Imitation strategy in the Rosenzweig-MacArthur model

Przemyslaw Gawronski[1], Alfio Borzì[2], Krzysztof Kułakowski[1]

[1]Agh University Of Krakow, Krakow, Poland, [2]Universität Würzburg, Würzburg, Germany

We perform simulations of two consumers and two resources within the Rosenzweig-MacArthur model and interpret the resulting dynamics using tools from game theory and reinforcement learning [1]. The dynamic consumption rates, introduced in our previous works [2,3], determine how each consumer allocates effort between resources. Previously, these rates were optimized along the gradient of consumer density, leading to destabilization of limit cycles, extinction of one resource [2], and transient chaos [3]. In contrast to previous studies, where chaos was transient, we find that in the competitive setting chaotic dynamics becomes persistent.

Here, we extend the model to a competitive setting of two consumers, where consumption rates are treated as adaptive strategies evolving via imitation. The less successful consumer adjusts its strategy toward that of the more successful one, following the "win-stay, lose-shift" rule. This leads to convergence of strategies, with equal consumption rates corresponding to a Nash equilibrium.

From a reinforcement learning perspective, as one interpretation of the model, each consumer updates its strategy based on payoff comparison. We show that the distribution of consumption rates determines the dynamical regime, including cyclic, quasiperiodic, and chaotic behavior.

To control instability, we analyze several modifications of the imitation dynamics, including reduced update rates, smoothing, cautious updates, and regularization toward balanced allocation. While most modifications primarily affect convergence speed, regularization toward symmetric allocation suppresses chaos and stabilizes the dynamics by enforcing limit cycles.

We also compare four update strategies within a payoff-based framework: "win-stay, lose-shift", "win-stay, lose-stay", "win-shift, lose-shift", and "win-shift, lose-stay". In the periodic regime, multiple equivalent Nash equilibria coexist, whereas in the chaotic regime the "win-stay, lose-shift" rule emerges as the unique symmetric equilibrium.

Finally, we show that chaos is associated with uneven resource allocation, whereas balanced strategies promote regular dynamics. Regularization toward symmetry fully suppresses chaos and acts as a structural stabilizer. These results identify a minimal mechanism by which uneven resource allocation generates chaos, whereas symmetric allocation restores stability in a competitive system of two consumers and two resources in the Rosenzweig-MacArthur model.

References:

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