Coevolutionary games and dynamic fitness landscapes: A synthesis?

A main feature of Darwinian evolution is that success in survival and reproduction is directed by selective pressure and entails competition among individuals. In other words, it is largely justified to recognize the proverbial survival of the fittest as an important mechanism of evolution. However, looking at nature we find, of course, fierce competition and struggle, but also wide-spread cooperative and even altruistic behavior, not only among individuals, but also between groups of individuals or even species. How can competition and cooperation sit side by side and be equally true in describing the driving forces of evolution? Possible answers to this question may be given by evolutionary and coevolutionary games. Both types of games are computational models which enable to discuss whether, when and under what circumstances cooperating may be evolutionary better than competing. These games define a population of individuals as players interacting with each other, and behavioral choices of individuals to be adoptable strategies, for instance competing or cooperating. A player receives payoff from interacting with other players depending on its own strategy, the strategies of its coplayers, and the values of a payoff matrix specifying rewards and punishments. Discussing player-and-coplayer interactions allocating payoff becomes most clear and definite by so-called social dilemmas, most famously prisoner's dilemma, but also snowdrift, stag hunt or harmony. These games express evolutionary dynamics by players that change their strategies (evolutionary games) or additionally recast the network describing who interacts with whom (coevolutionary games).
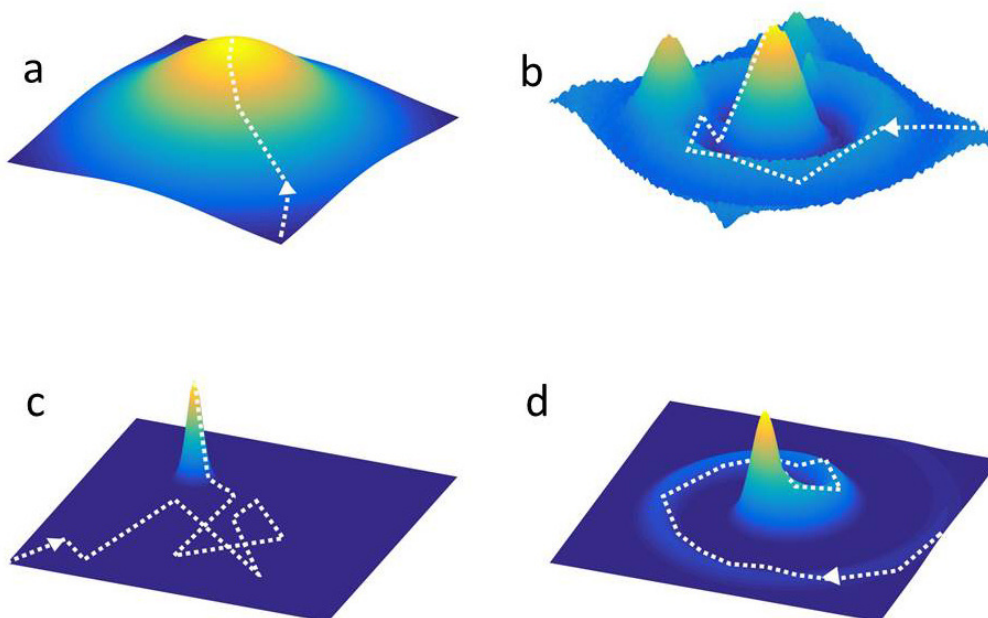

Fig. 1. Topological types of fitness landscapes: a) Mt. Fuji landscape (single, smoothly accessible unimodal peak), b) Barrier landscape with ruggedness and multimodal peaks, c) Neutral landscape (flatness with a single sharp peak), d) Detour landscape (single peak with a long path).

Fitness landscapes are another framework of mathematical tools that can be used to conceptualize and computationally analyze evolutionary dynamics. Fitness landscapes were introduced in evolutionary biology and formulate relationships between genetic specifications, individual instantiations, and their fitness. If we postulate differences in fitness over all possible genetic specifications and a moving bias towards higher fitness, then the landscape setup suggests the picture of an evolving population that is moving directedly on the landscape. On a conceptual level, this picture is based on the notion of evolutionary paths that are created by the topological features of the fitness landscape. Evolutionary paths are a succession of moves on the landscape with ascending fitness values. The existence and abundance of such evolutionary paths gives rise to estimates about how likely a transition is from low-fitness regions to high-fitness regions in the landscape.

It is generally acknowledged that by interpreting payoff as fitness, evolutionary games can be linked with fitness landscapes. However, it is equally well understood that the payoff-as-fitness depends on not only the player's own strategy, but also on how often this strategy is used by its coplayers, which is known as frequency-dependence. This situation can be remedied, as shown in the paper, by modelling strategies of players and coplayers together and defining these strategy combinations to be configurations of the game. Thus, for evolutionary and coevolutionary games, we obtain strategy-to-payoff maps and finally game landscapes. These game landscapes can be subsequently used in computational experiments. These experiments show that quantities of the landscapes correlate well with fixation properties and allow to differentiate between different game landscapes. Game dynamics has been intensively analyzed and discussed with respect to fixation properties such as fixation probability and time from both a theoretical as well as an experimental point of view. The results about dynamic game landscapes contribute to this discussion by offering a fitness landscape view as an alternative explanatory framework.

Hendrik Richter
Faculty of Electrical Engineering and Information Technology,
HTWK Leipzig University of Applied Sciences, Leipzig, Germany

Publication