TomoGAN: Low-Dose X-Ray Tomography with Generative Adversarial Networks

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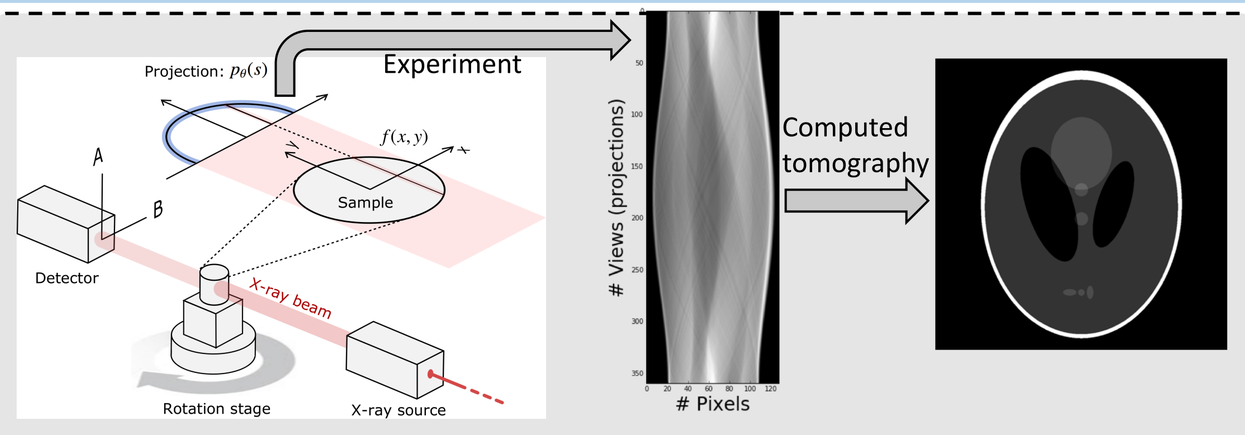
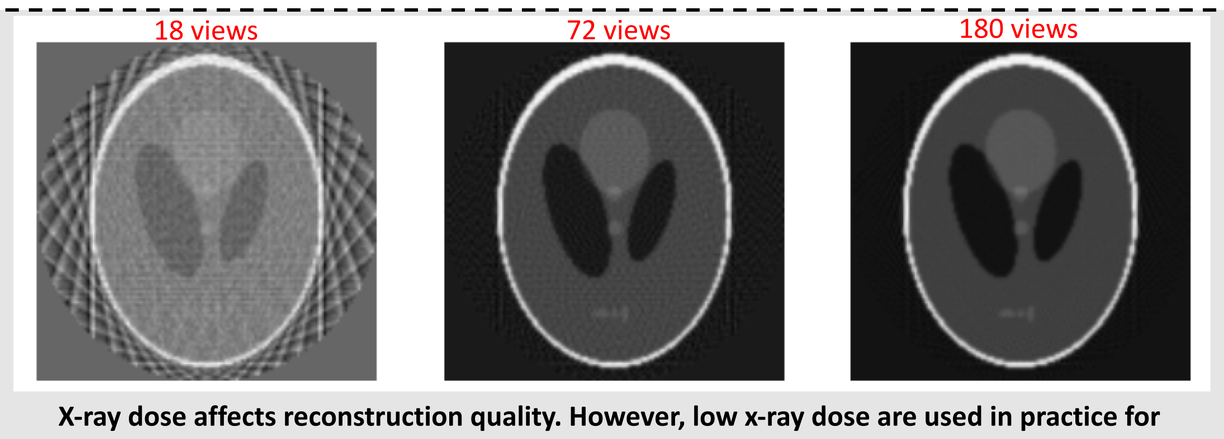
Summary: Synchrotron-based X-ray tomography is a noninvasive imaging technique that allows for reconstructing the internal structure of materials at high spatial resolutions. Only limitted X-ray is allowed for in situ or dose-sensitive experiments to avoid sample damage or capture relevant dynamic phenomena. These low X-ray dose imaging conditions yield noisy measurements that significantly impact the quality of the resulting reconstructions. We present TomoGAN, a denoising technique based on GAN, for low-dose imaging conditions. TomoGAN has been evaluated in two photon-budget-limited experimental conditions: (1) **sufficient number of *low-dose* projections** (based on Nyquist sampling), and (2) **insufficient number of *high-dose* projections**. In both cases, angular sampling is isotropic, and the photon budget is fixed based on the maximum allowable radiation dose. Evaluation with both simulated and experimental datasets shows that TomoGAN can reduce noise in reconstructed images significantly. Furthermore, the quality of the reconstructed images with filtered back projection followed by TomoGAN exceeds that of reconstructions with the simultaneous iterative reconstruction technique, showing the computational superiority of our approach.

1. The problem

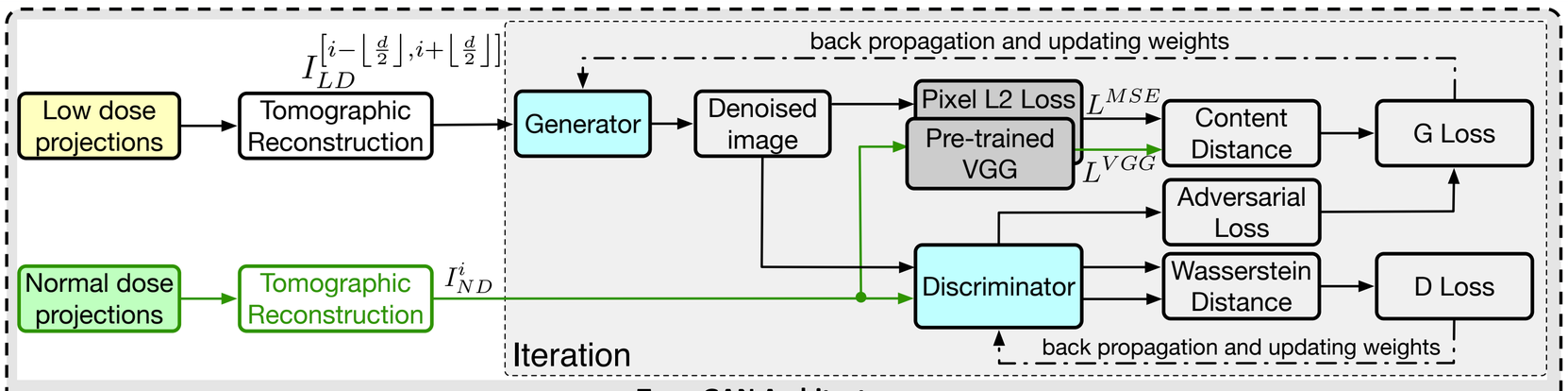


Hard X-ray Tomography setup

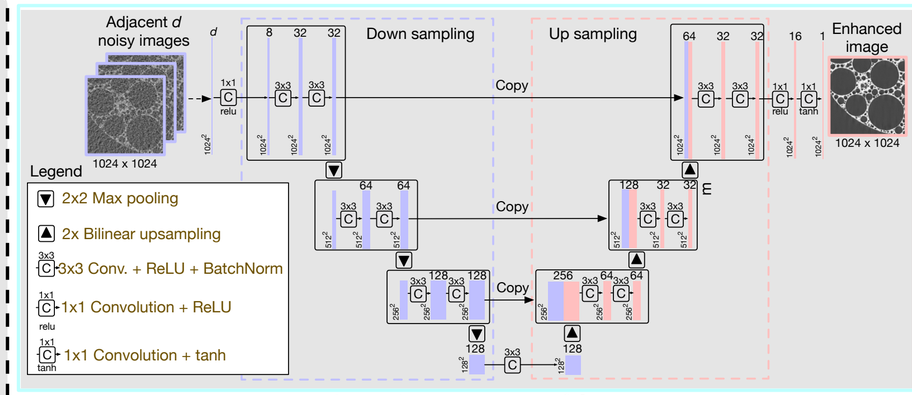


X-ray dose affects reconstruction quality. However, low x-ray dose are used in practice for sensitive samples or samples with dynamic phenomena.

2. The proposed solution

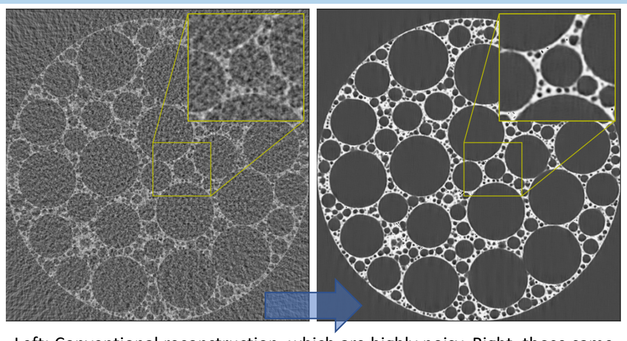


TomoGAN Architecture

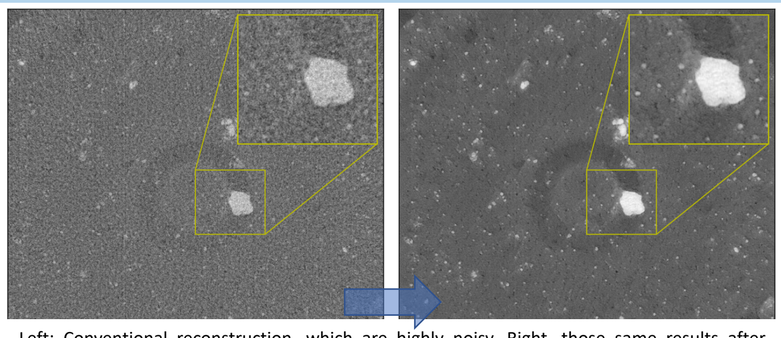


TomoGAN Generator Architecture

3. Experiment results



Left: Conventional reconstruction, which are highly noisy. Right, those same results after denoising with TomoGAN; the features are much more visible.



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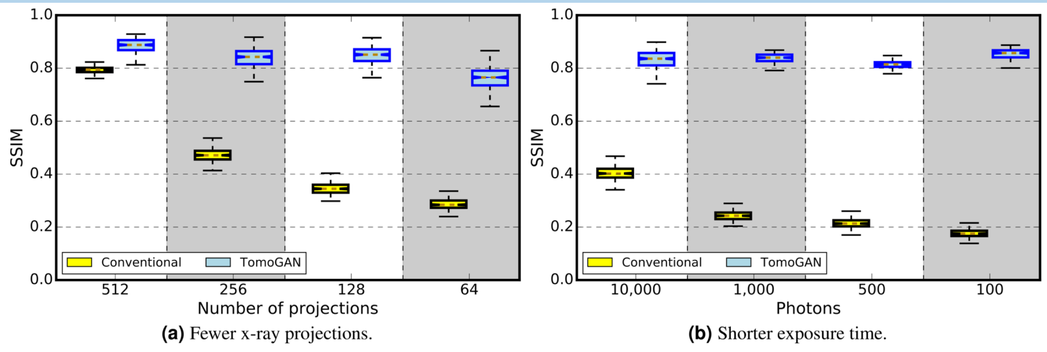
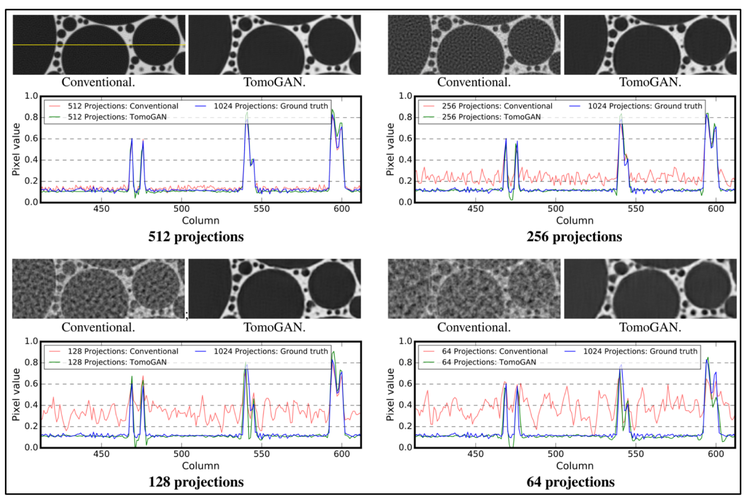
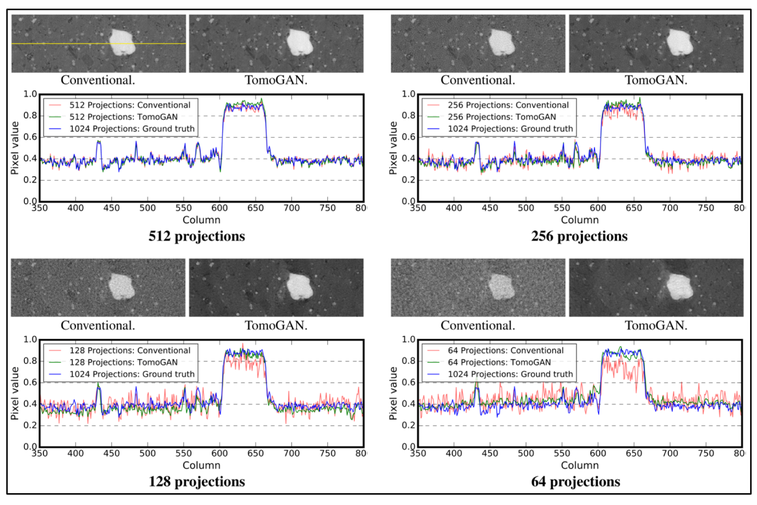


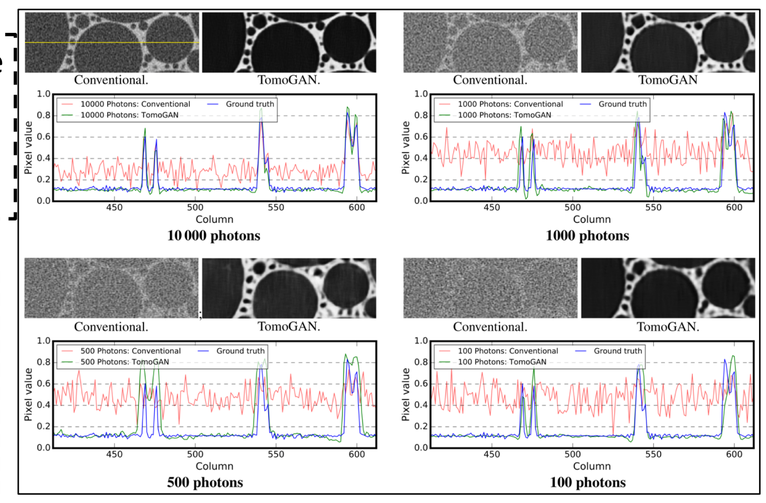
(a) Fewer x-ray projections. **(b)** Shorter exposure time.



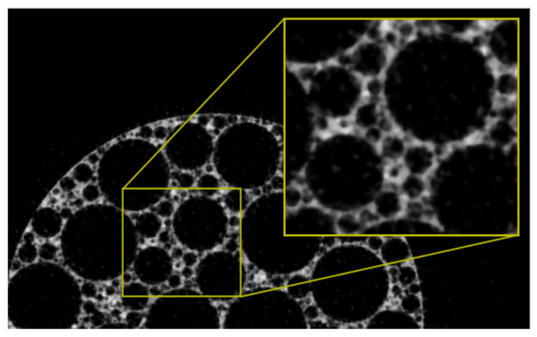


Conventional vs. TomoGAN-enhanced reconstructions of simulated data (left) and shale sample (right), subsampled to (512, 256, 128, 64) projections. In each group of three elements, the two images show conventional and TomoGAN reconstructions, while the plot shows conventional, TomoGAN, and ground truth values for the 200 pixels on the horizontal line in the top left image.

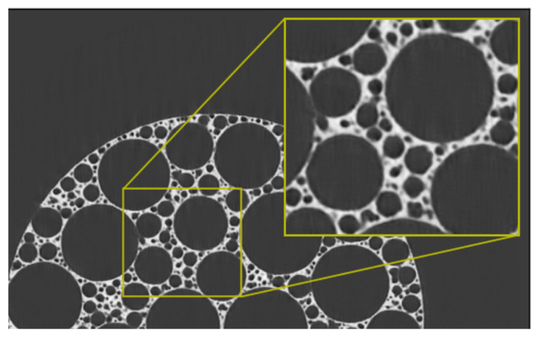
Hybrid Surrogate of SIRT with computational superiority



FBP takes 42 ms to reconstruct one image (using TomoPy) and TomoGAN takes 4 ms to enhance the reconstruction, totals 46 ms per image. In contrast, the SIRT based solution (using TomoPy) takes 550 ms (400 iterations), i.e., 12x faster. Times are measured using one Tesla V100 graphic card. Moreover, iterative reconstruction does not provide better image quality than does our method.



SIRT + total variation (conventional SOTA, 550ms)

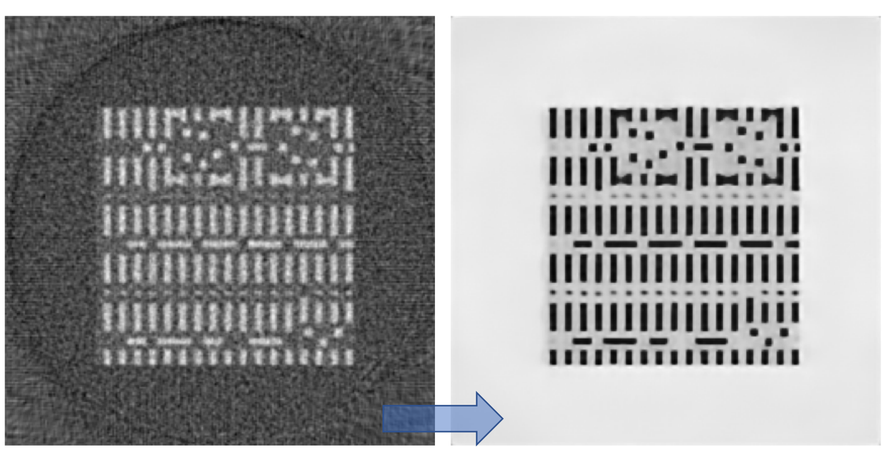


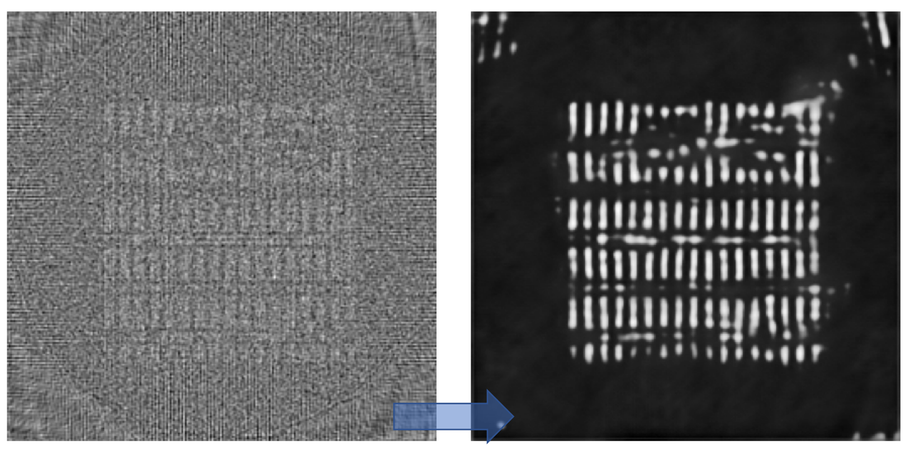
Filtered Back Projection (42ms) + TomoGAN (4ms)

Conventional method versus TomoGAN enhanced reconstructions of simulated data with intensity of 10,000, 1,000, 500, 100 photons per pixel (i.e., different exposure time).

4. One more successful case

The proposed TomoGAN has also been applied for the joint ptycho-tomography problem for reconstructing the complex refractive index of a 3D object. Specifically, there is a ptychography process to reconstruct projections needed for tomography. However, ptychography experiment is very time consuming (~month) and less datapoints results in noisier ptychography reconstruction and worse tomography images. TomoGAN was used to enhance tomography images with less data points needed, i.e., faster experiment.





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