The physics of active biological materials across scales.

Abstract

Materials made from constituents that use energy to move are called active. These inherently out of equilibrium systems have attractive physical properties: active materials can spontaneously form patterns, collectively move, self-organize into structures, and do work. Biology, through evolution, has found ways to exploit this potential. The cytoskeleton, an active material made from biopolymer filaments and molecular scale motors, drives cellular functions with remarkable spatial and temporal coordination. The ability of cells to move, divide, and deform relies on this robust, dynamic and adaptive material. Tissues are assemblies of cells, and are capable to collectively organize into organs by exploiting the intricate interplay between mechanics and biochemical signalling. To understand these materials and design similarly useful active matter systems in the lab, theories which predict their behaviors from the interactions between their constituents are needed. This is what I propose to address with my proposed lab. Much of our current understanding of active matter comes from the impressive success-story of broken-symmetry hydrodynamics. In these theories large scale equations of motion are obtained by exploiting physical constraints, such as momentum and angular momentum conservation, and the symmetries of the system, without making reference to the details of the microscopic structures, from which the materials derive. This approach has allowed to explore many of the phenomenological properties of active and living system even before knowing the details of the underlying biological processes, which have often remained opaque. The question which symmetry based theories leave unanswered is how specific changes to the constituents of a living material will affect its large scale material properties. This knowledge however, is required if designing and modifying active biological systems is to become a reality. To bridge the gap between microscale interactions and the large scale physics of active materials three largely unsolved problems need to addressed: (i) models for microscale interactions need to be developed; (ii) a robust framework to coarse grain microscale properties up to material properties need to be developed; (iii) analytical and numerical tools to solve the emergent equations of motion in relevant geometries need to be developed. In my lab, I plan to build on my expertise acquired in my earlier work and attack all three of these problems with a strong focus on two classes of active materials: cytoskeletal networks and tissues. Vienna, and in particular TU-Wien, could be the perfect homebase to address these issues from. Synergies with the very active research groups there, which study the physics of complex materials (Kahl, Valtiner), the biophysics of cellular sensing (Schuetz), and how the properties of microscale structures such as collagens shape the large scale mechanical properties of biological structures (Thurner, Hellmich), could be fruitfully explored to develop models for living materials. Beyond that, the larger Viennese research environment offers the potential to find the collaboration partners necessary to forward this novel approach to living materials.

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106006 - Biophysics (70%) | 106052 - Cell biology (15%) | 106010 - Developmental biology (15%)

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