Title: Multi-scale modeling of multi-cellular systems - A physical approach

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Abstract:
Modeling phenomena in biology often requires the inclusion of processes occurring at different spatial and temporal scales. To this end, theories from Mathematics and Physics can provide tools for the modeling and analysis of multiscale phenomena. In this talk, we introduce a theoretical framework called "Dynamic Density Functional Theory" that we apply to derive a modeling approach for multi-cellular systems that is consistent across the scales.

Our starting point is to model the spatio-temporal evolution of a multi-cellular system by means of the stochastic Langevin equations. In this approach, each cell moves as the result of a balance of forces exerted among the surrounding cells and by the cell microenvironment. A random contribution arises from the local exploration of the neighborhood by the cells.

Then methods from statistical physics can be used to derive the corresponding generalized Fokker-Planck equation, which gives the spatio-temporal evolution of the probability distribution of finding the cells of the system at specific locations in the domain.

An interesting level of description consists in assuming the scalar density field as the relevant variable for describing the dynamics of the system. We show how to derive the corresponding functional Fokker-Planck equation, which gives the spatio-temporal evolution of the probability that the cells adopt a particular density profile. At this level of description, we show how to include cell proliferation and apoptosis as a stochastic birth-death process in the framework.

Finally, we present the derivation of a deterministic macroscopic equation that describes the spatio-temporal evolution of the cell density, including cell movement as a result of a balance of forces, and cell proliferation and death. In this equation, the dynamics of the cell density are regulated by a free energy functional that accounts for interactions among cells and with the microenvironment.

We illustrate our approach for well-established mean-field approximations such as Keller-Segel- and Fisher-Kolmogorov-like models classically used for a macroscopic description of a multi-cellular system at the tissue level..