Spontaneous symmetry breaking of cooperation between species

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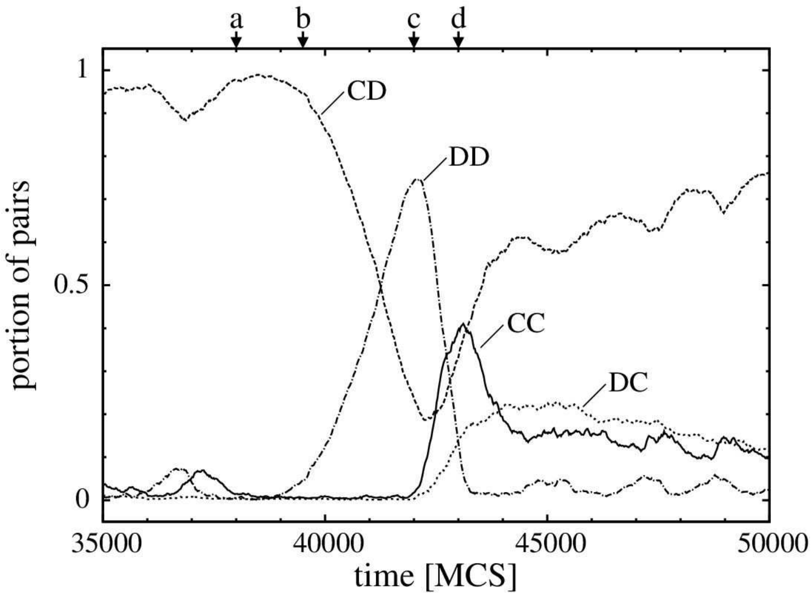
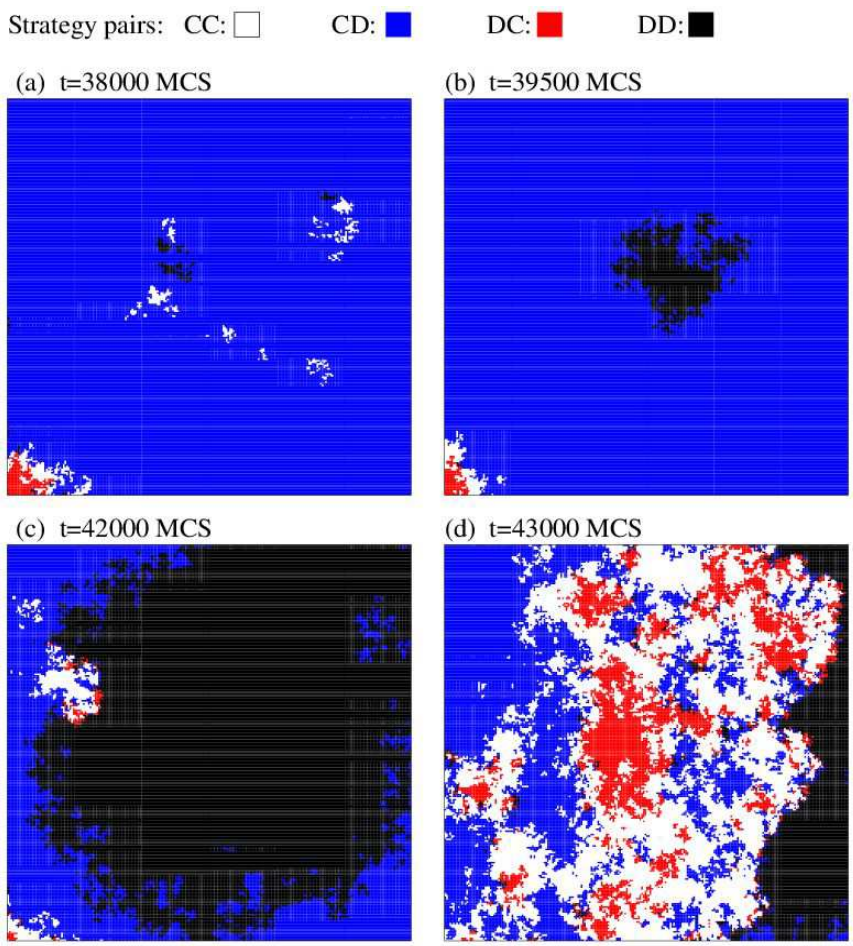
The evolutionary game theory provides a mathematical background for understanding the biological and the social processes. One of the most important issues in this area is to reduce the social damages caused by social trap situations. The simplest game theory model of this life situation is the donation game, when two players independently decide whether they are willing to pay a cost that provides higher income for the other. In this game the individual interest would dictate that neither of them pays the cost (called D strategy). Thus, the players don't receive any income. In contrast to this if both players pay the cost (called C strategy or cooperation), they will receive the higher total income. The social trap means that if the two players keep their own selfish interest in mind then they receive lower income compared to what collective interest would have been yielded. Similar sacrifice can be utilized in environment protection, healthcare and traffic because this behavior is necessary to achieve the social well-fare in these areas. The previous researches in the evolutionary game theory pointed out the enormous possibilities that can be used to avoid a social trap (e.g., punishment, reward or voluntary participation in repeated games). Similar positive effects can be achieved in multi-agent evolutionary systems if the interactions and the strategy imitations are limited to a small local environment.

Christoph Hauert and György Szabó further developed these researches in such a direction where the interaction and imitation networks are distinguished. In this mathematical model the players are located at lattice points of a two-layer square lattice. The income of players comes from donation game that they play with their five nearest neighbors located on the other layer. At the same time, for the imitation of a more successful neighbor the players take into consideration the neighbors within the same layer. Computer simulations were used to investigate how the frequency of cooperation is changed on both layers when the cost/benefit ratio is varied. If the cost/benefit ratio exceeds a critical value then cooperation becomes extinct. The cooperation appears at a lower cost/benefit ratio and their proportion increases equally on both layers in case of decreasing the cost/benefit ratio. Further decrease of the cost/benefit ratio yields different levels of cooperation on the layers. In this case the participants of one layer exploit the members of the other layer. Speciality of this phenomenon is that the selection of the exploitation layer is random similarly to how it appears in physical models of magnetism.

Another interesting phenomenon is that at very low cost/benefit ratio there appear growing and shrinking domains of mutual exploitation. This phenomenon is quantified by the time-dependence of the portion of four possible strategy pairs (CC, CD, DC, and DD) on a small region (containing 240*240 lattice points) for the significantly larger two-layer square lattice.



To explain the appearance of the peak in the portion of DD strategy pair the spatial distribution is also illustrated for four values of time (a, b, c, and d).



At the beginning (pattern a) the players of the upper layer exploit their co-players located on the lower layer within the region of the dominant strategy pair CD. Opposite exploitation appears in smaller DC regions of the whole system. The small groups of CC and DD strategy pairs are created along the boundaries separating the CD and DC regions. Due to the evolutionary dynamics these small DD and CC domains can spread, grow, and shrink inside the CD region. For this interaction and dynamics these DD domains can expand and invade the territory of CD (or CD) regions if their size exceeds a critical value (see pattern b). The extension of DD domains, however, is blocked and reversed by the CC groups (see pattern c) that are also created permanently along the CD/DC interfaces. Finally, the cyclic dominance among the domains of strategy pairs (DD invades CD or DC invades CC invades DD) drives the evolution towards the dominance of CD where further (smaller or larger) bursty events can occur sooner or later. The repetition of these processes causes huge fluctuations and slow evolutions towards the equilibrium states.

Reference:
https://academic.oup.com/pnasnexus/article/3/9/pgae326/7730428