

Image Denoising For Low-Electron-Dose Transmission Electron Microscopy (TEM)

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Motivation

- TEM investigation of **weakly bonded** or **reactive materials** is hindered by rapid structural damage under high energy electron beam.
- Direct electron detector enables **low-electron-dose imaging** in TEM. Fast acquisition and low electron dosage can now be utilized to avoid beam damage.
- Low electron dose results in **poor signal-to-noise ratio (SNR)** of the acquired micrographs. Difficult to extract the desired critical information from the noisy images.

Related Work

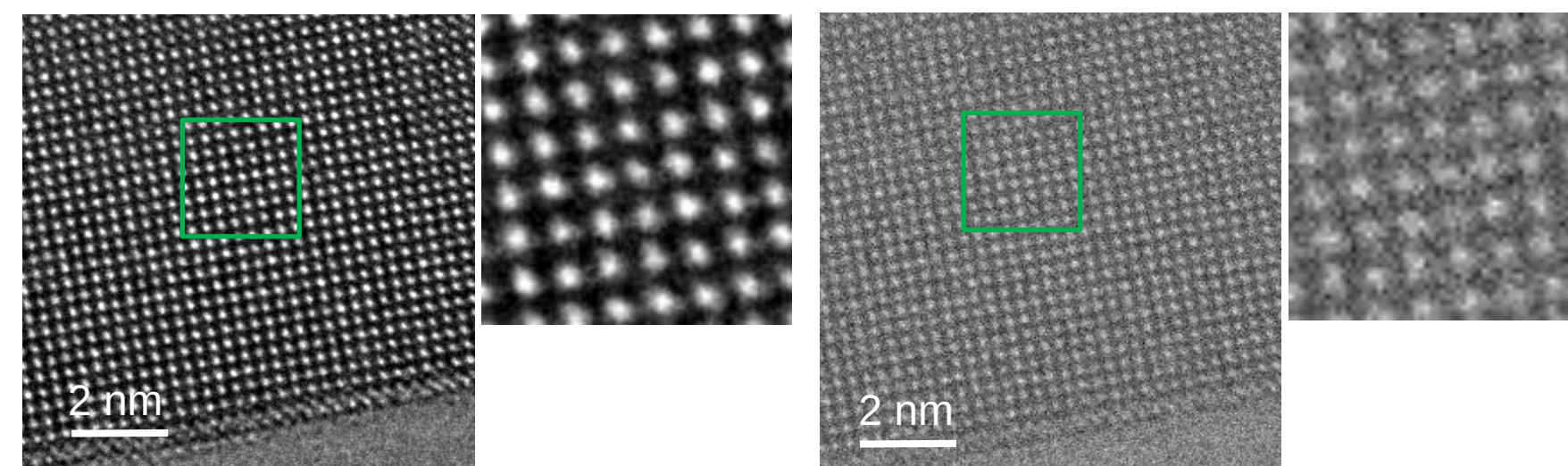
- TEM image denoising in materials science often accomplished by **simple spatial filters** like Wiener filters[1], Gaussian filter[2], Average background subtraction filter (ABSF) [3], or their combinations.
- Non-local Means (NLM)** has been applied to TEM images of biological samples[4].
- Block-matching and 3D filtering (BM3D)**, is one of the most successful NLM variant for image denoising[5].
- NLM and its variants in principle well suit low-dose TEM denoising for crystalline materials.

References

- [1] L. D. Marks. Wiener-filter enhancement of noisy HREM images. Ultramicroscopy. 1996.
- [2] O. L. Krivanek et al. Atom-by-atom structural and chemical analysis by annular dark-field electron microscopy. Nature. 2010.
- [3] R. Kilaas. Optimal and near-optimal filters in high-resolution electron microscopy. Journal of Microscopy. 1998
- [4] A. Buades, et al. A non-local algorithm for image denoising. IEEE Computer Society Conference on Computer Vision and Pattern Recognition. 2005.
- [5] K. Dabov, et al. Image Denoising by Sparse 3-D Transform-Domain Collaborative Filtering. IEEE Trans. Image Process., 2007

Workflow

Method Evaluation: High electron dose TEM image blurred with Gaussian kernel and noise.

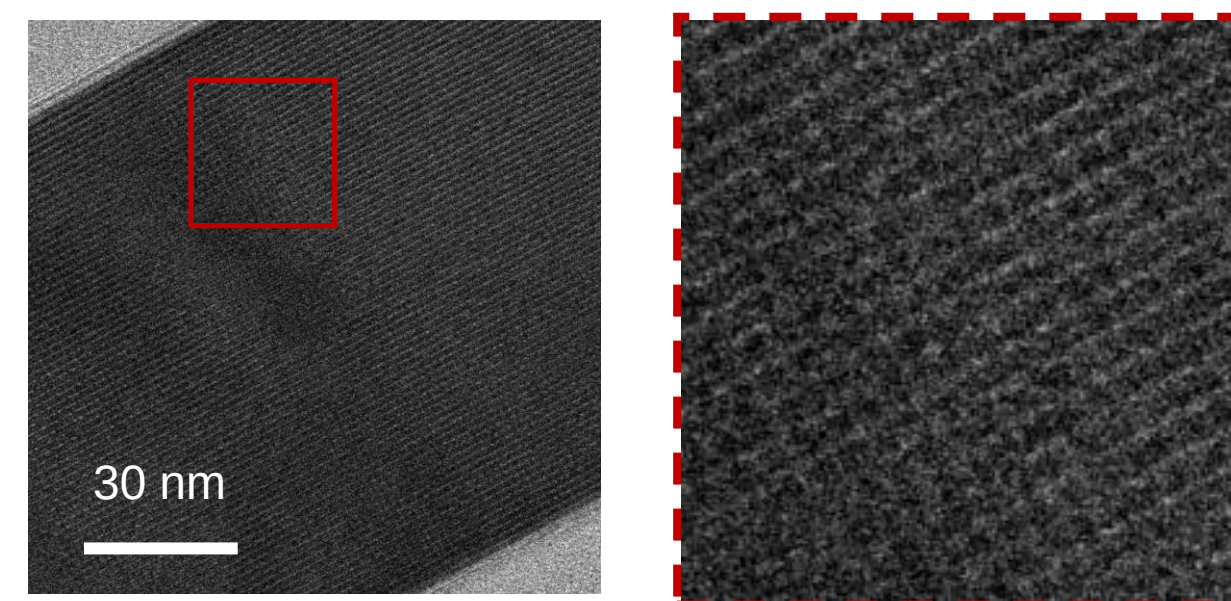


Images: high resolution TEM image taken at $> 10^4$ e-/A² of crystalline silicon materials as noiseless ground truth image

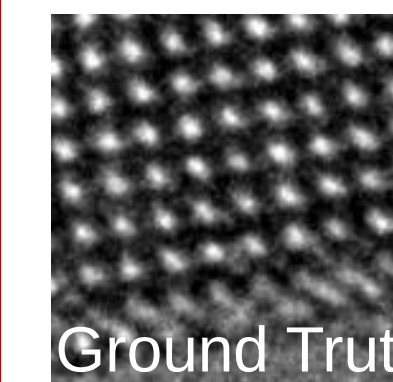
Filters: simple spatial filters and non-local detection-based methods

Evaluation Metrics: peak signal-to-noise(PSNR) and Structural Similarity Index Measure (SSIM) as evaluation metrics

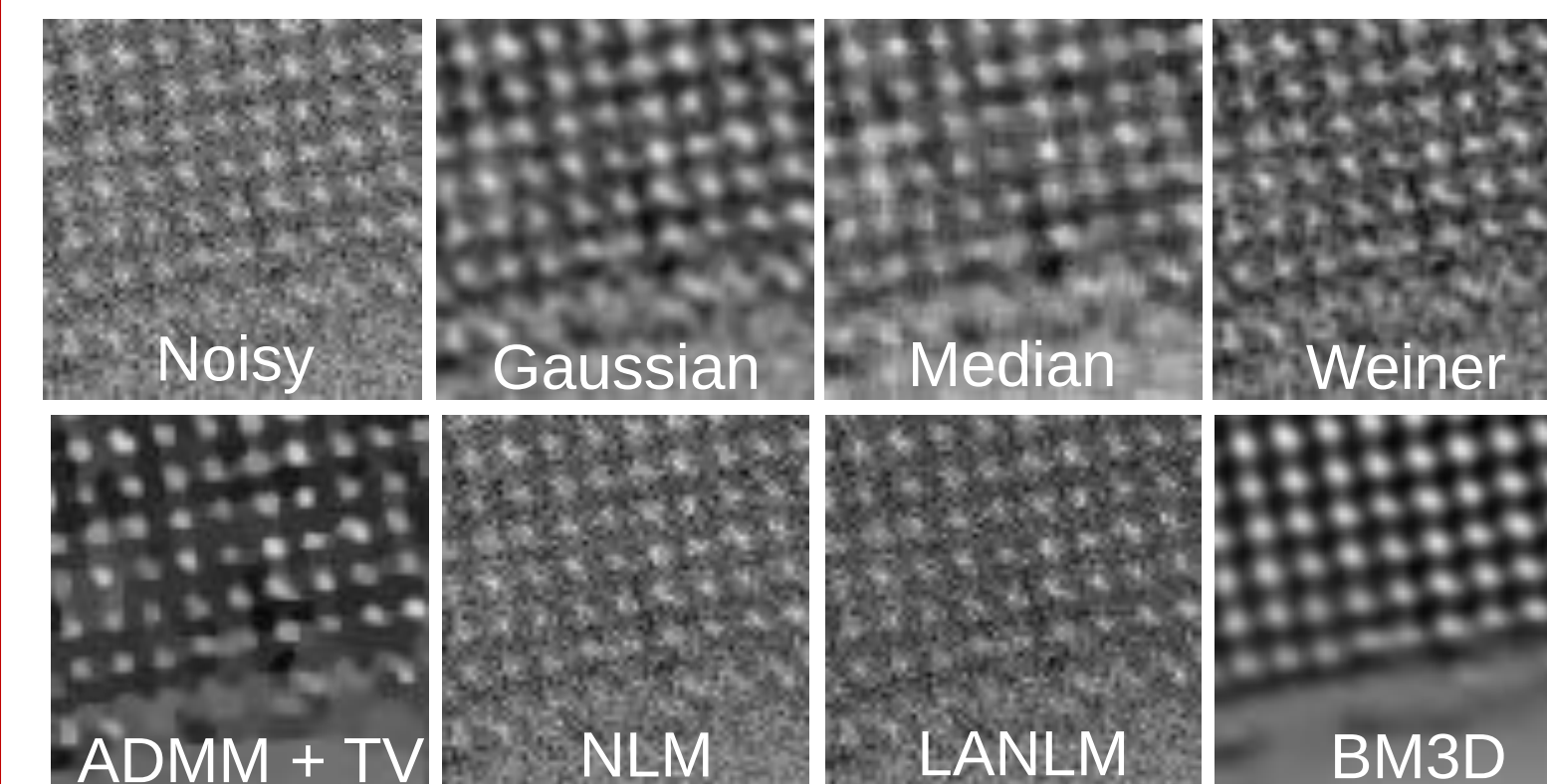
Target: Denoise low-dose TEM image of hybrid halide perovskite materials taken at 12 e-/A²



Experiment Result Part 1 - Silicon



	noisy	Gaussian	Median	Weiner	ADMM	NLM	LANLM	BM3D
PSNR	13.05	16.67	14.45	16.38	18.99	14.31	14.23	19.86
SSIM	0.54	0.78	0.66	0.72	0.72	0.56	0.59	0.85

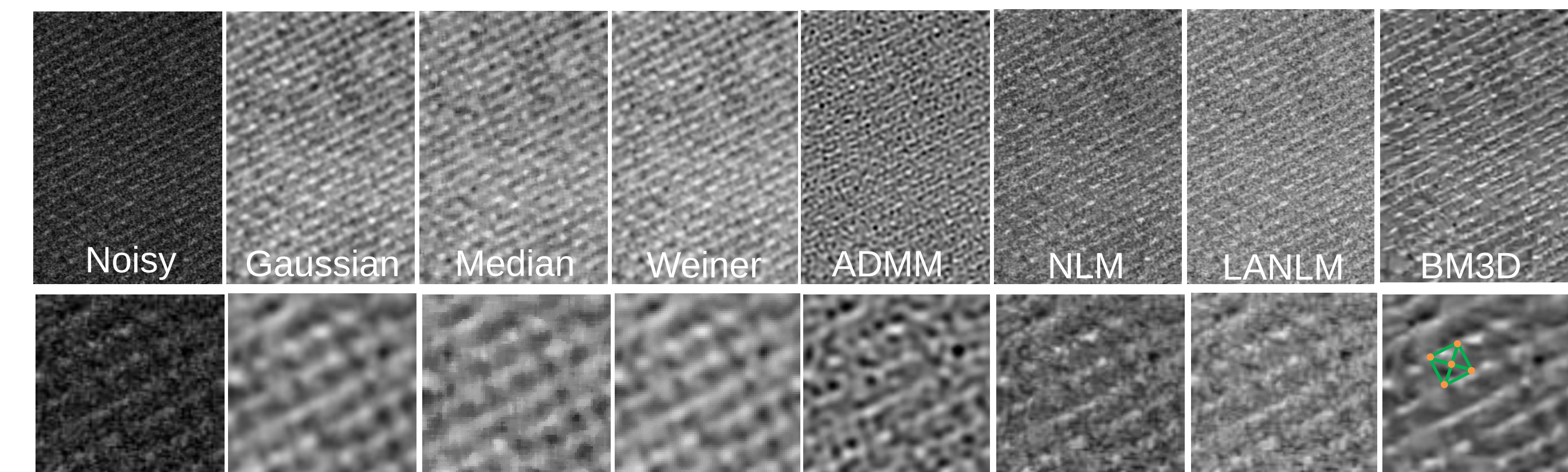
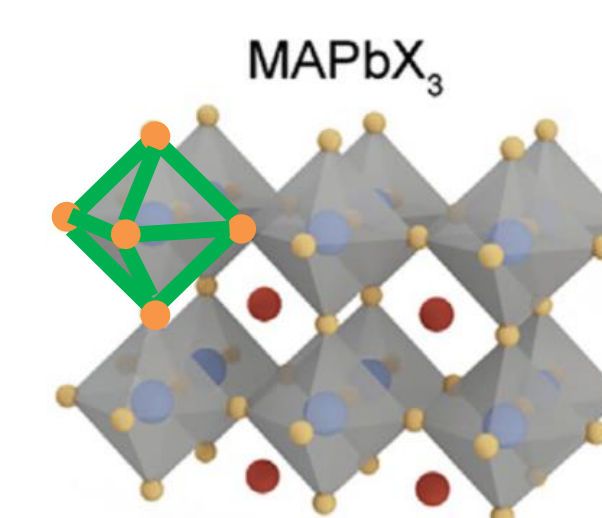


- BM3D gives the highest PSNR, SSIM, and best visual quality, but there are certain distortion of at the edge.
- NLM and LANLM do not work well here, probably limited by our implementation, where we can't do larger search window.

- Conventional spatial filters still valid, but not as good.
- PSNR and SSIM might not be good metrics for TEM denoise

Experiment Result Part 2 - Hybrid Halide Perovskite

- Min-max filter applied to improve visual quality
- No ground truth image possible



- Real low-dose image can be even noisier. Conventional methods barely improves the image quality.
- BM3D gives best quality, with pyramid structure shown in the denoised image.
- The pyramid structure matches with lattice structure. Need to be careful if these are artifacts from the denoising.