Collective motion of virtual amoebae: interactions among deformable swimmers

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The coupling of the internal mechanisms of cell polarization to cell shape deformations and subsequent cell crawling poses many interdisciplinary scientific challenges. Several mathematical approaches have been proposed to model the coupling of both processes, where one of the most successful methods relies on a phase field that encodes the morphology of the cell, together with the integration of partial differential equations that account for the polarization mechanism inside the cell domain as defined by the phase field [1]. This approach has been previously employed to model the motion of single cells of the social amoeba Dictyostelium discoideum, a widely used model organism to study actin-driven motility and chemotaxis of eukaryotic cells [2].

Besides single cell motility, Dictyostelium discoideum is also well-known for its collective behavior. We extend the previously introduced model for single cell motility [2] to describe the collective motion of large populations of interacting amoebae by including repulsive interactions between the cells [3]. We performed numerical simulations of this model, first characterizing the motion of single cells in terms of their polarity and velocity vectors, see Fig.1(A,B). We then systematically studied the collisions between two cells that provided the basic interaction scenarios also observed in larger ensembles of interacting amoebae, see Fig.1(C). Finally, the relevance of the cell density was analyzed, revealing a systematic decrease of the motility with density, associated with the formation of transient cell clusters that emerge in this system even though our model does not include any attractive interactions between cells.

This model is a prototypical active matter system for the investigation of the emergent collective dynamics of deformable, self-driven cells with a highly complex, nonlinear coupling of cell shape deformations, self-propulsion and repulsive cell-cell interactions. Understanding these self-organization processes of cells like their autonomous aggregation is of high relevance as collective amoeboid motility is part of wound healing, embryonic morphogenesis or pathological processes like the spreading of metastatic cancer cells.

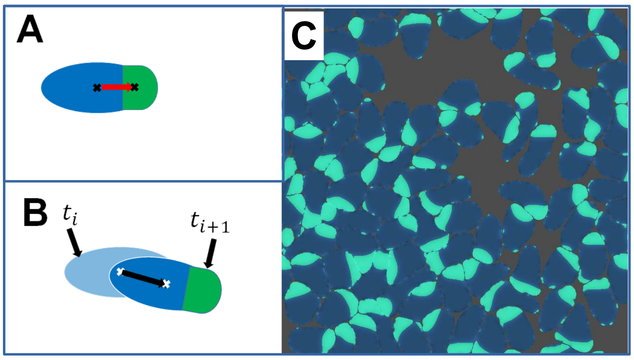

Fig. 1. A) Definition of the polarization vector of a single polarized cell. B) Definition of the velocity vector after the motion of the cell. C) Set of 81 cells moving and colliding with the other cells in a square domain with periodic boundary conditions.

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