An analytic approch to understand strain-stiffening in disordered biopolymer networks

Master intern project
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I will start my research group on self-organization and collective effects in living systems and disordered materials in January 2019, and I am looking for an excellent and motivated master intern student (physics, biophysics, biotechnology, informatics) to work on the theory of biopolymer networks. A prominent example of a biopolymer network is collagen (Fig. 1), which is an important part of connective tissues in virtually all animals. Even if the mechanical properties of single fibers of such biopolymer networks were precisely known, the disordered nature of the network makes the behavior of the whole system hard to predict. To overcome this, I recently developed an analytic approach to understand the behavior of such disordered networks in a special case [1]. The aim of the intern project will be to generalize this work. The results will be published in a peer-reviewed journal, and if desired could also be presented at an international conference.

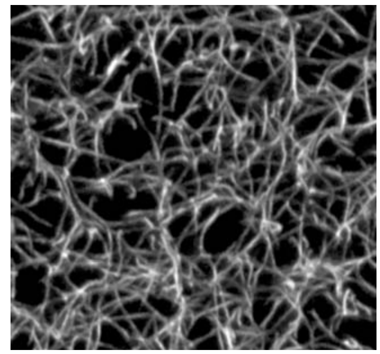

Figure 1: Confocal microscope image of collagen (width 100 microns). Taken from Lindström et al, PRE, 2010.

Details: The mechanical behavior of biopolymer networks has been successfully described by fiber network models. Such models consist of a set of fibers that are rigidly connected to one another, where each fiber exhibits both stretching and bending rigidity. In particular, these models have been successful in recapitulating the strain stiffening behavior of biopolymer networks, i.e. a strong increase in network rigidity upon deformation. In the past, there was mostly only experimental and numerical work on this, but no exact analytical results. Moreover, there have been controversies about the precise nature and cause of the strain-stiffening. For example, while previously the stiffening has been attributed to a non-linear mechanical characteristic of the individual fibers, more recent work shows that purely geometric effects can be sufficient to create the stiffening. In particular, I developed a generic analytical theory for rigidity in a broad class of under-constrained materials, including fiber networks in the limit without fiber bending rigidity (Fig. 2) [1]. The next step is now to include the fiber bending rigidity, and use both computer simulations and analytical derivations in parallel to make precise quantitative predictions that can be compared to the existing experimental data.

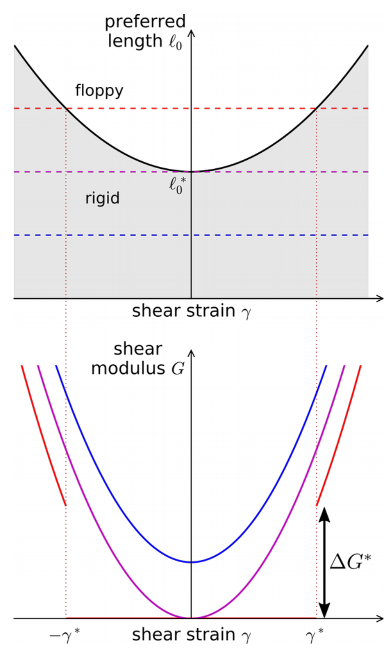

Figure 2: Generic analytic theory for strain stiffening in under-constrained materials (like fiber networks without bending rigidity) [1].

Project work: The project includes both numerical work (implementing a fiber network model with bending rigidity, running simulations, and analyzing the data) and analytical work. The student will learn about biopolymer networks, fiber network models, continuum mechanics, and the mechanics of disordered, under-constrained systems.

Please do not hesitate to contact me in case of interest or further questions: mmerkel@syr.edu

[1] M. Merkel, K. Baumgarten, B. Tighe, L. Manning, arXiv:1809.01586