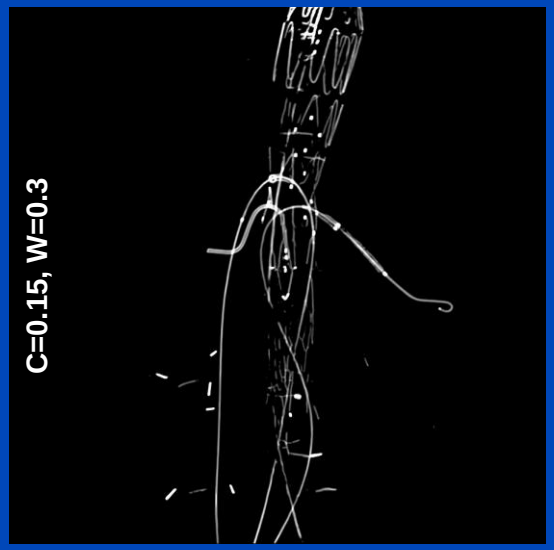
DTE Example 2



Input

Attention U-net



U-net

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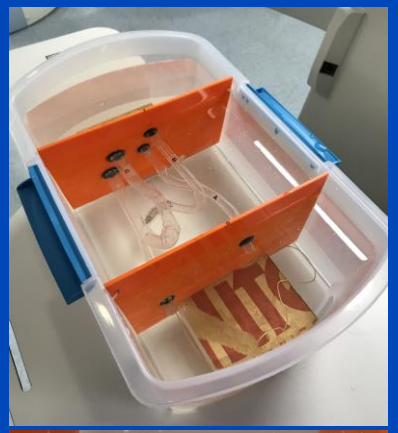
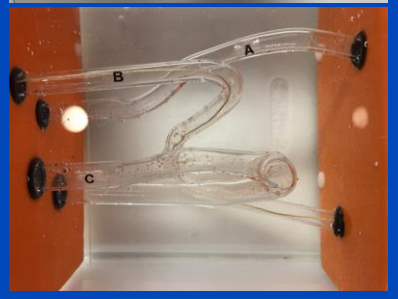
Zeego @ Stanford University





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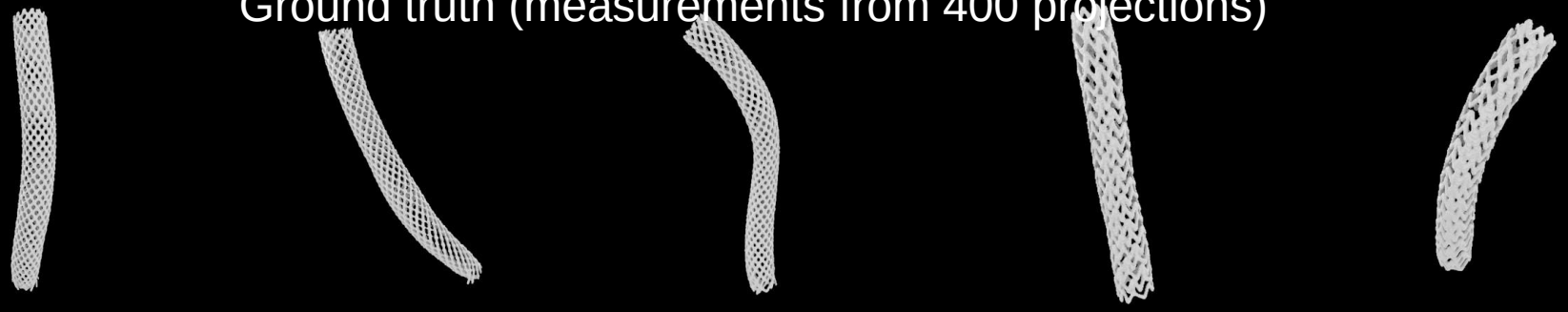
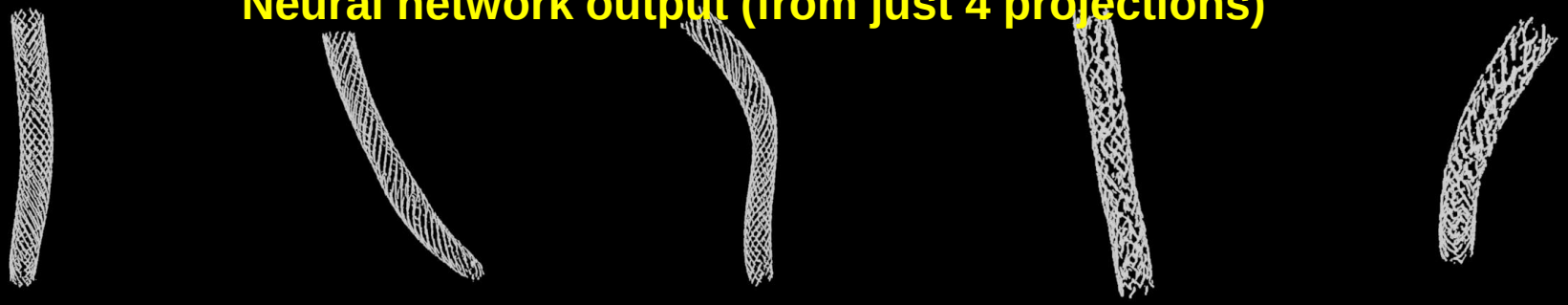
Zeego Measurements with Just 4 Projections

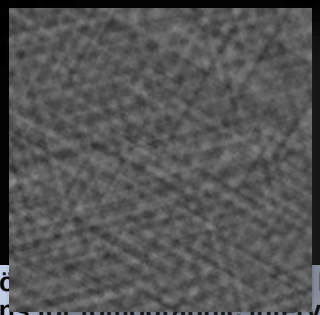
Ground truth (measurements from 400 projections)



Neural network output (from just 4 projections)



Loop through slices reconstructed from just 4 projections without AI:



Stent examples:

E. Eulig, J. Maier, M. Knaup, R. Bennett, K. Hö Kachelrieß. Deep lea al tools and devices from four x-ray projections ventional guidance. Med. Phys. 48(10):5857-5870, October, 2021.
This paper received the Sylvia&Moses Greenfield Award for the best scientific paper in Medical Physics in 2021.

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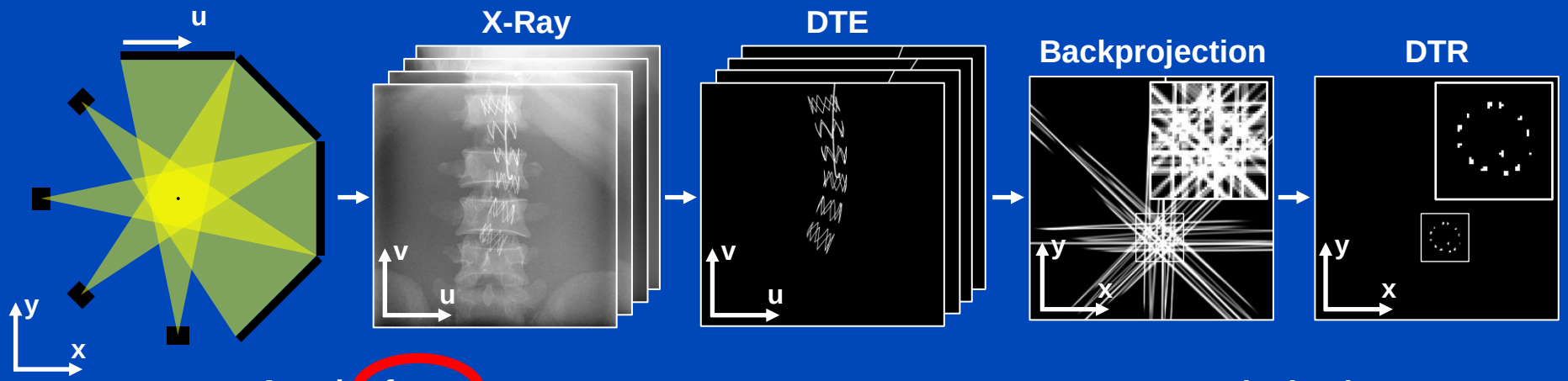
So Far: Four-View Pipeline



Acquire four x-rays simultaneously

Apply the deep tool extraction (DTE)

Backproject the DTE output images

Apply the deep tool reconstruction (DTR)

Four is too many!
Let's find out how to do it with two!

E. Eulig, J. Maier, M. Knaup, R. Bennett, K. Hörndler, A. Wang, and M. Kachelrieß. Deep learning-based reconstruction of interventional tools and devices from four x-ray projections for tomographic interventional guidance. Med. Phys. 48(10):5837-5850, October, 2021.
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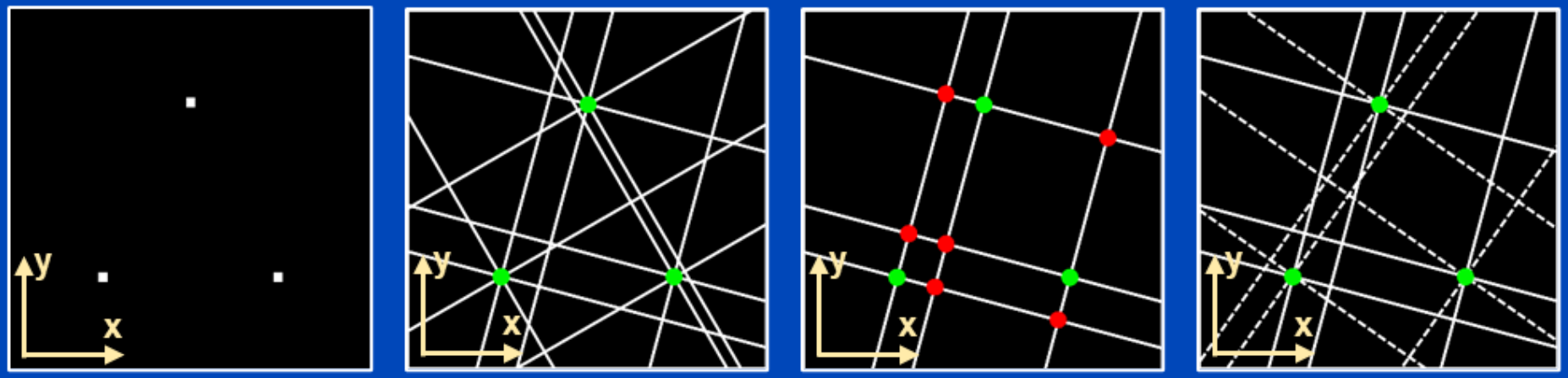
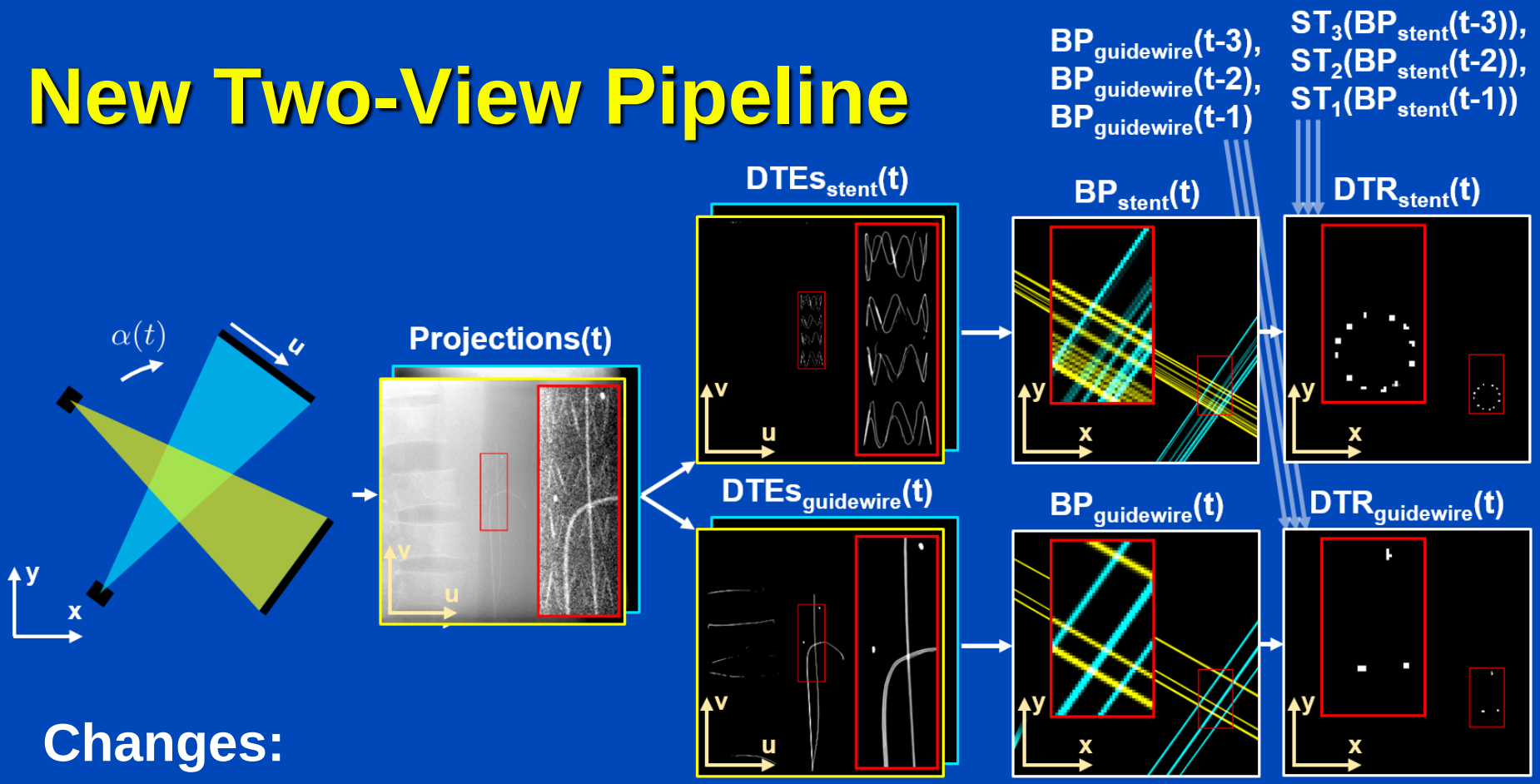
Challenge

true object	4 views 1 time point	2 views 1 time point	2 views 2 time points



New Two-View Pipeline

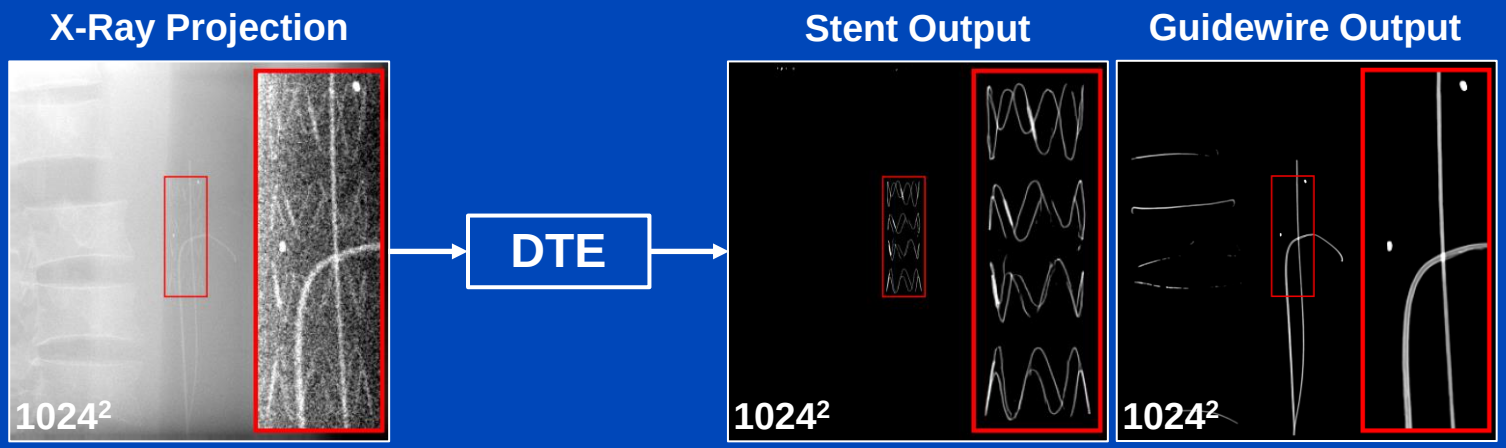


Changes:

- Rotating x-ray system
- Two instead of four imaging threads
- Semantic DSE (separate stent and guidewire channels)
- Motion compensation (MoCo) by spatial transformers (STs)
- Per-view backprojection

T. Vöth, T. König, E. Eulig, M. Knaup, V. Wiesmann, K. Hörndler, and M. Kachelrieß. Real-time 3D reconstruction of guidewires and stents using two update x-ray projections in a rotating imaging setup. Med. Phys. 50(9):5312-5330, September 2023.

Semantic DTE



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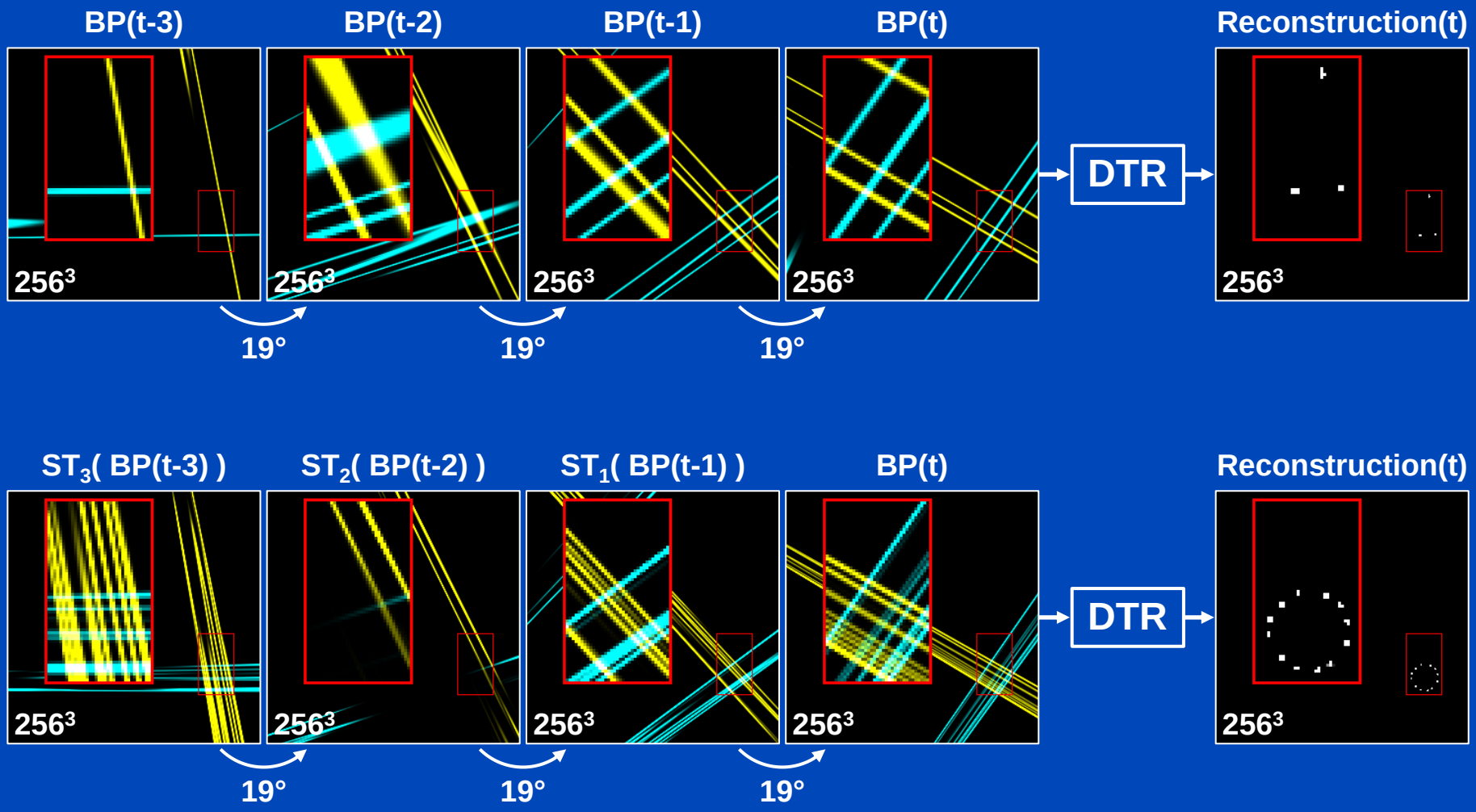
Guidewire and Stent DTR



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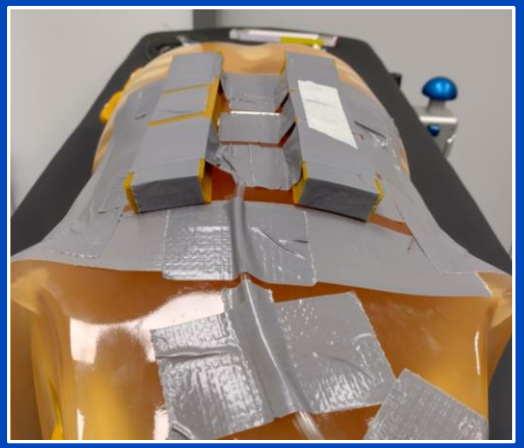
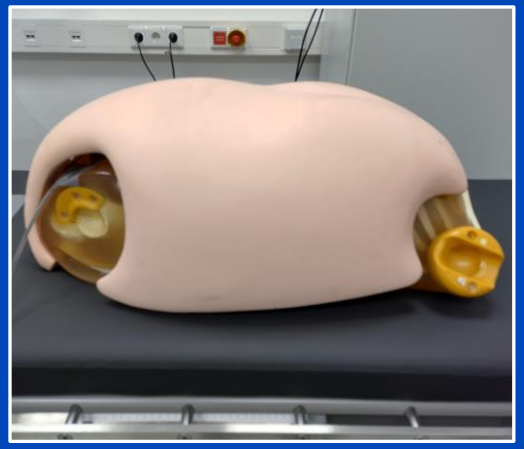
Stop Motion Measurements

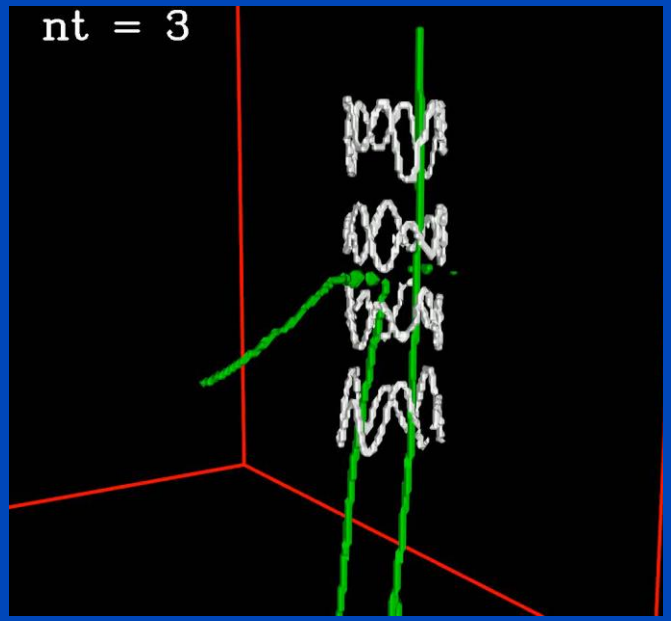
- Training: simulated data
- Results: stop motion measurements
- Flat detector
- For each time step *t*: 3D scan with fine angular sampling
- Choose two orthogonal projections from each 3D scan:
  - *t* = 1: 0°, 90°
  - *t* = 2: 19°, 109°
  - …
- Objects: anthropomorphic trunk phantom + extension + interventional material placed between phantom and extension
- Motion: sinusoidal motion of phantom in superior-inferior direction (mimicking respiratory motion) + pulling of guidewire
- Parameters used during stop-motion measurement:
  U = 100 kV, I = 30 mA, T_{rot} = 25 s, T_{pulse} = 20 ms
- Simulated parameters:
  U = 100 kV, I = 197 mA, T_{rot} = 3.8 s, T_{pulse} = 3 ms, Δt = 200 ms



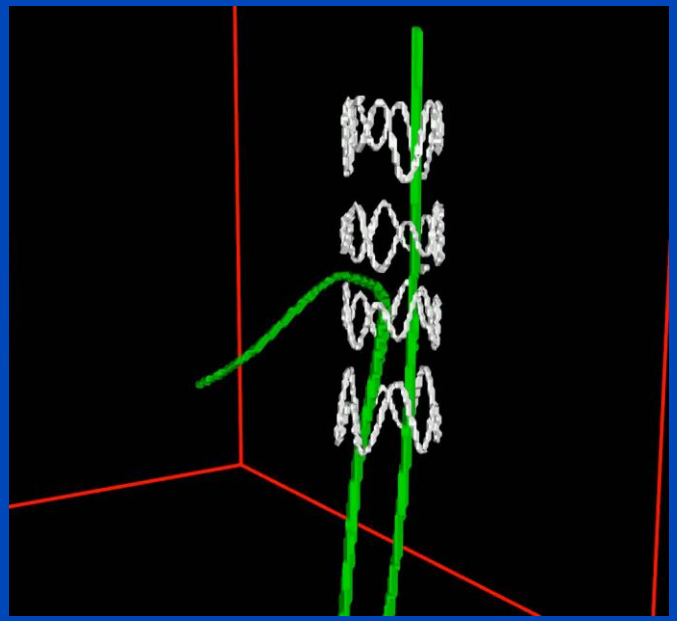


Results

Reconstruction

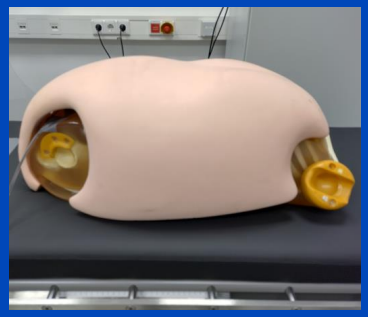


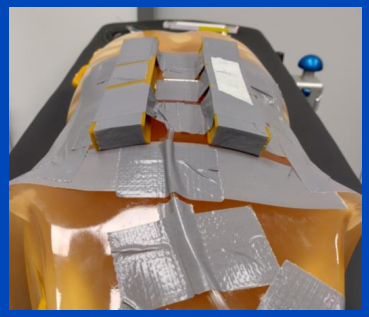
Ground Truth



5 fps video of stop motion scan with 57 time steps.
Sinusoidal 15 rpm motion of whole phantom with 11 mm amplitude.

Trunc phantom (with fat extension and interventional material) used for stop motion measurements.
U = 100 kV, I = 30 mA, T_{rot} = 25 s, T_{pulse} = 20 ms





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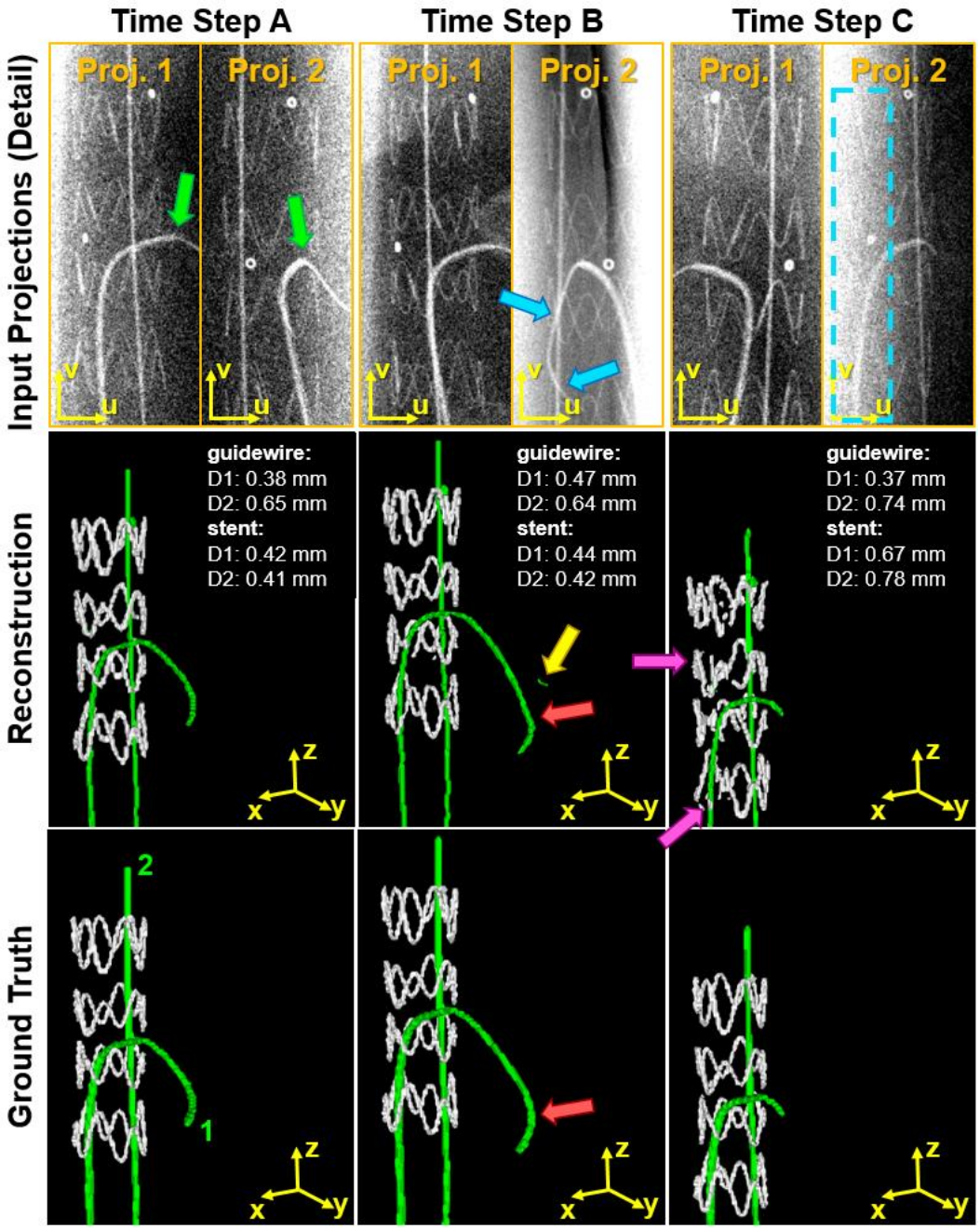
Results

- **Figures of merit:**
  - D_1: average distance between a skeleton of the ground truth and a skeleton of the reconstruction
  - D_2: average distance between a skeleton of the reconstruction and a skeleton of the ground truth
- **Median over 57 time steps:**
  - Guidewire:
    D_1 = 0.37 mm
    D_2 = 0.62 mm
  - Stent:
    D_1 = 0.44 mm
    D_2 = 0.44 mm



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Summary and Outlook

- 3D fluoroscopy at very low dose levels is possible.
- May enable new ways of interventions (3D navigation)
- Requires special device, a double-threaded CBCT

- Next step: Develop DTR for just a single projection.

Thank You!

The 8th International Conference on

Image Formation in X-Ray Computed Tomography

August 5 – August 9, 2024, Bamberg, Germany

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.

Job opportunities through DKFZ's international PhD programs or through marc.kachelriess@dkfz.de.

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