

## Material Dynamics Analysis with Deep Generative Model

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Studying material dynamics is essential for predicting degradation, failure, and specific behaviors under various conditions, enabling efficient material design, enhanced performance, and driving innovation in materials science. Microscopic techniques have advanced significantly to document the dynamic evolution of materials during experimental progression. However, experimental observations from microscopy images are inherently biased to drive subsequent analysis to observable behaviors and excluding those in unobserved scenarios. To address this issue, we designed an analysis framework integrating a deep generative model to synthesize hypothetical material states that could emerge under realistic experimental conditions. This approach enables Monte Carlo simulations of material state variations driven by dynamic progression, reflecting more generalized and predictive dynamic behaviors. Applied to various microscopy image datasets, our framework effectively uncovers hidden physical phenomena in materials science experiments. Furthermore, this research supports a shift towards data-driven methodologies, advocating the adoption of deep learning technologies to foster innovative research practices in materials science.

**Keywords:** material dynamics, data analysis, microscopy images, deep generative model