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TEM Video Compressive Sensing

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One of the main limitations of imaging at high spatial and temporal resolution during *in-situ* TEM experiments is the frame rate of the camera being used to image the dynamic process. While the recent development of direct detectors has provided the hardware to achieve frame rates approaching 0.1ms, the cameras are expensive and must replace existing detectors. In this paper, we examine the use of coded aperture compressive sensing methods [1, 2, 3, 4] to increase the framerate of any camera with simple, low-cost hardware modifications. The coded aperture approach allows multiple sub-frames to be coded and integrated into a single camera frame during the acquisition process, and then extracted upon readout using statistical compressive sensing inversion. Our simulations show that it should be possible to increase the speed of any camera by at least an order of magnitude.

Compressive Sensing (CS) combines sensing and compression in one operation, and thus provides an approach that could further improve the temporal resolution while correspondingly reducing the electron dose rate. Because the signal is measured in a compressive manner, fewer total measurements are required. When applied to TEM video capture, compressive imaging could improve acquisition speed and reduce the electron dose rate. CS is a recent concept, and has come to the forefront due the seminal work of Candès [5]. Since the publication of Candès, there has been enormous growth in the application of CS and development of CS variants. For electron microscopy applications, the concept of CS has also been recently applied to electron tomography [6], and reduction of electron dose in scanning transmission electron microscopy (STEM) imaging [7].

To demonstrate the applicability of coded aperture CS video reconstruction for atomic level imaging, we simulate compressive sensing on observations of Pd nanoparticles and Ag nanoparticles during exposure to high temperatures and other environmental conditions. Figure 1 highlights the results from the Pd nanoparticle experiment. On the left, 10 frames are reconstructed from a single coded frame—the original frames are shown for comparison. On the right a selection of three frames are shown from reconstructions at compression levels 10, 20, 30. The reconstructions, which are *not* post-processed, are true to the original and degrade in a straightforward manner. The final choice of compression level will obviously depend on both the temporal and spatial resolution required for a specific imaging task, but the results indicate that an increase in speed of better than an order of magnitude should be possible for all experiments [8].

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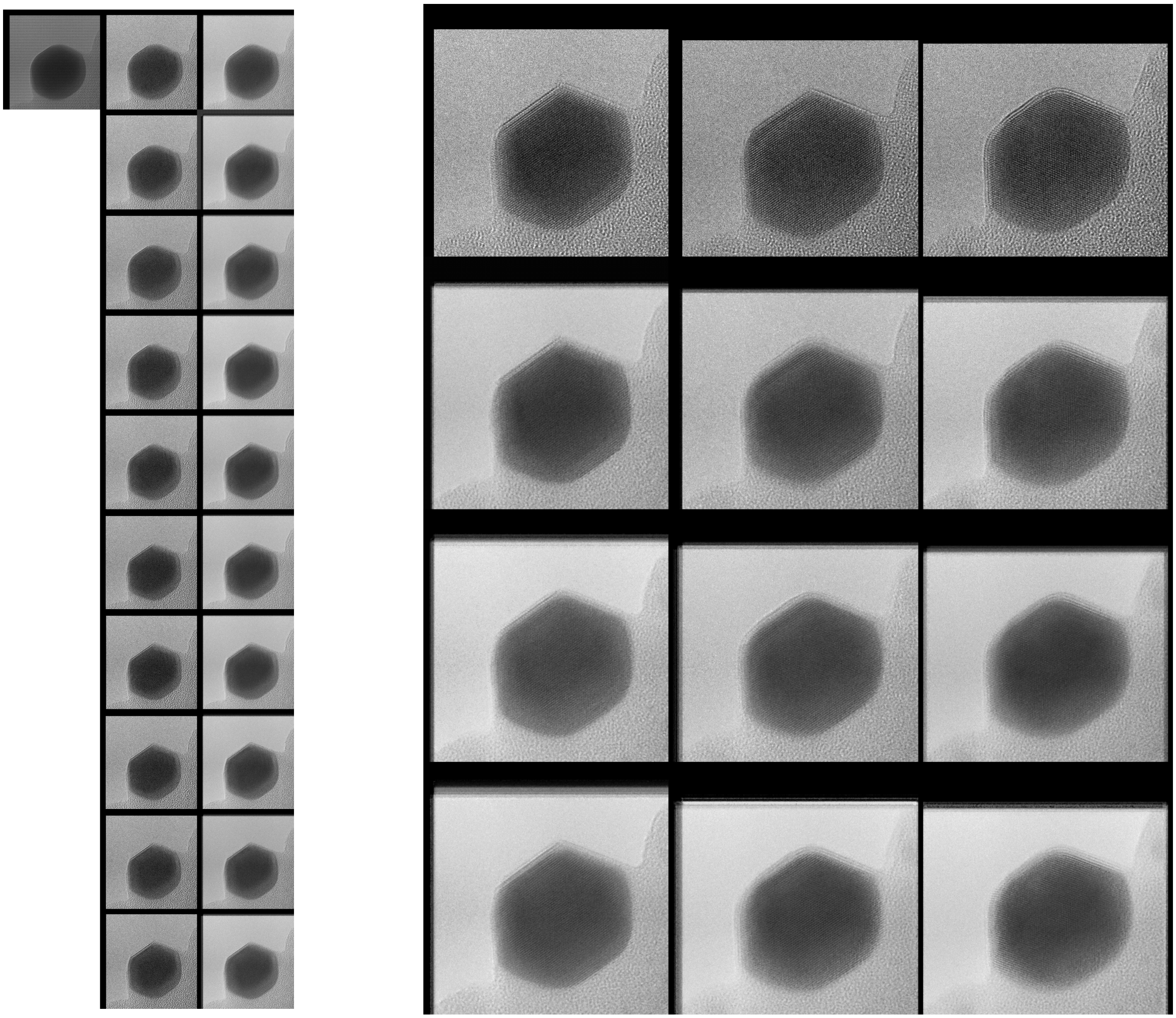

Figure 1: *Left*: An illustration of CS inversion from 10 frames compressed into 1. The top left image shows the compressed frame, the middle column of images shows the reconstructed frames, and the right column shows the original frames. During the sequence a peak atop the nanoparticle forms. Even though the peak is not visible in the compressed data it is accurately reconstructed. *Right*: From top to bottom original, $10\times$, $20\times$, and $30\times$ compressed reconstruction; from left to right frames 109, 127, and 157. There is a significant denoising effect in the reconstructed images. The salient features remain, but contrast reduces as compression increases. The width of the imaged region is 26.67nm. *Full resolution visible with zoom.*

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