Adaptive Computational Microscopy for Nanomaterials & Cell Biology

Overview: Modern microscopy, coupled with cheap storage capacity, enables the study of nanomaterials and living cells with unprecedented detail but generates terabytes of data, only a tiny fraction of which is information-rich. Sifting through such data by traditional means is so time intensive that only the low-hanging information fruit is used, leaving potentially more pertinent data unexplored. We propose to develop a PhD training program around the interdisciplinary concept of algorithmically driven acquisition and analysis of both optical and electron multidimensional microscopies. We will leverage our expertise in signal processing and machine learning algorithms, as well as our strong history of interdisciplinary research across science and engineering. We will train students and foster partnerships in a new field, Adaptive Computational Microscopy, via three teaching/research thrusts:

- ***Expanded Data Processing and Analysis**:* Our education goals in this area are twofold: (1) exposure to the state-of-the-art algorithms for microscopic image processing for scientists and engineers to replace more traditional methods developed decades ago when computational power was limited; and, (2) building a solid, real data driven foundation that moves beyond pixel-level computation for the mathematicians and computer scientists to gain a greater appreciation and understanding of the science underlying microscopic images.
- ***New Approach to Interdisciplinary Microscopy Training**:* Our team will create a new centrally focused lab on the Rice University campus that applies machine learning philosophy for students being trained in optical, electron, and scanning probe microscopy. We will develop lab modules on big data and microscopy to supplement the many existing departmental courses to gain more interdisciplinary breadth without further expanding the curricula.
- ***Scholarly Introduction to Innovative Instrumentation**:* We will develop revolutionary approaches to image acquisition, currently deployed in only a handful of research labs, and apply them to cutting-edge nanomaterials and cell biology projects.

Intellectual merit: By connecting instrument design to the mathematical optimization necessary for image reconstruction, and by focusing these towards specific scientific questions in materials and biology, we will train future academic, government, and industry leaders in advanced microscopic techniques but also with the skills to develop new tools that increase our knowledge of the nanoscale cellular and material worlds. Coupling our ever growing computational abilities with the continued need for improved scientific understanding at smaller and faster time scales is analogous in many ways to the development of nanotechnology over time. Engineers, physicists, and chemists learned each other's terminologies and research goals before collaborative breakthroughs emerged. This project marks a new beginning by expanding the dialog between scientists and engineers to include applied mathematicians, and merges Rice's historical expertise in both nanoscale science and signal processing (e.g. OpenStax) to form a new field: Adaptive Computational Microscopy.

Broader Impacts: Image-based characterization and classification are at the heart of many 21st century industries including medical diagnostics, aviation safety, geological analysis, and defect characterization of semiconductors. At the same time, collecting more data for its own sake has implications for public health and national security. Thus, students trained by this project will possess a skill set beyond microscopy that also strongly overlaps with other technological areas such as medical imaging, satellite remote sensing, machine vision, and seismic exploration. *Finally, this project constitutes a breakthrough in the field of imaging; we will move beyond traditional capture, process, and display methodologies as we develop and implement methods that best exploit our modern data processing capabilities.*

Keywords:* *Microscopy, Compressed Sensing, Multimodal Imaging, Cell Biology, Materials