Deformable 3D-2D Registration-Based Running Prior for Low Dose Tomographic X-Ray Fluoroscopy

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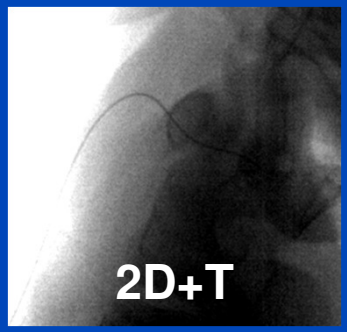
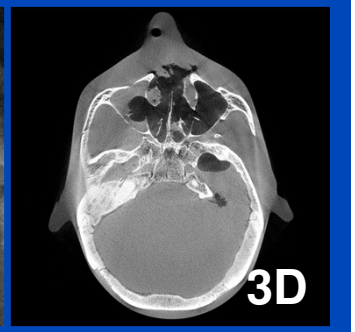
Interventional Radiology

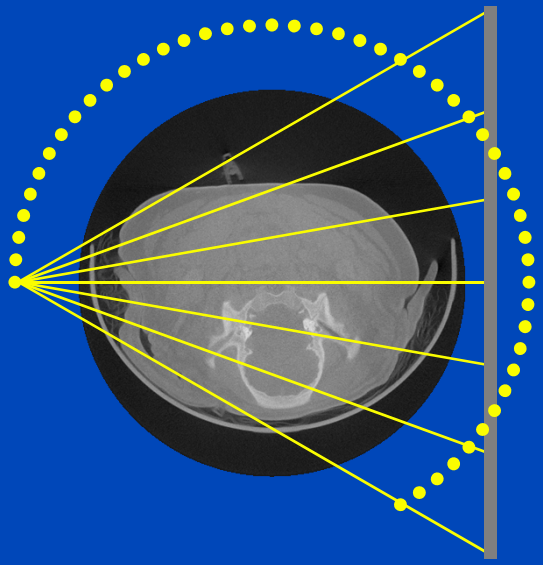
- **Interventional radiology:**
  - Minimally invasive interventions guided by x-ray imaging techniques
  - C-arm systems
- **Projective fluoroscopy:**
  - 2D projections
  - Position of interventional material is often ambiguous.
  - To clarify a 3D volume has to be acquired or trial-and-error approaches are applied.
- **Low dose tomographic fluoroscopy:**
  - 3D volumes
  - For clinical acceptance the dose should be limited to the same level as that of projective fluoroscopy.
  - Volumes have to be reconstructed from very few projections acquired at a very low dose level.





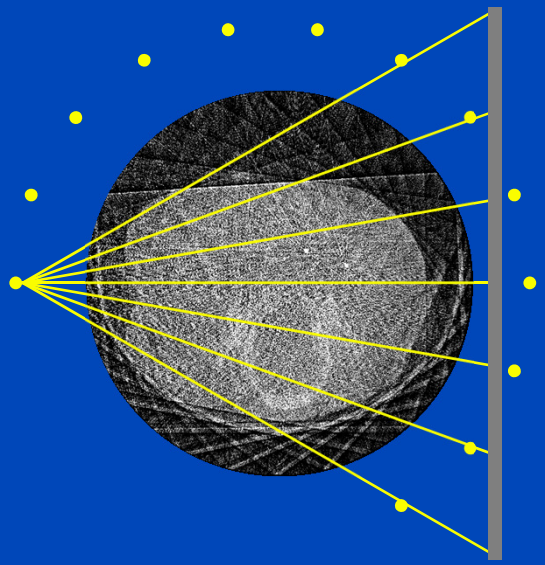
Idea of PrIDICT-Algorithm

Prior scan
many projections, before intervention

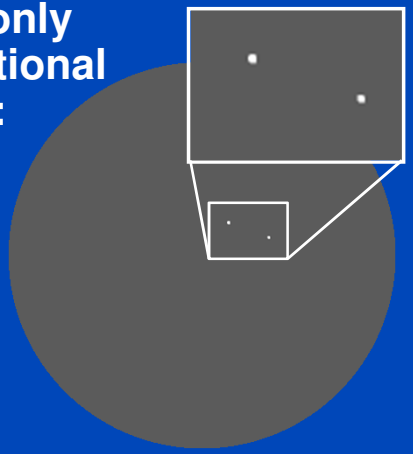


Represents anatomy of patient during whole intervention

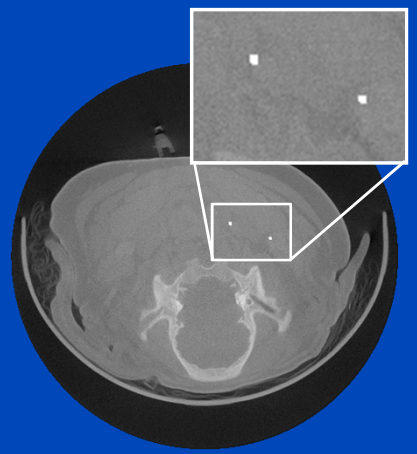
Intervention scan
few projections per time step (e.g. 15)



Extract only interventional material:



Reconstructed time frame



- Shows interventional material in relation to surrounding tissue
- Can be combined with a roadmap showing the vasculature originating from a contrast-enhanced scan

J. Kuntz, B. Flach, R. Kueres, W. Semmler, M. Kachelrieß, and S. Bartling, "Constrained reconstructions for 4D intervention guidance", Phys. Med. Biol. 58(10): 3283-3300, May 2013.

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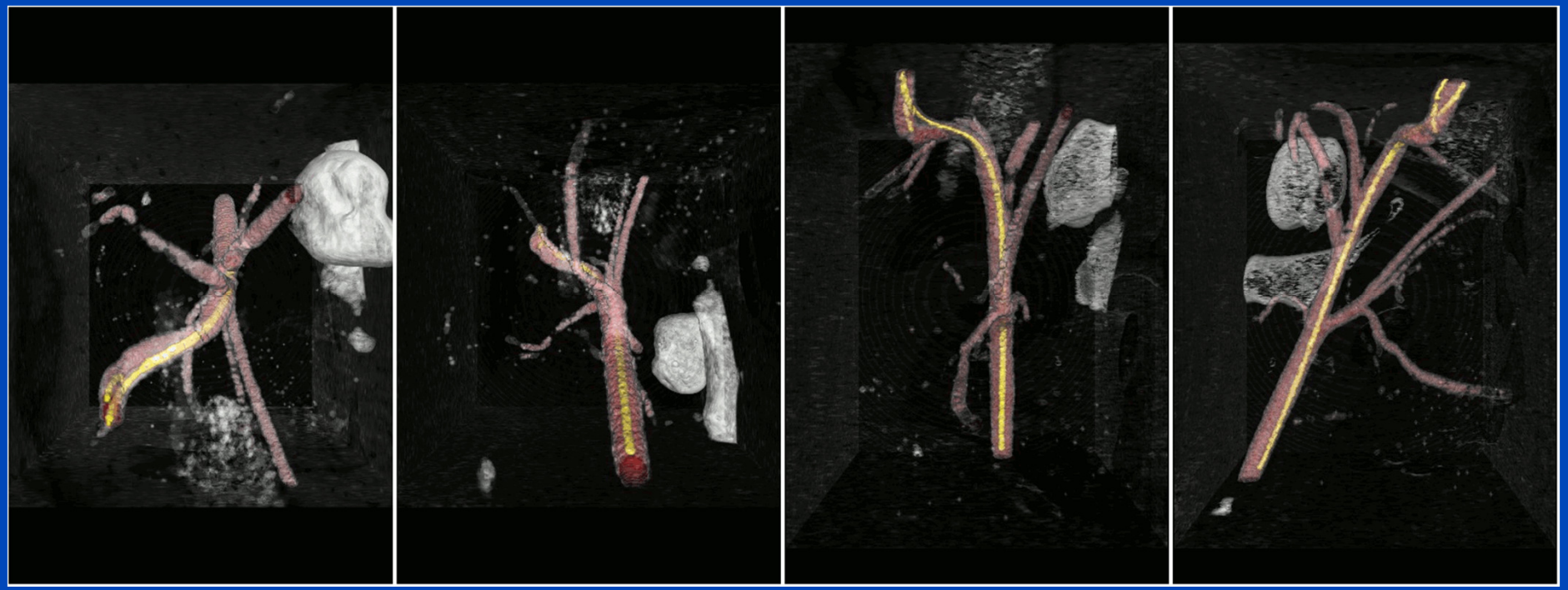
3D+T Fluoroscopy at 2D+T Dose

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



Dose of the yet unoptimized approach: 20 to 50 µGy/s.

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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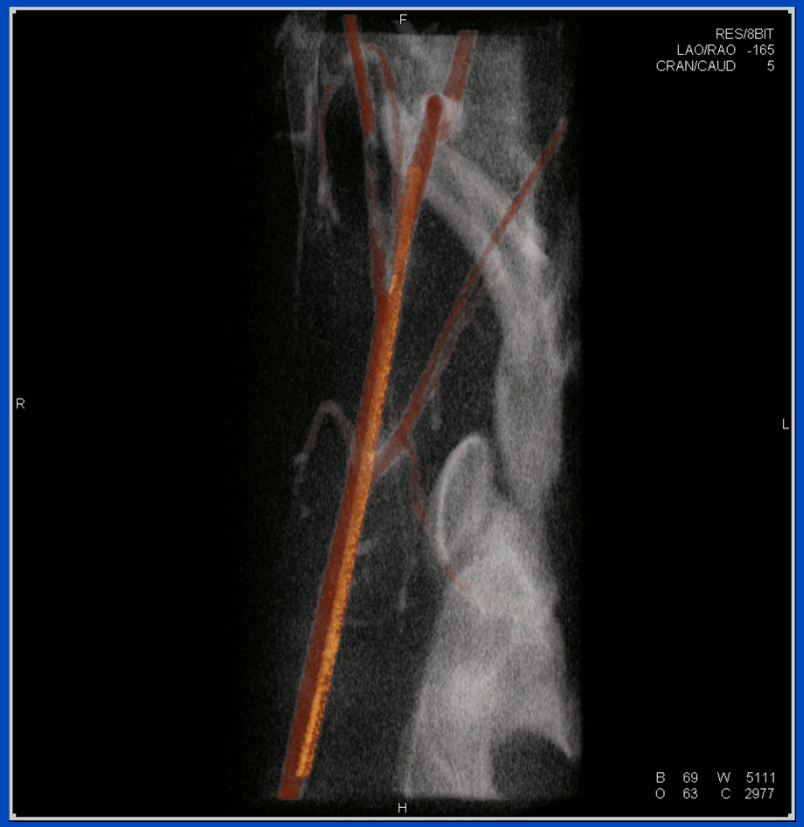
3D+T Image Guidance at 2D+T Dose

Stent Expansion in the Carotis of a Pig with Angio Roadmap Overlay



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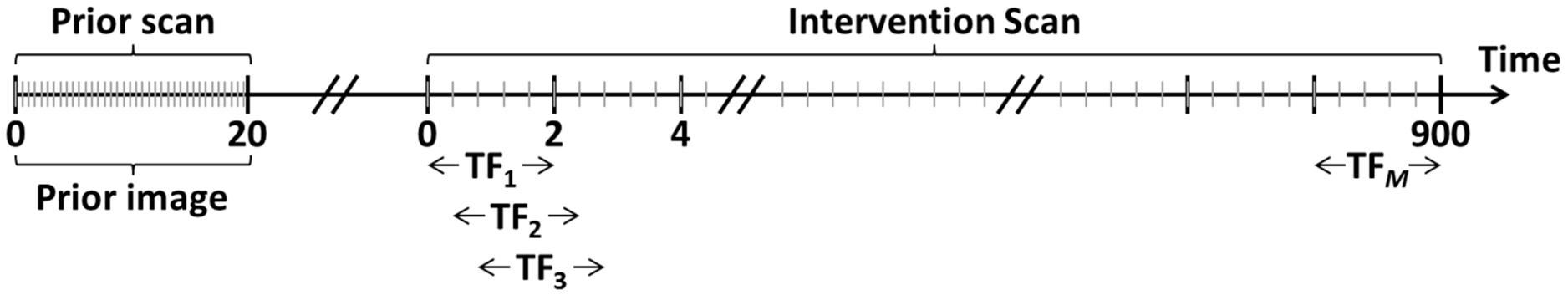
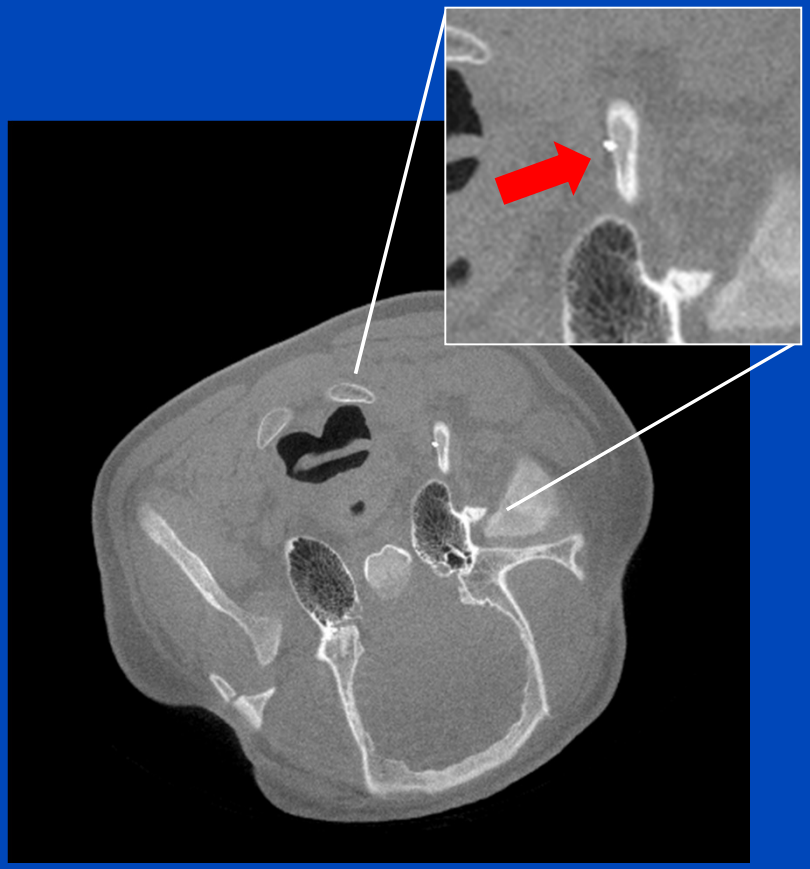
Workflow of Intervention



- Apart from the prior scan the workflow is identical to projective fluoroscopy.
- In contrast to projective fluoroscopy each projection is taken from a different view angle here.
- **Aims:**
  - Move the prior scan into the intervention scan
  - Continuosly update the prior data during the intervention
  - Do this with the sparse sampling only

Static Prior vs. Running Prior

PrIDICT using static prior



Wrong wire position

PrIDICT using running prior

Correct wire position

C = 0 HU, W = 1500 HU

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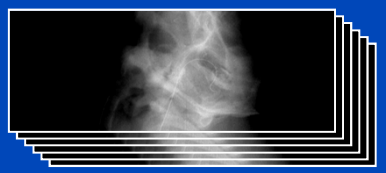
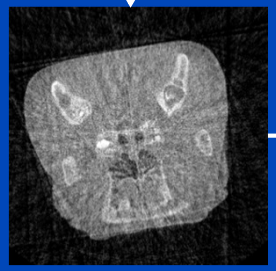
Workflow of Running Prior Technique[3]



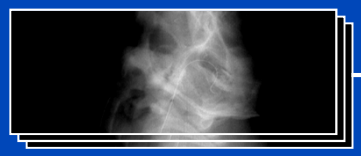
Last 60 projections
e.g. 8 seconds

FDK

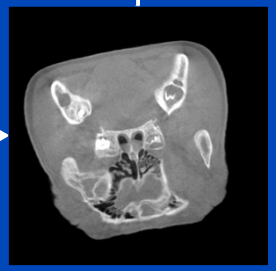


Target image

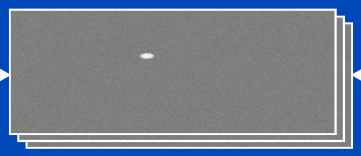
Registration
(3D-3D)



Forward projections
(same projection angles as
last 15 projections)

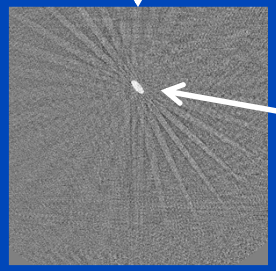


Deformed image

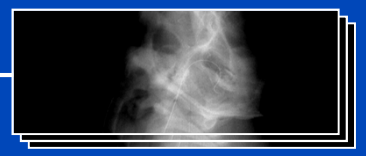


Difference
projections

FDK



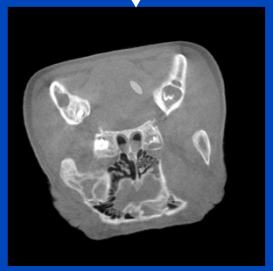
Difference
reconstruction



Last 15 projections
e.g. 2 seconds

e.g. intracranial
hematoma

Current running prior



Next running prior

[3] 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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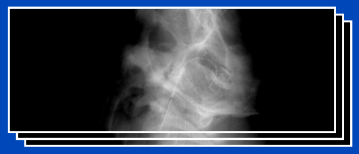
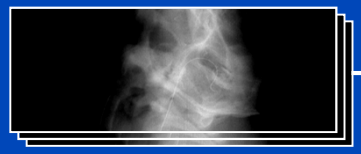
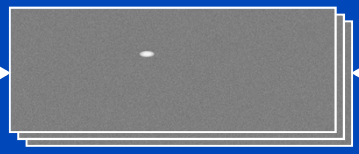
Workflow of Running Prior Technique[4]



Last 15 projections
e.g. 2 seconds

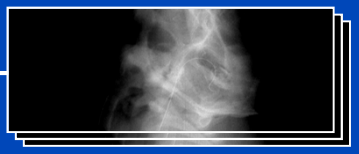


Forward projections
(same projection angles as last 15 projections)



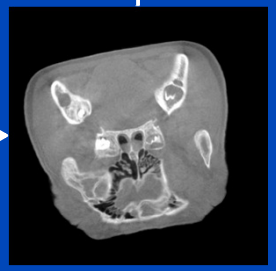
Difference projections

FDK

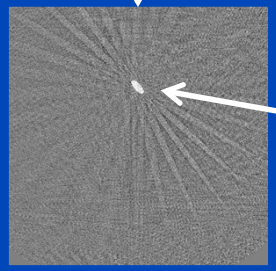


Last 15 projections
e.g. 2 seconds

Registration
(3D-2D)



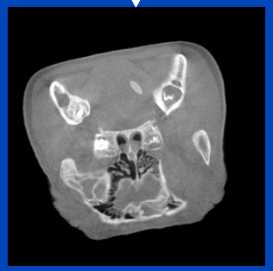
Deformed image



Difference reconstruction

e.g. intracranial hematoma

Current running prior



Next running prior

[4] B. Flach, M. Brehm, S. Sawall, and M. Kachelrieß, "Deformable 3D-2D registration and its application to low dose tomographic fluoroscopy", submitted to Phys. Med. Biol.

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Deformable 3D-2D Registration

- **Deform prior image $p(r)$ to match the rawdata q:**
  - **Displacement vector field (DVF):** $\boldsymbol{u}(\boldsymbol{r}) = (u_1(\boldsymbol{r}), u_2(\boldsymbol{r}), u_3(\boldsymbol{r}))^{\mathrm{T}}$
  - **Deformed image:** $p_{\boldsymbol{u}}(\boldsymbol{r}) = p(\boldsymbol{r} + \boldsymbol{u}(\boldsymbol{r})) = (p \circ (\mathrm{Id} + \boldsymbol{u}))(\boldsymbol{r})$
  - **Matching criterion:** $S[\boldsymbol{u}] = \|\mathsf{X}p(\boldsymbol{r} + \boldsymbol{u}(\boldsymbol{r})) - q\|_2^2$ **(rawdata fidelity)**
  - **Velocity vector field:** $\boldsymbol{v}(\boldsymbol{r}) = (v_1(\boldsymbol{r}), v_2(\boldsymbol{r}), v_3(\boldsymbol{r}))^{\mathrm{T}} = \partial_t \boldsymbol{u}(\boldsymbol{r})$
  - **Smoothness of a vector field** $\boldsymbol{w}(\boldsymbol{r}) = (w_1(\boldsymbol{r}), w_2(\boldsymbol{r}), w_3(\boldsymbol{r}))^{\mathrm{T}}$ **achieved by minimizing**
    $$R[\boldsymbol{w}] = \sum_{d=1}^{3} \sum_{\boldsymbol{r}} \langle \boldsymbol{\nabla}_{\boldsymbol{r}} w_d(\boldsymbol{r}), \boldsymbol{\nabla}_{\boldsymbol{r}} w_d(\boldsymbol{r}) \rangle$$
  - **Diffusive regularization:** $R[\boldsymbol{u}]$
  - **Fluid regularization:** $R[\boldsymbol{v}] = R[\partial_t \boldsymbol{u}]$
- **Determine the DVF u by minimizing the following cost function:**

$$C[\boldsymbol{u}] = S[\boldsymbol{u}] + \beta R[\boldsymbol{u}] + \gamma R[\partial_t \boldsymbol{u}]$$

Measurements

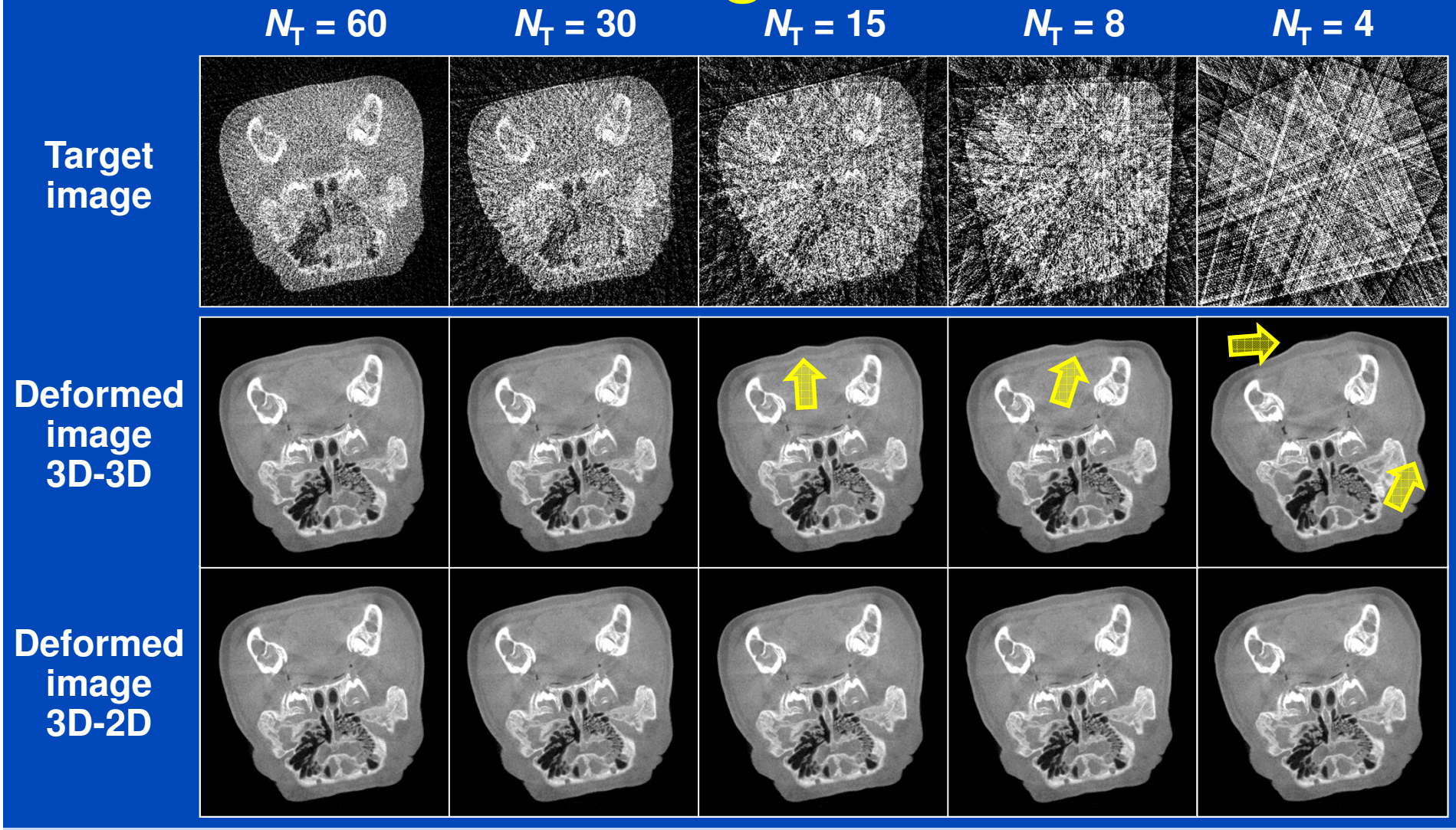
- **System:**

  Volume CT prototype
  - Flat detector on clinical CT gantry
  - Geometry like C-arm systems

Experimental setup

- **Prior scan:**
  - Before intervention
  - N_{360} = 600 projections per 360°
  - T_{rot} = 19 s/360°
  - 1 single rotation
- **Intervention scan:**
  - During intervention
  - N_{180} = 15 projections per 180°
  - T_{rot} = 4 s (= 2 s/180°)
  - Many rotations (depending on time needed for intervention)
  - Guide wire inserted into the carotid of the pig‘s neck during the scan
- **Data of two experiments with different pigs are presented.**
- **Pigs are moved manually between prior and intervention scan.**
- **Algorithms are always initialized with a DVF resulting from an affine registration.**

Decreasing Number of Projections (N_T)
Pig 1



C = 0 HU, W = 1500 HU

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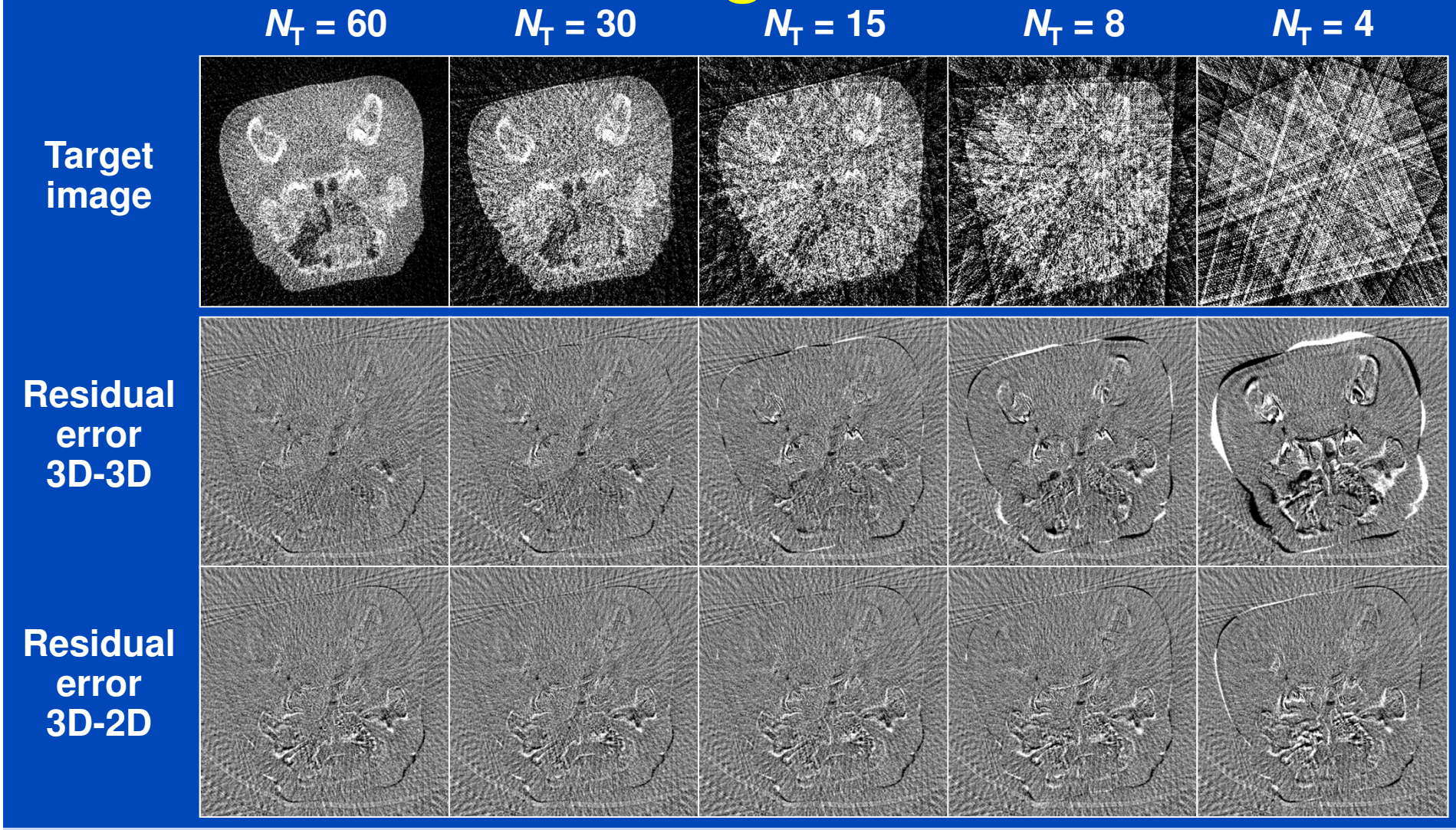
Decreasing Number of Projections (N_T)
Pig 1



Images: C = 0 HU, W = 1500 HU
Difference images: C = 0 HU, W = 1000 HU

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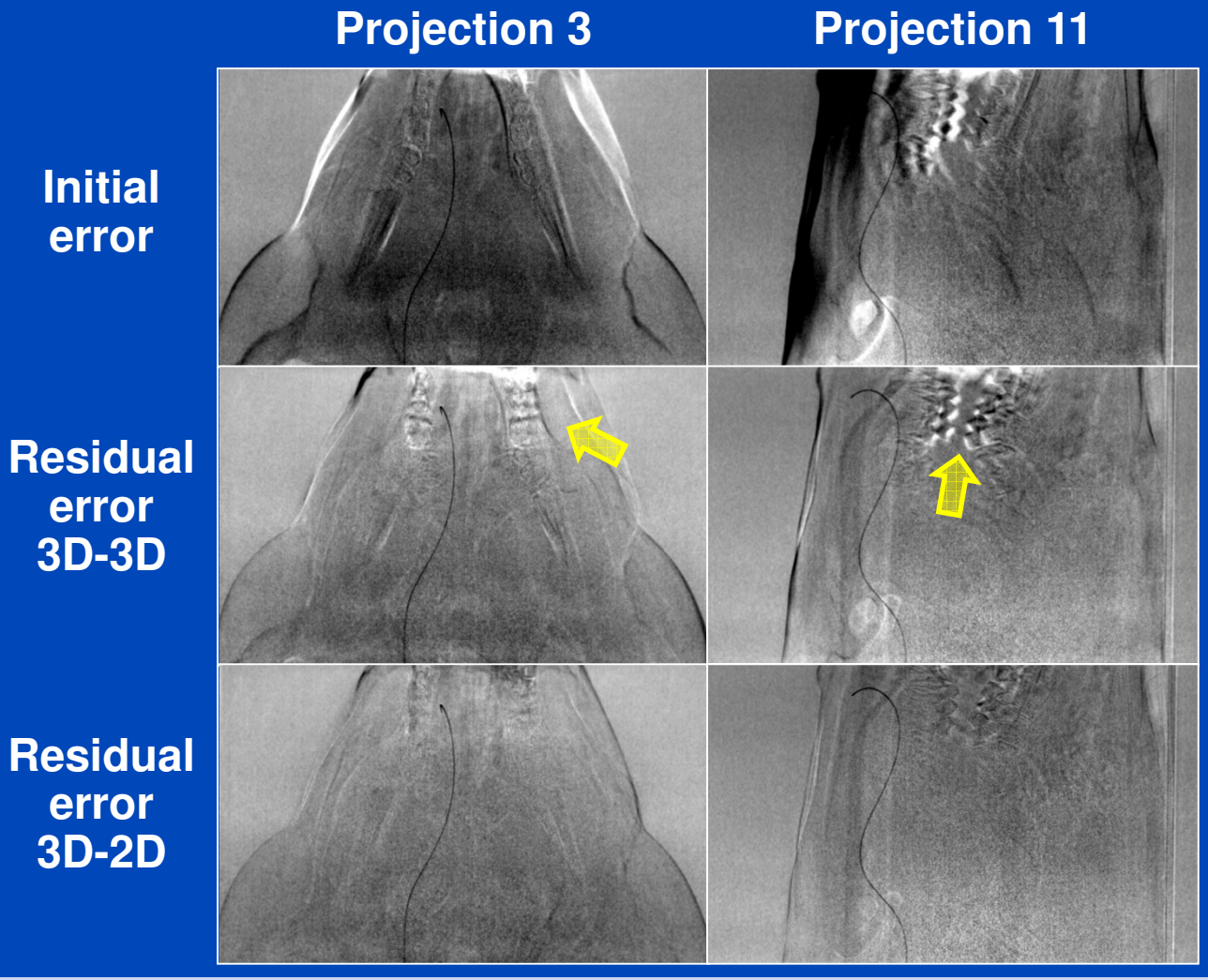
Error in Rawdata Domain
Pig 2 (15 Projections)



C = 0.0, W = 0.5

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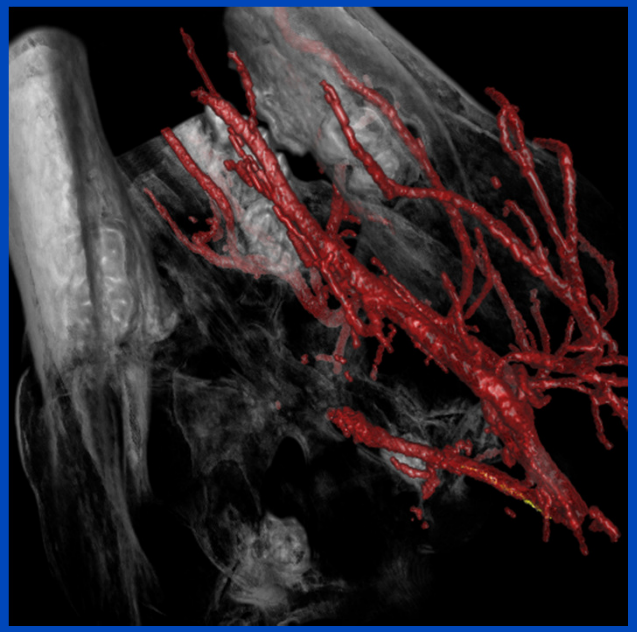
Conclusion

- Our proposed 3D-2D registration is robust and stable also in case of very few projections:
  - High matching in image as well as in rawdata domain
  - Without introducing artificial motion
- In case of few projections 3D-2D registration is superior to 3D-3D registration.



- Improves temporal resolution of low dose tomographic fluoroscopy.
- Method may be useful for many other applications.

Thank You!

The 4th International Conference on

Image Formation in X-Ray Computed Tomography

Conference Chair

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

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

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