Stack Transition Motion Compensation in Sequential and in Cardiac CT

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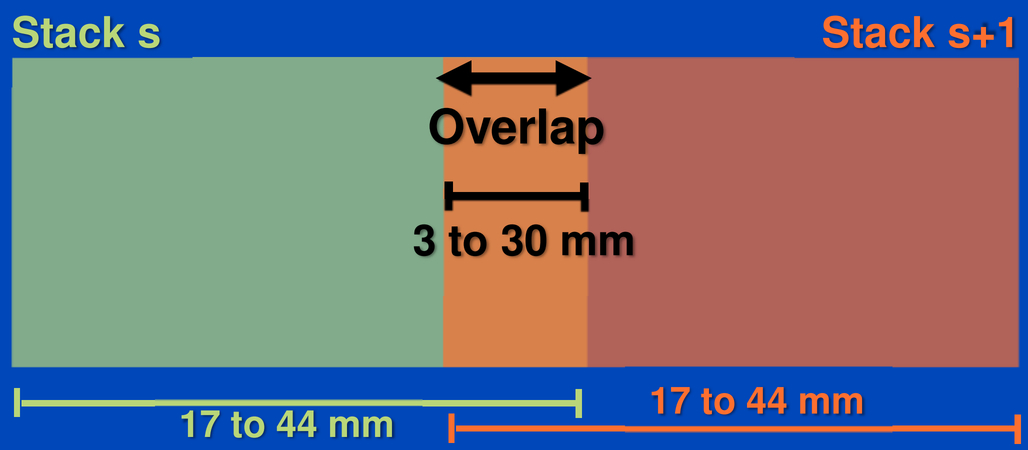
Cardiac CT

- Prospective or retrospective ECG-gating
- Low pitch sequence or spiral CT scans
- Reconstructions yield sub volumes (stacks) corresponding to the same heart beat and phase.
- The depth of the stacks depends on the collimation, pitch value, and heart beat.
- The stacks have a longitudinal overlap.
- Stack size and overlap values depend on pitch, heart rate, and heart rate variability.



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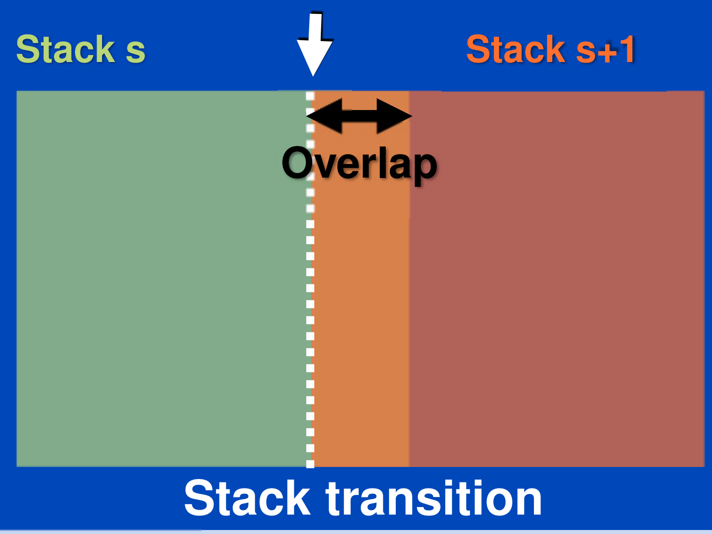
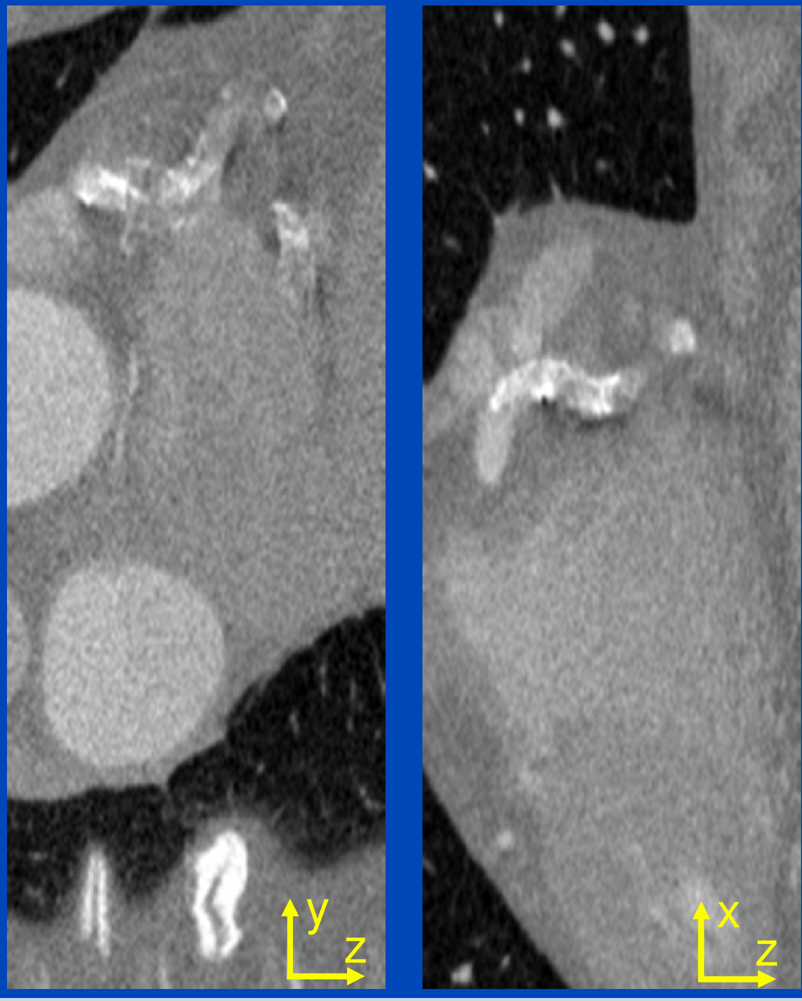
Stacks

- 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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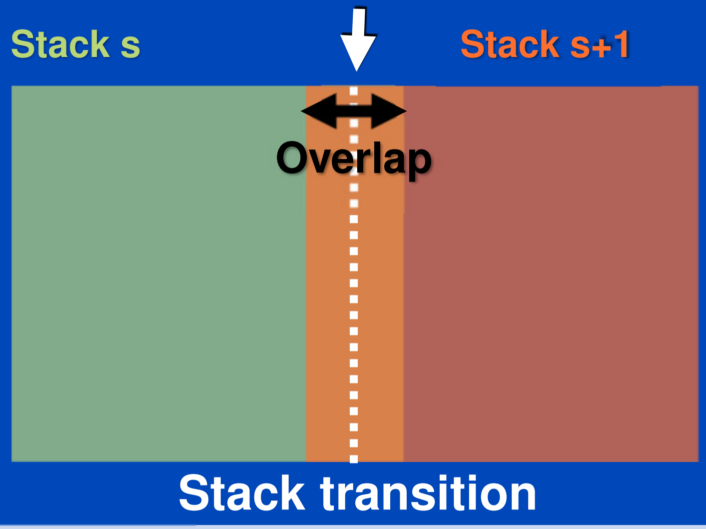

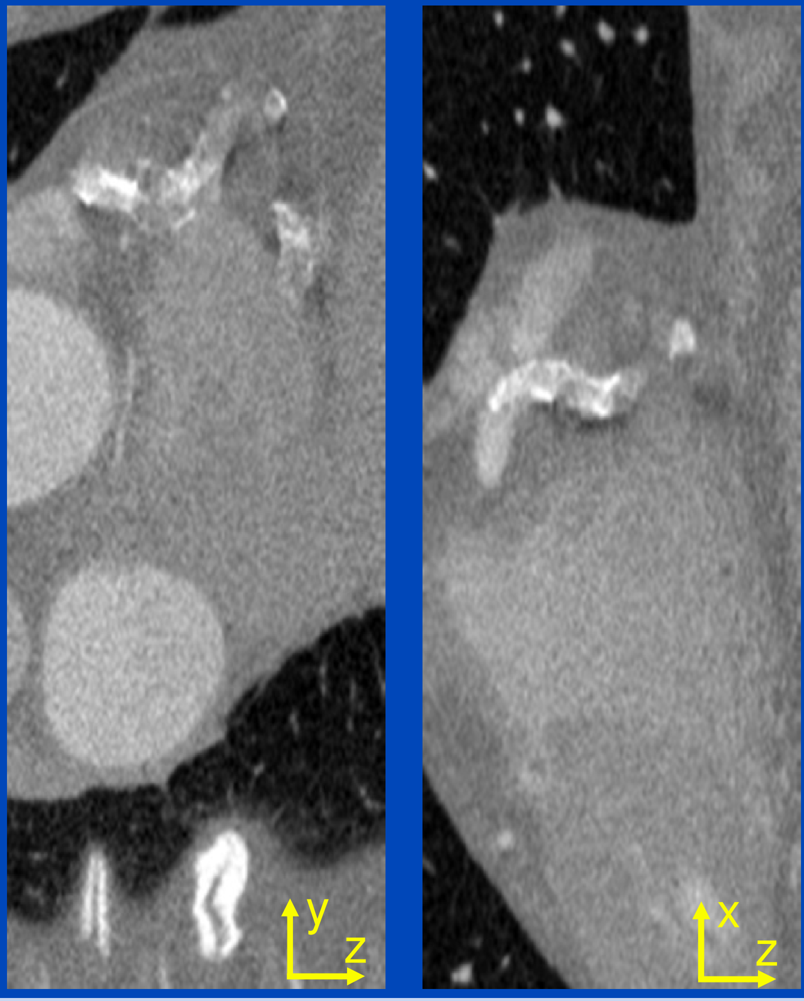

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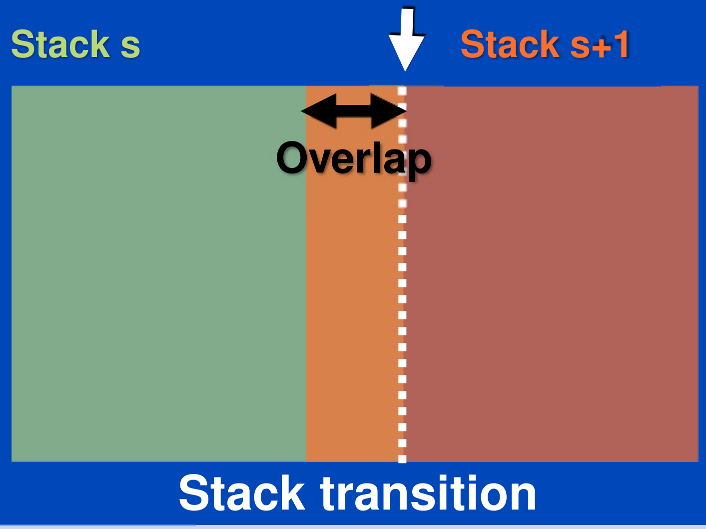

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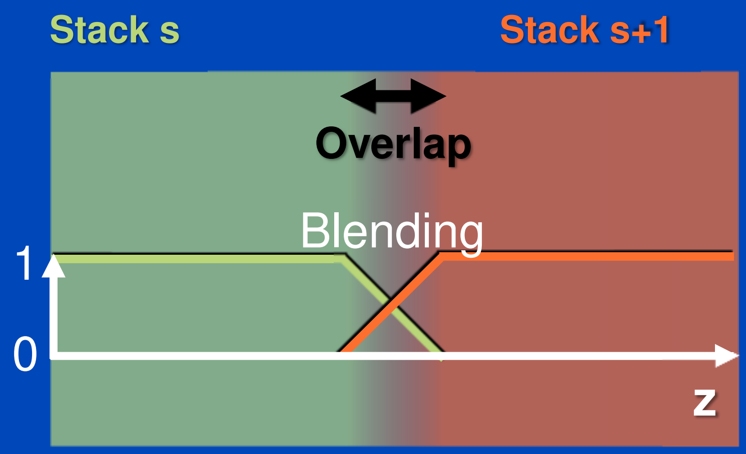
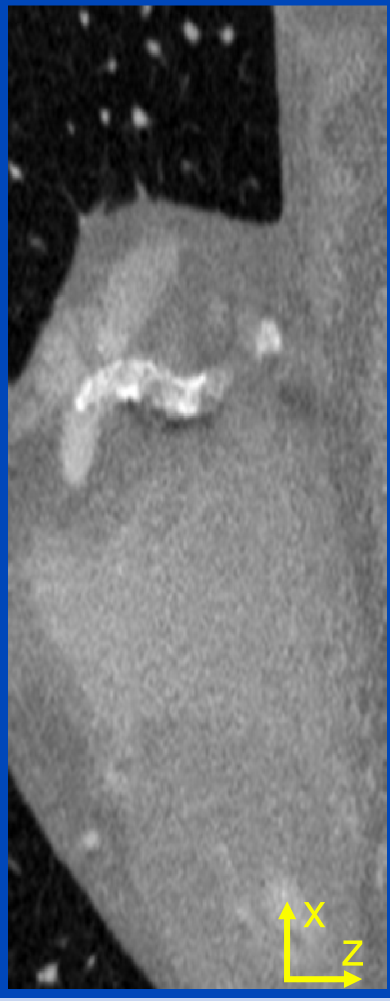
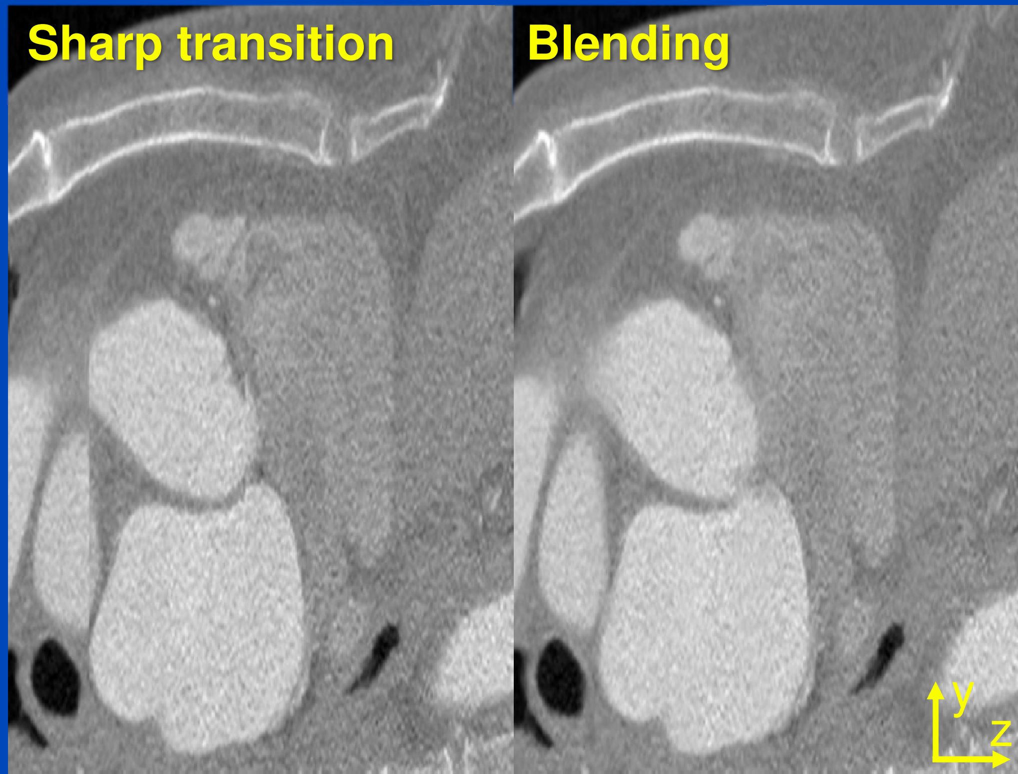


Stack transition



Stack Transition Artifacts

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



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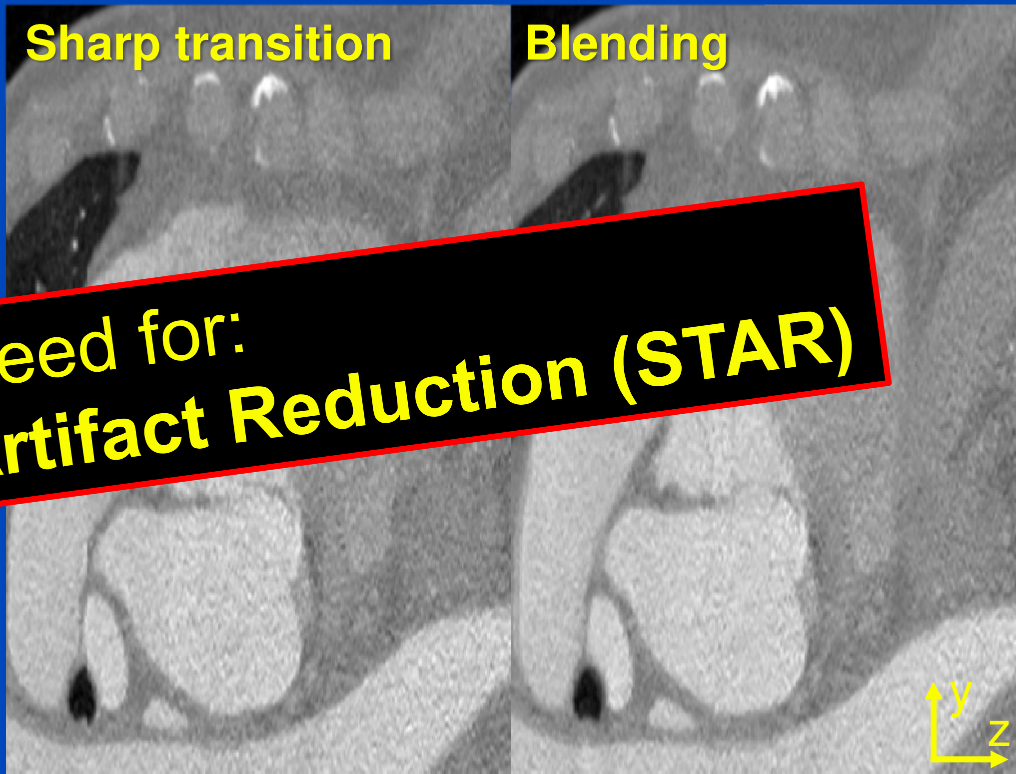


Need for:

Stack Transition Artifact Reduction (STAR)

STAR

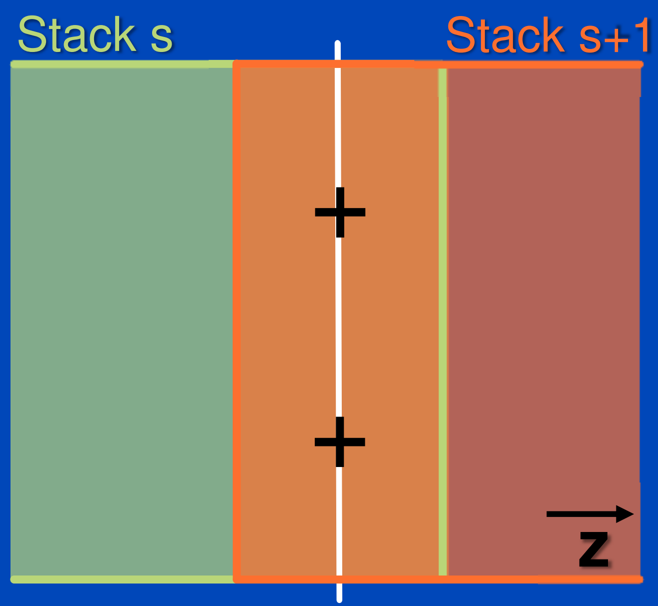
- Given two stacks $f_1(r)$ and $f_2(r)$, compute a DVF $d(r)$ that will symmetrically register them.

$$g_1(\boldsymbol{r}) = f_1(\boldsymbol{r} + \boldsymbol{d}(\boldsymbol{r}))$$
$$g_2(\boldsymbol{r}) = f_2(\boldsymbol{r} - \boldsymbol{d}(\boldsymbol{r})).$$

- The deformed stacks $g_1(r)$ and $g_2(r)$ need to be as similar as possible in the overlap region.
- The DVFs shall be smooth throughout the whole volume.

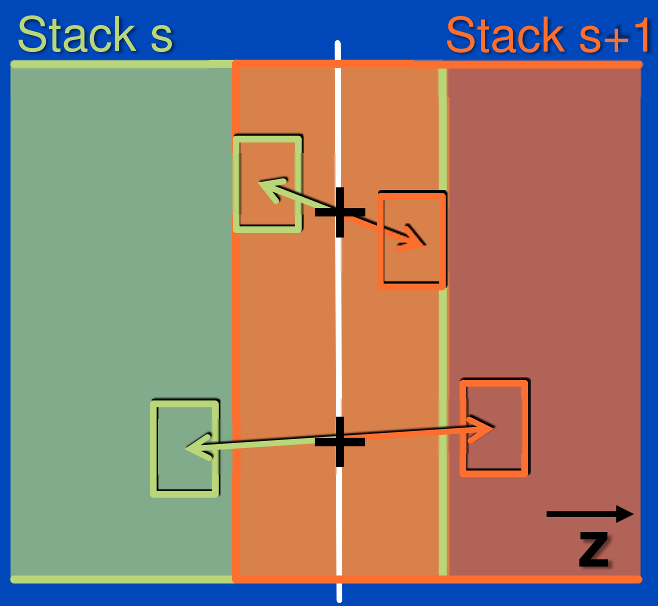
Symmetric Patch Matching

1. Evenly distribute control points (CPs) in the center plane of each overlapping region.



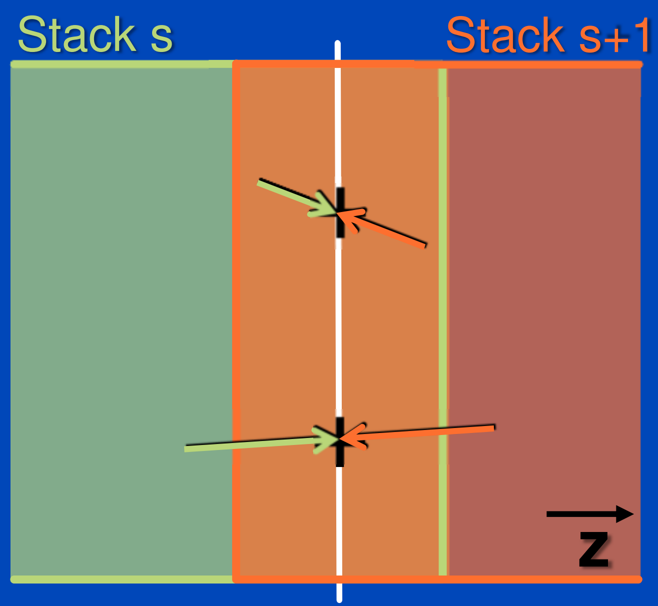
Symmetric Patch Matching

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



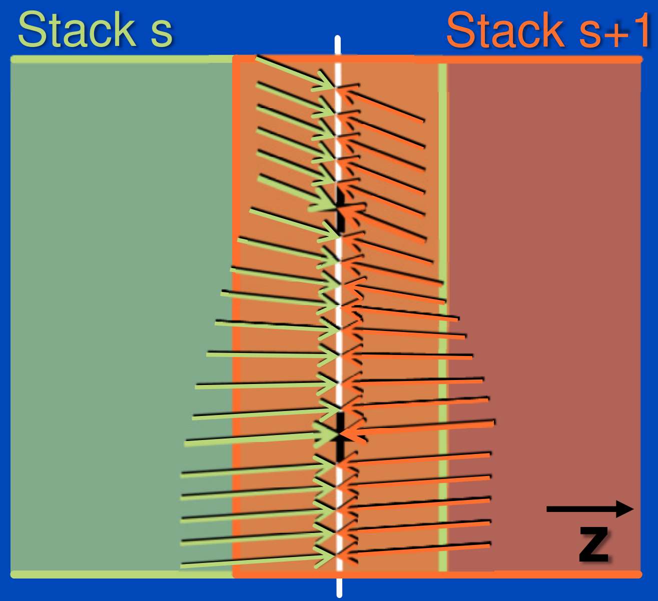
Symmetric Patch Matching

1. Evenly distribute control points (CPs) in the center plane of each overlapping region.
2. Look for the most similar sub volume (patch) pairs at opposite offsets from a CP within the two stacks.
3. Invert the offset vectors to get deformation vectors for a source driven transformation (at the CPs).



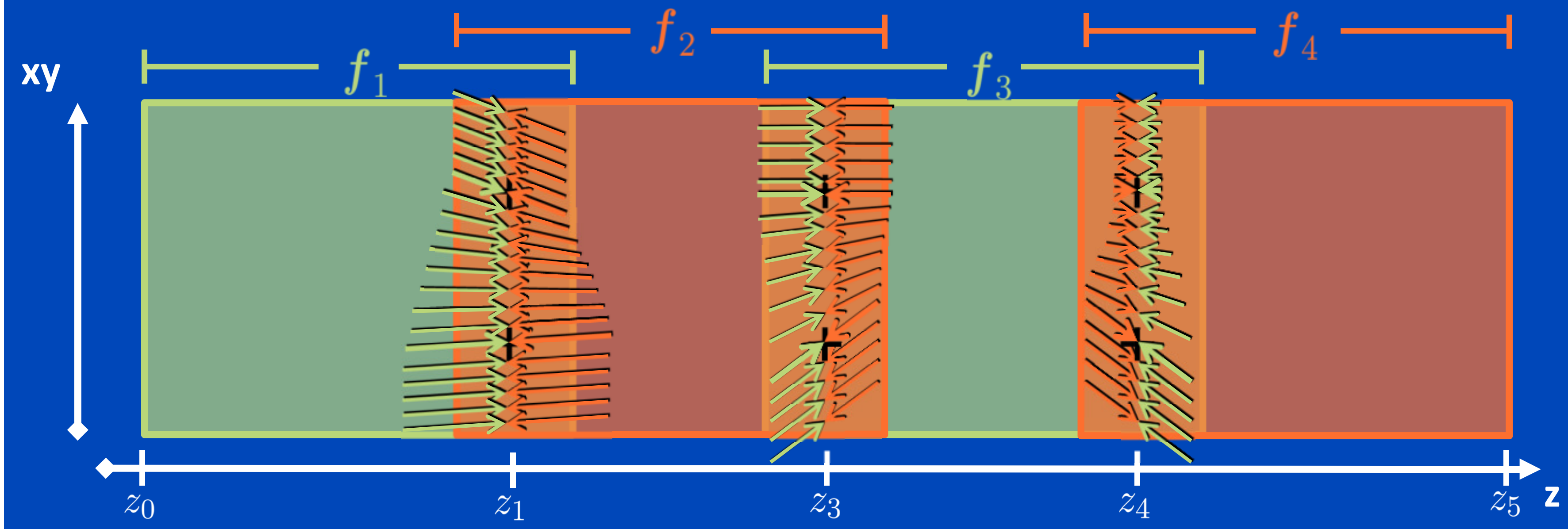
Symmetric Patch Matching

1. **Evenly distribute control points (CPs) in the center plane of each overlapping region.**
2. **Look for the most similar sub volume (patch) pairs at opposite offsets from a CP within the two stacks.**
3. **Invert the offset vectors to get deformation vectors for a source driven transformation (at the CPs).**
4. **In order to get a smooth DVF on the central plane perform a bilinear interpolation in *x* and *y*.**
5. **Finally, perform a linear interpolation in *z*.**



DVF Interpolation along *z*

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



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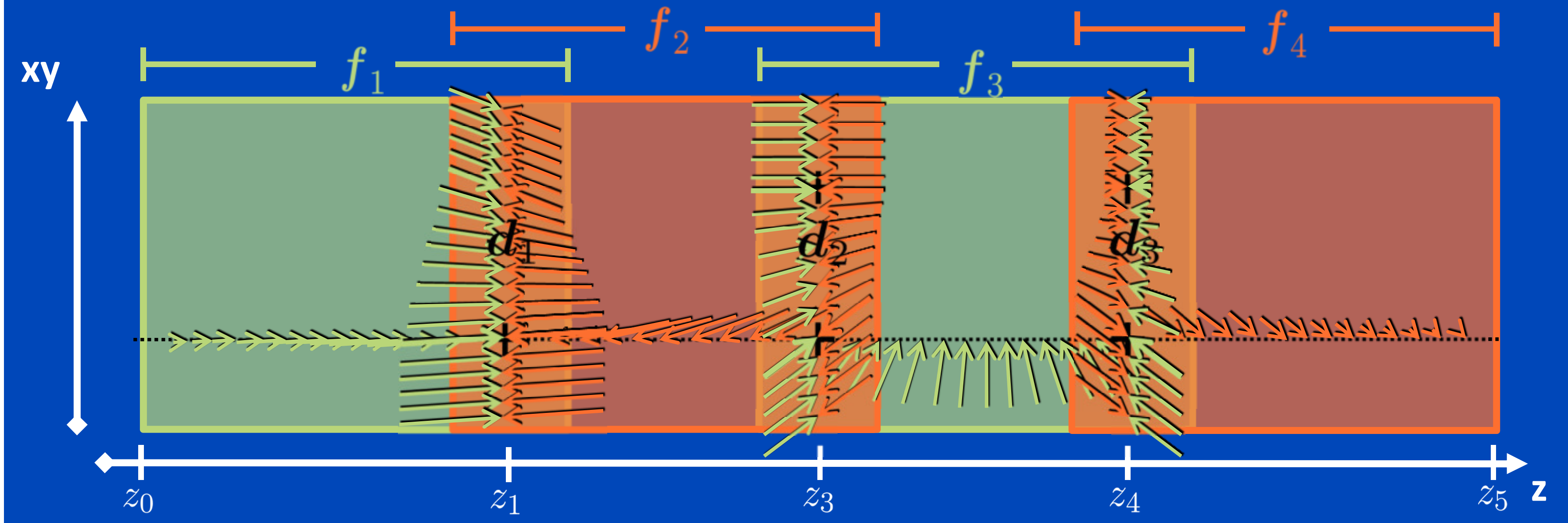

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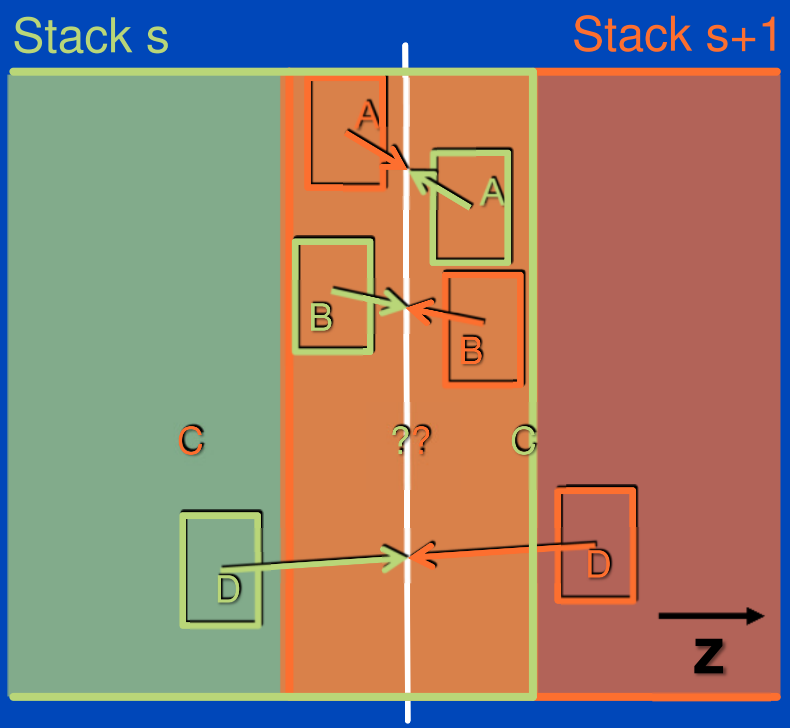
Methods

Symmetric Patch Matching

- Ideally the patches are matched based on anatomical landmarks.
- Patches can be placed on either side of a control point in and outside the overlap region (cases A, B, and D)
- Patches must remain inside the stack and there is a maximum allowed displacement
- If an anatomical landmark is located outside one of the stacks they cannot be matched (case C).



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Parameters

STAR parameters

- Similarity metric:
  Sum of squared differences
- Patch size: 15×15×2…5 mm^3 (overlap/2)
- Patch sampling: 10×10 mm^2
- Number of control points: 16×16×1
- DVF vectors restricted to 6 mm length. Thus, deformations of up to 12 mm are permitted.

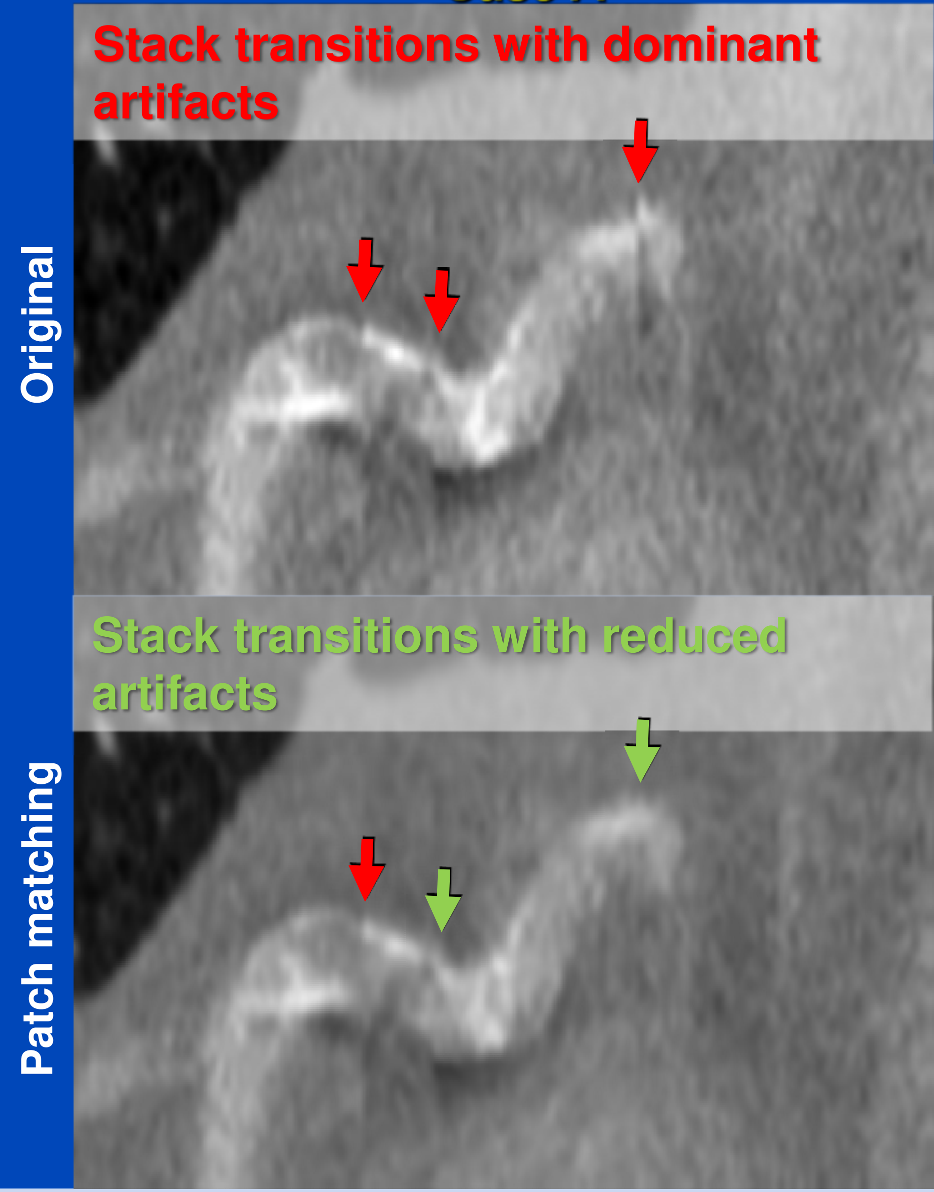
Scan parameters

- Siemens Somatom Definition Flash and AS+
- Standard partial scan WFBP reconstructions
- 285 ms rotation time
- 92…374 mAs_{eff}
- 80…125 kV
- 7…82 mGy $CTDI_{vol}$
- 110…1254 mGy·cm DLP

Results

C = 0 HU, W=2000 HU

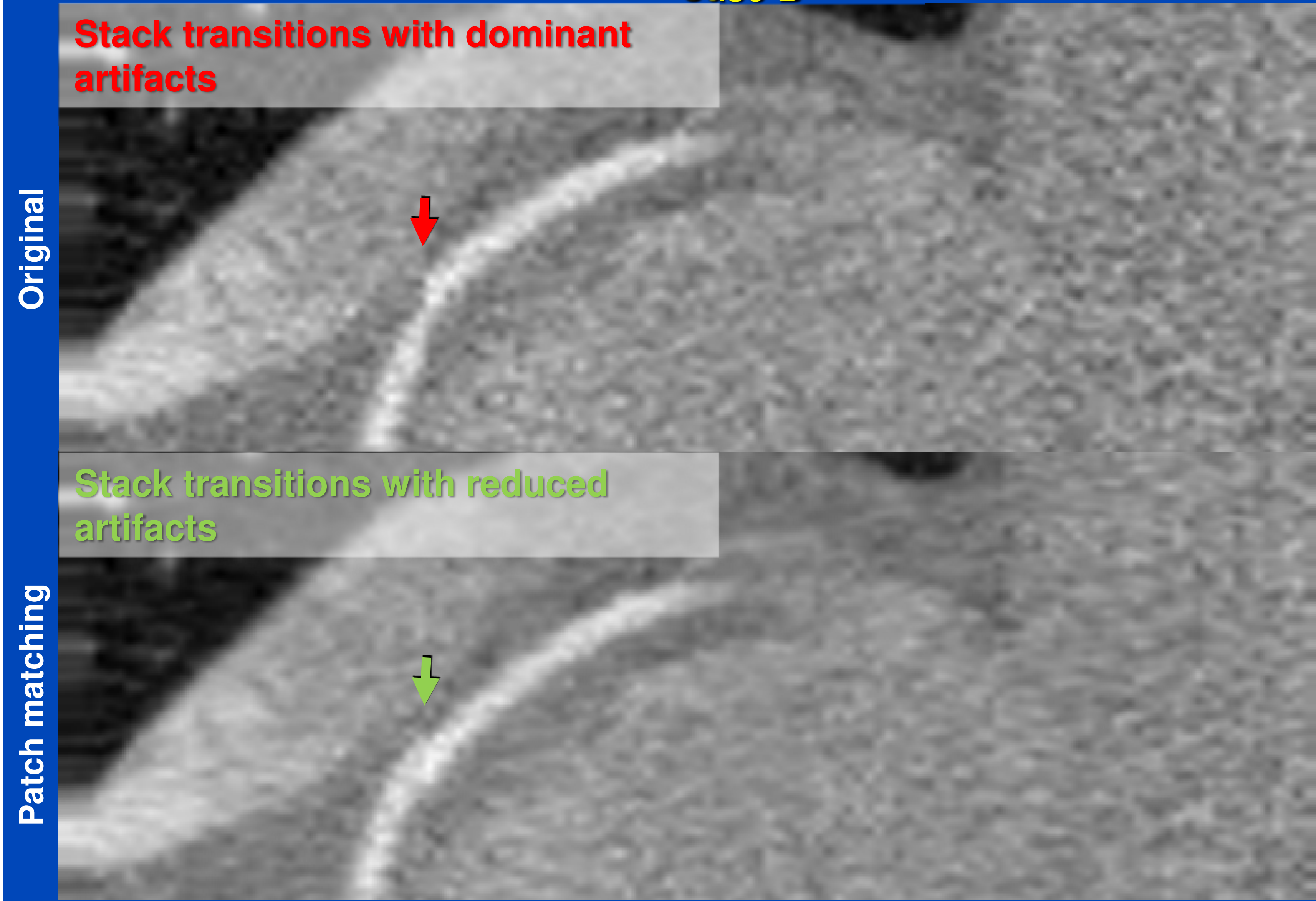
Case A



Results

Case B

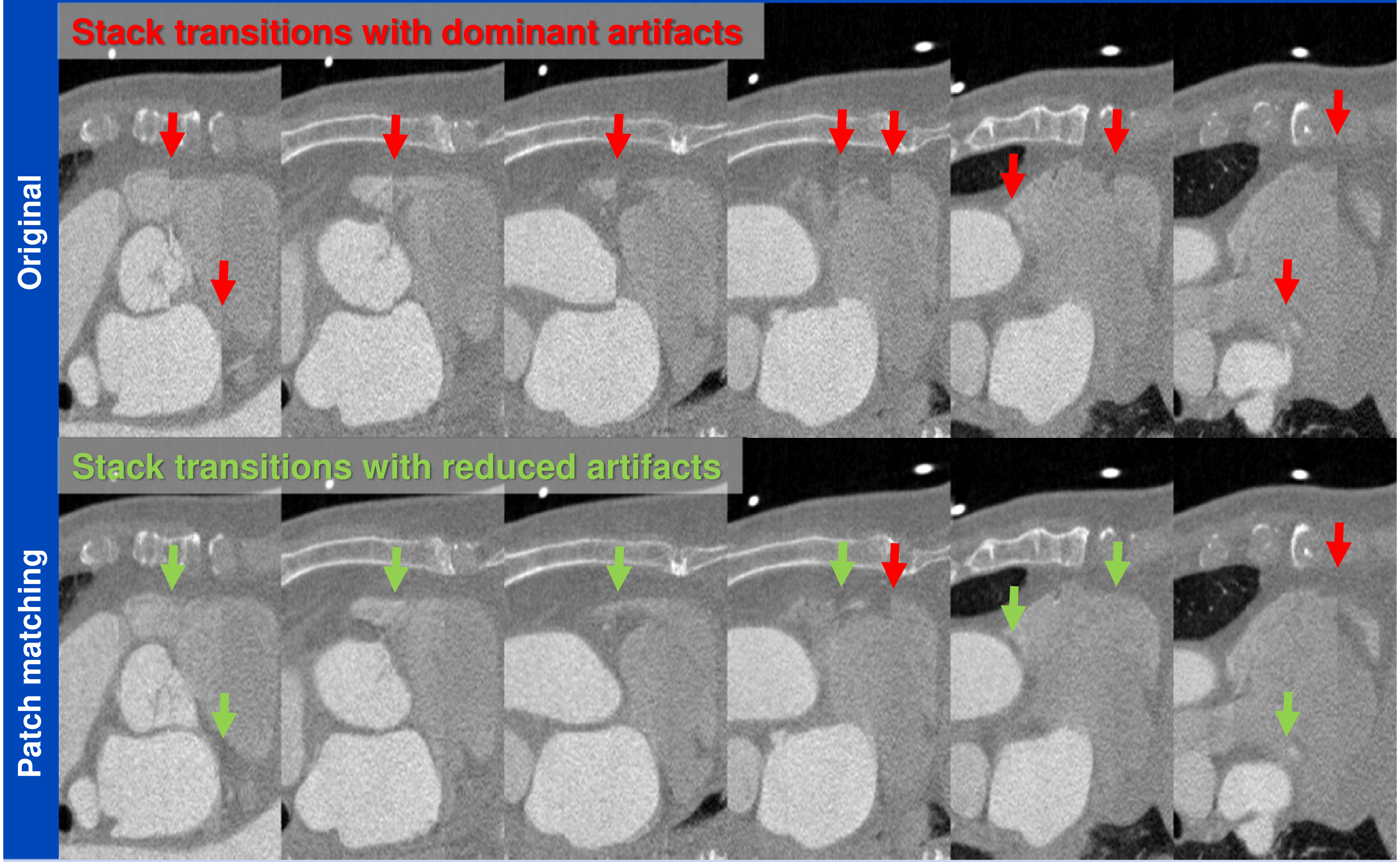
C = 0 HU, W=2000 HU



Results

Case C

C = 0 HU, W=2000 HU

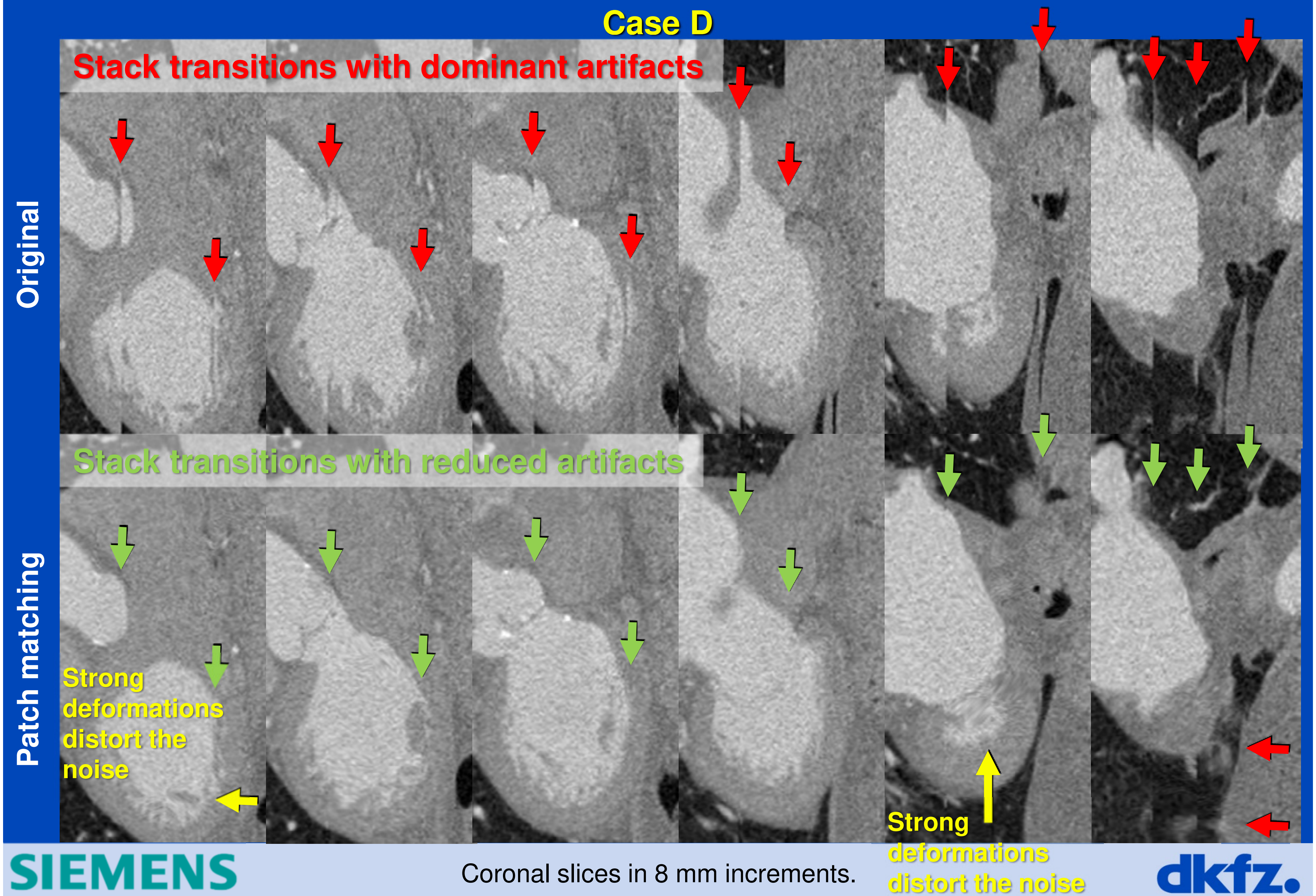


Sagittal slices in 8 mm increments.

Results

Case D

C = 0 HU, W=2000 HU



Coronal slices in 8 mm increments.

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Conclusions on STAR

- STAR improves image quality considerably.
- Some stack transition artifacts may remain.
- Variations in gray value for the same tissue will be addressed in the future.
- DVFs obtained by our patch-based STAR are useful to initialize a demons-based STAR algorithm*.

* Sergej Lebedev, Eric Fournie, Karl Stierstorfer, and Marc Kachelrieß. Stack transition artifact removal (STAR) for cardiac CT using a symmetric demons algorithm. Conference Program of the 5th International Conference on Image Formation in X-Ray Computed Tomography, May 2018

Thank You!

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

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

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