Evolutionary Dynamics and the Problem of Cooperation

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Abstract

Evolutionary dynamics in finite populations reflects a balance between Darwinian selection and random drift. For a long time population structures were assumed to leave this balance unaffected provided that the individuals' fitness is frequency independent, i.e. both mutants and residents have fixed fitness values. This result indeed holds for a certain (large) class of population structures or graphs. However, other structures can tilt the balance to the extend that either selection is eliminated and drift rules or drift is eliminated and only selection matters.

In nature, fitness is generally frequency depended, i.e. is affected by interactions with other members of the population. The most important case refers to the evolution of cooperation under Darwinian selection and represents a major challenge in evolutionary biology and behavioral ecology. The essence of the evolutionary conundrum is captured by social dilemmas where cooperators provide a benefit to the group at some cost, while defectors attempt to exploit the group by reaping the benefits without bearing the costs of cooperation. The most prominent game theoretical models to study this problem are the Prisoner's Dilemma (PD) and the Snowdrift game (SD). In the PD cooperators are doomed if interactions occur randomly but in structured populations, they may form clusters and thereby reduce exploitation by defectors. This results in stable co-existence of cooperators and defectors and has lead to the general belief that space is beneficial for cooperation. Interestingly, however, when relaxing the social dilemma and considering the SD, this no longer holds. Due to the less stringent conditions, cooperators persist in random interactions but spatial structure often tends to be deleterious and may even eliminate cooperation altogether.

In many biological situations it is more appropriate to consider a continuous range of cooperative investment levels instead of two a priori fixed strategic types. This situation can be analyzed using the framework of adaptive dynamics. The continuous SD exhibits rich dynamics but most importantly provides an intriguing natural explanation for phenotypic diversification and the evolutionary origin of cooperators and defectors. It turns out that selection may not always favor equal contributions but rather promotes states where two distinct types co-exist - those that fully cooperate and those that exploit. In the context of human societies and cultural evolution this could be termed the 'Tragedy of the Commune' because differences in contributions to a communal enterprise have significant potential for conflicts on the basis of accepted notions of fairness.