Learning Image Similarity Manifolds for Materials Microscopy

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Abstract

Instruments of scientific discovery (e.g., electron microscopes, scanning probe microscopes, and others) acquire vast collections of images that contain physical insight. Humans, however, struggle to search and draw correlations from enormous databases of images; therefore, only a small fraction of the data collected is translated into knowledge. Researchers need an analytical toolbox that can create an image similarity manifold and allow visual interaction in an informative, comprehensive, and intuitive way. Here, we develop machine learning algorithms to create image similarity projections of microscopy images.

Methods

Dataset: 25,000 piezoelectric force microscopy (PFM) images from UC Berkeley (Lane Martin and Ramamoorthy Ramesh)

Schematic of Machine Learning Algorithms

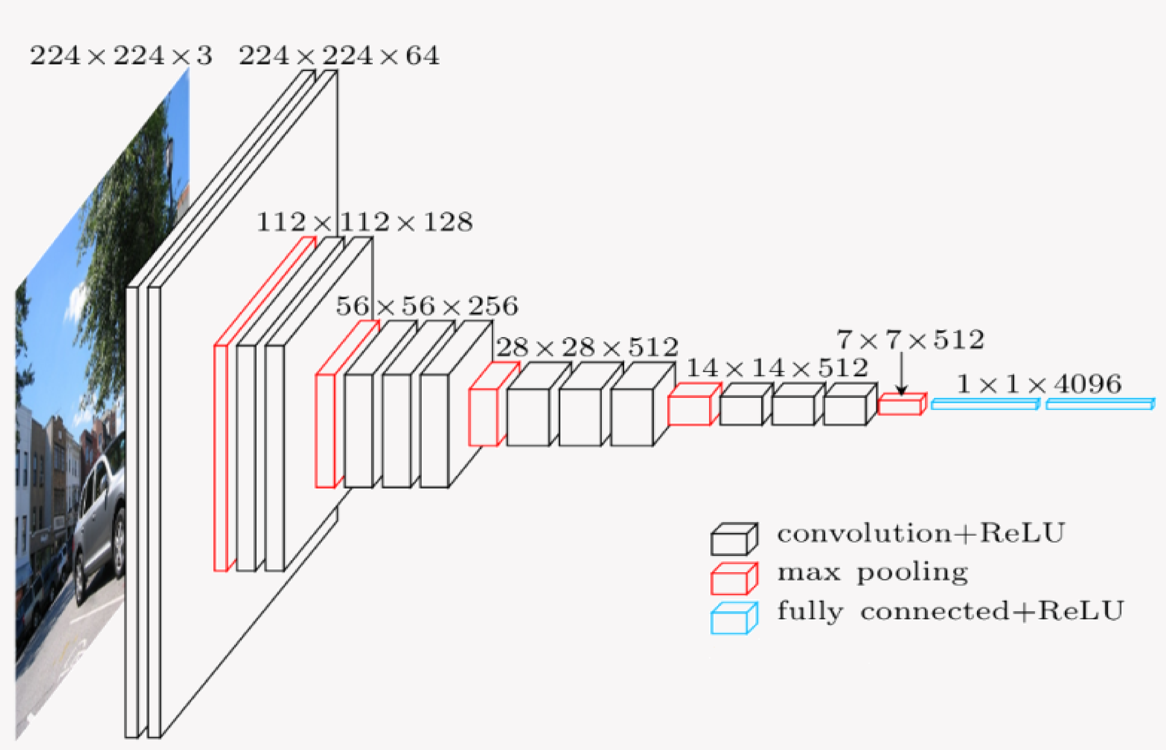
Create simpler representation of images → Keep characteristic features → Explore that simpler region

Featurization VGG-16

Manifold Learning t-SNE & UMAP

VGG-16 Convolution Neural Networks

- Pre-trained on approximately 14 million images (1,000 object categories) from the ImageNet dataset
- Large dataset builds robust features similar to human-designed computer vision algorithms
- Apply Transfer Learning to transfer information learned from one domain with lots of data to new domain with limited data
- Extract high dimensional features of size [1x1x4096]

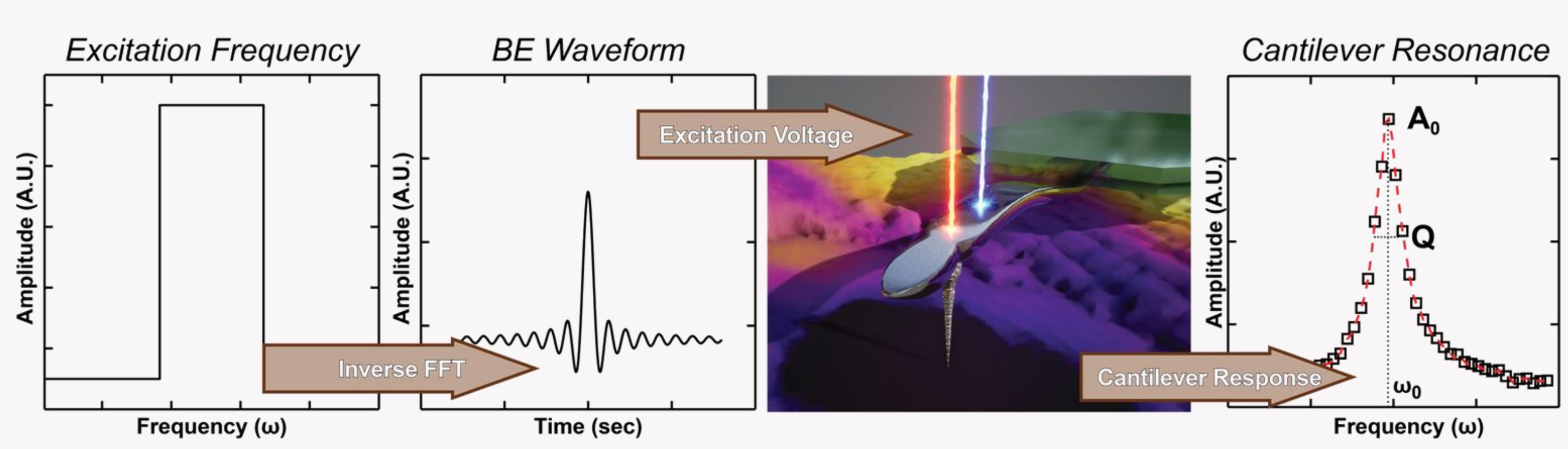


t-SNE and UMAP

- Manifold unfolding techniques
- Generate interpretable 2D projections of these features

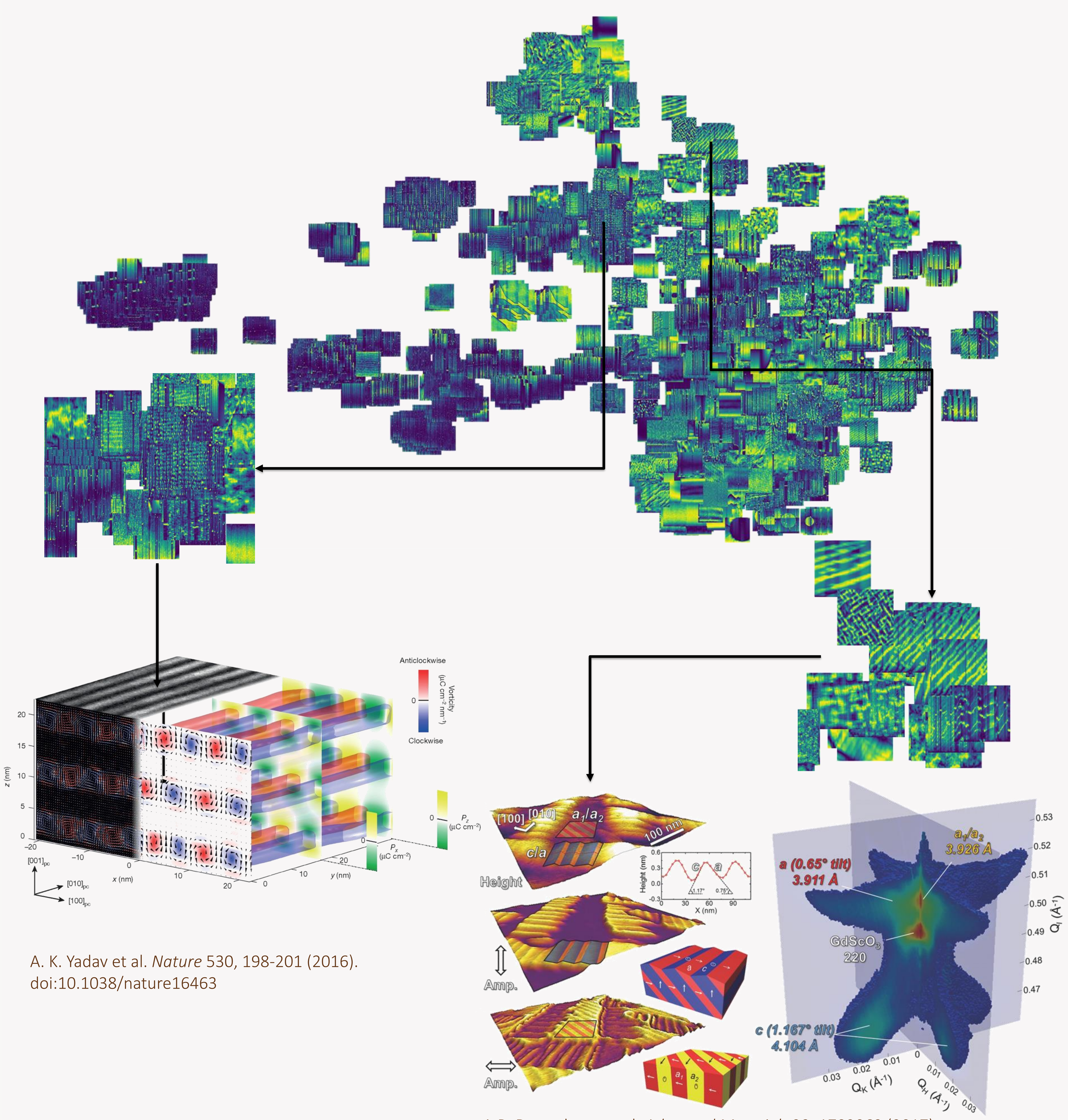
Band Excitation PFM

- PFM imaging technique based on exciting and monitoring the electromechanical response within a band of frequency near the cantilever's frequency



Results

- Clusters of PFM images with similar microstructure are observed
- PFM images of the same material and structure (hierarchical $PbTiO_3$ domain structure) at different scales are grouped together
  → The technique is insensitive to image size



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Conclusions

- Demonstrated the efficacy of transfer learning in creating image similarity manifold for piezoresponse force microscopy images
- Identified micro/domain structure similarity in diverse microscopy images

Future Work

- Implement this approach to other microscopy and imaging techniques
- Develop an interactive image viewer where researchers can actively explore the data

Acknowledgements

David and Lorraine Freed Undergraduate Research Symposium, Lehigh University

This work was supported by the Nano/Human Interface Initiative and National Science Foundation (1839234).

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