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Super-Resolution Electron Microscopy using Multi-Resolution Data Fusion

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Scanning transmission electron microscopes are widely used for characterization of samples at the nanometer scale. However, raster scanning an electron beam across a large field of view is time consuming and can often damage the sample. In fact, the sum total of all electron microscopy (EM) data collected to date, represents less than a cubic millimeter of material [1]. Consequently, there is an enormous demand in the materials and biological sciences to image at greater speed and lower dosage, while maintaining resolution. Traditional EM imaging based on homogeneous raster-order scanning severely limits the volume of high-resolution data that can be collected, and presents a fundamental limitation to understanding physical processes such as material deformation, crack propagation, and pyrolysis. For these reasons, there is growing interest in reconstructing full-resolution images from sparsely-sampled [2, 4] and low-resolution images [3].

In this talk, we introduce a novel multi-resolution data fusion (MDF) method [5] for super-resolution computational EM. Our method combines innovative data acquisition with novel algorithmic techniques to dramatically improve the resolution/volume/speed trade-off. Our method depends on a Bayesian framework for the fusion of low- and high-resolution data without the need for training. The key to our approach is to collect the entire sample at low resolution, while simultaneously collecting a small fraction of data at high resolution. The high-resolution measurements are then used to create a material-specific patch-library that is used within the "plug-and-play" (P&P) framework [4] to dramatically improve super-resolution of the low-resolution data.

The P&P framework is based on the alternating direction method of multipliers (ADMM) and decouples the forward model and the prior terms in the maximum a posteriori cost function. This results in an algorithm that involves repeated application of two steps: an inversion step only dependent on the forward model, and a denoising step only dependent on the image prior model. The P&P takes ADMM one step further by replacing the prior model optimization by a denoising operator of choice.

We present results using FEI electron microscope data that demonstrate super-resolution factors of 4x, 8x, and 16x, while substantially maintaining high image quality and reducing dosage [6].

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[6] This work was supported by AFOSR/MURI grant #FA9550-12-1-0458, by UES Inc.

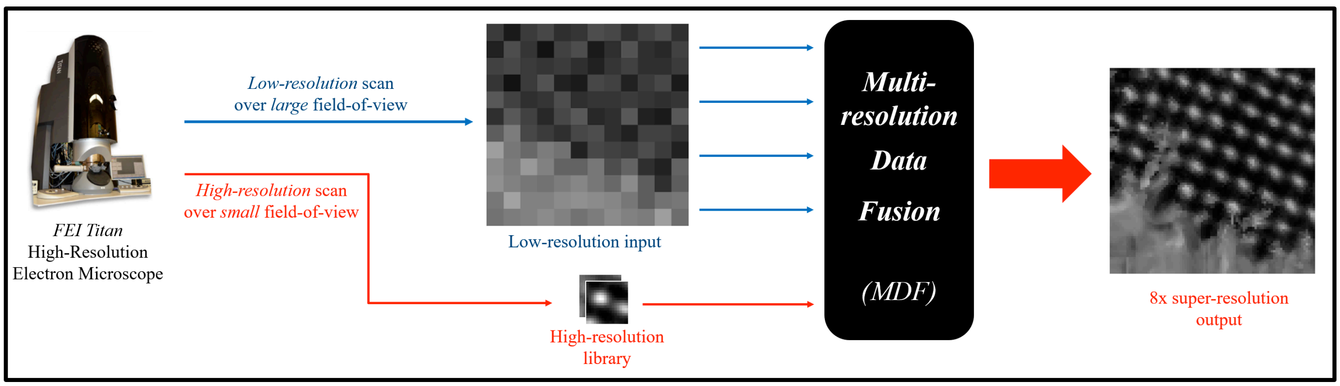

Figure 1. Illustration of multi-resolution data fusion (MDF) for 8x super-resolution of a TEM image of gold atoms.

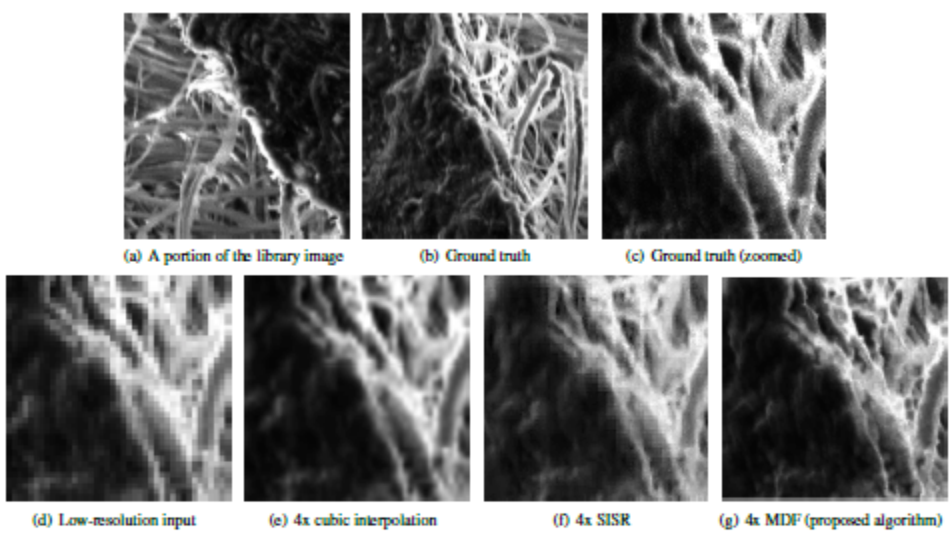

Figure 2. 4x super-resolution of a 100×100 SEM image of surface crack in the shell of the marine mollusk *Hinea brasiliana*. We compare our result against Technion's single image super-resolution (SISR) algorithm, and observe that our MDF algorithm lacks block artifacts and jaggies.