Retardance to Orientation Using Deep Learning

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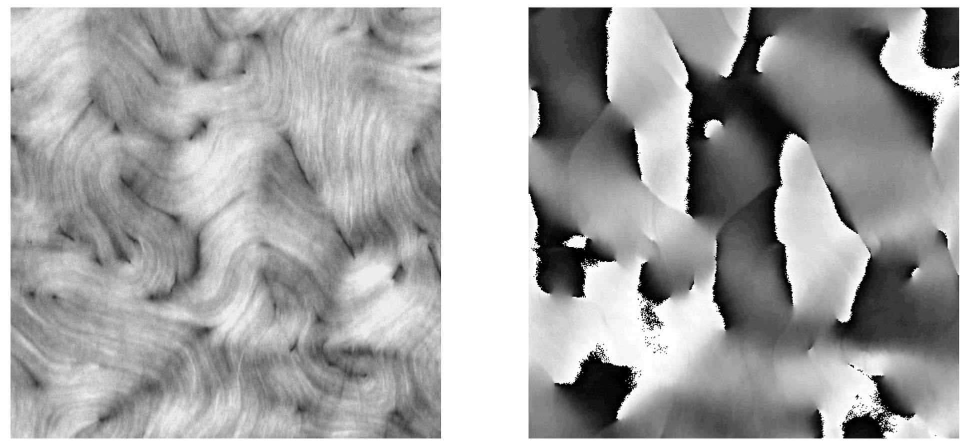
Introduction/Abstract

Active nematics (an example shown in left image below), are far-from-equilibrium materials with local orientational order, whose anisotropic constituents consume energy at the particle scale to generate forces and motions. Being driven away from equilibrium, active nematics have the potential to transform materials science by enabling a new class of materials with capabilities currently found only within living organisms. Uniformly aligned active nematics are inherently unstable.

To understand more about this material, one important step is to be able to predict its movement captured by the microscopy. Since the retardance image (left image) contains many noises generated from camera, light reflection, etc., the orientation field (right image) might be a better starting point for image processing and computer vision tasks. Because of this, the ability to generate the orientation image from the retardance image is necessary.



Retardance Image Orientation Image

Methods

Dataset:

- Retardance and Orientation fields produced by PolScope microscopy of 2D active nematics of extensile microtubule bundles.
- Original size of each frame was 1040 * 1040. Each frame is divided into 520 * 520 views.
- The Orientation ground truth was measured by PolScope. The defect ground was obtained by the defect detection method.
- We used 4000 images for training and 400 for testing.

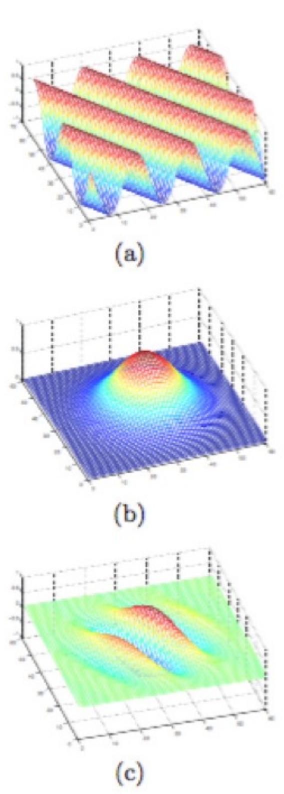
Gabor Filter

- A linear filter used for texture analysis in the image processing field.
- It is consisted of a wave function, multiplied by a Gaussian function.

$$g_{\lambda,\theta,\varphi,\sigma,\gamma}(x,y) = e^{-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}} \cos\left(2\pi\frac{x'}{\lambda}+\varphi\right)$$

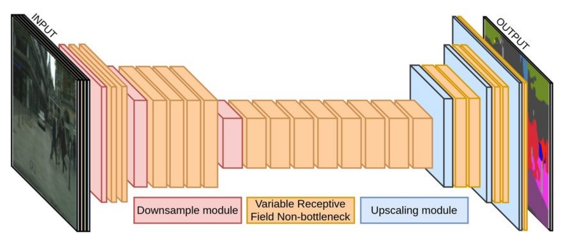
$$x' = x\cos\theta + y\sin\theta$$
$$y' = -x\sin\theta + y\cos\theta$$

- θ: Orientation of the filter
- φ: Phase offset of the wave function
- λ: Wave Length



(a) (b) (c)

Encoder & Decoder

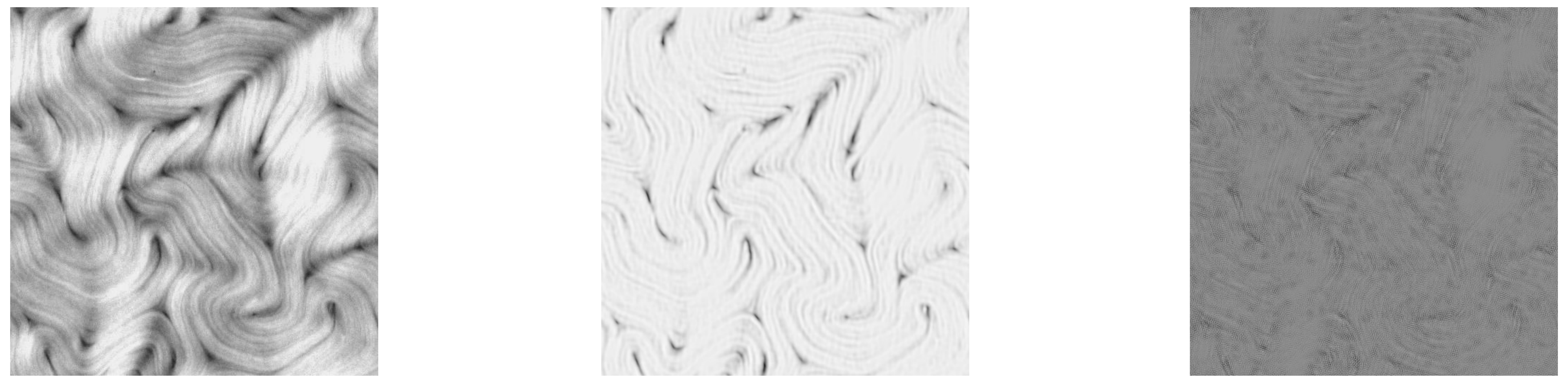


Error Function

- $Qxx = \cos(x)^2 - \frac{1}{2}$
- $Qxy = \cos(x)\sin(x)$

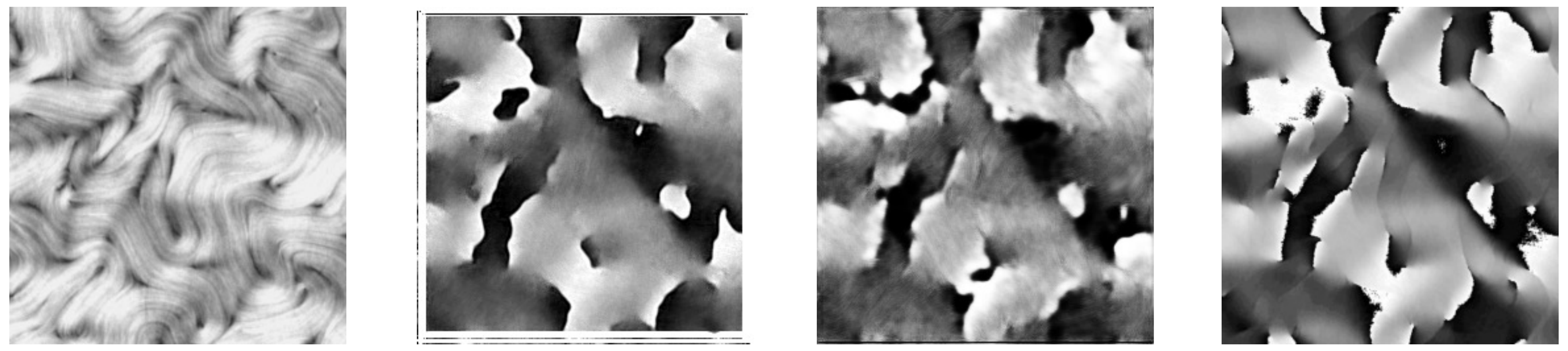
Results

- Gabor Filter: Removal of noises
  - With different wave lengths



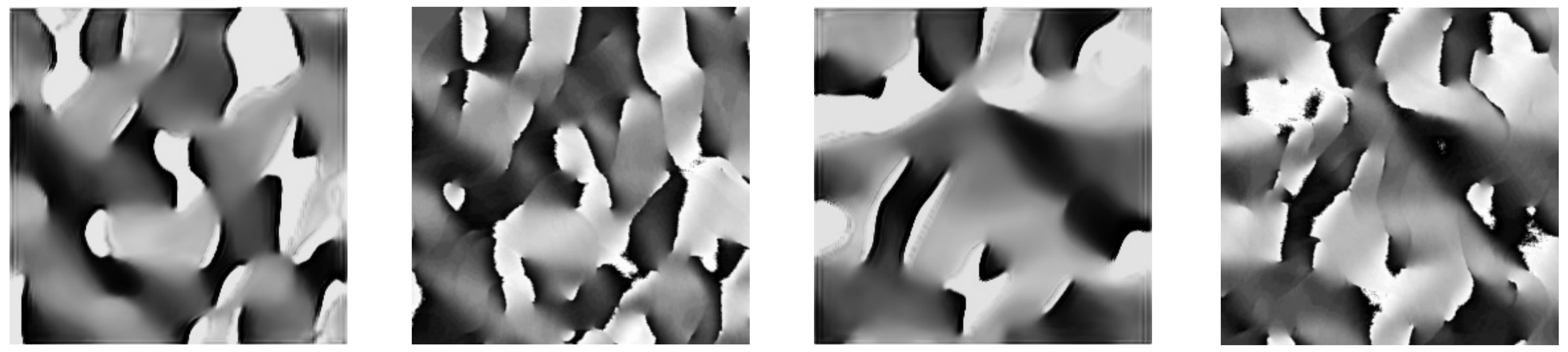
Original Image Lambda = 10 Lambda = 2

- Impact of Gabor Filter

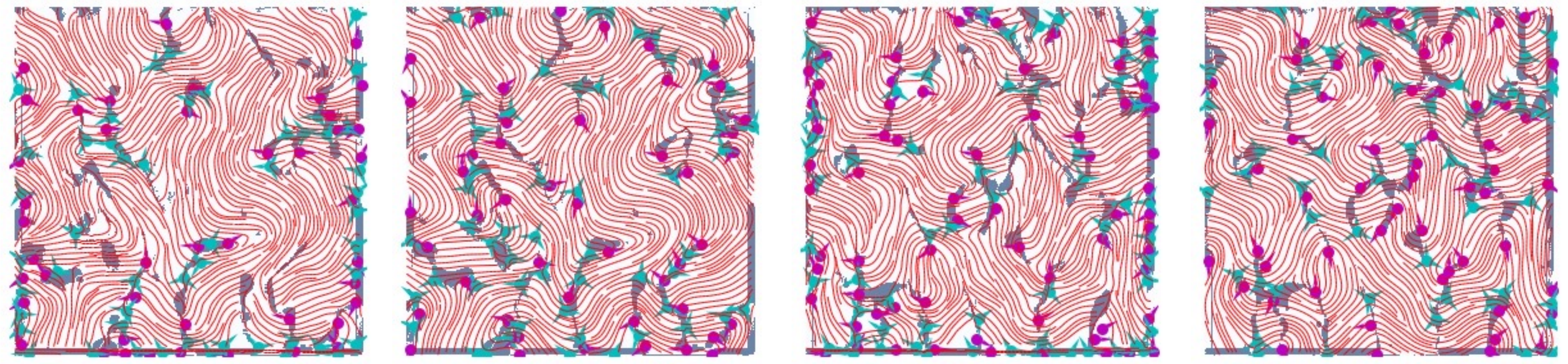


Original Image Prediction with Gabor Prediction without Gabor Target

- Encoder/Decoder Network

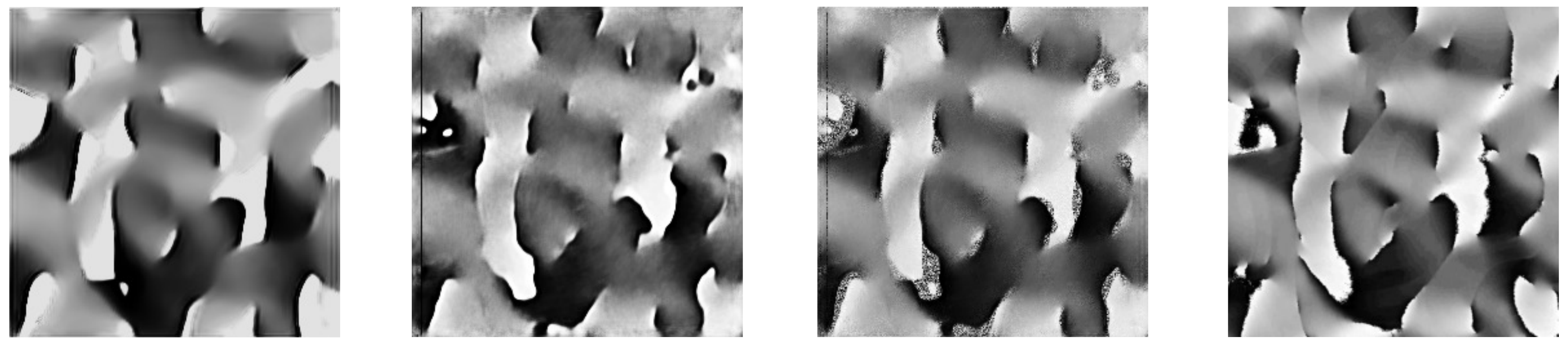


Prediction example 1 Target example 1 Prediction example 2 Target example 2



Prediction Orientation 1 Target Orientation 1 Prediction Orientation 2 Target Orientation 2

- Stacking Multiple Networks with Weights



Prediction from Network1 Prediction from Network2 Weighted Combination Target Orientation

Conclusions

- Gabor Filter can effectively reduce noises in the original retardance dataset.
- Model prediction using the encoder/decoder structure can be trained in a much shorter period of time, but tend to overly smooth out the orientation field
- Ongoing and future work:
  - We can stack multiple networks together to achieve better results
  - Better ensemble strategy need to be explored

References

1. Zhou, Zhengyang, et al. "Machine learning forecasting of active nematics." *Soft matter* 17.3 (2021): 738-747.

Acknowledgments

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This research *(or study or work)* was completed at Brandeis University. The Brandeis campus sits on land that was sacred to the Massachusett nation, including four tribes existing today: the Mattakeeset, Natick, Ponkapoag, and Namasket. Both Native Americans and Africans were enslaved in the colony of Massachusetts.