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Corrected mean-field models for spatially-dependent advection-diffusion-reaction phenomena

In the exclusion-process literature, mean-field models are often derived by assuming that the occupancy status of lattice sites is independent. Although this assumption is questionable, it is the foundation of many mean-field models. In this work we develop methods to relax the independence assumption for a range of discrete exclusion process-based mechanisms motivated by applications from the cell biology literature. Previous investigations that focussed on relaxing the independence assumption have been limited to studying initially-uniform populations and ignored any spatial variations. These previous corrected mean-field models could not be applied to many important problems in cell biology such as invasion waves of cells that are characterised by moving fronts. Here we propose methods that relax the independence assumption leading to corrected mean-field descriptions of a range of exclusion process-based models that incorporate (i) unbiased motility, (ii) biased motility, and (iii) unbiased motility with agent birth and death processes. The corrected mean-field models derived here are applicable to spatially-variable processes including invasion wave-type problems. We show that there can be large deviations between simulation data and traditional mean-field models based on invoking the independence assumption. Furthermore, we show that the corrected mean-field models give an improved match to the simulation data in all cases considered.