A spin-glass approach to spatial distributions in biology

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We propose a data-driven method, based on the framework of spin-glasses (SG), to interpret the collective dynamics of biological populations, where occupation (vacancies) of regions of a spatial domain spatial point are interpreted as up (down) states of the glass particles (Fig. 1). While tracking data from real experiments can be used in general to feed any learning algorithms, using Ising and spin-glass as reference models for this purpose has the advantages that (i) they are simple and admit a straight physical interpretation, and (ii) there is a vast amount of literature on the field to facilitate the corresponding analysis of the results. All this should help to reach sound descriptive capacity [1] to elucidate key mechanisms of interaction between individuals driving spatial occupancy.

The approach proposed solves the corresponding inverse Ising problem from the experimental occupancy patterns, and then implements an information-theoretic analysis to measure the amount of information and correlation patterns that the resulting SG model is able to capture at local and global spatial scales.

To illustrate the capacity of our approach to classify and/or interpret biological interactions, we first apply it to data generated from several lattice models. In particular, we use (i) Vicsek model, and (ii) a collective learning algorithm [2], as reference models of collective.

Then, as an experimental case study we analyze collective foraging in ants, i.e. *Aphaenogaster senilis*, exploring a large discrete arena where the food is located either at deterministic or random locations. Since the individuals of a colony adapt its movement to satisfy the colony requirements through the interaction and communication between them, it has been claimed that the colony adapts itself to the environment as a unique coordinated entity (or superorganism). This feature has been reported in several studies, where colony-level foraging strategies are shown to be adjustable to specific scenarios [1, 3].

We finally show how our spin-glass approach can be used to carry out further *in silico* experiments in order to address questions about collective search and dynamics. For this, we focus on the question of the exploration-exploitation trade-off, which is of great biological relevance. Optimal foraging draws from the balance between exploiting the known spots of resources and exploring new zones to obtain resources. So, uncertain scenarios (this is, when food is located randomly) would promote exploration, whereas resource exploitation plays a more prominent role in deterministic scenarios. While such exploration-exploitation trade-offs are very common across biological systems and scales but are difficult to quantify and study experimentally, even more at the collective level. So, we claim that *in silico* tools like the one proposed here can be of potential interest in order to help designing/directing adequately experiments.

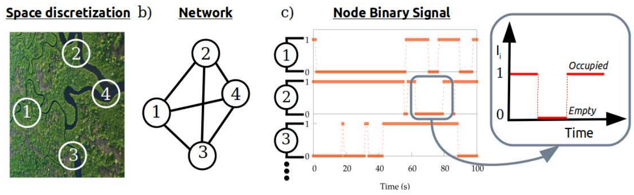

Fig. 1. Illustrative scheme of our approach to collective space use. (a) The biologically relevant regions of the space are considered as nodes of a network structure (b) The presence or absence of individuals at node i for a given time t is understood as a binary signal $I_i(t)$ representing occupancy of that region (with $I_i(t) = 1$ if occupied, and $I_i(t) = 0$ if empty).

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