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Social insect colony as a biological regulatory system: modelling information flow in dominance networks

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Social insects provide an excellent platform to investigate flow of information in regulatory systems since their successful social organization is essentially achieved by effective information transfer through complex connectivity patterns among the colony members. Network representation of such behavioural interactions offers a powerful tool for structural as well as dynamical analysis of the underlying regulatory systems. In this paper, we focus on the dominance interaction networks in the tropical social wasp *Ropalidia marginata*—a species where behavioural observations indicate that such interactions are principally responsible for the transfer of information between individuals about their colony needs, resulting in a regulation of their own activities. Our research reveals that the dominance networks of *R. marginata* are structurally similar to a class of naturally evolved information processing networks, a fact confirmed also by the predominance of a specific substructure—the 'feed-forward loop'—a key functional component in many other information transfer networks. The dynamical analysis through Boolean modelling confirms that the networks are sufficiently stable under small fluctuations and yet capable of more efficient information transfer compared to their randomized counterparts. Our results suggest the involvement of a common structural design principle in different biological regulatory systems and a possible similarity with respect to the effect of selection on the organization levels of such systems. The findings are also consistent with the hypothesis that dominance behaviour has been shaped by natural selection to co-opt the information transfer process in such social insect species, in addition to its primal function of mediation of reproductive competition in the colony.

1. Introduction

1.1. Information flow in biological systems

Living organisms are characterized by various sequential processes operating at different biological levels, such as genetic, proteomic, cellular, neuronal, etc. Their survival depends heavily on the proper functioning of such coordinated processes and hence on an efficient dissemination of information through the communication systems of the respective levels [1]. Also for human-engineered systems such as electronic circuits or the Internet, the primary task is to pass information from one part of the system to another [2]. All these systems are known to maximize their performance under time or energy constraints. While structural stability and economics are responsible for the optimization of artificial systems, biological systems are generally optimized under natural selection. Therefore, it is of particular interest to know how such systems achieve their effective process of information transfer and what factors are responsible for their efficiency.

Flow of information is also an important criterion for the coordinated activities of group-living animals. Information transfer is crucial in processes such as