Stack Transition Artifact Removal for Cardiac CT Using Patch-Based Similarities

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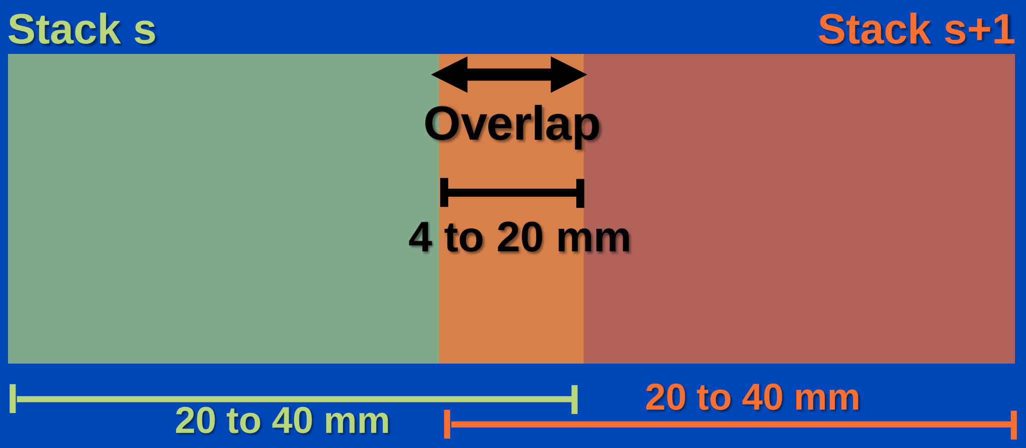
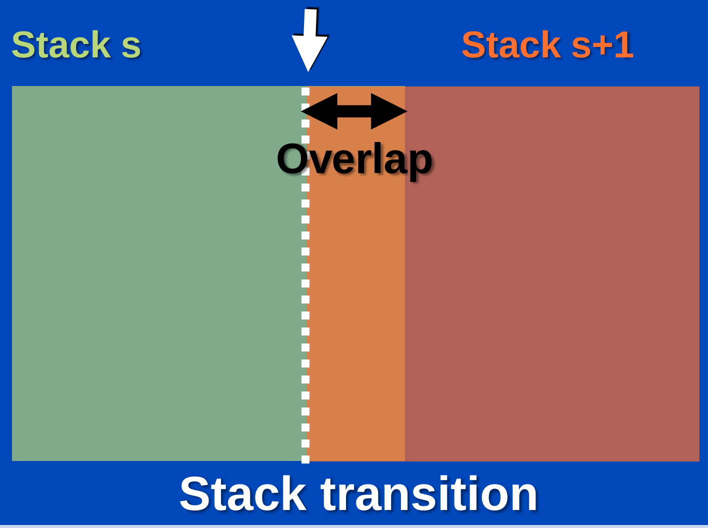
Introduction
Cardiac Imaging

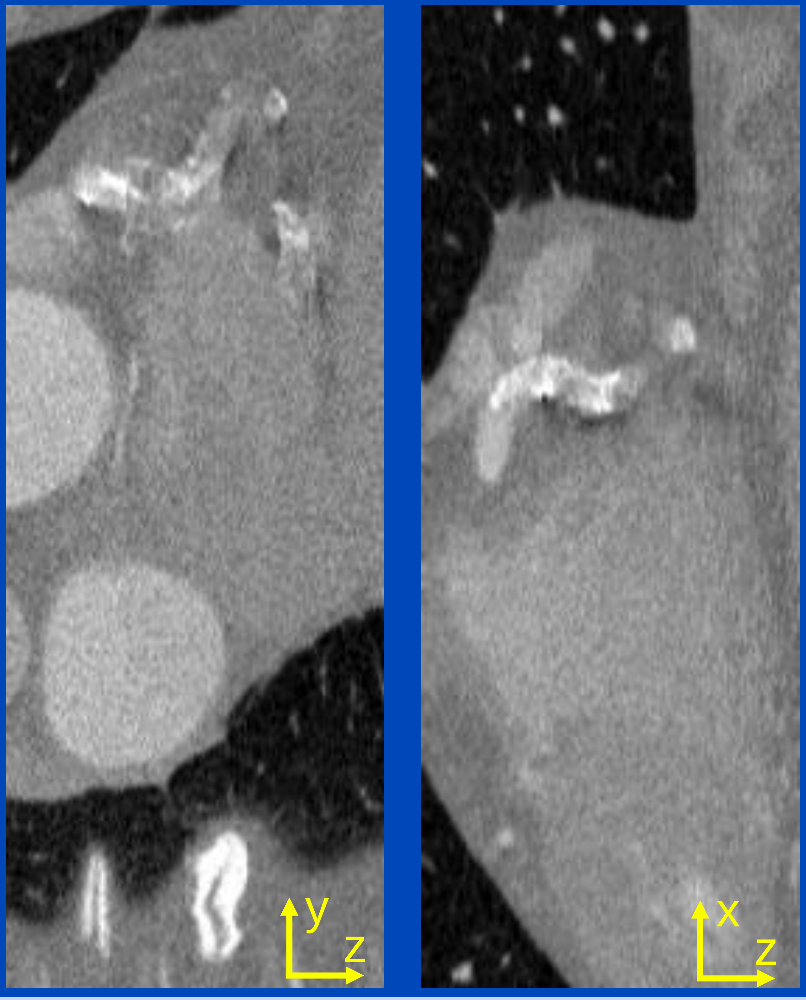
- Data of from one cardiac phase can be acquired via prospective ECG-gating or extracted from a retrospectively gated data set.
- Cardiac reconstructions can yield sub volumes (stacks) corresponding to different times and, ideally, to the same heart phase.
- The depth of the stacks depends on the longitudinal collimation of the CT scanner.
- The stacks generally have a longitudinal overlap.



Introduction
Stacks

- The final CT volume is assembled from the stacks.
- The stack transition, from which the next stack is used, can theoretically be set to any position within the stack overlap.
- A blending between the stacks can also be performed.





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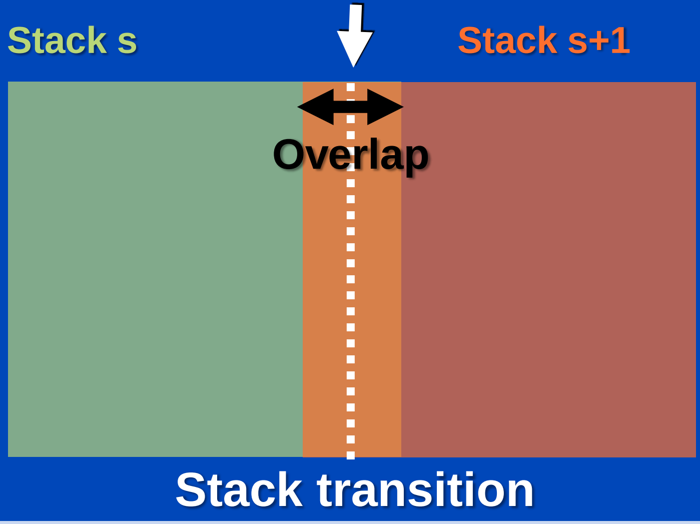

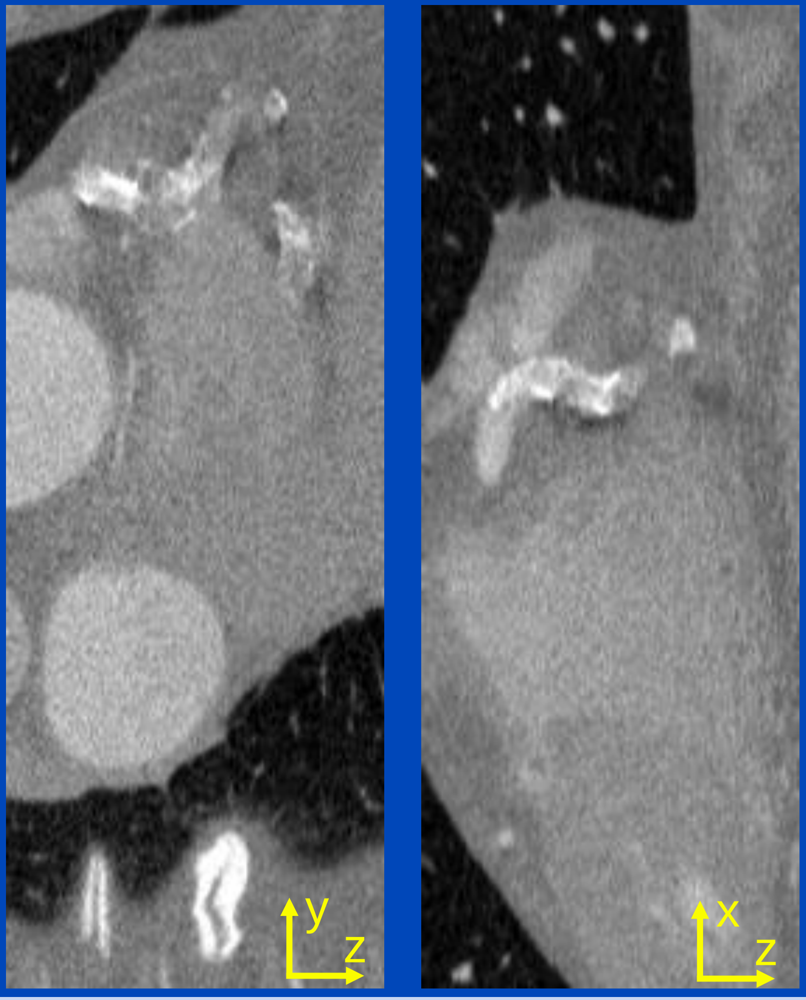

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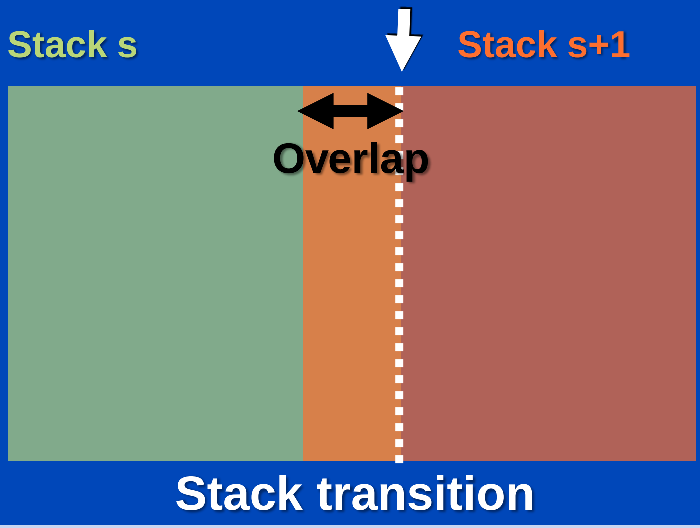

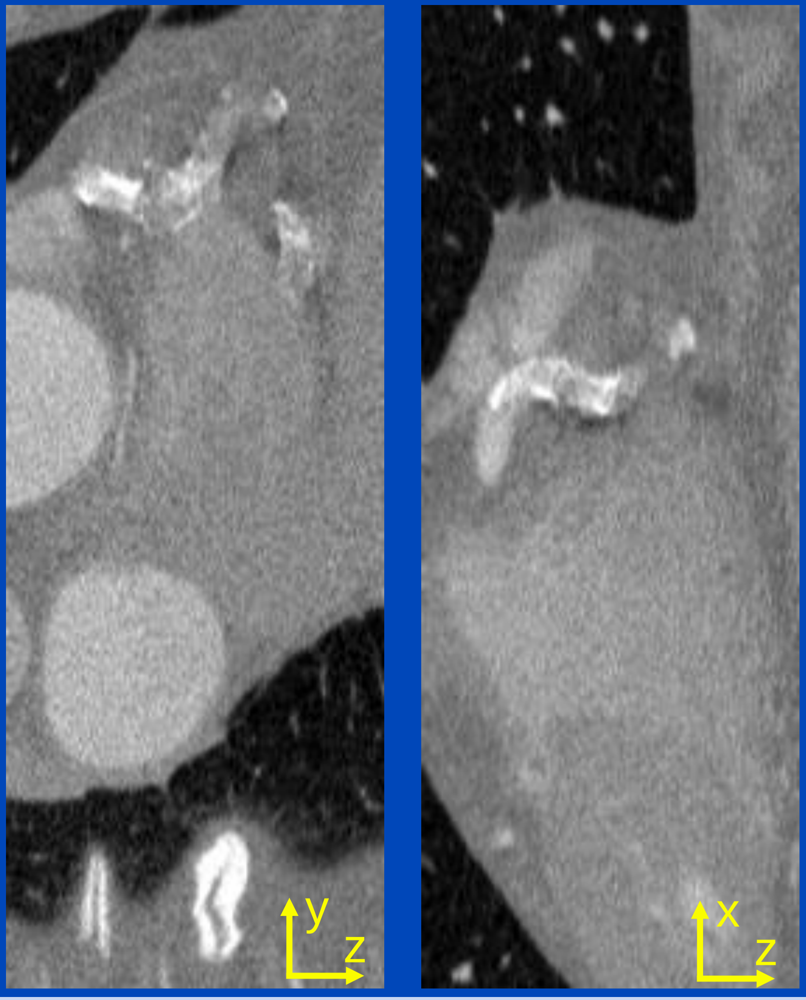

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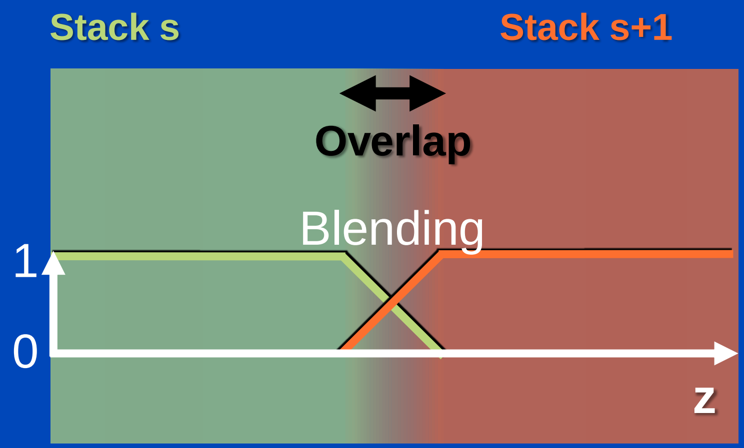
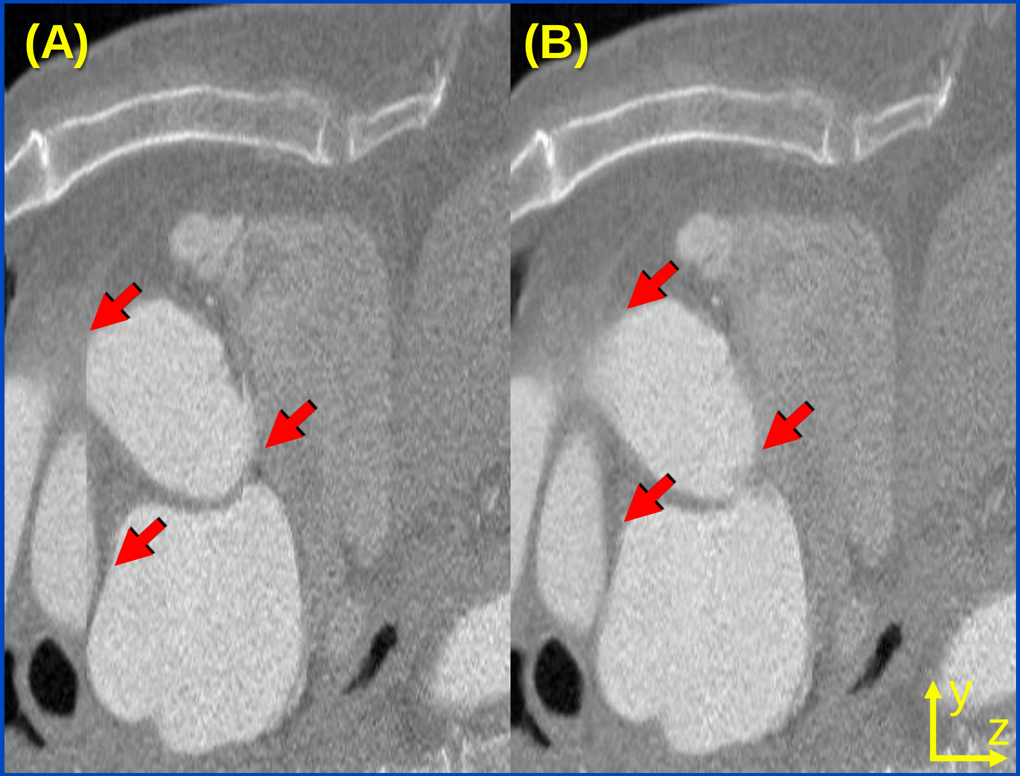


Stack transition

Introduction
Stack transition artifacts

- Irregular motion leads to stacks that do not represent exactly the same volume.
- Discontinuities (misalignment) at stack transitions arise when stitching the stacks together to yield the complete CT volume.



Two sagittal slices from a cardiac data set with strong stack transition artifacts. (A) Sharp stack transition. (B) Blending between stacks.

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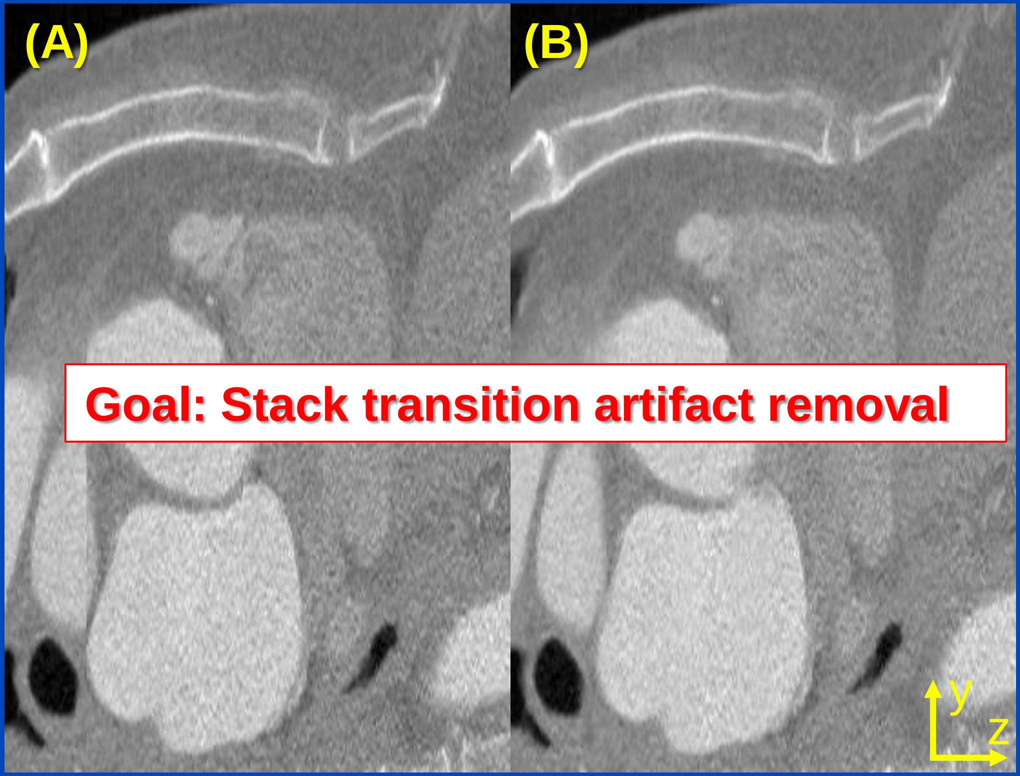


Two sagittal slices from a cardiac data set with strong stack transition artifacts. (A) Sharp stack transition. (B) Blending between stacks.

Methods

Symmetric registration

- **Many registration approaches assume one volume that is registered onto a target volume.**
- **Given two volumes $f_1(\boldsymbol{r})$, $f_2(\boldsymbol{r})$, compute a DVF $\boldsymbol{d}$(r) that will match the two.**
- **Herein, symmetric means that a method is symmetric in terms of the deformations that are applied to both volumes so that the transformed volumes $\hat{f}_1(r)$ and $\hat{f}_2(r)$ match:**

$$\hat{f}_1(\boldsymbol{r}) = f_1(\boldsymbol{r} + \boldsymbol{d}(\boldsymbol{r}))$$

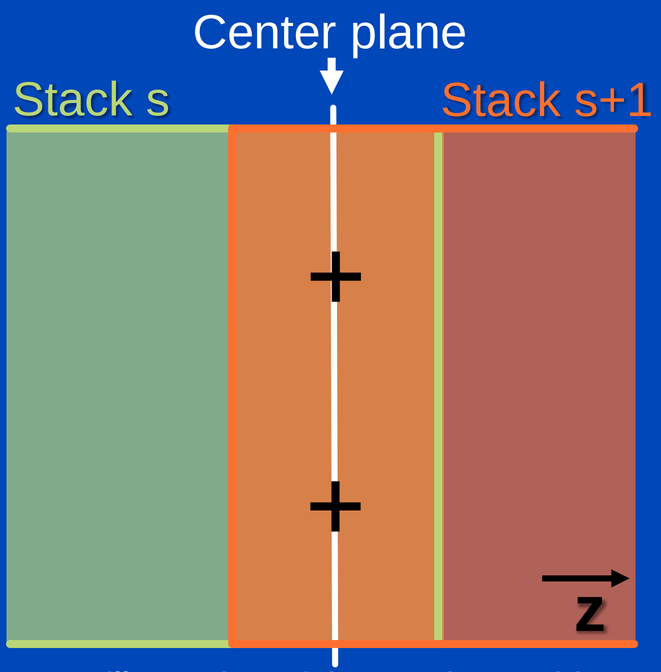
$$\hat{f}_2(\boldsymbol{r}) = f_2(\boldsymbol{r} - \boldsymbol{d}(\boldsymbol{r})).$$

↑

DVF applied in
opposing directions

Methods
Symmetric Patch Matching

1. **Evenly distribute control points (CP, +) in the center plane of each overlapping region.**



2D illustration of the patch matching method with two CPs.

Methods

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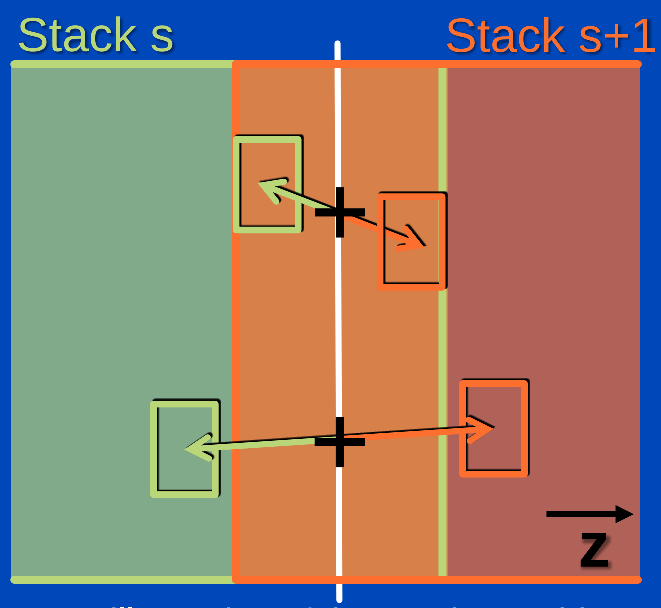
1. Evenly distribute control points (CP, +) in the center plane of each overlapping region.
2. Look for the most similar* 3D sub volume (patch) pairs at opposite offsets from a CP within the two stacks.



2D illustration of the patch matching method with two CPs.

* w.r.t. to a similarity metric, e.g. sum of squared differences

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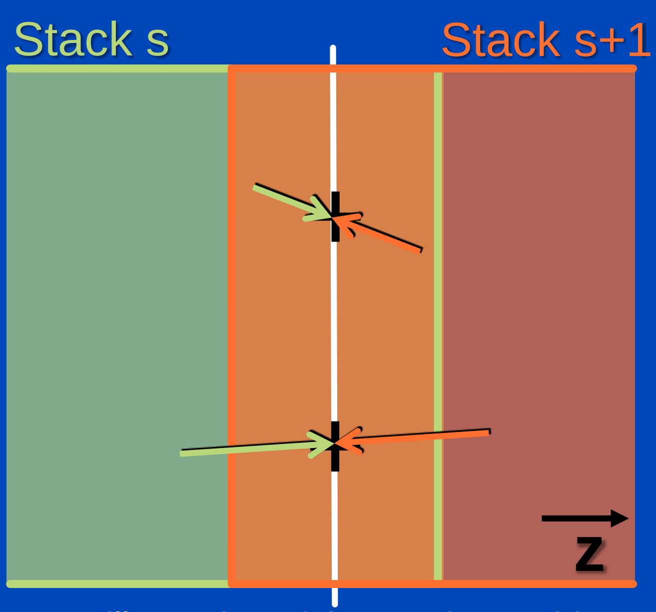
3. **Invert the offset vectors to get deformation vectors for a source driven transformation (at the CPs).**



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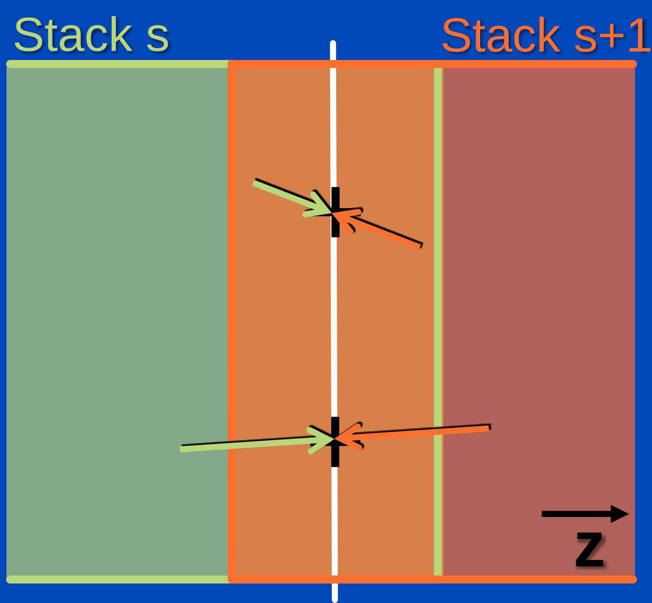

2D illustration of the patch matching method with two CPs.

If a patch pair did not contain anatomical details the deformation vector at the respective CP is replaced with an interpolation from neighboring, “valid” CPs.

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Methods
Dealing with Homogeneous Patches

- Two patches with soft tissue can be wrongly associated if the cost function is minimized due to noise alone.
- A method to detect CPs (+) around which noise is dominant must be used.
- Perform a simple edge detection on the original volume and check found patch pairs for the presence of edges at each CP.
- CPs deformation vectors, where patches have none or insufficient edges are replaced with an interpolation from neighboring, valid CPs.

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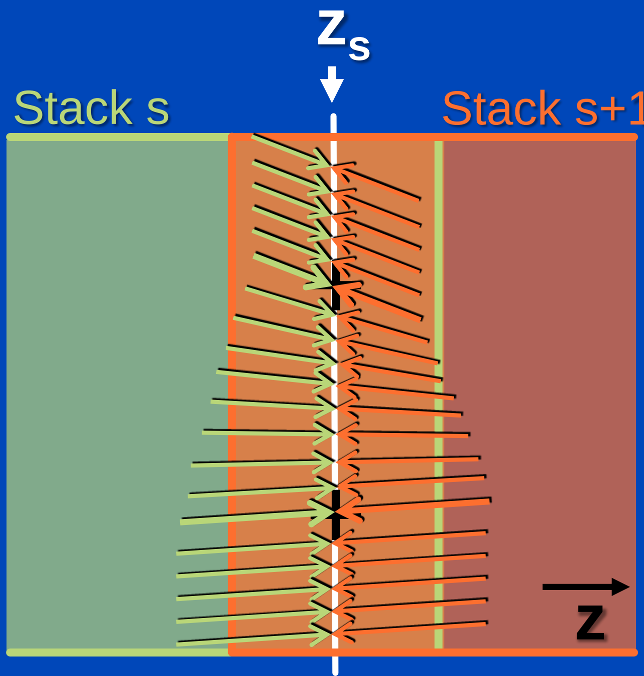
4. **In order to get a smooth DVF on the central plane a billinear interpolation can be performed yielding a DVF $d(r_{xy}, z_s)$.**



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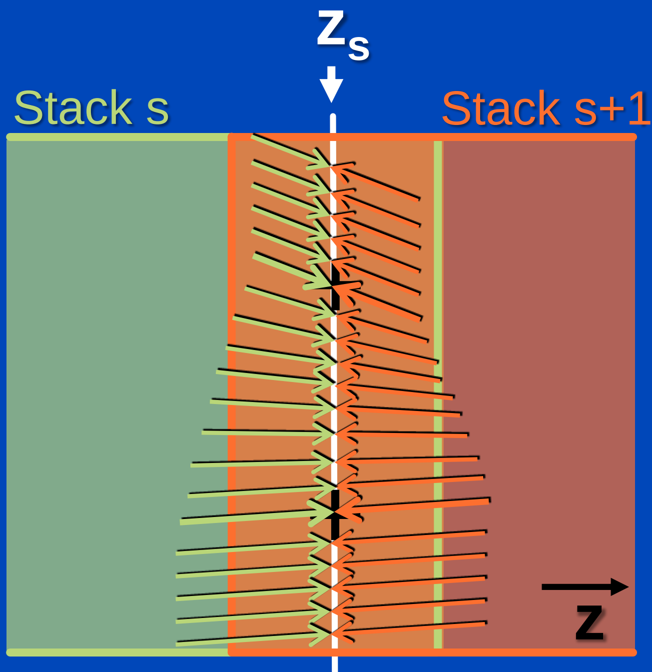

2D illustration of the patch matching method with two CPs.

Smooth DVFs valid on an entire stack, for all stacks are required!

SIEMENS * w.r.t. to a similarity metric, e.g. sum of squared differences dkfz.

Method
Symmetric Patch Matching

5. **An interpolation (in longitudinal direction) can be performed between the DVFs d(r_{xy},z_s) on the central planes. Let d_0, d_S = 0.**
   A transformed stack $g_s(r)$ can be computed as:

$$\hat{g}_s(\boldsymbol{r}) = g_s\left(\boldsymbol{r} - \left(\frac{z_s - z}{z_s - z_{s-1}}\right)\boldsymbol{d}_{s-1}(\boldsymbol{r}_{x,y}, z_{s-1}) + \left(1 - \frac{z_s - z}{z_s - z_{s-1}}\right)\boldsymbol{d}_s(\boldsymbol{r}_{x,y}, z_s)\right)$$

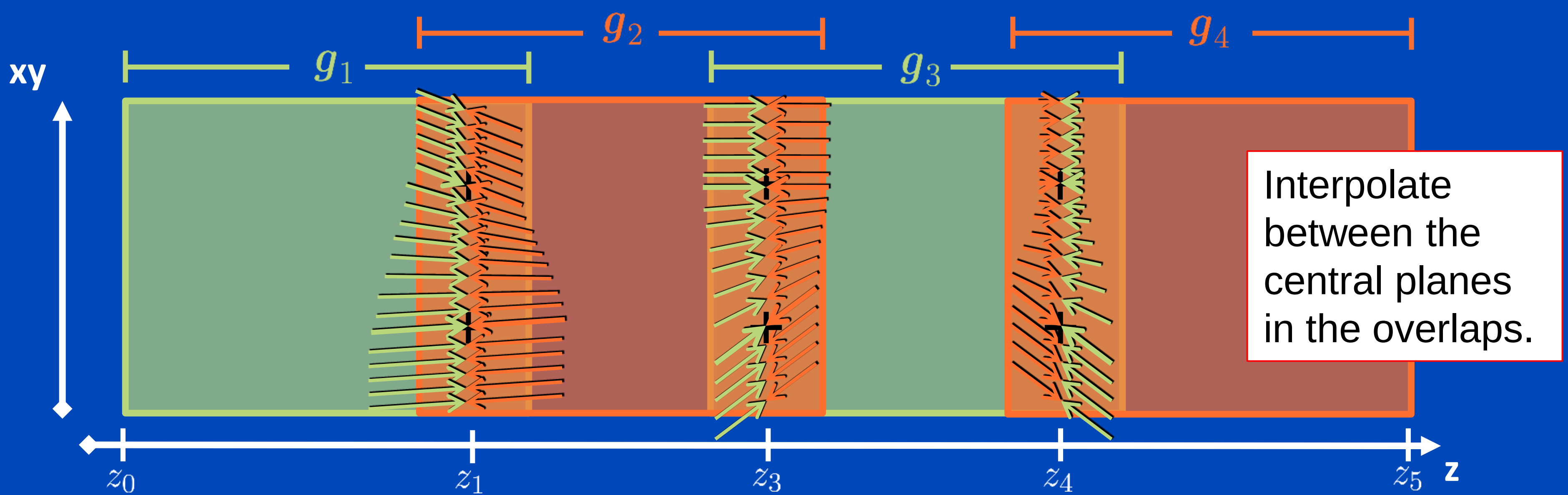

Illustration for four stacks and two CPs per overlap.

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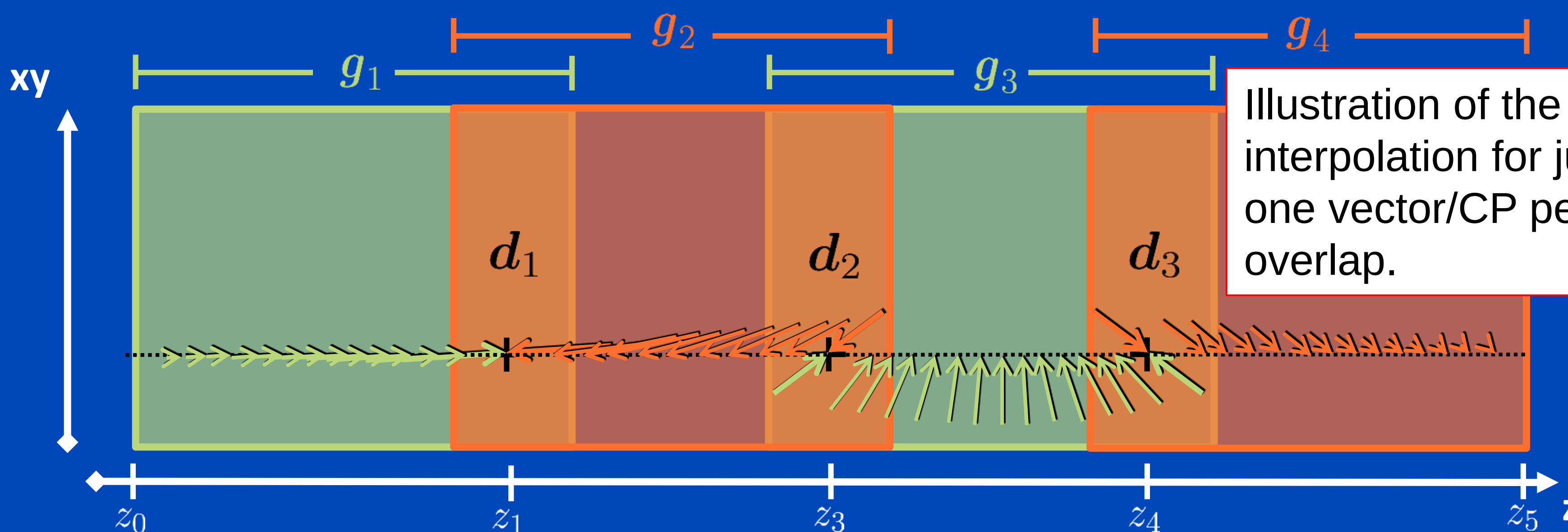


Illustration of the interpolation for just one vector/CP per overlap.

Illustration for four stacks and one vector/CPs per overlap.

Parameters & Materials

Parameters for the patch matching:

- Patch size: 15×15×2 to 3 mm (depth overlap/2)
- Control point distances: 10×10 mm
- Number of control points: 16×16
- Maximum allowed displacement vector length: 6 mm (i.e. up to 12 mm deformations are possible)

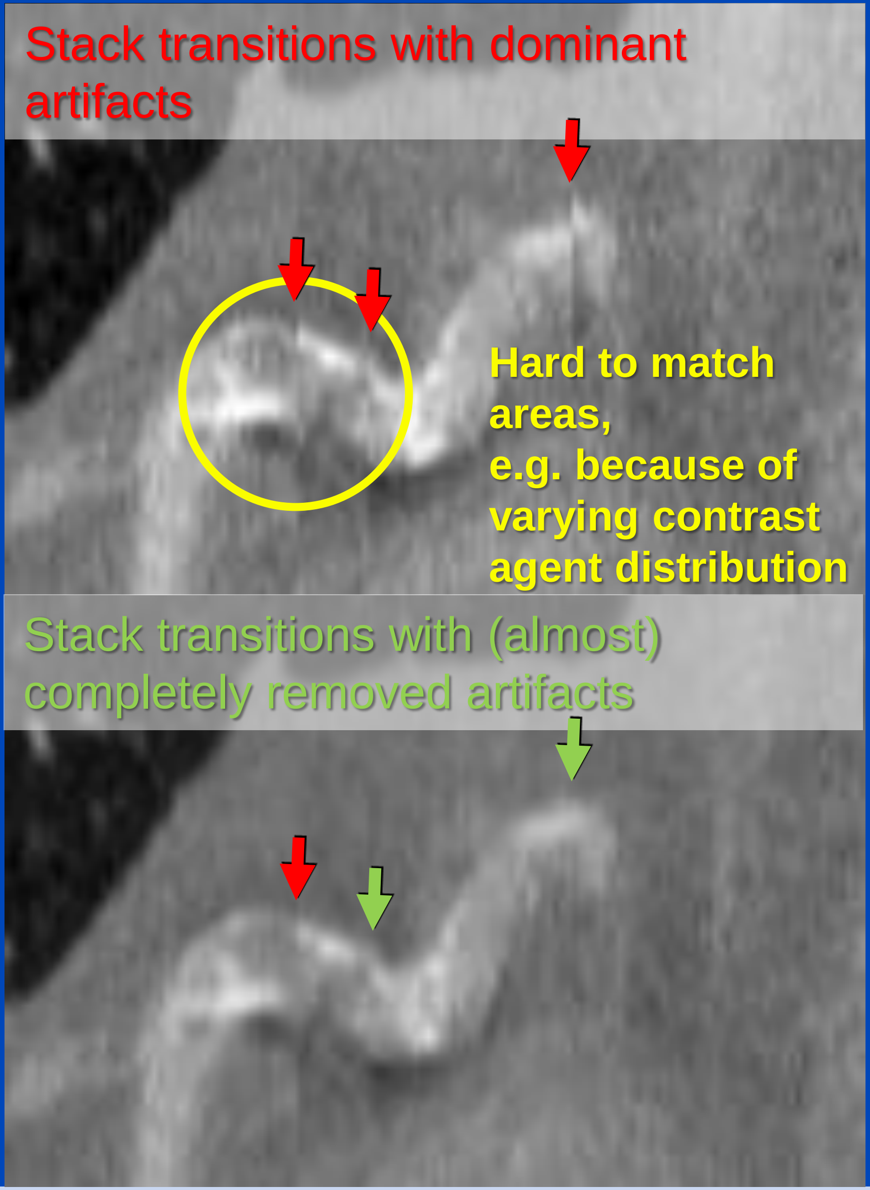
Materials:

- Data acquired with a Somatom Definition Flash and Somatom Definition AS+ (Siemens Healthineers, Forchheim Germany).
- Standard partial scan WFBP reconstructions
- t_{rot} = 285 ms
- eff. mAs = 92 - 374 mAs
- Tube voltage = 80 - 125 kV
- CTDI vol = 7 - 82 mGy
- DLP = 110 - 1254 mGy cm

Results

Case A

C = 0 HU, W=2000 HU



Some dominant stack transition artifacts are marked. 2 out of 3 artifacts have been mostly or completely removed.

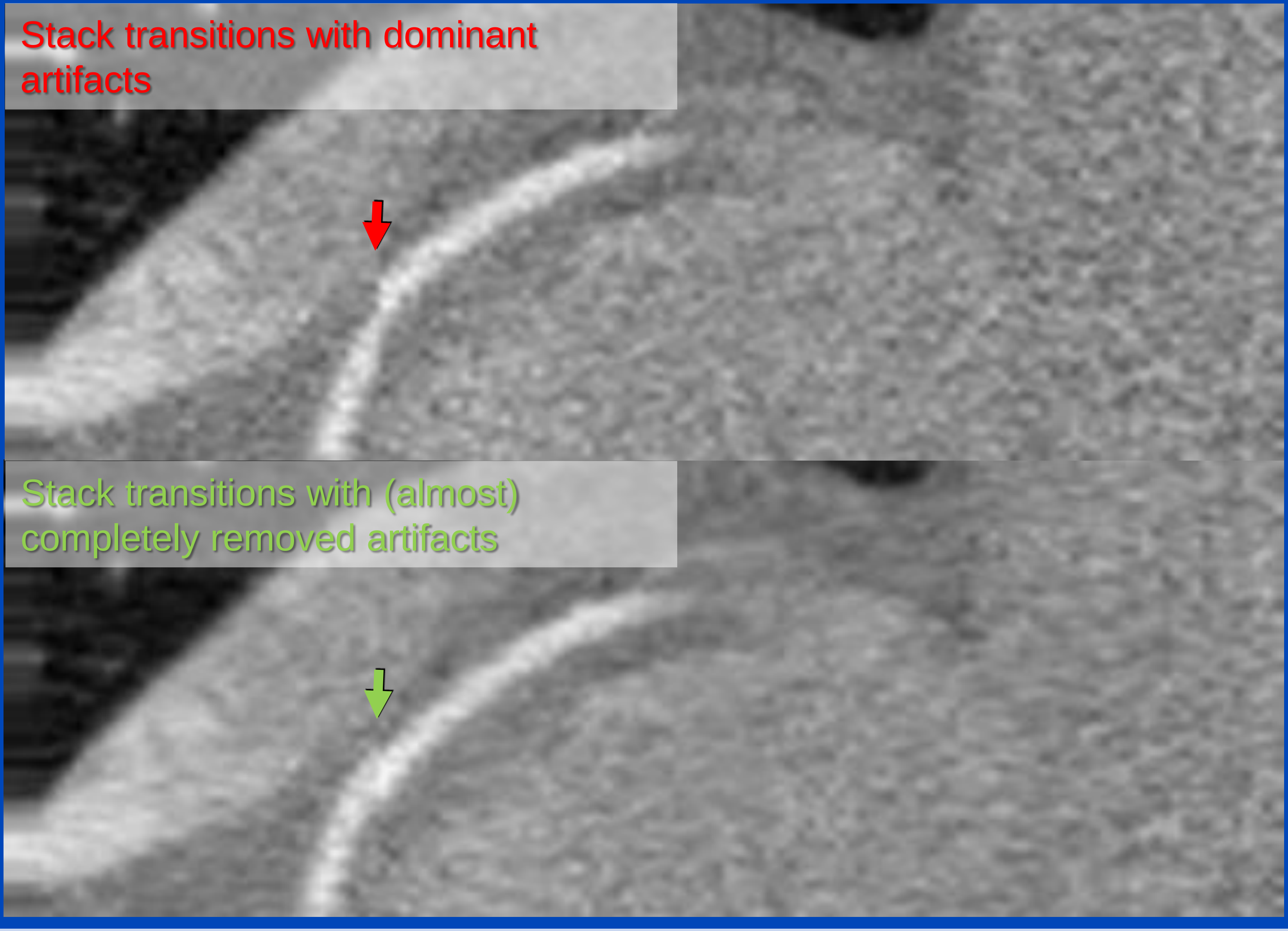
Results

Case B

C = 0 HU, W=2000 HU

Original

Patch matching



Some dominant stack transition artifacts are marked. 1 out of 1 artifacts have been mostly or completely removed.

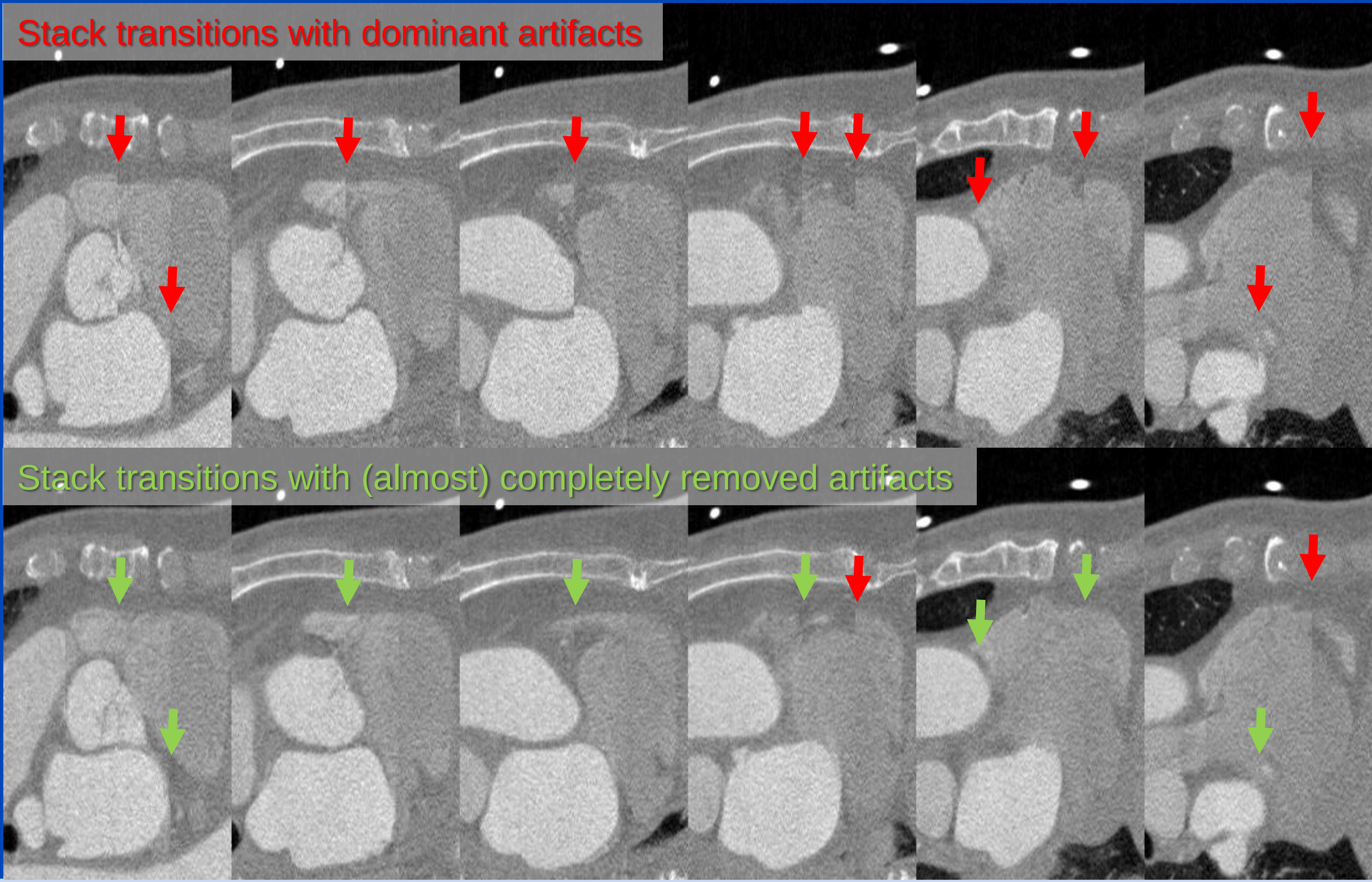
Results

Case C

C = 0 HU, W=2000 HU

Original

Patch matching

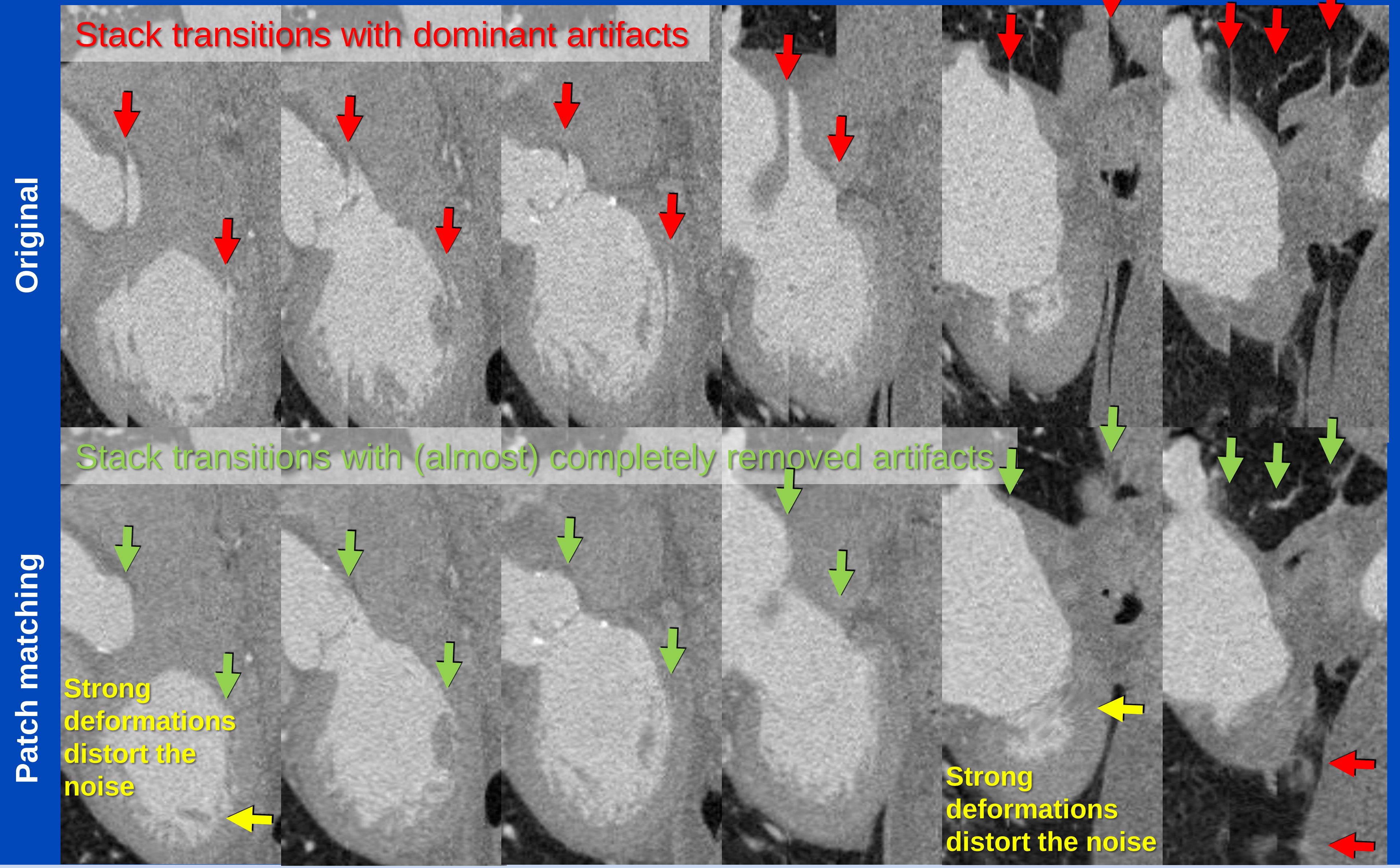


Sagittal slices in steps of 8 mm. Some dominant stack transition artifacts are marked. 14 out of 17 artifacts have been mostly or completely removed.

Results

Case D

C = 0 HU, W=2000 HU



Coronal slices in steps of 8 mm. Some dominant stack transition artifacts are marked. 22 out of 25 artifacts have been mostly or completely removed.

Conclusions and Outlook

- Stack transition artifact removal (STAR), based on a symmetric registration, improves image quality considerably.
- Some stack transition artifacts may remain.
- Variations in gray value for the same tissue may occour between stacks and may be addressed in the future.
- Method can be used to initialize more sophisticated registration algorithms, i.e. Demons algorithm.
  - May increase precision and reduce unnatural distortion of the volume. Ideally combines two methods strengths.

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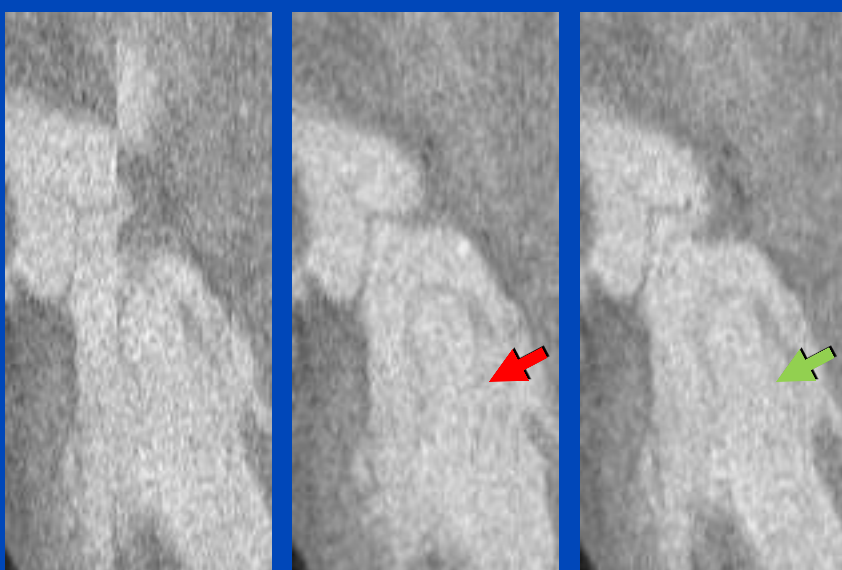
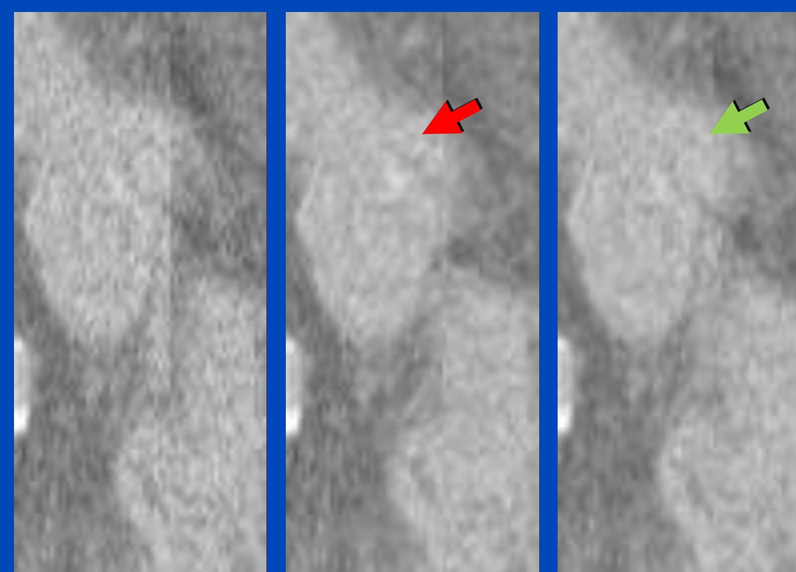


Original   Patch matching   Demons algorithm



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C = 0 HU, W=2000 HU

Thank You!

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

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or through Marc Kachelriess (marc.kachelriess@dkfz.de).

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