Novel Methods for Shape Classification, Analysis, and Synthesis Using the Isoperimetric Profile and Mathematical Morphology

Chheda, Dev (School: Ardrey Kell High School)

Image and shape classification have been studied extensively with the growing popularity of convolutional neural networks (CNNs). However, CNNs operate on rasterized images rather than geometric shape data, limiting their precision and applicability. Significant strides have recently been made in computing the isoperimetric profile (IP) of shapes. Motivated by this work, I studied using the IP and its morphological approximations to perform shape analysis and synthesis tasks on geometric data. In Phase 1 of the project, I developed a novel top-performing shape classifier for geometric data using the IP. I constructed and tested multilayer perceptrons which use the morphological opening bound, an approximation of the IP, to classify shapes. I also experimented using other morphological operations as features, finding that these classifiers perform extremely well on simple datasets. I produced groundbreaking evidence that the IP and morphological operations contain valuable information about shapes, and can be utilized in computer vision applications. In Phase 2 of the project, I approached the problem of geometric shape synthesis, modifying a shape by editing its IP, through gradient descent optimization. I made significant progress on computing the gradient of the morphological opening. I discovered an elegant formula for computing the gradient of the perimeter of the morphological dilation. This formula's simplicity indicates promising uses for the IP in computer vision and geometry processing. These geometric data processing methods have applications in robotics, autonomous driving, cellular biology, etc. for shape classification, synthesis, feature extraction, and denoising, changing the way we approach geometric problems in a plethora of use cases.

Awards Won:
Third Award of $1,000
American Mathematical Society: Certificate of Honorable Mention
Air Force Research Laboratory on behalf of the United States Air Force: First Award of $750 in each Regeneron ISEF Category