Research Statement

Michael Hillman

My long-term career goal is to become a leading scholar in computational mechanics, with emphasis on data-driven failure analysis of complex material microstructures with application to multiscale material modeling. The essence of my research is to develop new computational models that can perform simulations of problems that are difficult or impossible to analyze by conventional methods. My focus is on the fundamental development of meshfree methods, which are well-suited for simulating failure and constructing models based on images due to their flexibility. Toward achieving my long-term goals, I have contributed major advances in the general area meshfree methods that have enabled accurate and efficient simulations involving extreme deformations and failure. Applications have included earth moving and tillage, and man-made and natural disasters such as blast, bullet penetration, and landslides. A summary of select contributions are given as follows, concluding with my current research directions.

Accelerated, high-order and stable meshfree methods. My contributions have essentially eliminated the efficiency bottlenecks in meshfree methods for extreme deformation and failure. I have derived the requirements to achieve arbitrary-order accurate solutions in the variational formulation, called *variational consistency*, and proposed an efficient method to achieve these requirements. In addition, I have developed an accelerated stabilized quadrature, with a speed-up of over an order of magnitude over previous methods, also free of tunable parameters typical of these approaches. Used in conjunction, these methods have enabled high accuracy, stability and efficiency in meshfree methods for extreme event simulation not previously possible. It has further been demonstrated that without these techniques, essential physics and failure modes cannot be captured. This research has been implemented into LS-DYNA, and codes used by Karagozian & Case Inc., Case New Holland America LLC, the U.S. Army, and Sandia National Laboratories. More recently, I have formulated a new finite-volume type Petrov-Galerkin meshfree technique that is inherently variationally consistent and stabile with even higher efficiency.

Contributions to non-local meshfree methods. I have made contributions to the recently introduced class of non-local meshfree methods, which are particularly advantageous in solving problems involving complex fracture and fragmentation. I proposed a general unifying framework for non-local and local meshfree methods called *generalized reproducing kernel peridynamics*, which resulted in two other main contributions: the generalization of the concept of non-local derivative operations, and a high-order accurate non-local meshfree method. The latter provides convergent solutions which were not available in the standard formulation. In turn, this allows accuracy in complex fracture simulations not previously feasible. For practical application of these methods to problems with strong dynamics, essential shock physics is also key. I further introduced a physics-based shock treatment, not previously available.

Current focus. I intend to leverage these advances for performing failure analysis in direct simulation of X-ray micro-CT scans of complex microstructures, real and statistically representative. In the future, I will use these methods as the basis for data-driven constitutive models, multi-scale (traditional and machine learning based) analysis, and material microstructure optimization and design. These research thrusts are currently being supported by two multi-year federal grants on simulation of microstructural failure evolution in composite materials (polymer-ceramic, concrete). Micro-CT scans of pristine and damaged material samples serve as the basis for both model development and validation. For these projects, I have developed an immersed method for composite analysis, allowing seamless model development based on micro-CT scans. This technique is also currently being extended to fluid-structure interaction where the representation of fragmenting structures immersed in fluids is generally intractable for existing methods. Finally, the aforementioned finite-volume approach is being developed as a framework for robust simulation of arbitrary three-dimensional fracture, a long-standing challenge in computational mechanics I intend to address. These advances in image-based analysis, modeling of material failure, and composite analysis serve as the basis for my future directions and support my long-term goals.