Modelling Anisotropic Tissues With Weak Forms

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Abstract

Tissues and cellular assemblies can often be modeled as multiphasic fluids or as active anisotropic materials, such as liquid crystals [1]. The governing equations for such systems may be derived either by coarse-graining microscopic models or by applying principles like Onsager's Variational Principle [2,3]. In this work, we implement these equations using the Weak Form Physics interface in COMSOL Multiphysics, enabling direct comparison with experimental data and analytical predictions [2-4].

A particularly compelling case study involves cancer-associated fibroblast (CAF) monolayers, which exhibit complex dynamics due to their interactions with the extracellular matrix (ECM). CAFs deposit ECM that acquires orientational order and, in turn, exerts torques on the cells. Dissipative processes—such as friction between CAFs and the ECM—also play a critical role in shaping collective cell behavior. Clinical data show that CAFs encapsulate tumors, notably in colorectal cancer, and modeling the dynamic properties of this capsule is key to understanding tumor growth and metastasis.

We focus in particular on the evolution and behavior of topological defects within the fibroblast monolayer. Simulations performed in COMSOL are benchmarked against both experimental observations and theoretical predictions, offering insights into both cancer physics and active matter dynamics in biological systems [5,6].

The ability to directly implement custom governing equations in weak form provides a powerful and flexible framework for simulating complex active materials in COMSOL Multiphysics.

Reference

[1] Marchetti, M. Cristina, et al. "Hydrodynamics of soft active matter." Reviews of modern physics 85.3 (2013): 1143-1189.
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[3] Ackermann, Joseph, and Martine Ben Amar. "Onsager's variational principle in proliferating biological tissues, in the presence of activity and anisotropy." The European Physical Journal Plus 138.12 (2023): 1103.
[4] Ackermann, Joseph, et al. "Mechanistic insight for T-cell exclusion by cancer-associated fibroblasts in human lung cancer." eLife 13 (2025): RP101885.
[5] Jacques, Cécile, et al. "Aging and freezing of active nematic dynamics of cancer-associated fibroblasts by fibronectin matrix remodeling." bioRxiv (2023): 2023-11.
[6] Bell, Samuel, et al. "Ordering spontaneous flows and aging in active fluids depositing tracks." Physical Review E 111.2 (2025): L023405.

Figures used in the abstract

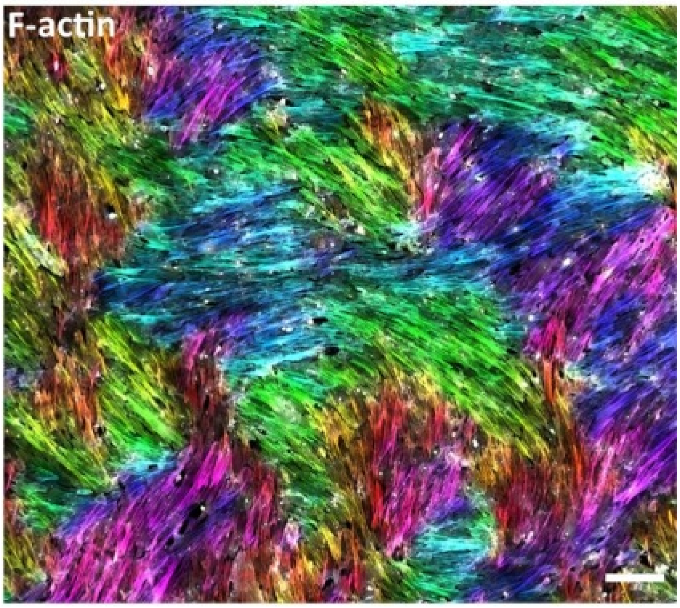

Figure 1 : Orientation of CAFs based on F-actin staining (phalloidin). The color map corresponds to the orientations.

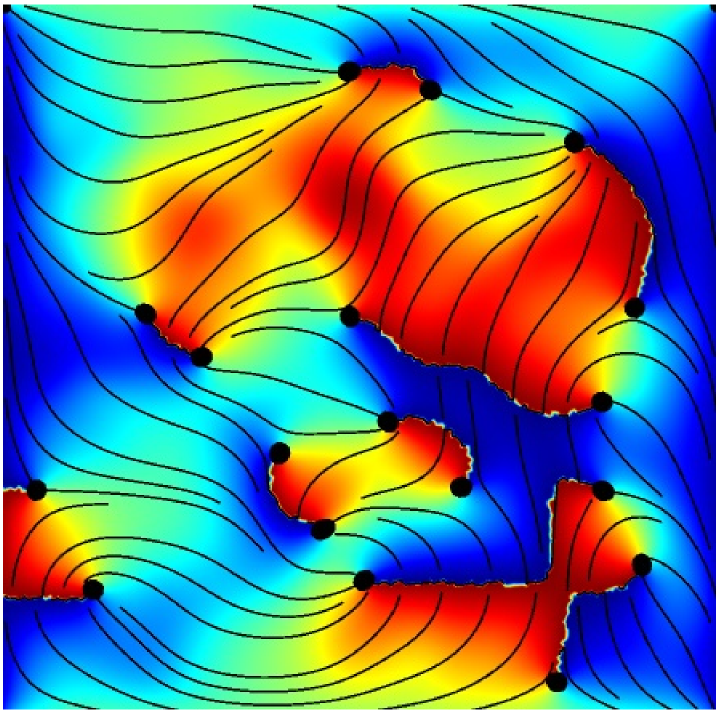

Figure 2 : Comsol numerical simulation of CAFs as active nematics. The color map corresponds to the orientations (streamlines), and topological defects are indicated as black dots.