From individual motion to collective cell migration

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The motion of living cells plays an important role in many important processes, like in wound healing, as part of the immune system, and in tissue development. Modeling the migration of cells thereby involves the study of the motion of a single cell and on collective behavior of many cells.

Various different mechanisms have been proposed and studied to describe motility of a single cell in different situations. We study the motility mechanisms of eukaryotic cells by polymerization and depolymerization of and contractile stresses between cytoskeletal actin filaments. A (hydrodynamic) active polar gel model is presented with the polarity as mean alignment of actin fibres in the cytoskeleton. Modeling the fibre network as a field of polar liquid crystals, i.e. rod-like particles with polar order, a spontaneous symmetry breaking in the alignment leads to cell motility. Shape changes and an internal flow flow of actin push the cell forward. The model combines a Helfrich-Navier-Stokes model with surface tension and an active polar gel theory in a diffuse-interface setting.

While the mechanics, dynamics and motility of individual cells have received considerable attention, the understanding of collective behavior of cells, the interaction and influence of their motion, remains challenging. We consider a continuum model for collective cell movement. Each cell is modeled by a phase field, driven by an active polar gel model and the cells interact via steric interactions. The collision dynamics of two cells is studied in detail and the collective behavior of about 1000 cells in a crowded environment is considered. This process is computational challenging due to the high number of individuals, their local resolution and individual motion driven by principles shown before. This leads to a highly parallelized multi-phase field model.

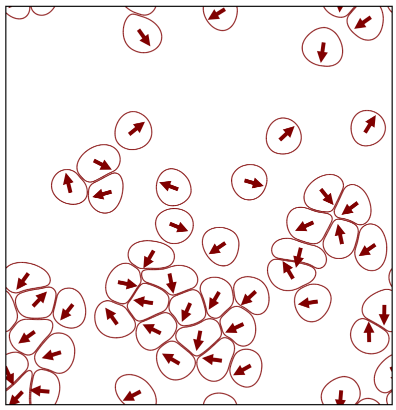

Figure 1: Interaction of 48 cells in a periodic environment. Shown is the cell membrane as contour plot, with direction of motion indicated by an arrow. Deformation and cell-cell interaction may eventually lead to a collective motion in a common direction.

References

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