Intelligent locomotion of eukaryotic cells

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Eukaryotic cells such as cellular slime molds (Dictyostelium descoideum) and other animal cells are thought to share unified mechanisms for locomotion. In this work, emergence of "intelligent" behaviors of cells is discussed by developing a simple computational model of locomotion. The model describes changes in cell shape on the two-dimensional plane by considering a cell membrane, actin filaments embedded in the membrane, and an intracellular control factor called "cortical factor". Actin filaments polymerized on the membrane push it outward to change the cell shape, whereas cortical factor suppresses polymerization of actin filaments. Cortical factor is conveyed from the leading edge to the rear of a moving cell by the intracellular flow of cortex and accumulates at the rear of the cell. This flow of cortical factor leads to the spontaneous locomotion of cells by amplifying the initial fluctuation in cell movement: If a fluctuating cell slightly moves into a direction, cortical factor begins to accumulate at the rear of the moving cell, which suppresses actin polymerization there and further promotes cellular locomotion in the initial direction. This positive feedback mechanism reproduces the experimentally observed amoeboid-like and keratocyte-like locomotion and cytokinesis B- and C-like cytofission depending on the kinetic rate and the threshold value for actin polymerization in the model, where the amoeboid-like locomotion is a repeat of stop-and-go motion, and the cell usually changes its moving direction after the stopping phase, while the keratocyte-like locomotion maintains a moving direction for long duration. Cytokinesis B-like cytofission divides a cell into two parts, and a cell is torn into several pieces in cytokinesis C-like cytofission. Based on this model of eukaryotic cells, emergence of intelligent behaviors in locomotion is demonstrated. We assume that the reception of external chemical signal suppresses the activity of cortical factor, leading to chemotaxis of a cell toward the source of the chemical signal. We consider that there exist obstacles intercepting a cell on its way to the source of signal. When signal permeates through some obstacles to attract the cell (i.e. traps), the simulated cell falls into a trap at first but it suddenly escapes from the trap to find a way to get it around. The cell finds this detour because the distribution pattern of cortical factor is flushed while the cell is trapped and the occasional fluctuation in cortical factor amplifies locomotion against the gradient of the external signal. In this way, the feedback loop between cell movement and cortical factor is a key mechanism of the emergent behavior to find a detour. We also discuss efficient food finding and cells' hunting moving bacteria. Cognitive locomotion of the model eukaryotic cells is the result of the fluctuating dynamics in which the interaction with the environment and the internal chemical reactions are coupled through the feedback between cell movement and cortical factor.