

Spatial and nonspatial evolutionary games and their applications

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Summary

This thesis focuses on modeling and understanding biological interactions through spatial and nonspatial evolutionary game theory (EGT). In these interactions, one's well-being often depends on how the others are doing, making EGT an appropriate tool for understanding biological problems.

In this thesis we apply three different game-theoretical (spatial and nonspatial) models for studying three different kinds of biological interactions, respectively: a nonspatial model for the predator-prey interactions among mites (Chapter 2), a discrete-space model for competition among microbial strains (Chapter 4) and a continuous-space model for tumor growth involving three distinct types of cancer cells (Chapter 5). In Chapter 3 we investigate properties of spatial structures which may influence the eco-evolutionary (population and frequency) dynamics dramatically. Each of the Chapters 2 to 5 deals with a specific research question, and how we apply spatial/nonspatial game-theoretical models for addressing these research questions shapes this thesis.

In Chapter 2 we implement a nonspatial game for modeling the summer-season interactions between the predatory mites (*Acari: Phytoseiidae*) and the fruit-tree red spider mites (*Acari: Tetranychidae*). Based on biological observations, we design a nonspatial game which expands the classical Lotka-Volterra two dimensional system of ordinary differential equations. In this nonspatial game, player decisions (“joining” or “opting out”) are time-varying, fitness of the prey is an integral function with respect to the number of individuals playing “opting out” during the entire summer season, and fitness of the predator is only dependent on the number of individuals (regardless of which strategy is played) at the end of the summer season. Combining analytical and numerical methods, we seek time-varying optimal decisions for the predator and prey which maximize their fitnesses. Our results do not match empirical observations. Our nonspatial model may be oversimplified and overlooking internal properties of the predator and the prey. A more complex game-theoretical model, proposed in Staňková et al. (2013a), suggests that one should include energy levels of predator and prey individuals to reflect the studied predator-prey interactions more realistically.

Chapter 3 focuses on a comparison of dynamics of discrete-space, continuous-space and nonspatial games. We propose discrete-space and continuous-space dynamics as spatial extensions of the (nonspatial) replicator dynamics. We use agent-based simulations to track the eco-evolutionary dynamics of the spatial models. We observe that the two types of spatial models generate strikingly different eco-evolutionary dynamics, which are also different from those of the nonspatial ones. We hypothesize that this difference between discrete-space and continuous-space games is caused by the so-called dispersal conflict (i.e., when more individuals try to disperse simultaneously into exactly the same position in the discrete space). When compared to the discrete-space model, we find the continuous-space model to be more robust to variations per run, due to the stochastic nature of game rules, but much less computationally efficient. To our best knowledge, this chapter is the first work that devotes itself to understanding how different types of specific spatial structures influence the predictions of spatial models.

Chapter 4 demonstrates an application of discrete-space games in studying scenarios that lead to coexistence of microbial species. In this chapter we use discrete-space models to mimic scenarios which examine the impact of the interaction matrix, of a varying fixed neighborhood size and of different manners how the microbes are selected for interaction. Here the interaction matrix is a binary matrix indicating whether cells of a specific type can or cannot kill cells of a certain other type. Through case studies we observe that a more dense interaction matrix leads to a lower coexistence rate. We also observe that a higher coexistence rate is achieved with a relatively low neighborhood size when square and hexagonal grids are compared. The exact manner of selecting a focal cell seems to have only a minor influence on the coexistence.

Chapter 5 demonstrates an application of continuous-space games in modeling tumorigenesis of metastatic castrate-resistant prostate cancer involving three distinct types of cancer cells. It is possible to achieve different levels of local saturation in a continuous-space model and this feature makes the continuous-space model more appropriate for modeling cancer, whose cells can grow throughout space and form very variable local densities. Based on the state of the art cancer biology for these types, 22 potential fitness matrices are examined. Further, we study the impact of three radii (i.e., frequency-dependence, density-dependence and dispersal radii) on the eco-evolutionary dynamics of a tumor. We use agent-based simulations to track the eco-evolutionary dynamics. Some of the predictions of our spatial models nicely match observations on the development of real tumors. Moreover, we see that the spatial dynamics are very different from the nonspatial ones, unless we make one of the three radii very large. This supports our claim that nonspatial models are insufficient for modeling tumorigenesis.

Finally in Chapter 6 we conclude the results of this thesis through a global perspective and pose several directions for future research.