Emergent versus Individual-Based Multicellular Chemotaxis

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***Short Abstract* — Multicellular chemotaxis can occur via individually chemotaxing cells that are mechanically coupled. Alternatively, it can emerge collectively, such as from cells on the exterior of the collective responding to chemical signals while bulk cells remain uninvolved. We find that the precision of this type of emergent chemotaxis is higher than that of individual-based chemotaxis for one-dimensional cell chains and two-dimensional cell sheets, but not three-dimensional cell clusters. We describe the physical origins of these results, discuss their biological implications, and show how they can be tested using experimental measures. Lastly, we discuss expansions to this work through the use of long distance chemical signaling rather than mechanical coupling.**

***Keywords* — Chemotaxis, collective migration, sensing**

I. Background

Collective migration is ubiquitous in cell biology, occurring in organism development [1], tissue morphogenesis [2], and metastatic invasion [3]. Collective migration often occurs in response to chemical cues in the environment, a process known as chemotaxis. The simplest way for cells to collectively chemotax is by individual detection and response: each cell measures and moves in the perceived direction of a chemical gradient, while mechanical coupling keeps the group together. This individual-based chemotaxis (IC, Fig. 1, left) is found throughout cell biology [4]. However, recent experiments have uncovered an alternative type of chemotaxis in which cells on the exterior of a group polarize while interior cells do not, a mechanism observed in neural crest cells [1]. This type of emergent chemotaxis (EC, Fig. 1, right) presupposes a machinery within cells that allows for behavior to change once a cell is in a group. Since this machinery may come at a cost, this raises the question of whether EC offers any fundamental advantages over IC.

II. Results

To address this question, we compare groups of cells undergoing IC and EC in 1D chains, 2D sheets, and 3D clusters. For cells undergoing IC, each cell is assumed to make measurements of a local gradient and polarize completely independently of all other cells. The polarization vector of the group is then taken to be sum of all individual polarization vectors. For cells undergoing EC, exterior cells

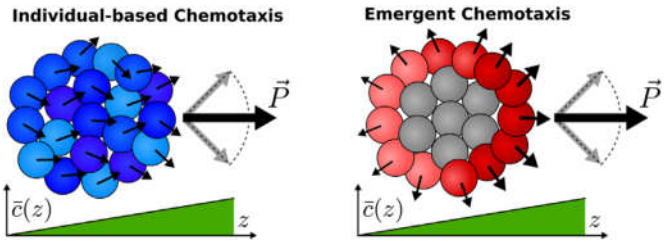

FIG. 1. Groups of cells undergoing IC (left) and EC (right).

polarize outward with a weight proportional to the local concentration. This allows cells in areas of higher concentration to dominate the group polarization vector. We find that both mechanisms cause the mean group polarization vector to scale linearly with population size. However, due to the stochastic nature of diffusion and cell sensing, these methods are shown to have different noise properties. In particular, we show that for 1D chains and 2D sheets, the relative noise in the group polarization vector decreases more rapidly with population size for cells undergoing EC, while no difference in scaling is seen for 3D clusters [5].

III. Future Works

Currently, we are expanding this work to look at groups of cells interacting not through mechanical coupling, but rather through long range chemical signaling. We will show preliminary work in which we model cells that through a combination of secreted attractant and repellent molecules create a preferred separation between themselves and neighboring cells. In a manner similar to the IC model, these cells measure and chemotax individually while being coupled to their neighbors via these secreted molecules. We will show the effects of population size, preferred separation length, and secretion rate on the precision with which these groups can successfully track a chemical gradient.

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