Department of Computer Science

UNIVERSITY OF CALGARY

Compressive Volume Rendering

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Assistant Professor

VISAGG
Visualization and Graphics Group

Outline

1. Motivation
2. Research Question
3. Methodologies
4. Results
5. Conclusion

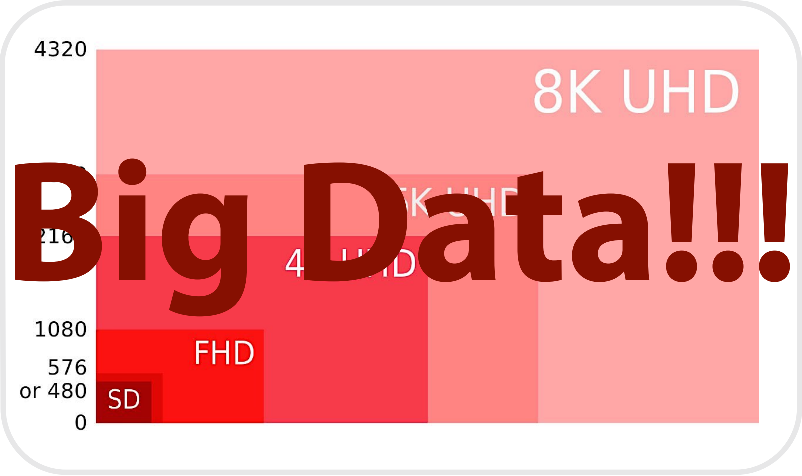
Motivation

High Density Displays ▶

Ray-Casting
for Volume Rendering ▶

Motivation

High Density Displays ▶

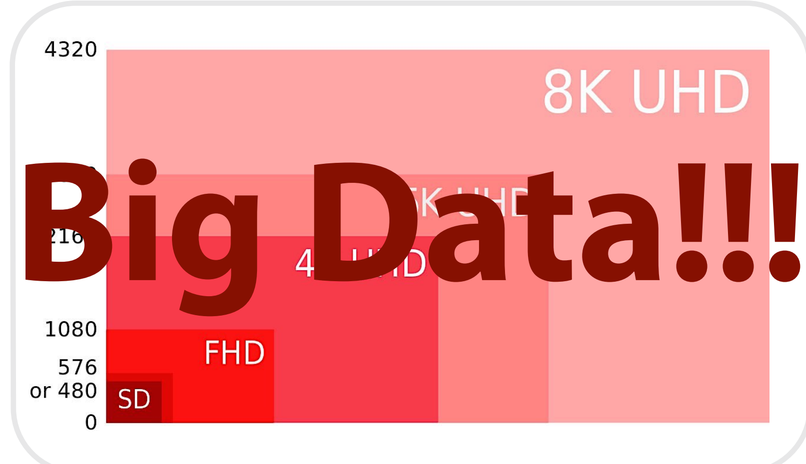


Big Data!!!

Ray-Casting
for Volume Rendering ▶

Motivation

High Density Displays ▶

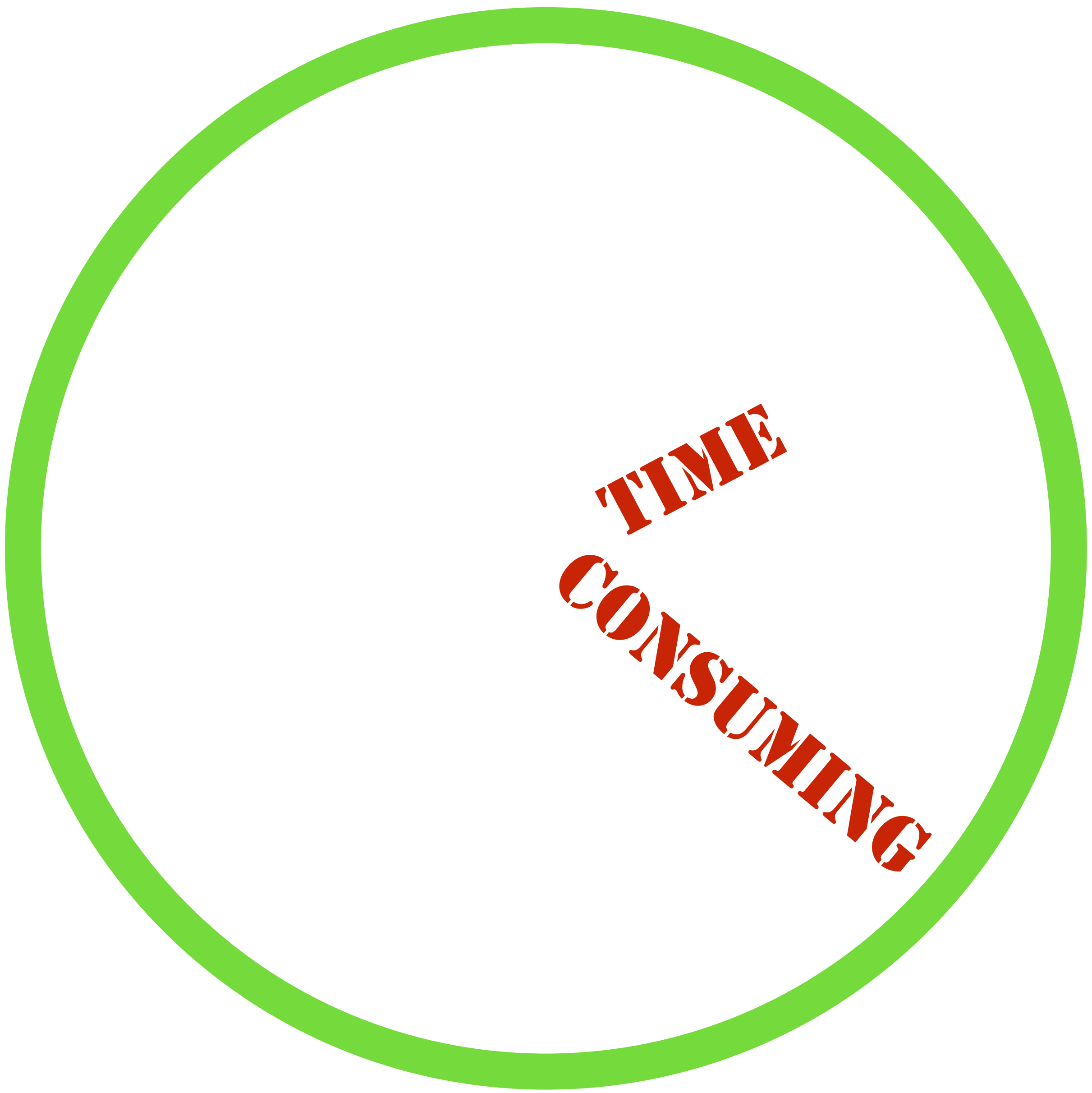


Big Data!!!

Ray-Casting
for Volume Rendering ▶

Rendering time is proportional to the number of pixels

Motivation



EFFICIENCY

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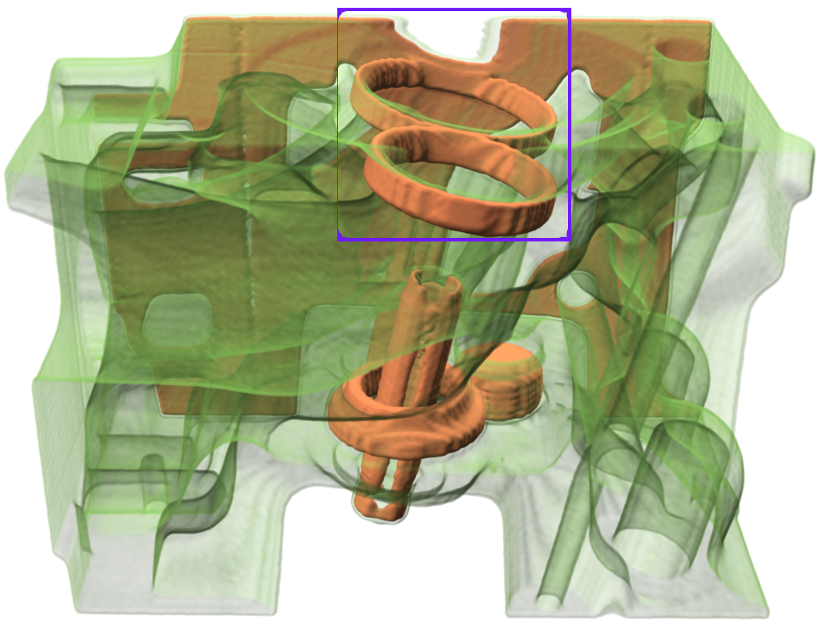
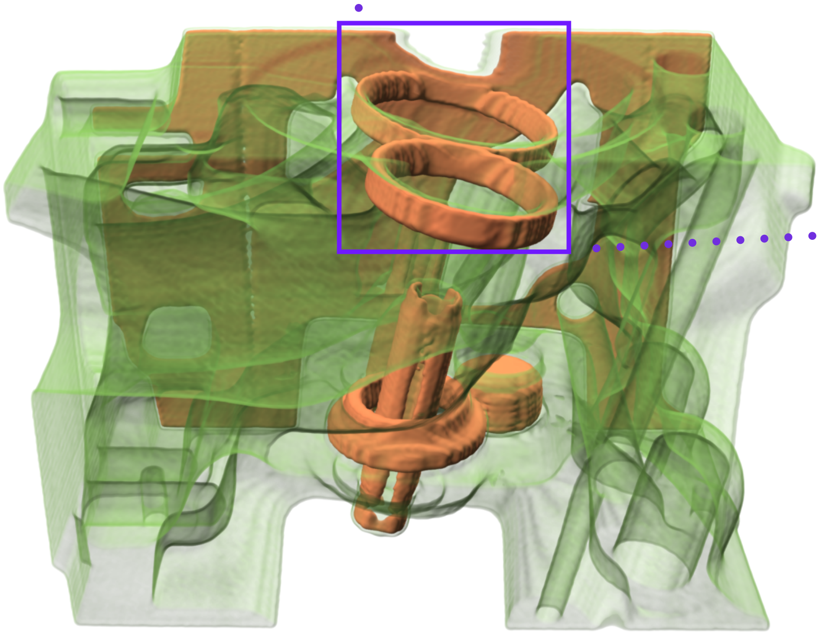
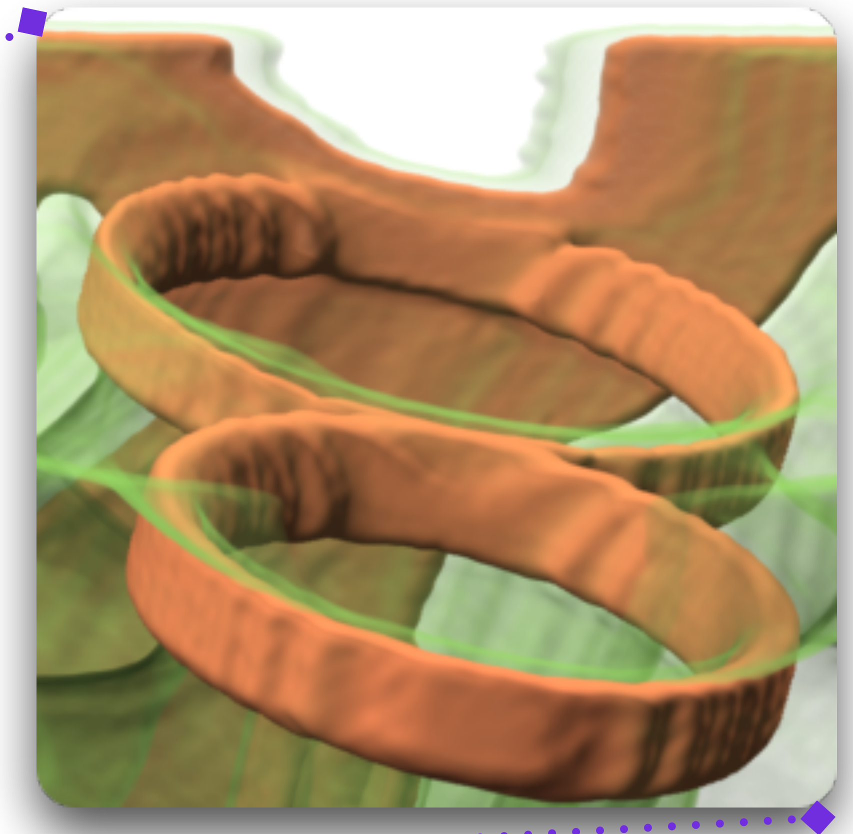
Research Question



Research Question





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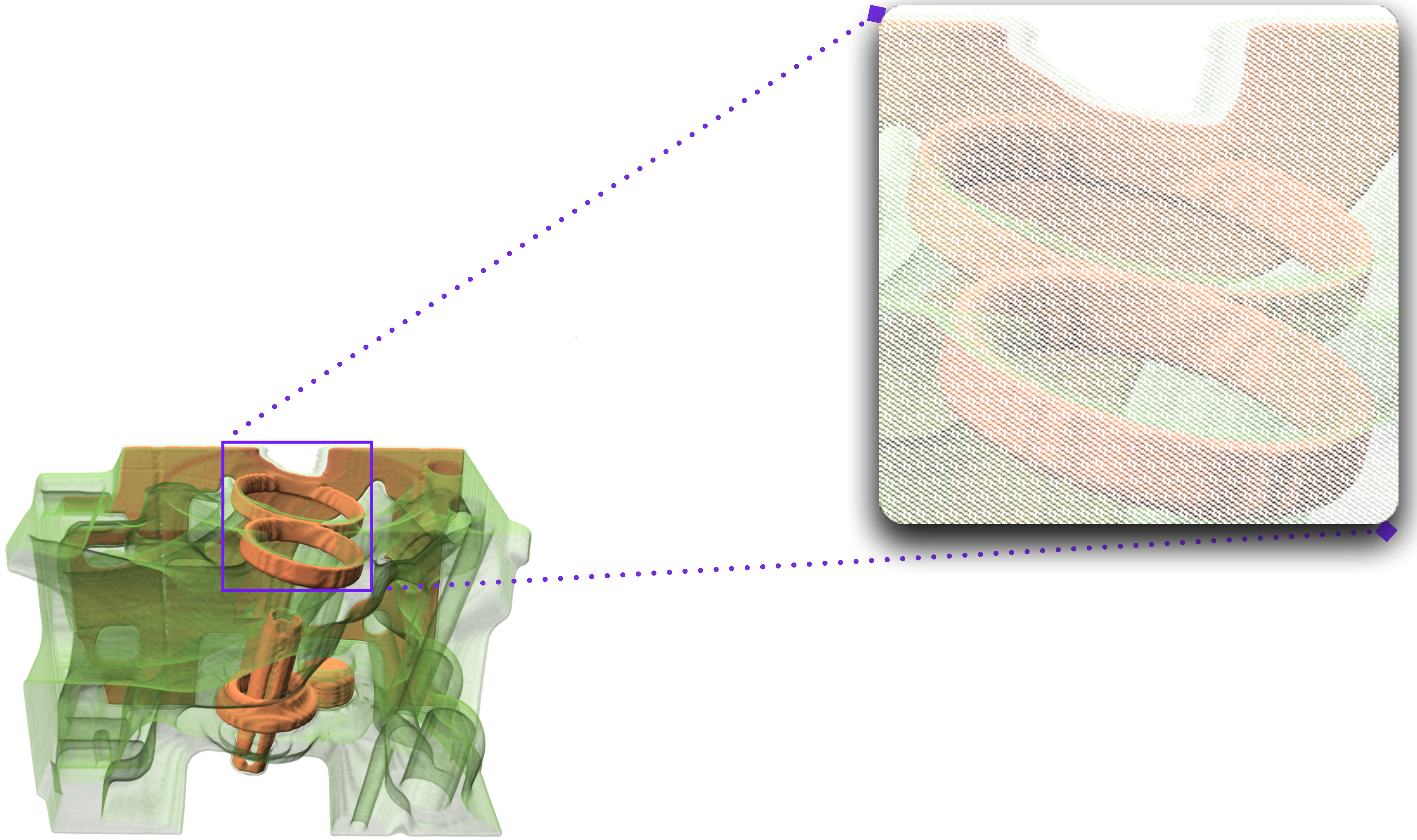
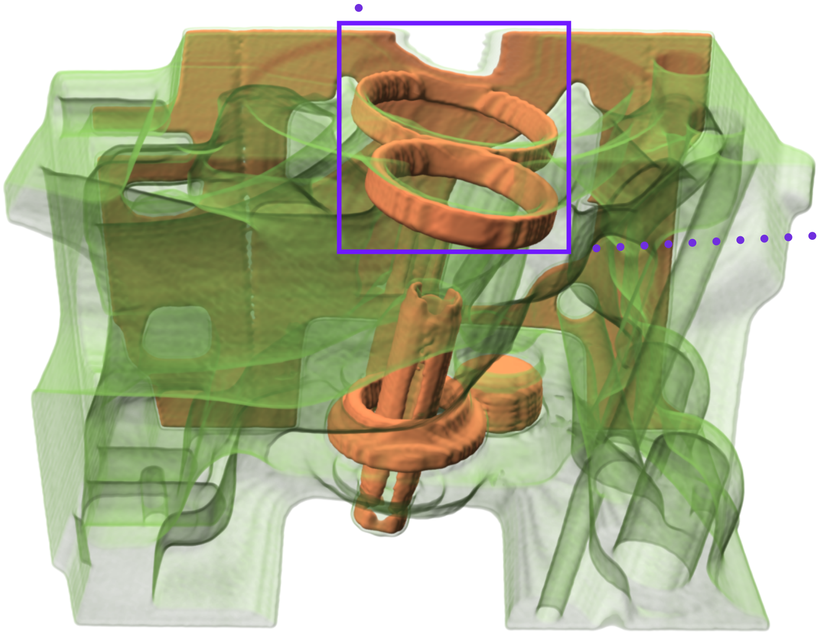
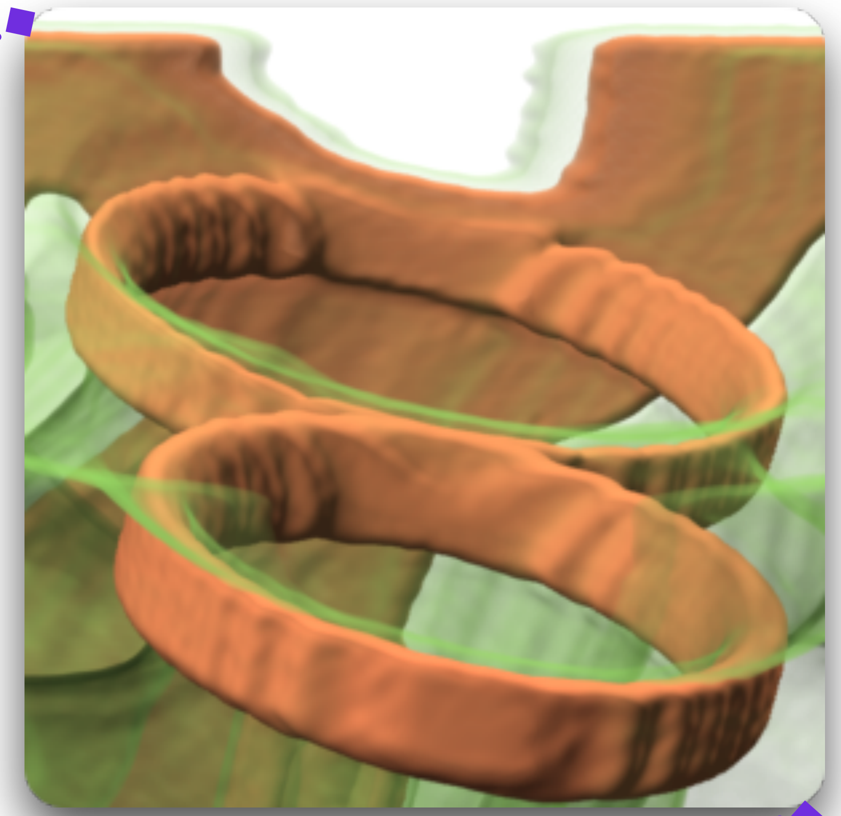


Research Question

How to do this?





With good quality?

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Distribution Algorithms

- Random Distribution

  - Inhomogeneous regions

- Low-Discrepancy Distribution

  - Allow for the progressive update

Methodologies

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Distribution Algorithms

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Methodologies

Distribution Algorithms

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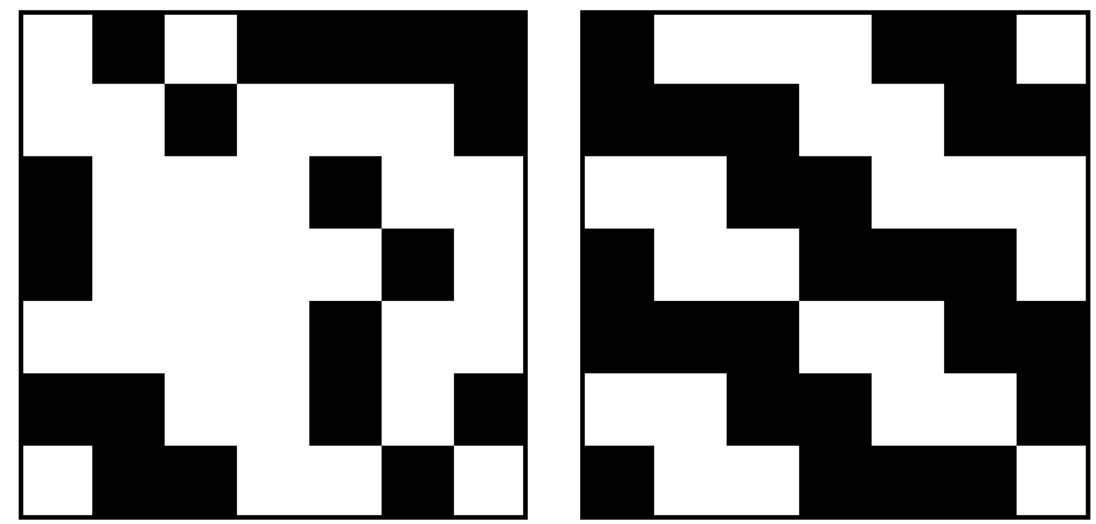
- Low-Discrepancy Distribution

  - Allow for the progressive update

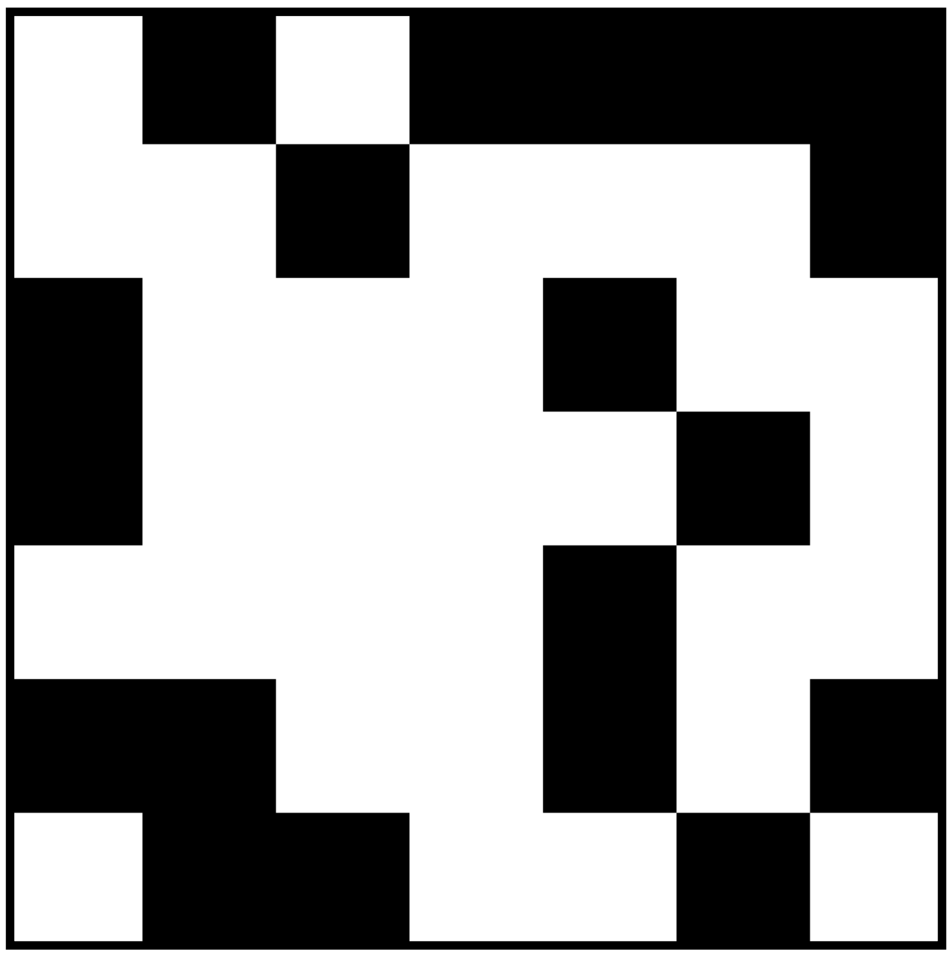
Masks for 50% missing pixels



Random Distribution

Low-Discrepancy (LD) Distribution via Pixel Shuffle

Methodologies



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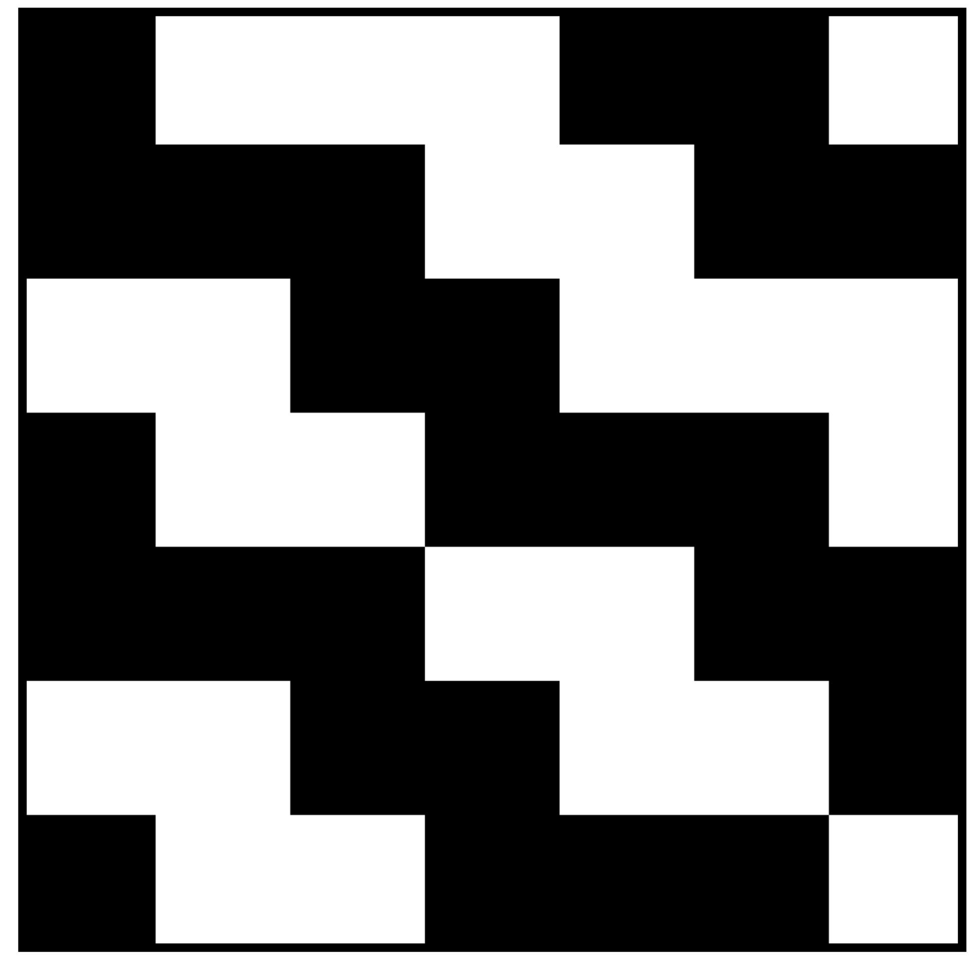

Low-Discrepancy (LD) Distribution via Pixel Shuffle

CS-Wavelet [Sen and Darabi, 2011, TVCG]

Compressed Sensing ▶

$$\mathbf{y} = \mathbf{A}\hat{\mathbf{x}}$$

Sensing Mechanism ▶

$$\mathbf{y} = \underbrace{\mathbf{S}\Phi^{-1}\mathbf{W}^{-1}}_{\mathbf{A}}\hat{\mathbf{x}}_b$$

Restricted Isometry Condition (RIC) ▶

Methodologies

CS-Wavelet [Sen and Darabi, 2011, TVCG]

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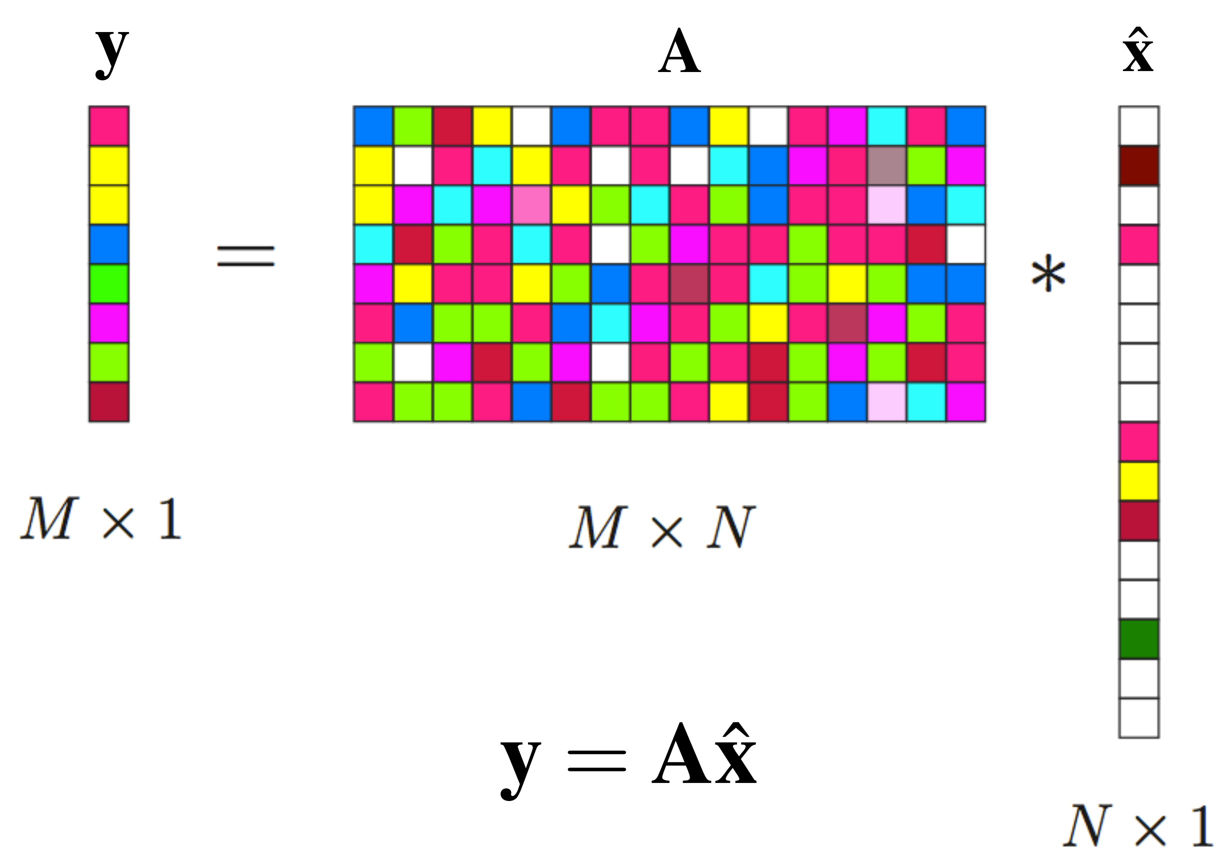

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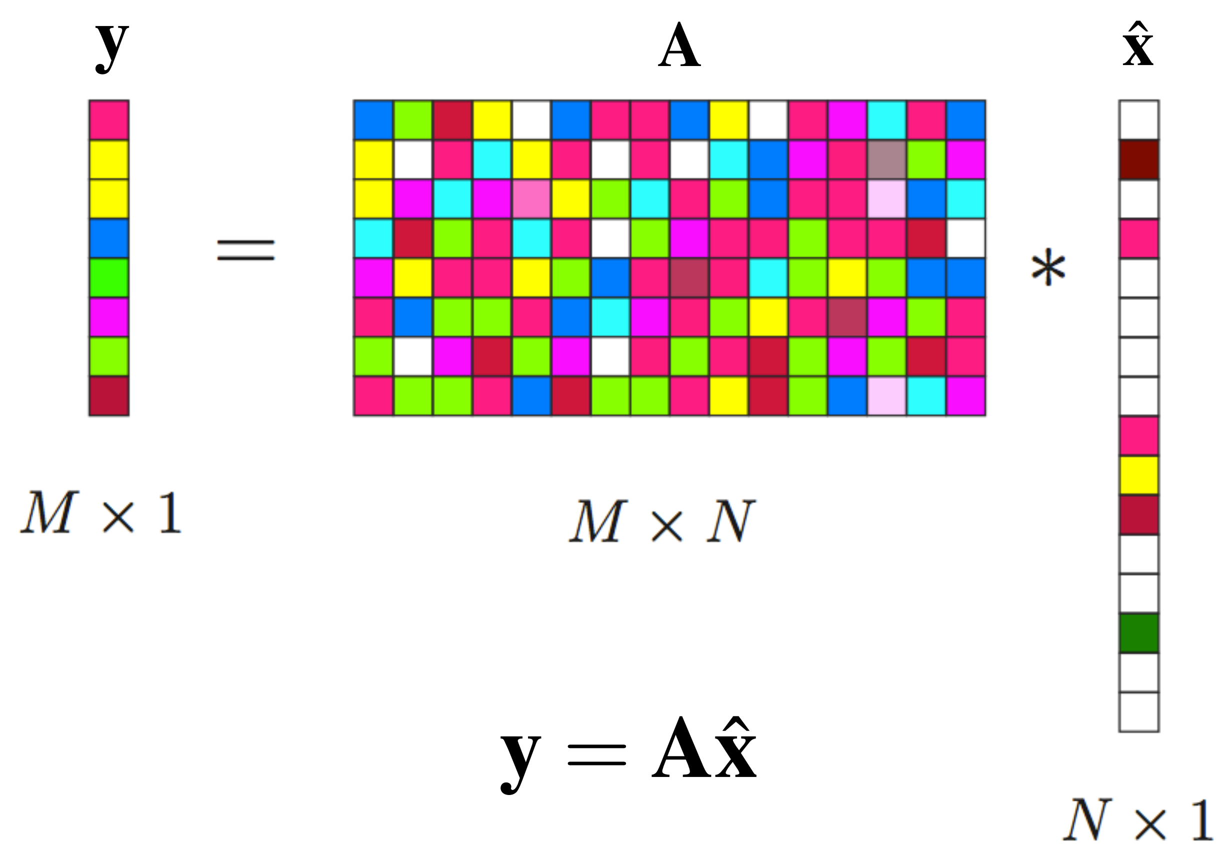

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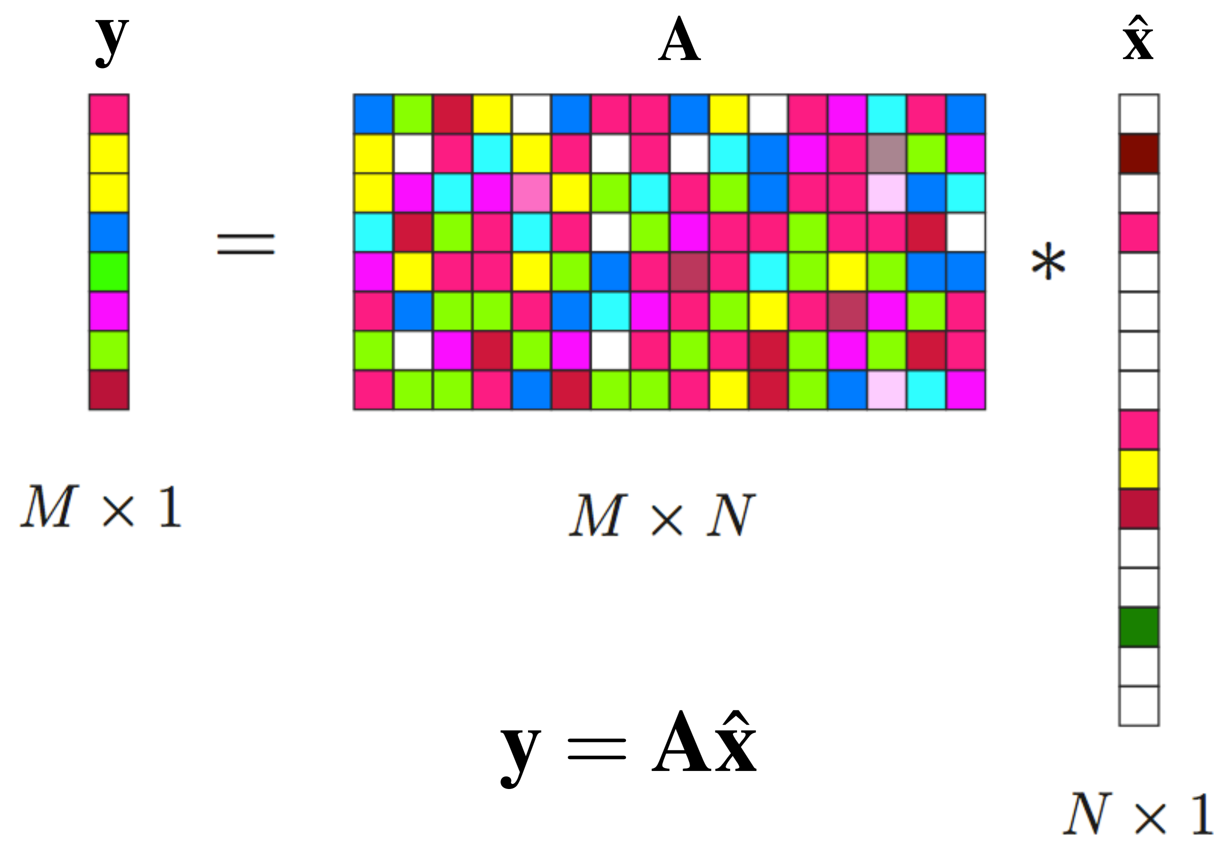

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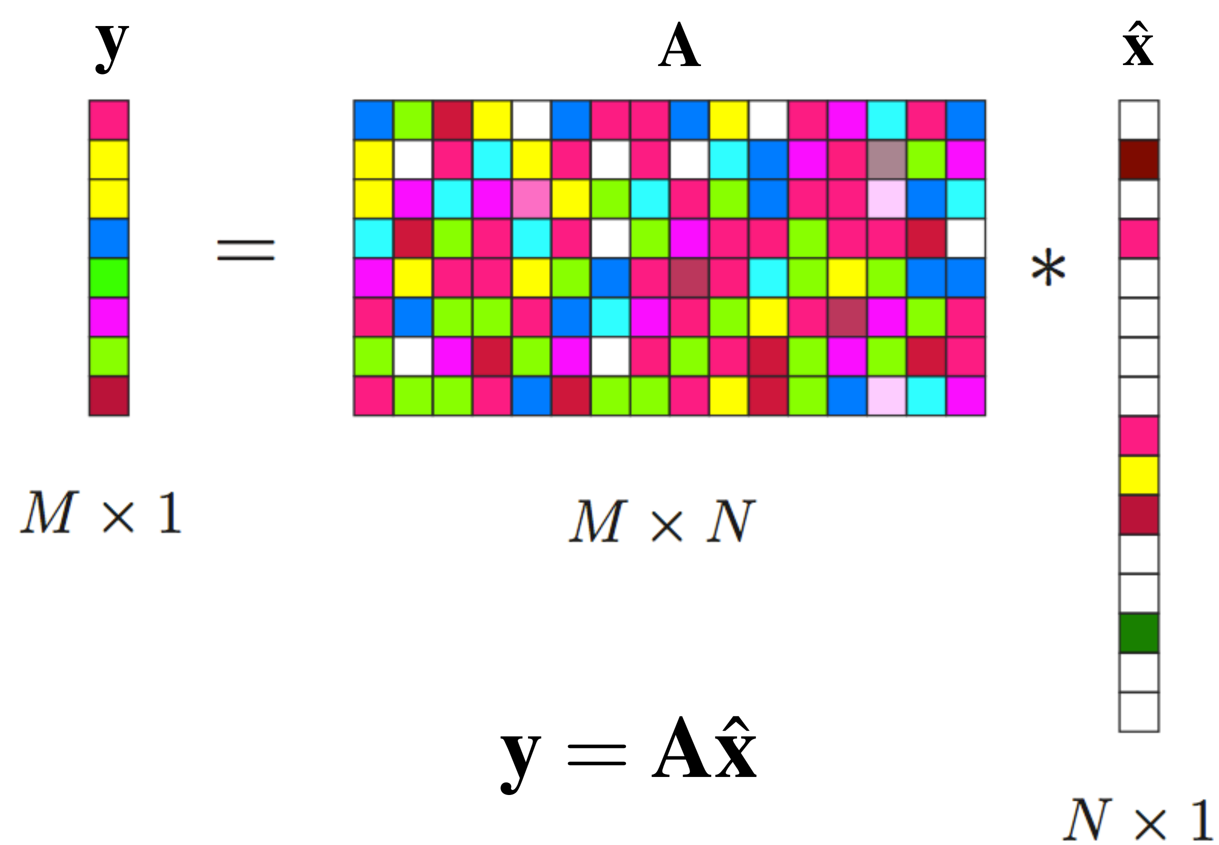

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Incoherence ▶

Methodologies

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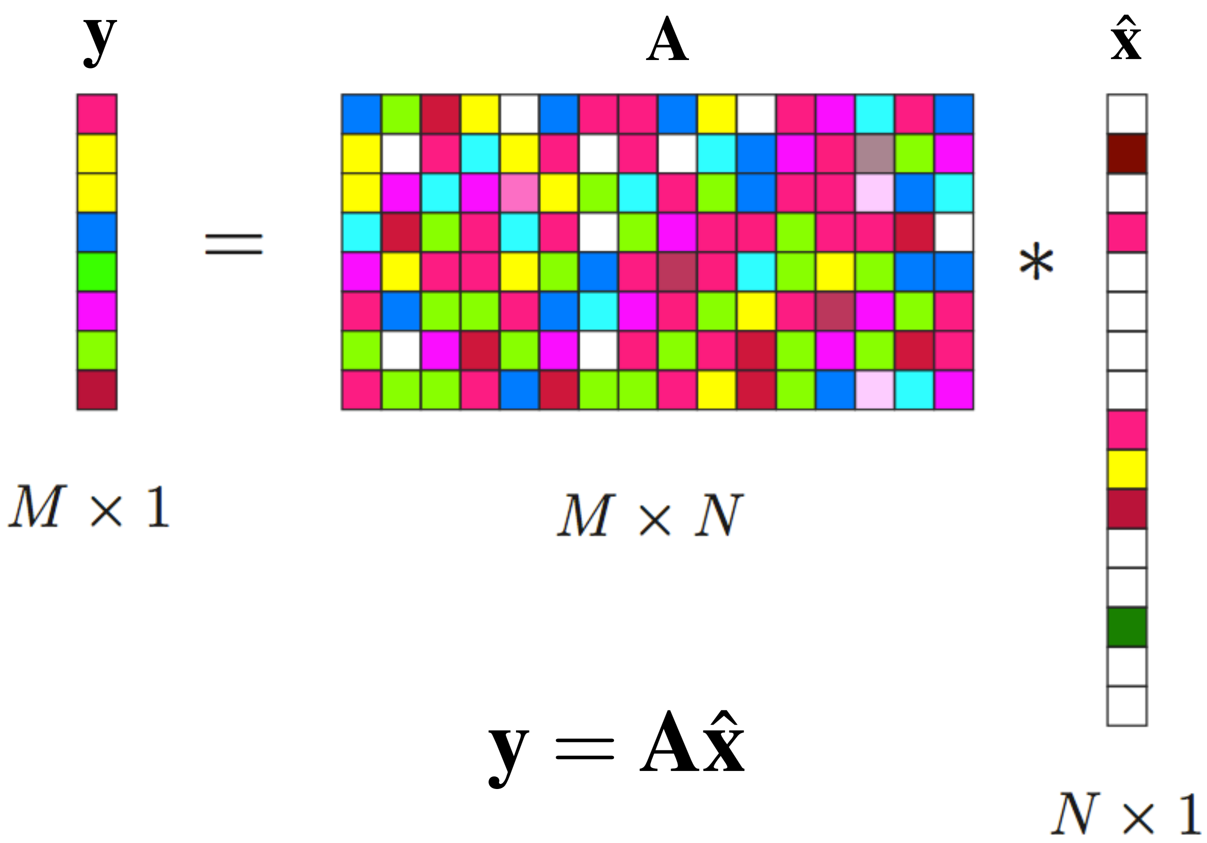

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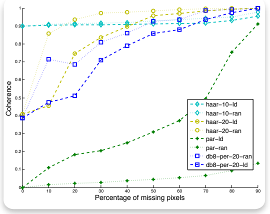
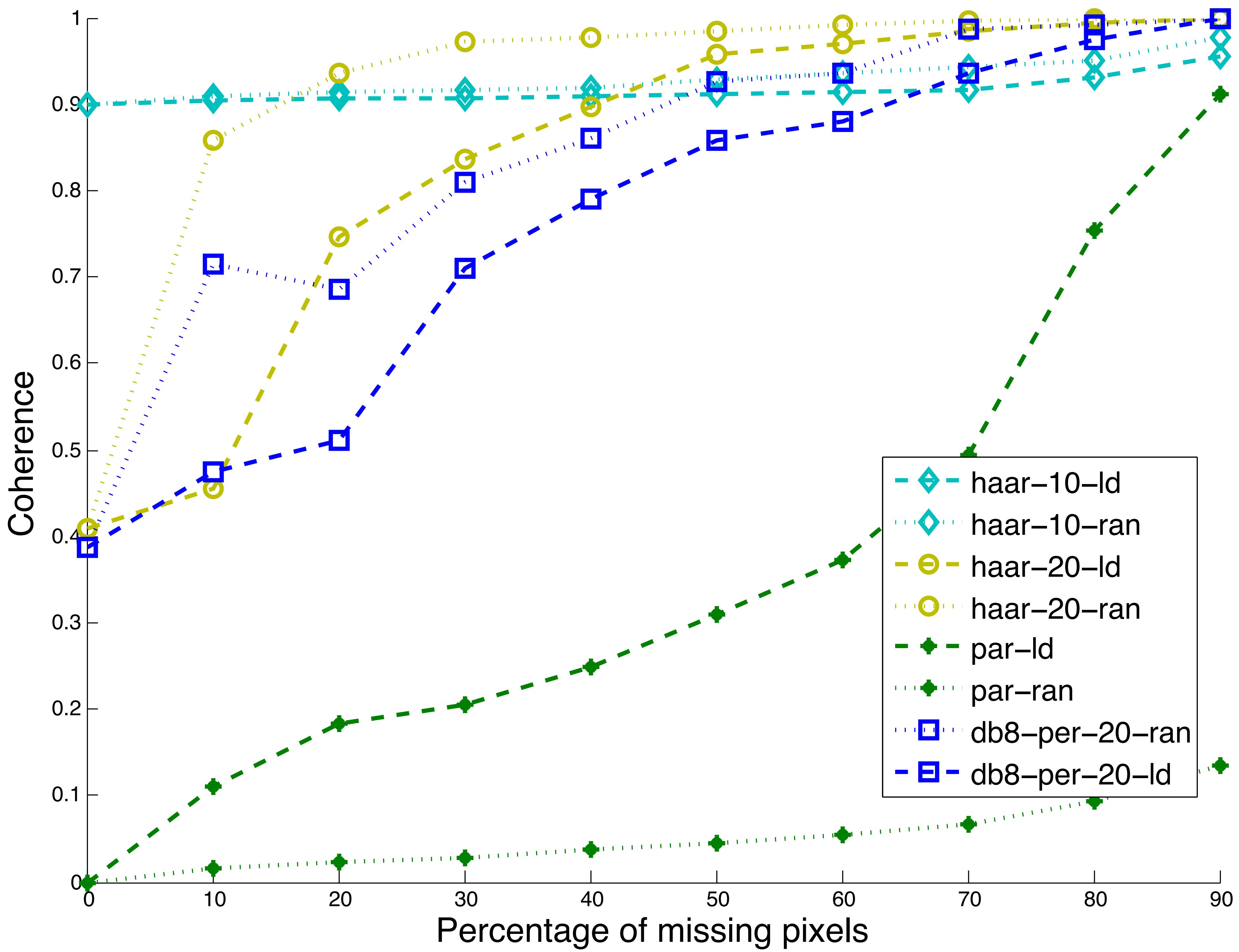


Methodologies



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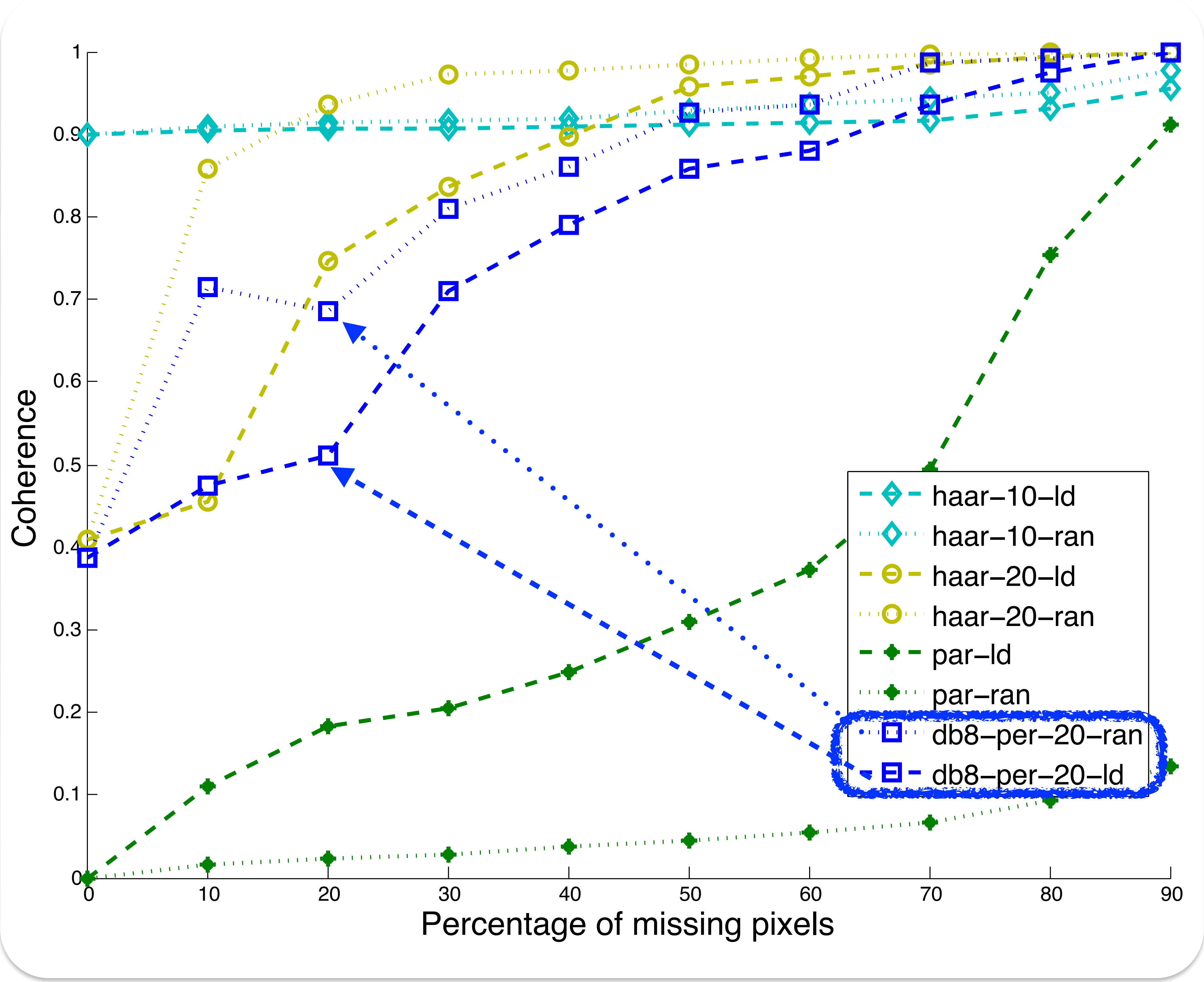

Methodologies

CS-Wavelet [Sen and Darabi, 2011, TVCG]

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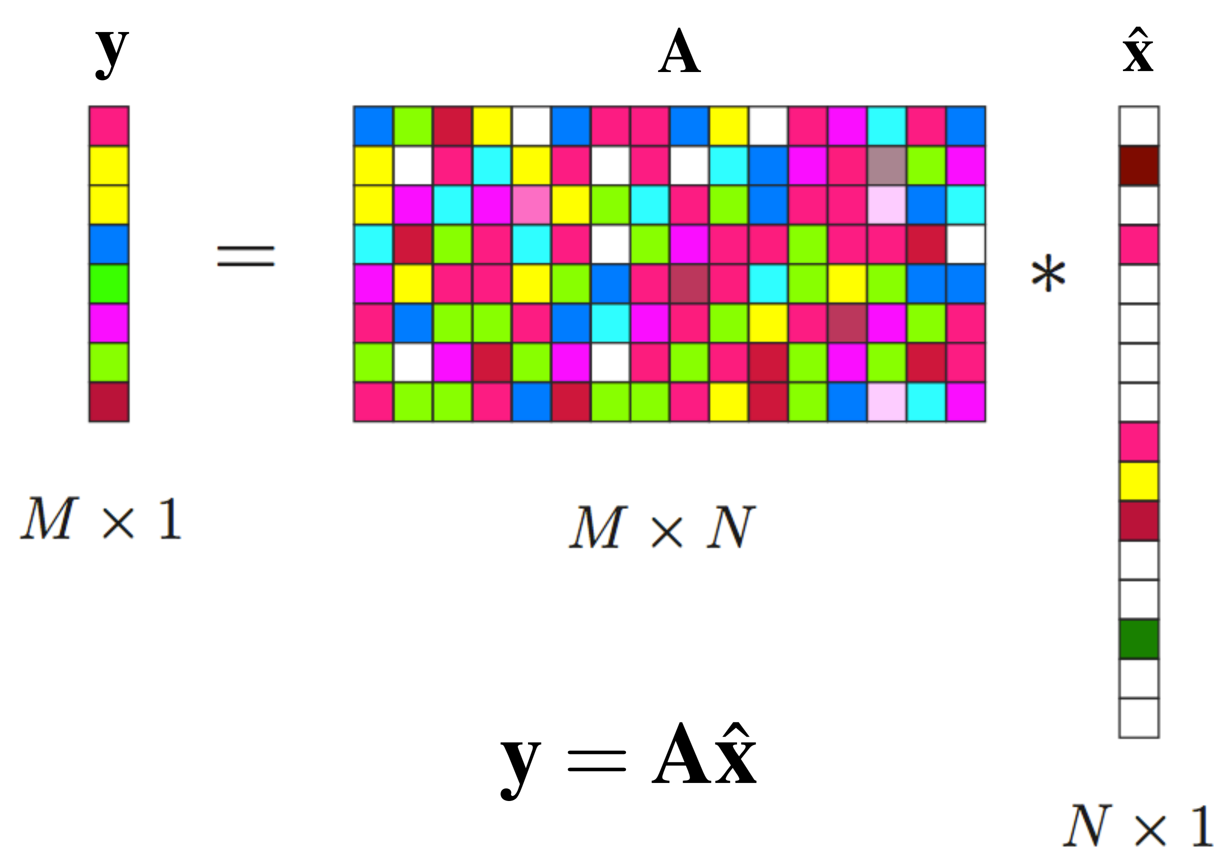

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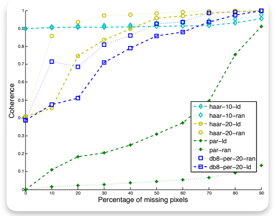


Methodologies

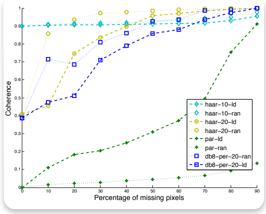
CS-Gradient

Incoherence ▶

Sparsity in gradient domain ▶

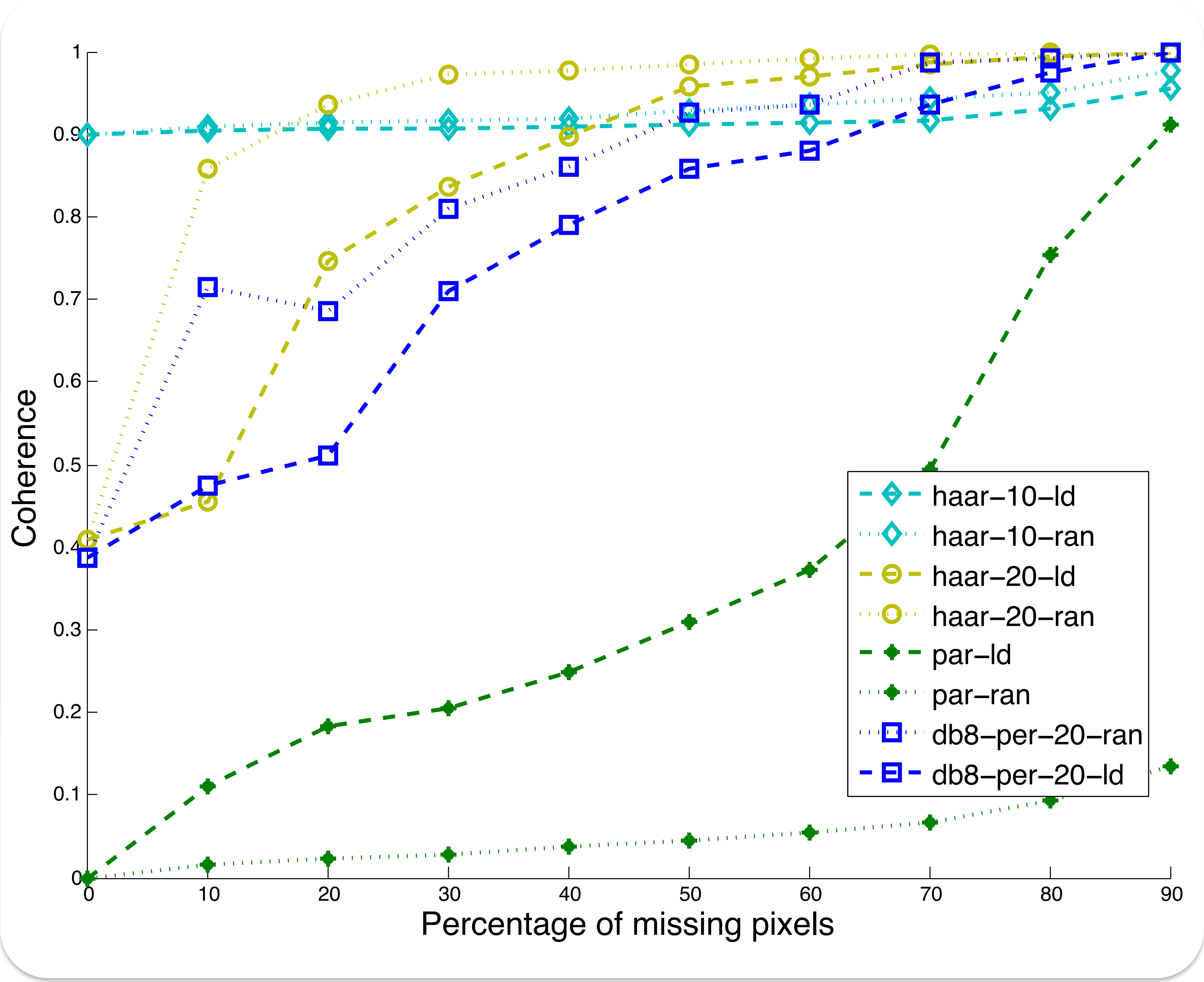
CS-Gradient

Incoherence ▶

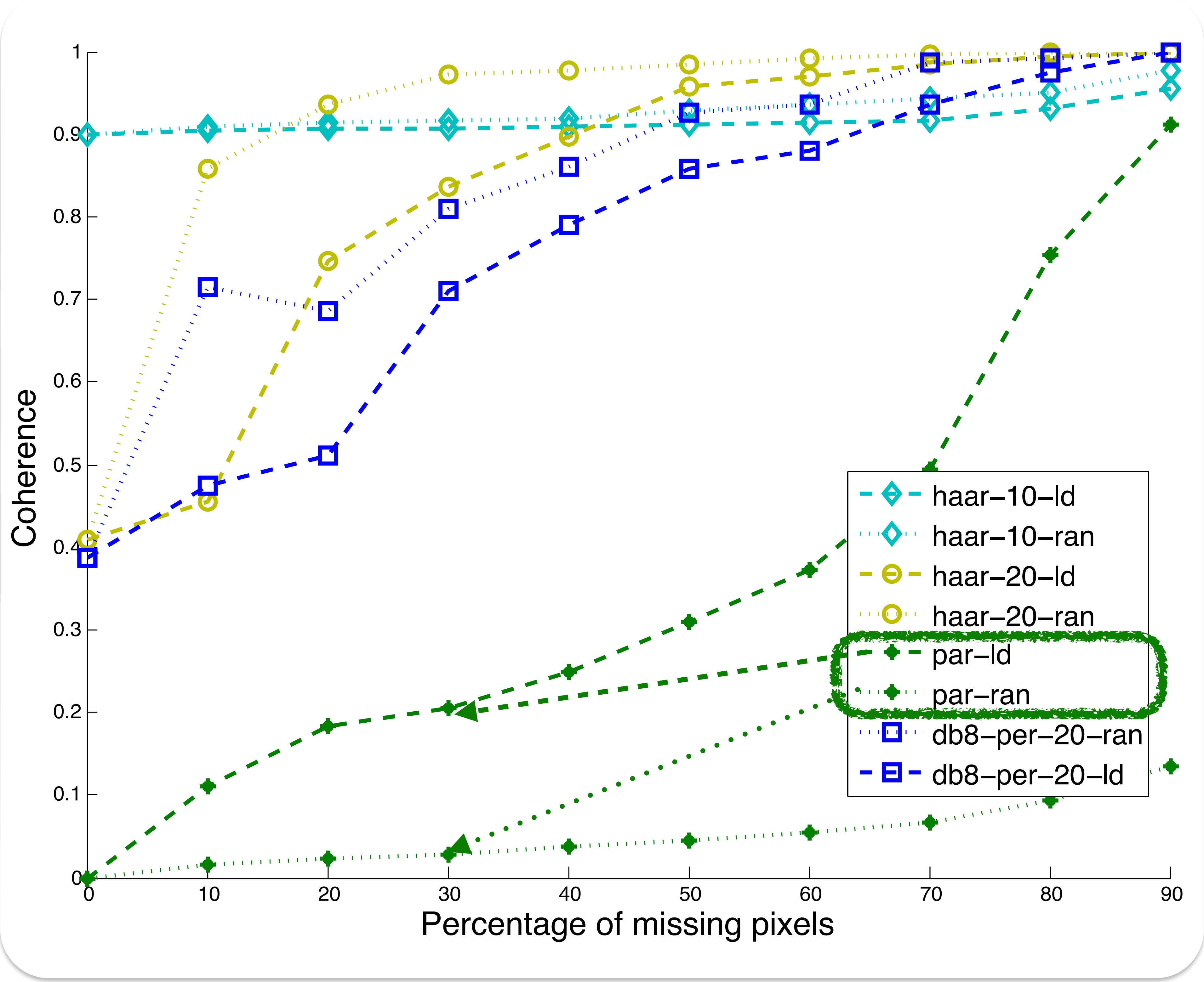


Sparsity in gradient domain ▶

Methodologies



Methodologies



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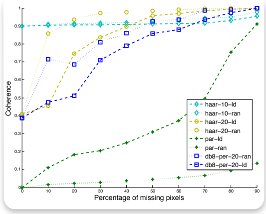
CS-Gradient

Incoherence ▶

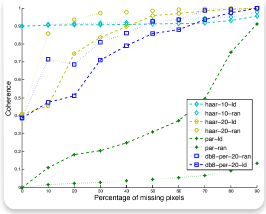


Sparsity in gradient domain ▶

Methodologies

CS-Gradient

Incoherence ▶



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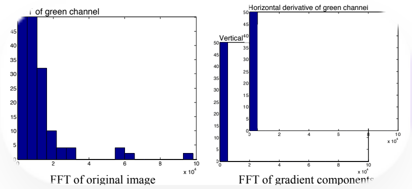
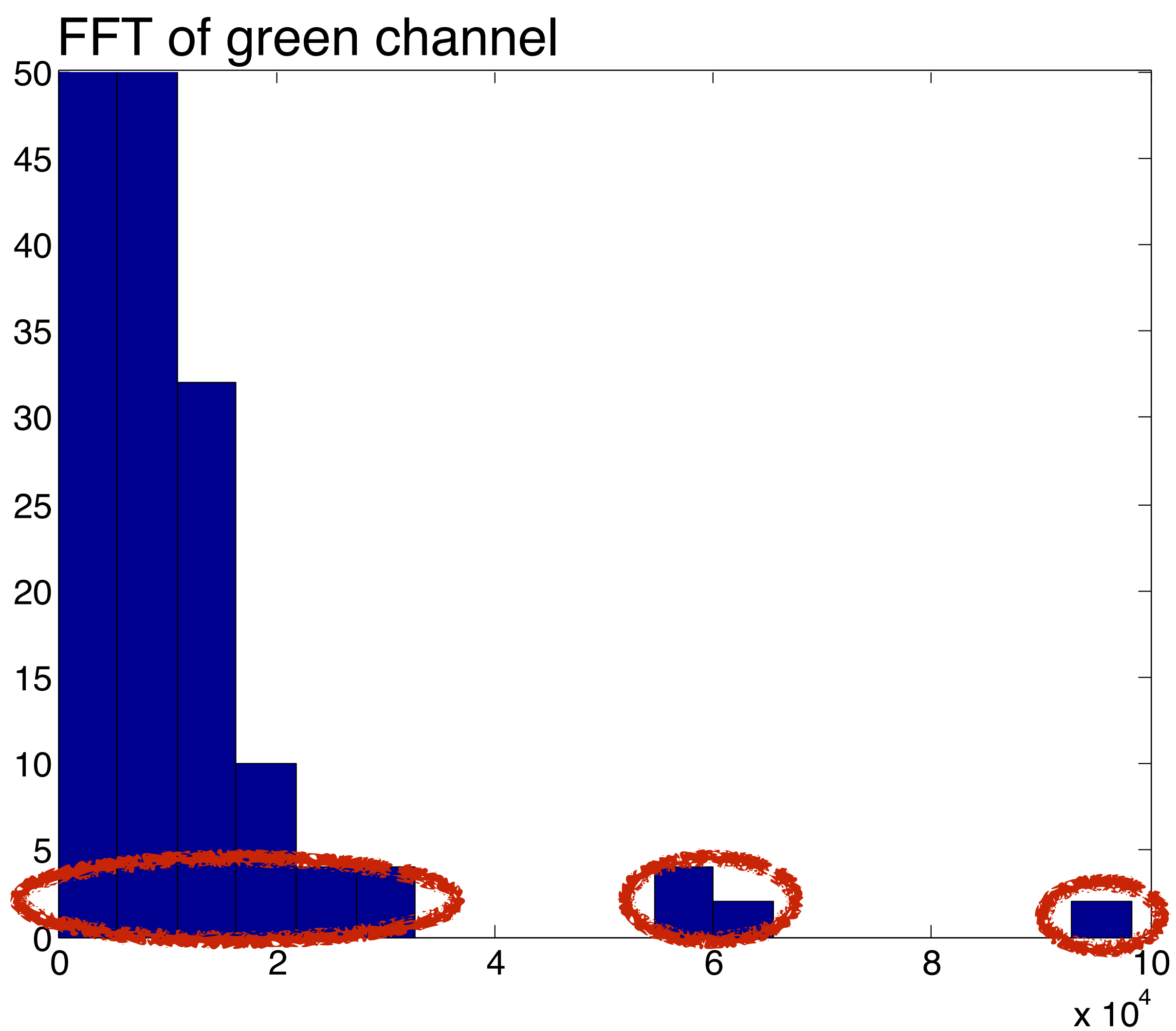
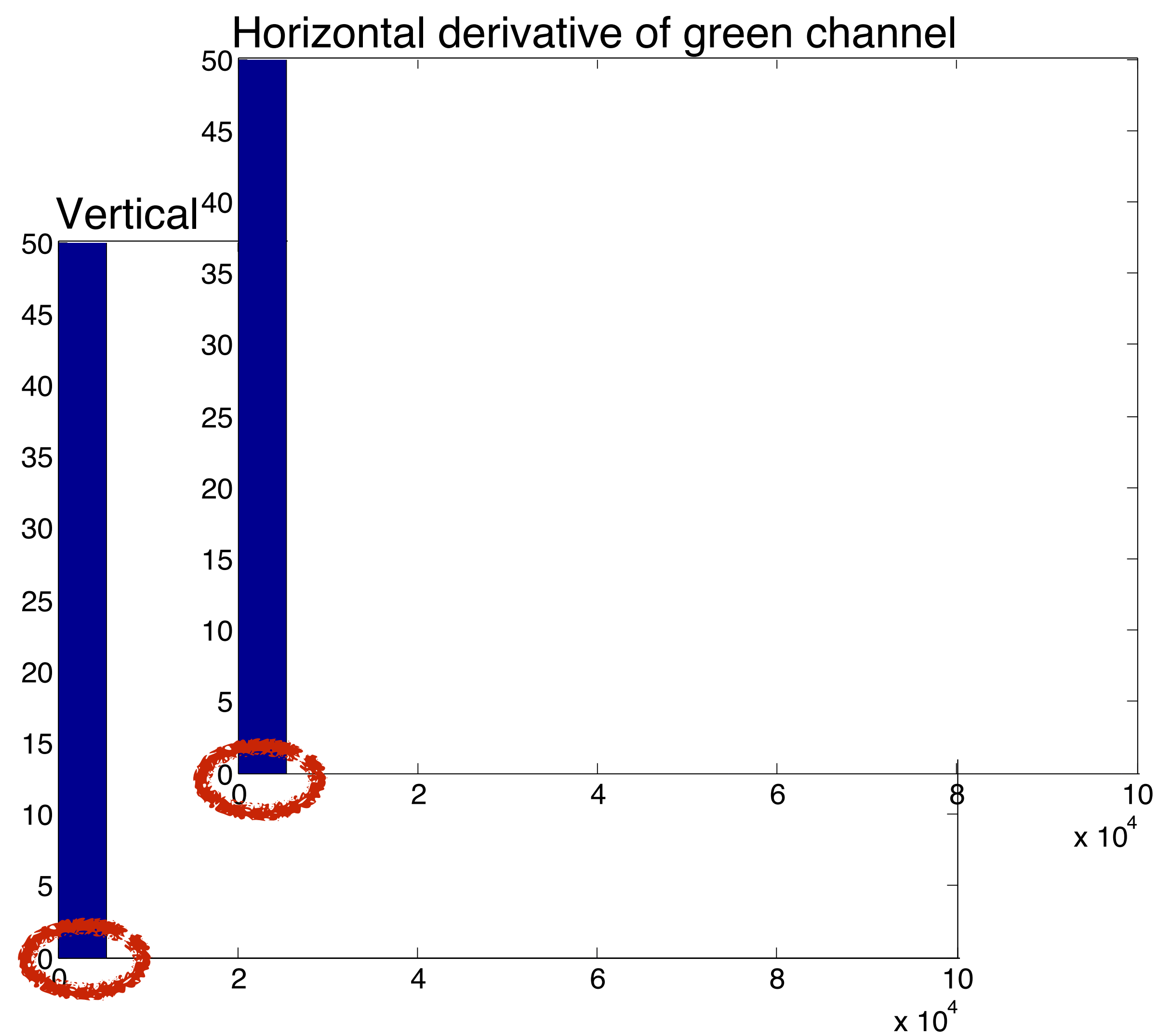


CS-Gradient



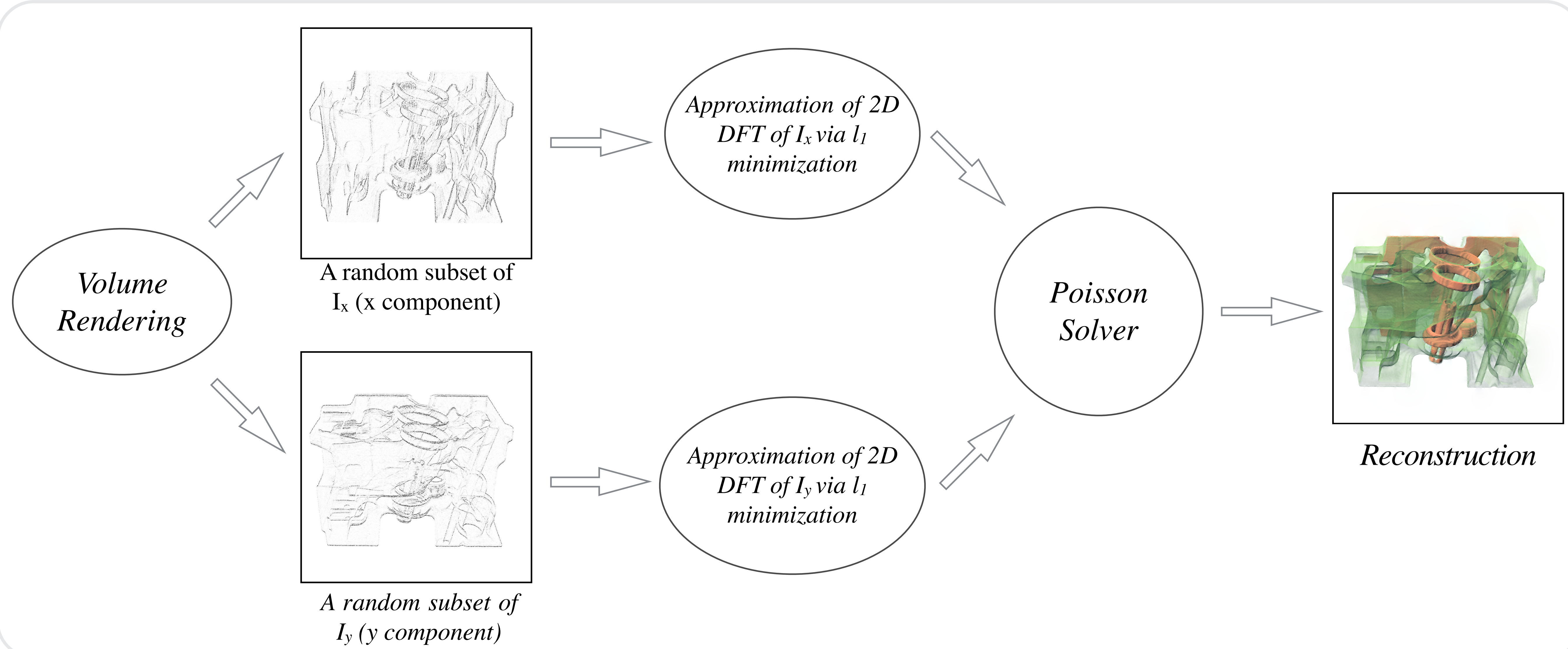
FFT of original image



FFT of gradient components

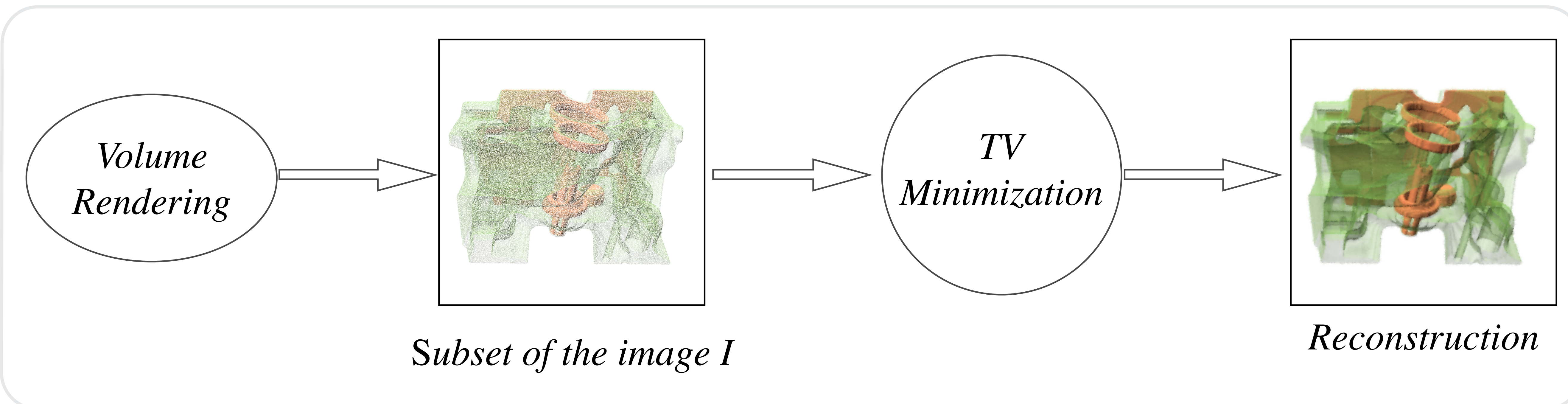
CS-Gradient

$$\min \|\hat{\mathbf{x}}_1\|_1 \quad \text{subject to} \quad \|\mathbf{SF}^{-1}\hat{\mathbf{x}}_1 - \mathbf{y}_1\|_2 \le \varepsilon.$$



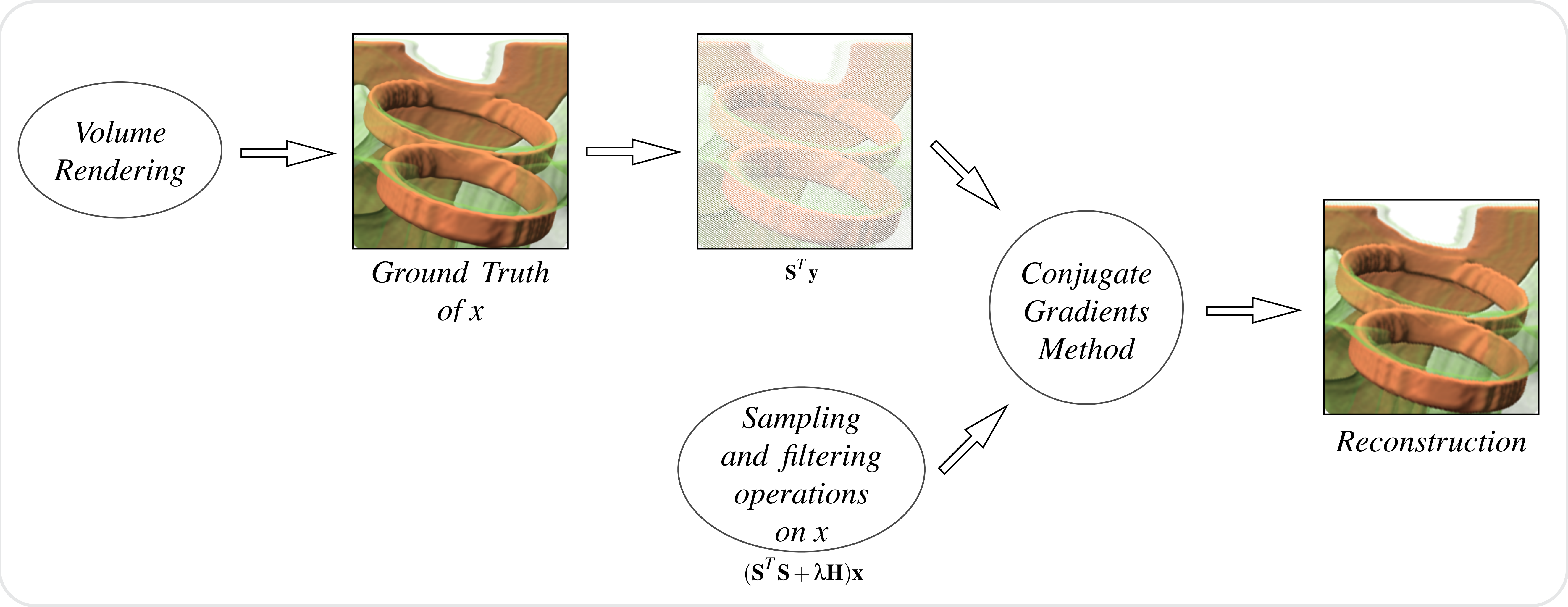
Total Variation(TV) Minimization

$$\min \|\mathbf{x}\|_{TV} \quad \text{subject to} \quad \|\mathbf{Sx}-\mathbf{y}\|_2 \leq \varepsilon$$



Smoothness Splines(SS)

$$\min_{\mathbf{x}} \|\mathbf{S}\mathbf{x}-\mathbf{y}\|_2^2 + \lambda \mathbf{x}^T \mathbf{H}\mathbf{x} \quad \Longrightarrow \quad (\mathbf{S}^T\mathbf{S}+\lambda\mathbf{H})\mathbf{x} = \mathbf{S}^T\mathbf{y}$$



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4. **Results**
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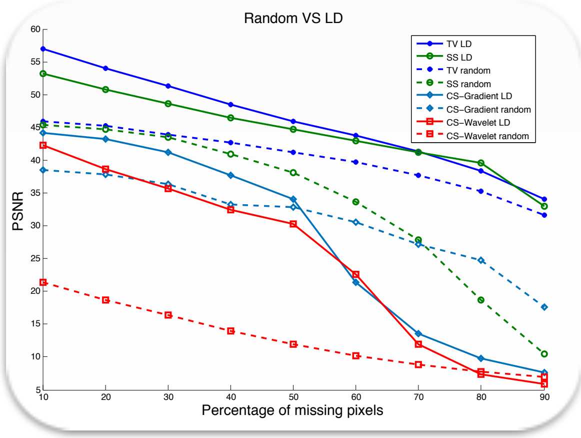
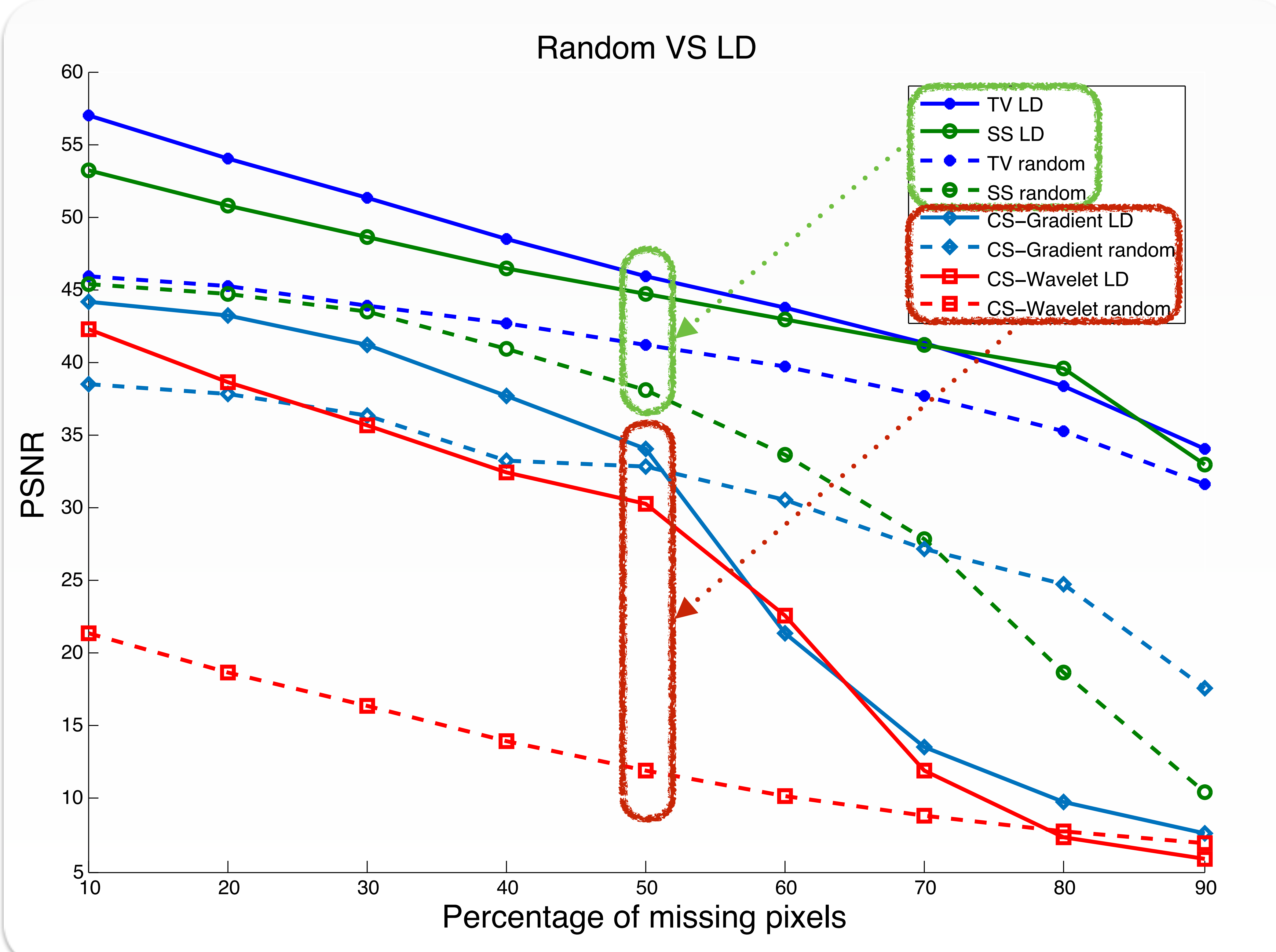
Results

- We recovered the images from a fraction of the pixels and experimented with different percentages of pixels.



- To measure recovery quality
    1. Peek signal-to-noise ratio (
    2. Error images

Results



Random VS LD
PSNR
Percentage of missing pixels
TV LD
SS LD
TV random
SS random
CS–Gradient LD
CS–Gradient random
CS–Wavelet LD
CS–Wavelet random
60
55
50
45
40
35
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90

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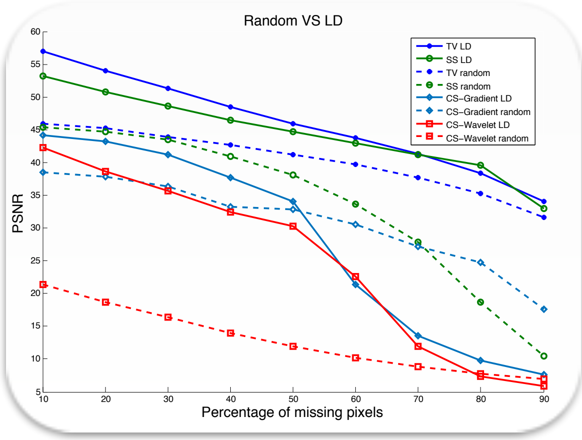

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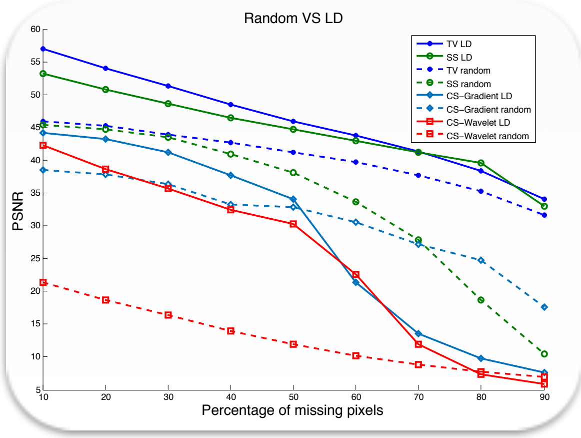
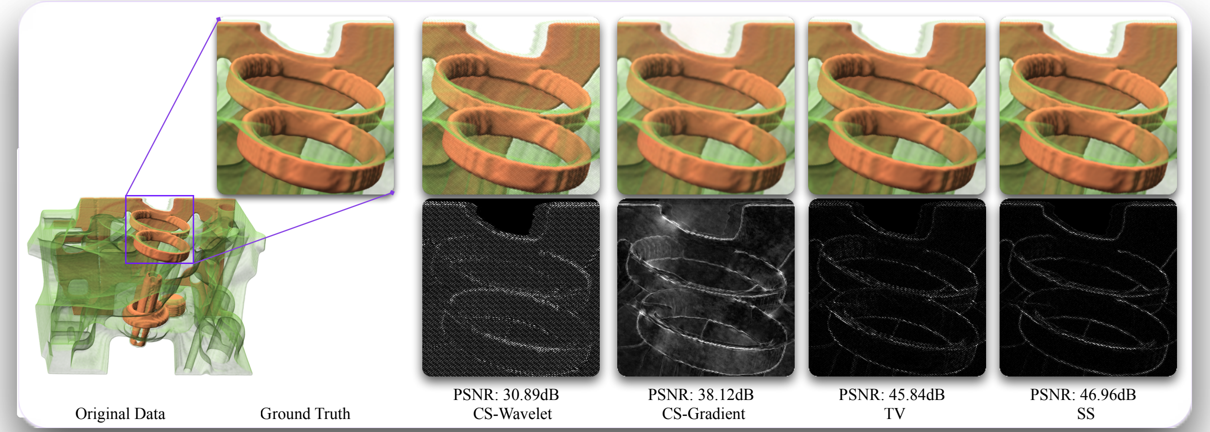


- To measure recovery quality
  1. Peek signal-to-noise ratio (PSNR)
  2. Error images in the CIELUV colorspace.



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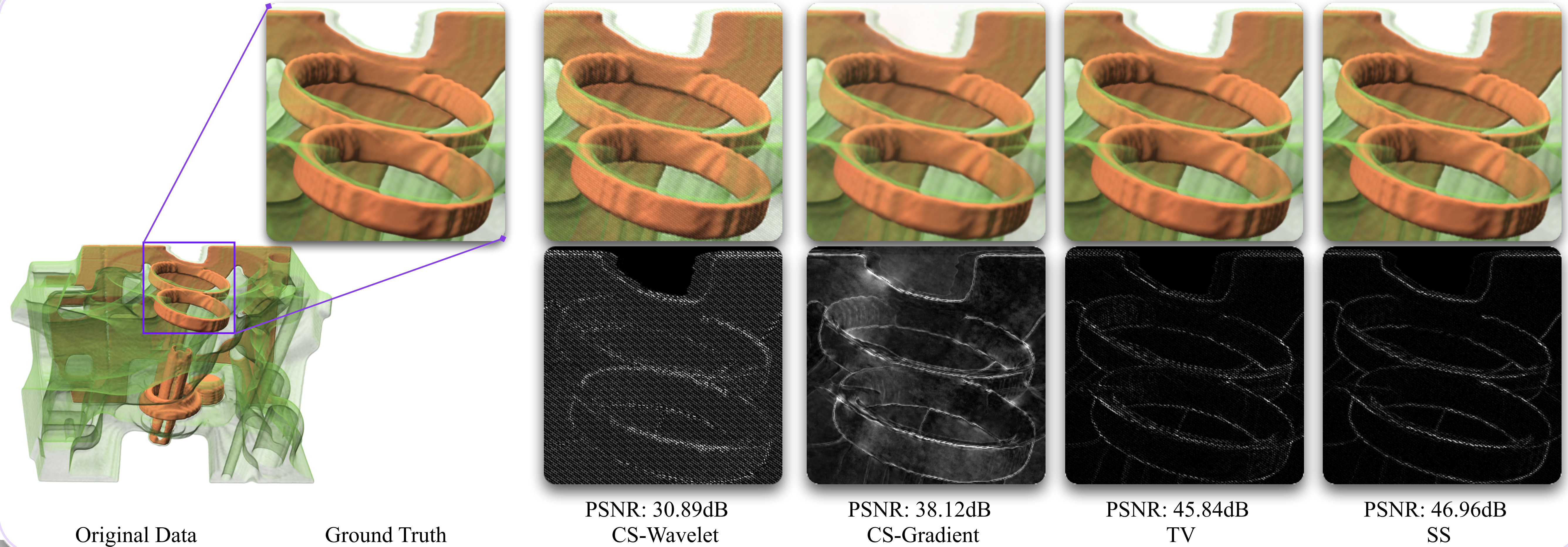
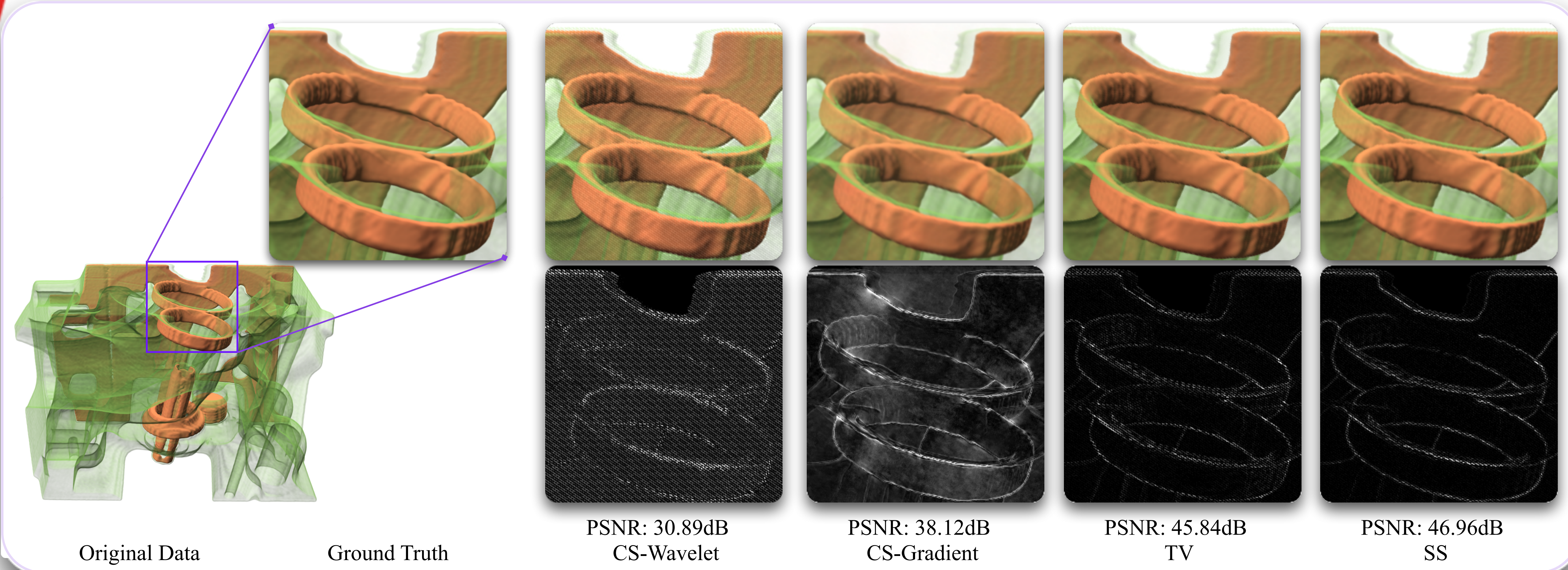


PSNR: 30.89dB
PSNR: 38.12dB
PSNR: 45.84dB
PSNR: 46.96dB
Original Data
Ground Truth
CS-Wavelet
CS-Gradient
TV
SS

Results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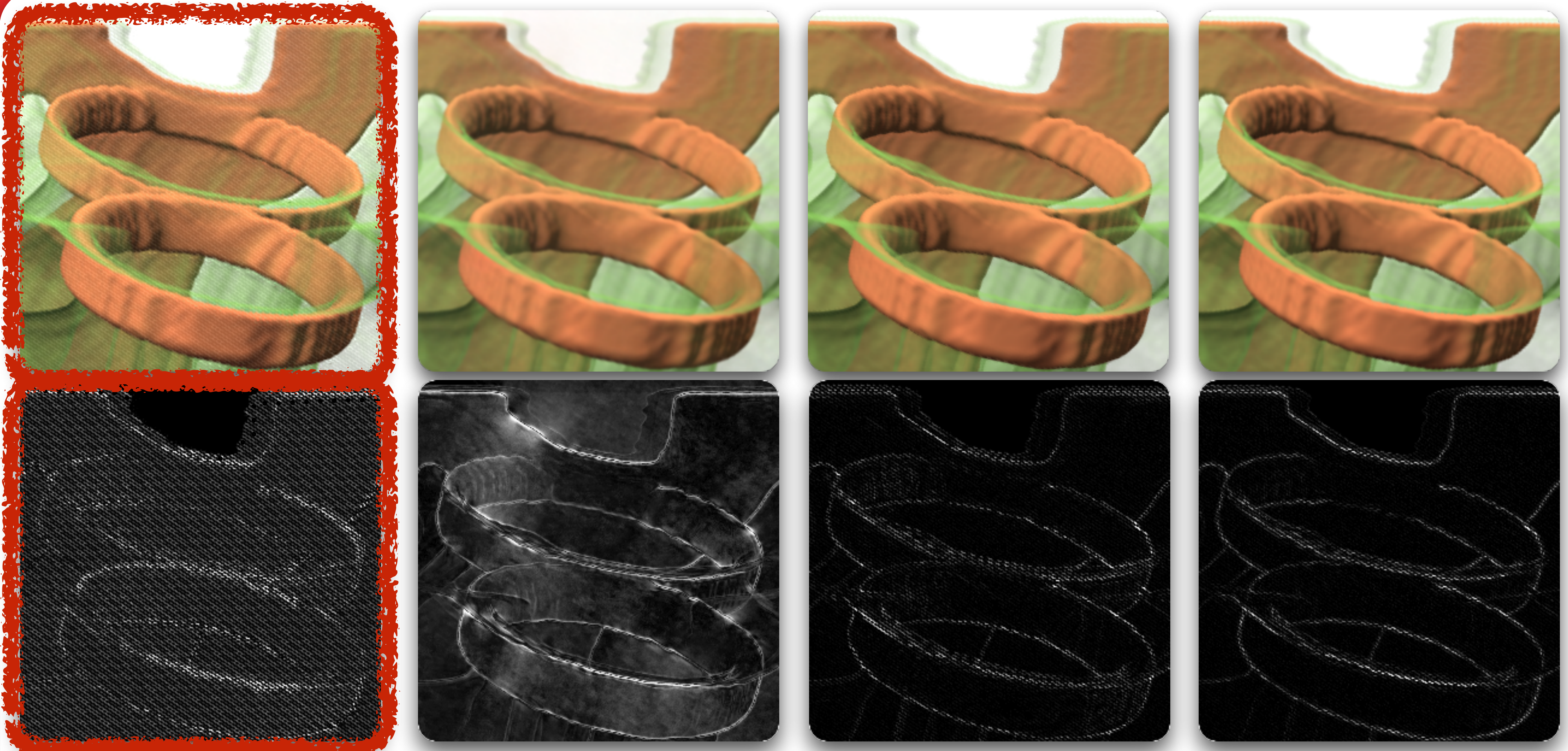

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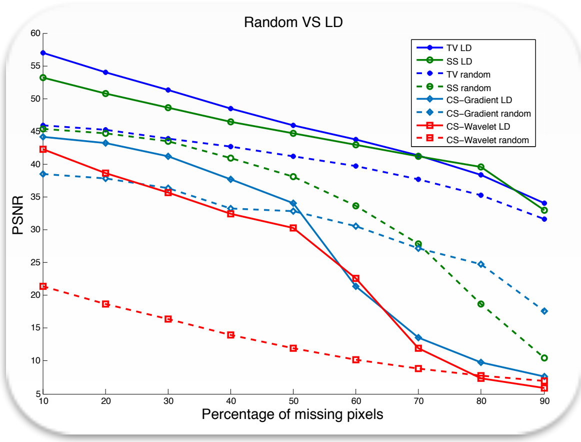

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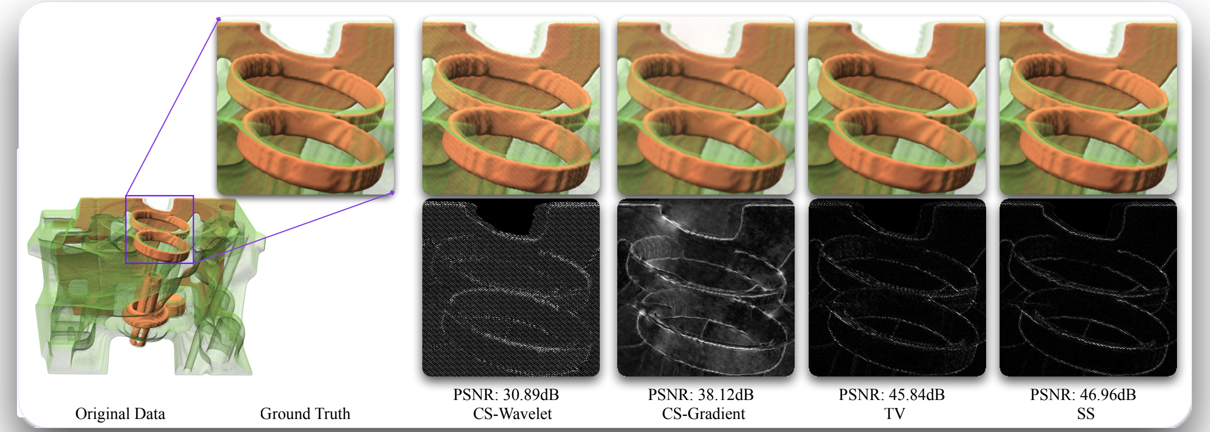
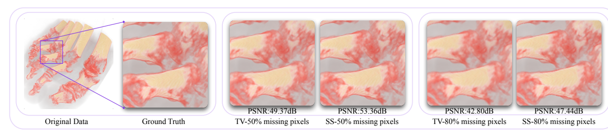
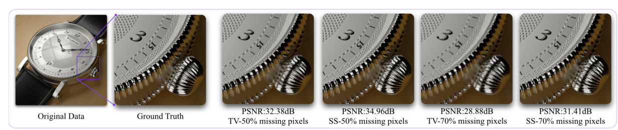
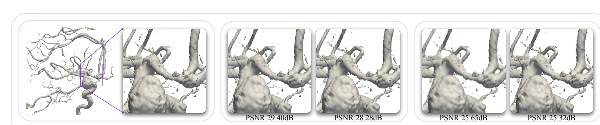
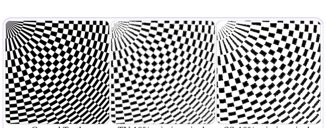


Results

Category	Images	TV/SS with LD
Direct Volume Rendering		
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

☹ — Unacceptable recovery

Results

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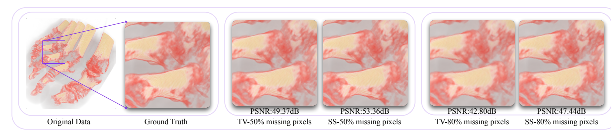
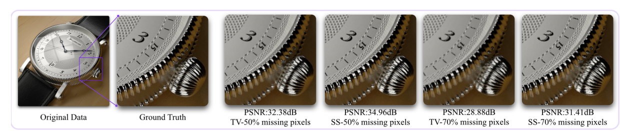
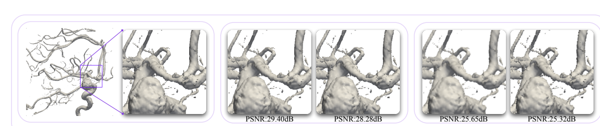
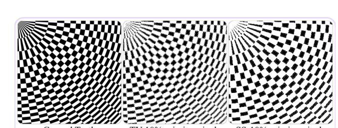
Direct Volume Rendering		
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

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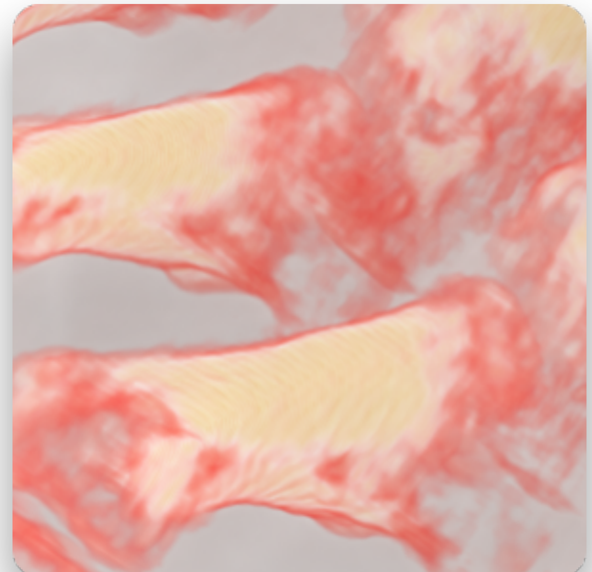
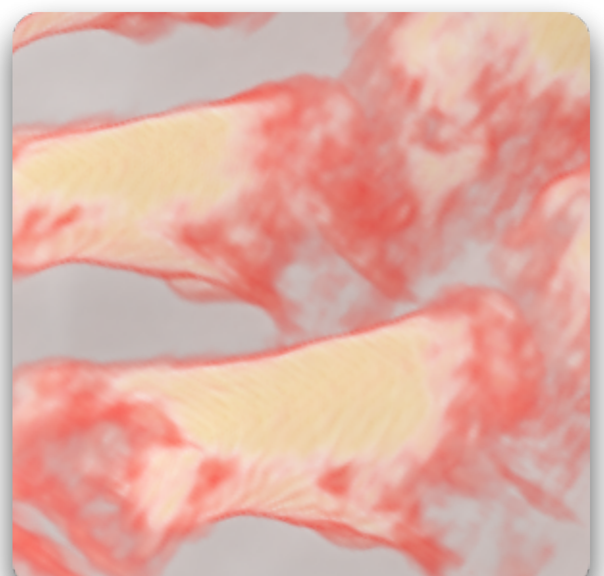
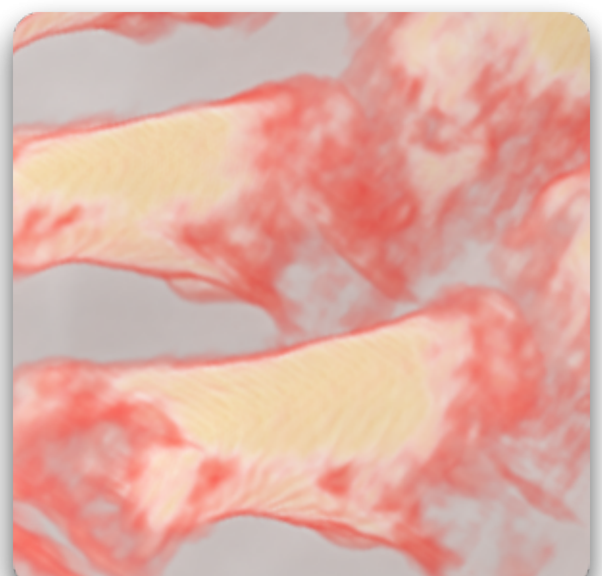


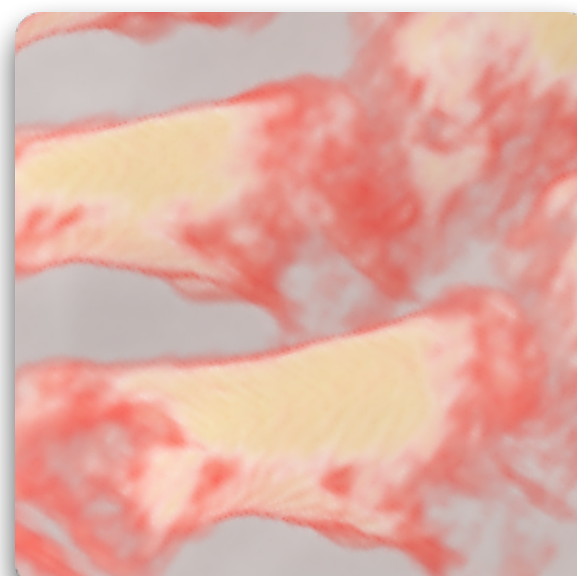
Ground Truth



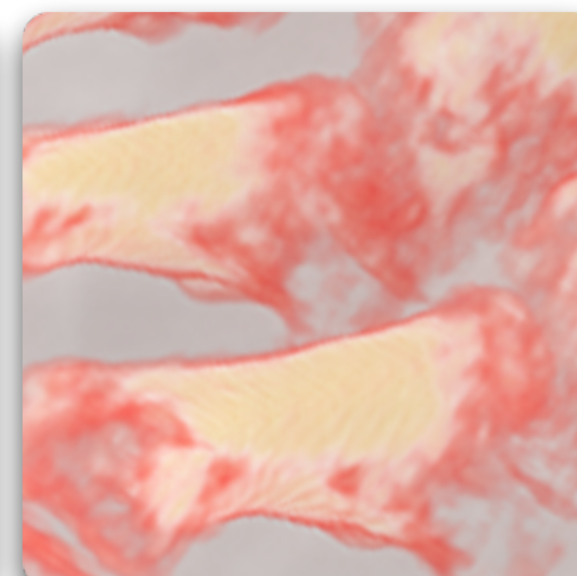
PSNR:49.37dB
TV-50% missing pixels



PSNR:53.36dB
SS-50% missing pixels

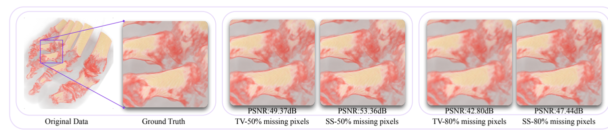
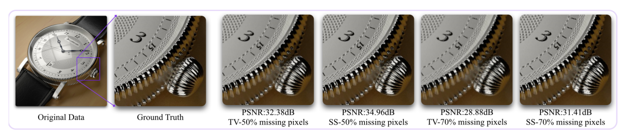
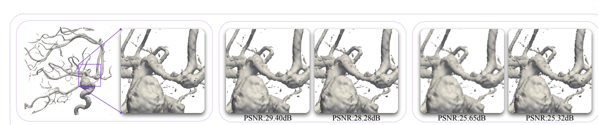
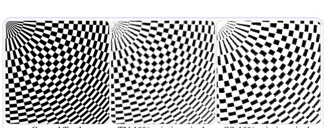


PSNR:42.80dB
TV-80% missing pixels



PSNR:47.44dB
SS-80% missing pixels

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

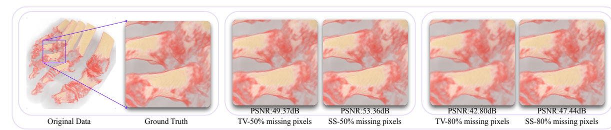
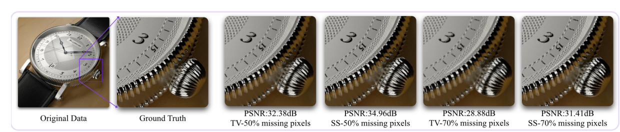
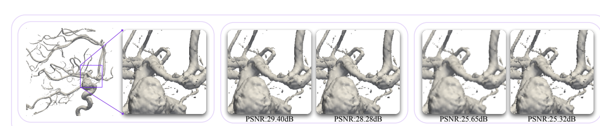
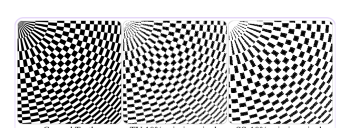
★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

☹ — Unacceptable recovery

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

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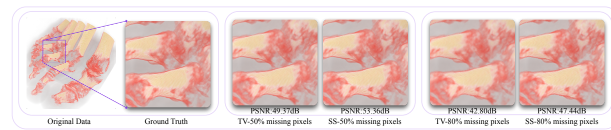
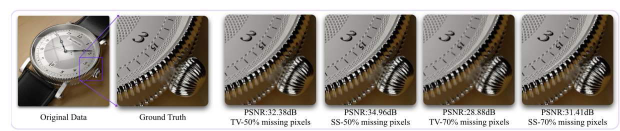
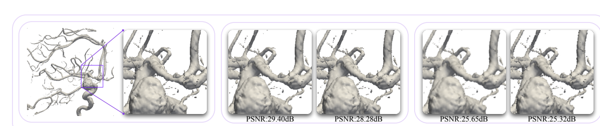
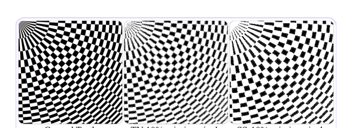
Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

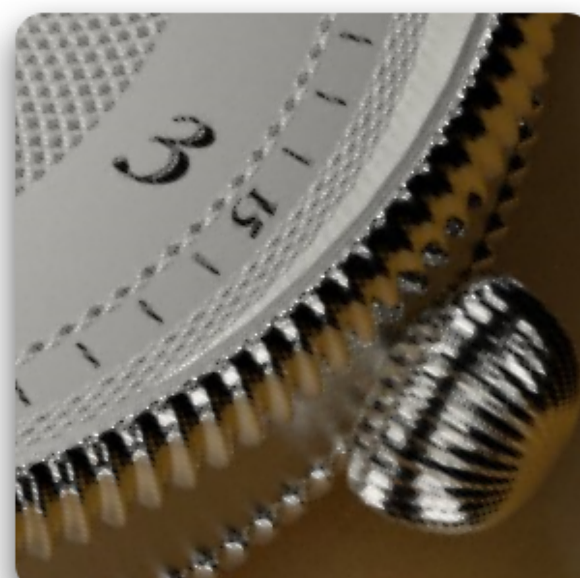
☹ — Unacceptable recovery

Results

Ground Truth

PSNR:32.38dB
TV-50% missing pixels

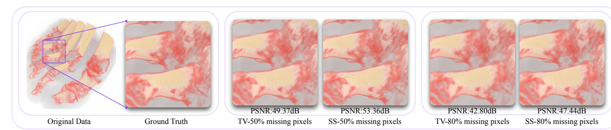
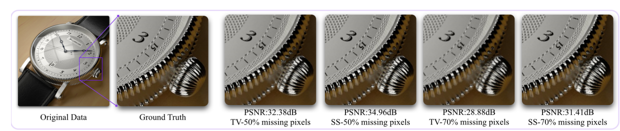
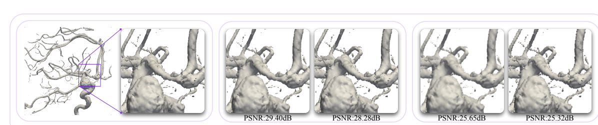
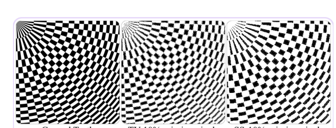
PSNR:34.96dB
SS-50% missing pixels



PSNR:28.88dB
TV-70% missing pixels

PSNR:31.41dB
SS-70% missing pixels

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		
Iso-Surface Rendering		
Non-Smooth Images		

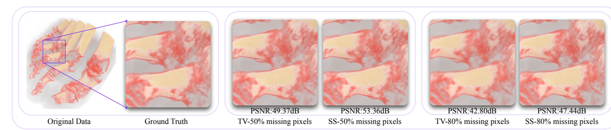
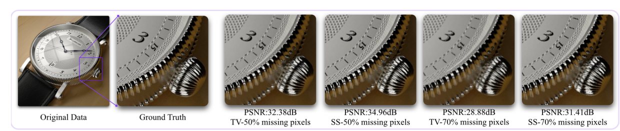
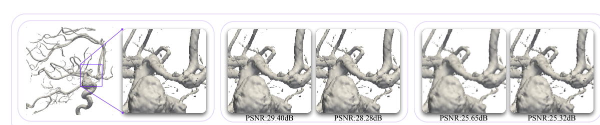
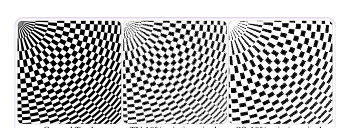
★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

☹ — Unacceptable recovery

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		
Non-Smooth Images		

★ ★ ★ — Consistent recovery

★ ★ — Good recovery

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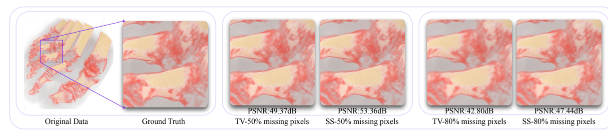
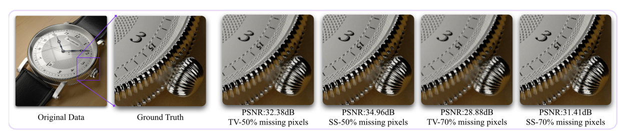
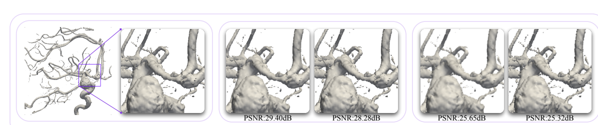
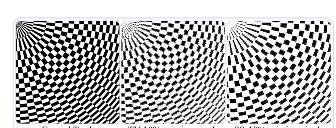
Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		
Non-Smooth Images		

★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

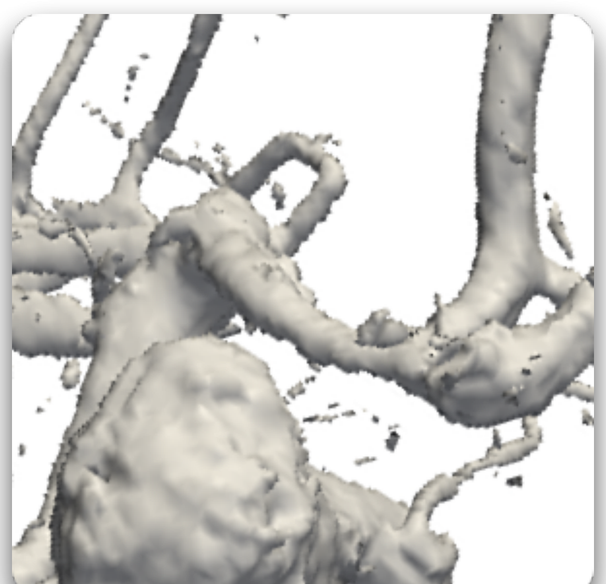
☹ — Unacceptable recovery

Results

Ground Truth

PSNR:29.40dB

TV-50% missing pixels



PSNR:28.28dB

SS-50% missing pixels

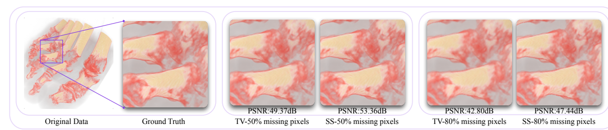
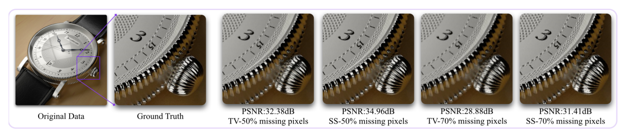
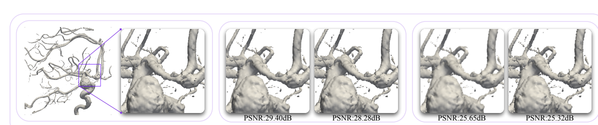
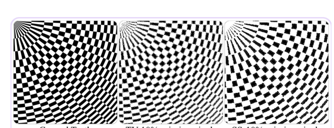
PSNR:25.65dB

TV-80% missing pixels

PSNR:25.32dB

SS-80% missing pixels

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		
Non-Smooth Images		

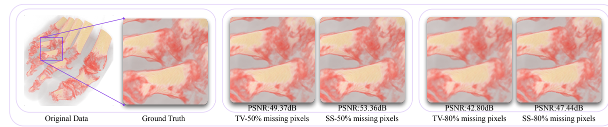
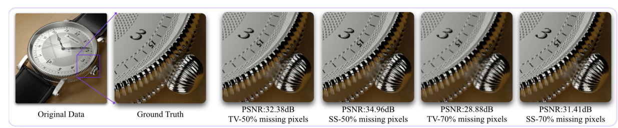
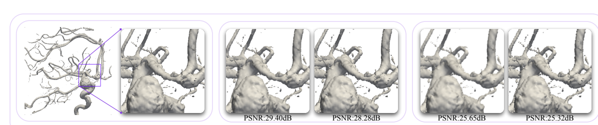
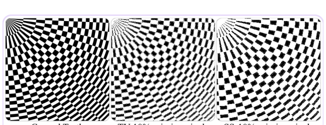
★ ★ ★ — Consistent recovery

★ — Acceptable recovery

★ ★ — Good recovery

☹ — Unacceptable recovery

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		★
Non-Smooth Images		

★ ★ ★ — Consistent recovery

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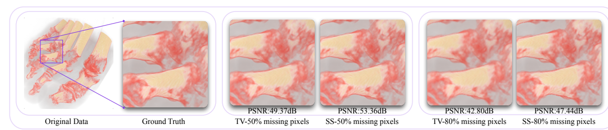
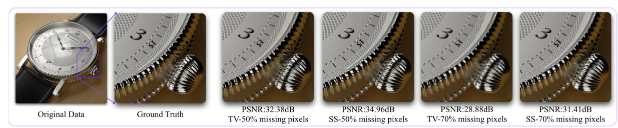
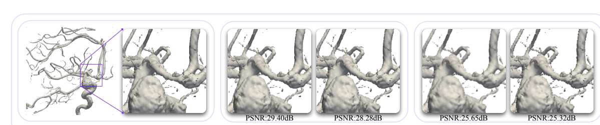
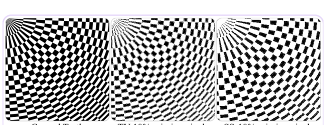
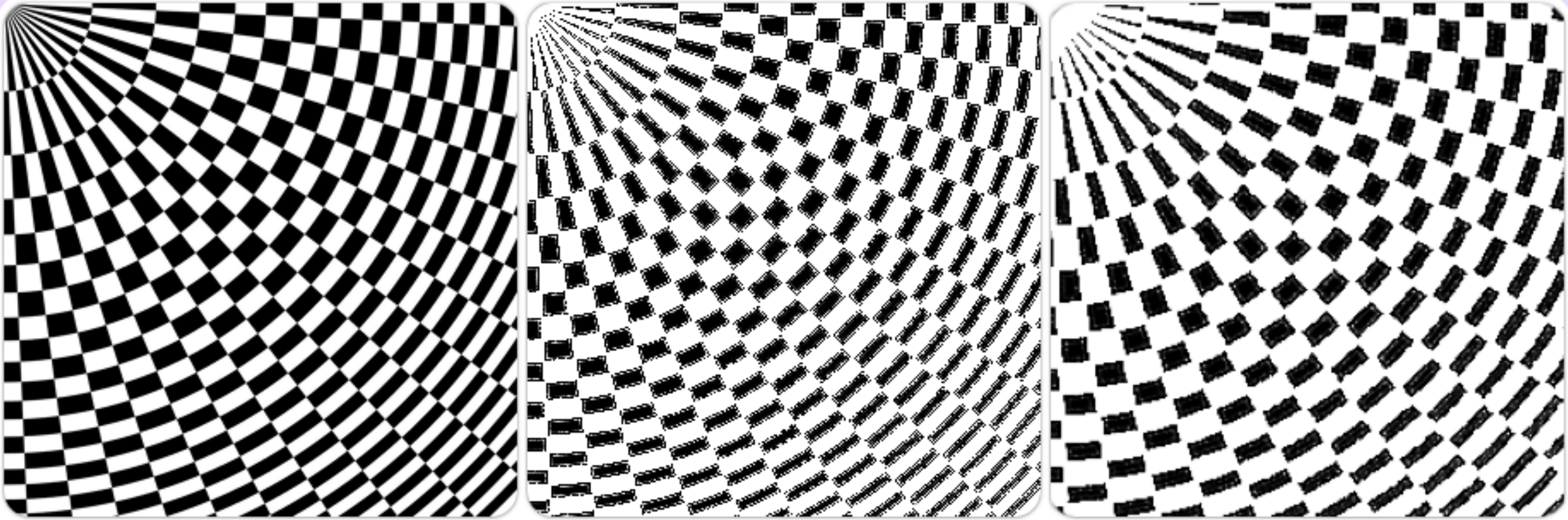
Results

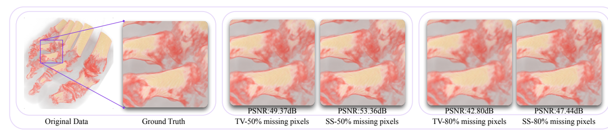
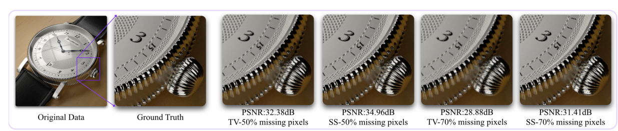
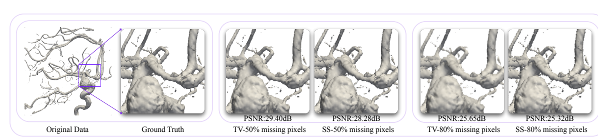
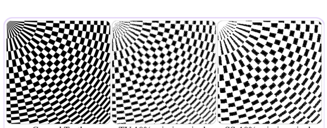
Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		★
Non-Smooth Images		

★ ★ ★ — Consistent recovery
★ — Acceptable recovery
★ ★ — Good recovery
☹ — Unacceptable recovery



Ground Truth TV-10% missing pixels SS-10% missing pixels

Results

Category	Images	TV/SS with LD
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		★
Non-Smooth Images		

★ ★ ★ — Consistent recovery
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Results

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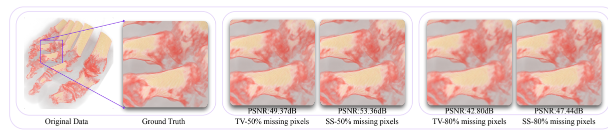
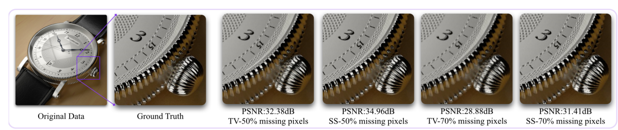
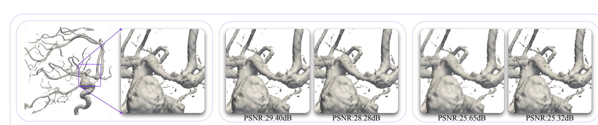
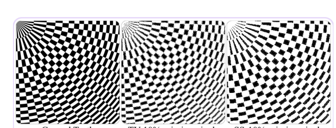
Direct Volume Rendering		★ ★ ★
Physically-based Rendering		★ ★
Iso-Surface Rendering		★
Non-Smooth Images		☹

★ ★ ★ — Consistent recovery

★ ★ — Good recovery

★ — Acceptable recovery

☹ — Unacceptable recovery

Outline

1. Motivation
2. Research Question
3. Methodologies
4. Results
5. Conclusion

Conclusion

- We presented three different methods for recovering images from a subset of the pixels
- CS-based approaches are not suitable for this problem as we are restricted to making pixel measurements
- Answer the question of which method is the most suitable for compressive volume rendering via a very small fraction of rendered pixels.

Conclusion

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- Answer the question of which method is the most suitable for compressive volume rendering via a very small fraction of rendered pixels.

Thank you!

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http://visagg.cpsc.ucalgary.ca

Performance

Resolution	1200 * 1200	600 * 600	900 * 900
Rendering Time	1	0.25	0.56
CS-Wavelet	0.024		
CS-Gradient	0.011		
TV	0.011		
SS	0.003		

- Rendering time for 1200 * 1200 image is the baseline
- Relative recovery time for different methods is compared against each other