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Emergent Collective Behavior of Microscopic Swimmers[1]

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The individual components of a biological system often express simple behaviors that lead to the spontaneous emergence of order and high levels of complexity; the whole is greater than the sum of its parts. Emergent complexity may arise spontaneously or, more interestingly, in response to external forces present in the surrounding environment. Here, we study the emergence of the emergent collective behavior of swimming *Escherichia coli* bacteria inside microfabricated environments. We first demonstrate how the swimming dynamics of single bacterium cells inside jagged, funnel-shaped geometries leads to the emergence of complex migratory patterns. In particular, by creating ratchet-like barriers that redirect the motion of single E. coli cells, we demonstrate that while a single bacterium is unable to "escape" an array of ratchets, a *population* of cells are able to collectively navigate against these motion-rectifying barriers. We then investigate the collective behavior of cells at increasing densities and witness the emergence of multicellularity in bacteria. As the local density of cell increases to reach physiologically relevant concentrations, individual swimming cells respond to the cell-cell interactions and collectively assemble into biofilms. We describe the physiological development of such biofilms inside microfluidics devices and, using in situ measurements, study the physical properties of various biofilms from their motion and deformation.

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