Advanced Data Acquisition in Electron Microscopy

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Modern developments in science and measurement technology resulted in new instrumentation that is able to register vast amounts of data at a scale and precision considered unworkable a few decades ago. This talk focuses on one class of data acquisition problems typical for scanning transmission electron microscopes (STEM) and presents the research conducted at the Interdisciplinary Mathematics Institute and the NanoCenter at the University of South Carolina.

Successful STEM data processing has become a challenge that can be completed only in very favorable situations severely limiting the use of the instruments since the collected data is subject to several unknown perturbations and distortions. The standard linear assimilation paradigm assumes that an ideal signal is convoluted with an approximately known operator depending on the characteristics of the instrument and that the noise components can be considered as additive. Proposed solutions to this challenge typically involve focusing on incrementally improving the instrumental characteristics and/or costly betterment of the environmental conditions during the data-gathering period. Recent advances in hardware-based aberration correction have significantly expanded the direct imaging capabilities of STEM. Currently, the exploitation of these emerging opportunities faces two main road blocks which are common to a wide class of instruments and sensors: (i) the extreme environmental sensitivity of the instruments and (ii) the damage induced by the electron beam. Both cause temporal geometric distortions to the imaged samples. These obstacles are addressed by designing a nonlinear dynamic mathematical model and a corresponding acquisition procedure that allow estimation and near-elimination of wide range of distortions treated as noise in the existing models.

In the first model, instead of the typical one pass scanning pattern row by row, we suggest to perform several low density passes and then register locally all these low resolution frames towards each other to adjust geometrical position of each sample. The result is then received as an assembly of all the frames in terms of a minimization procedure based on learning theory.

The second model relates to data gathering suggested by compressed sensing (CS), namely receiving each single measurement as a collection of the scanning at several positions. Although this requires new advanced STEM instrument that is still to be built, we investigate the theoretical aspects of the CS recovery procedures for such a problem characterized by an atypical sparsity notion and highly coherent dictionaries. Nevertheless, we were able to formulate a model that can use some existing minimization procedures to solve reliably the recovery problem using number of measurements that corresponds to a significantly reduced combined energy dose.