Title: An information-theoretic perspective on evolutionary game theory and population genetics

Author(s): Alexandre V. Morozov

Affiliation(s): Department of Physics and Astronomy (1) and Center for Quantitative Biology (2), Rutgers University, Piscataway, NJ 08854, USA

Abstract: Complex life would be impossible without cooperation at all levels of biological organization: genes cooperate to create regulatory networks and signaling pathways, cells become parts of multicellular organisms, animals participate in intricate cooperative arrangements both within and between species. Cooperation is ubiquitous in human societies and is credited with the rise and development of modern civilization. However, Darwinian selection is believed to promote selfish behavior - societies of cooperators are vulnerable to free-riders or cheaters that ultimately take over, destroying cooperation and leading to societal collapse. This apparent paradox has puzzled evolutionary biologists for more than half a century. A quintessential model of the paradox is provided by the celebrated Prisoner's Dilemma, a mathematical framework which favors cheaters, even though participating in a cooperative society brings about greater rewards. Here we use tools from information theory and non-equilibrium statistical mechanics to study Darwinian evolution in finite and infinite populations of game-playing agents. We demonstrate that it is possible to achieve high levels of cooperativity in the game of Prisoner's Dilemma if the probability of cooperation varies depending on the physical appearance and behavior of the opponent. We discuss the role of information transfer in the acts of deception and manipulation observed in animal and human societies. Finally, we show that fluctuation theorems (non-perturbative equalities in statistical mechanics that quantify probabilities of entropy-consuming fluctuations in non-equilibrium systems) can be used to re-derive and extend well-known results in population genetics. Taken together, our findings enable deeper comprehension of the role played by information theory in describing fundamental processes that underpin emergence and development of life on Earth.

Keywords: Evolution of cooperation (1); Prisoner's Dilemma (2); Fisher's fundamental theorem of natural selection (3); Fluctuation theorems (4)

References:

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