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Modeling of Tumor Cell Dynamics with Individual-based Lattice-gas Cellular Automata

Malignant tumors can be considered as populations of interacting cells with a high amount of phenotypic heterogeneity. To model cooperative phenomena (e.g. cancer growth) in interacting cell populations, lattice-gas cellular automaton (LGCA) models are increasingly used. Major advantages of LGCA models are that they admit computationally efficient simulations and often analytical treatment of the modeled problem. However, it has not been possible so far to distinguish individual biological cells in LGCA models making them unsuitable to model phenomena where the explicit description of individual cells is required. However, lattice-gas cellular automata have been successfully applied to model specific tumors without specifically considering individual cells, e.g. growth of glioblastoma tumors. Nonetheless, there are processes during tumor formation for which a "classical lattice-gas model" is unsuitable. One such process is the invasion of surrounding tissue by single tumor cells, a prerequisite for the formation of metastasis.

We propose an extension to (classical) lattice-gas cellular automata which allows the identification and tracking of individual cells. In particular, we derive stochastic differential equations (Langevin equations) corresponding to specific LGCA models. The LGCA model together with the knowledge of the corresponding Langevin equation allows computationally efficient simulations and feasible analytical treatment of the dynamics of individual cells in populations of interacting cells. Furthermore, our proposed approach facilitates the construction of individual-based LGCA models with cell-dependent dynamics. This also supports the incorporation of LGCA models into multi-scale models which consider processes at sub-cellular and cellular scales.

We present applications of our individual-based LGCA appoach to the following examples: random walk, adhesion, and collective motion. Furthermore, we use an individual-based LGCA model to investigate conditions for the onset of tissue invasion by single tumor cells.