Research Statement — Jadrian Miles

My research in medical imaging has focused on developing a novel mathematical model that accounts for structural features of brain tissue at two length scales: both larger and smaller than the resolution limit of brain-scan images. I also developed an associated optimization method for fitting the model to a given set of images. While interesting in its own right, this applied problem is also an instance of a general computational task: detecting and characterizing a discrete number of distinct objects with variable properties from observations made by a noisy, low-resolution spatial sensor. The essence of my solution is to account for features above and below the sensor resolution limit simultaneously in an iterative fitting process.

In the future I plan to investigate instances of this task involving other types of sensors, including multi-sensor human-scale scene reconstruction, environment modeling from multi-spectral satellite imagery, and image segmentation in cell microscopy. This research program would be especially well-suited to including undergraduate researchers. The concrete nature of the application areas will clarify the goals of each project, while allowing student researchers to explore and take ownership of newly-discovered subproblems.

Graduate Research

My particular subfield of medical imaging concentrates on modeling the structure of the brain from images produced by a scanning technique called diffusion MRI. The pixel size of the images, typically 1mm, naturally separates features into two regimes: larger “macrostructure” features that can be resolved independently and finer “microstructure” features that are only sensed in aggregate in a given pixel. While previous approaches in this field focused on only one of these regimes, my research develops a model that combines macrostructure and microstructure into a single representation. In this model, each discrete macrostructure element stores a statistical description of the microstructure properties throughout its volume that affect its image in the sensor.

I developed an iterative process for fitting this combined model to the observations that involves both discrete choices (whether to split, merge, add, or delete macrostructure elements) and continuous parameter adjustments (affecting the shape and position of each macrostructure element, and also the statistical properties of the microstructure within each element). Insights from both combinatorial and numerical optimization inform the design of this fitting process. Whereas objective functions for similar problems in this field have been ad-hoc and require tuning, I developed a rigorous statistical framework based on the chi-squared goodness-of-fit measure that may be applied even when sensor data exhibit non-Gaussian noise.

In addition to the computer-science contributions described above, this work advances the field of brain science. Diffusion MRI is the only non-invasive technique for observing the structure of the white matter, the network of billions of nerves that connect the different functional regions of the brain. Using diffusion MRI, brain researchers have investigated the important role the white matter plays in cognitive impairment due to HIV, Alzheimer’s, and multiple sclerosis, as well as in normal development during infancy and old age. My research improves on the state of the art in interpreting diffusion MRI, enabling future brain researchers to conduct more sophisticated studies.

Future Work in Brain Imaging

In the short term I plan to refine the brain-tissue model that I developed in my dissertation research. Both the macrostructure and microstructure components of the model are rudimentary and cannot precisely capture realistic properties of brain tissue. The improved macrostructure
model will use a triangle mesh to represent the bounding surface of each element, and the microstructure model will be adapted from a more detailed and biologically-motivated model already established in the literature. Though these changes will make the solution process more computationally intensive, I expect the improved model to provide a more precise and useful reconstruction of the tissue for use by brain researchers. For the computer science community, this more sophisticated model will provide a better demonstration of the modeling and optimization techniques I have developed.

This work will not require the acquisition of new brain scans; canonical datasets are established for the diffusion MRI community and are available for free online. However, if there are research groups outside of computer science that are interested in acquiring their own diffusion MRI data, I can consult on the design of scanning protocols, data-sharing plans, and data analysis practices. I have five years of experience collaborating with brain researchers around the world and can apply this experience to help researchers anticipate their future needs, and in turn make the most of their investments in data gathering, storage, and processing.

Future Work in Other Application Areas

**Scene Reconstruction:** The combination of video and range cameras has been established in the robotics community for some time, and the release of the Microsoft Kinect led to an explosion in research in scene understanding from multi-modal video. Established computer vision research on structure from motion supplements this combination of sensors with an additional source of depth information. The real-world scene in this case involves discrete structures (objects such as a person or a table) with continuous shape and appearance parameters. However, applying my previous work to this problem would involve novel challenges. My macrostructure modeling technique is likely too general to capture all the possible variation in objects that might exist in a scene while remaining tractable. Instead it might be necessary to leverage established object-recognition techniques to constrain the macro-scale shape model. Additionally, synthesizing two sources of depth data (both quite noisy) with standard video imagery involves a sophisticated mapping from 3-D shape and material properties to visual appearance. This is another well-studied area in which I would welcome the opportunity to learn the literature and collaborate with computer vision researchers to advance the state of the art.

**Earth Science:** Geophysical and ecological modeling from multi-spectral satellite imaging could benefit from the techniques I developed for brain-structure modeling. In this case the sensor is a set of satellite cameras, each detecting a different type of radiation at a different resolution. Real-world features at certain length scales may be above the resolution limit for one camera but below the limit for another, leading to a challenging modeling problem in which the distinction between “micro-scale” and “macro-scale” is not as clear as it is in the brain-imaging case. I have previously collaborated with NASA earth scientists for a different project, and I look forward to learning from other earth scientists about the literature and open problems in this field.

**Cell Microscopy:** Image segmentation for cell microscopy is an extremely well-studied computer vision task, and yet it remains challenging. This task shares characteristics with the brain-imaging problem I studied: a noisy and limited-resolution sensor, discrete elements larger than the sensor’s resolution limit, and interesting features at smaller length scales. I would like to investigate applying established appearance models of individual cells, whether based on principal component analysis, sparse image features, or another technique, in the interiors of independent shape models, and adapting my optimization technique to fit these models to cell micrographs.