Bayesian inference for identifying interaction rules in animal swarms

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Animal swarms produce complex patterns of behavior that give the appearance of group intelligence, enabling animal groups to avoid danger, make collective decisions and navigate more efficiently. Self-propelled particle (SPP) and other models [4, 2], inspired by statistical physics, have demonstrated that these patterns can emerge through simple rules that govern the interaction between neighboring particles.

The emergence of similar collective patterns in such models of animal groups points to a restricted set of "universal" classes for these patterns. Although universality is interesting, it is often the fine details of animal interactions that are of biological importance. Universality presents a challenge for inferring such interactions from macroscopic group dynamics because these can be consistent with many underlying interaction models. As noted by [3], the emergence of a desired pattern in a simulation can not be taken as evidence of model correctness.

Recent work has addressed not only which rules are necessary (and at what strengths) to produce realistic behavior, but also what determines who interacts with whom. The debate has focused on the how the neighborhood of each individual—the other animals it interacts with—should be defined. Traditional SPP models have allowed each individual to interact with others within some fixed *geometrical* distance [4, 2]. More recent work has considered a *topological* definition [1], allowing each individual to interact with a fixed number of closest neighbors, independent of the absolute value of the geometrical distance between them.

We present a Bayesian framework for learning animal interaction rules from fine-scale recordings of animal movements in swarms. We apply these techniques to the inverse problem of inferring interaction rules from simulation models, showing that parameters can often be inferred from a small number of observations. Our methodology allows us to quantify our confidence in parameter fitting. For example, we show that attraction and alignment terms can be reliably estimated when animals are milling in a torus shape, while the interaction radius that determines which neighbors an animal interacts with cannot be reliably measured in such a situation. We assess the importance of rate of data collection and show how to test different models, such as topological and geometric neighborhood models. Taken together, our results both inform the design of experiments on animal interactions and suggest how this data should be best analyzed.

References

[1] M. Ballerini, N. Cabibbo, R. Candelier, A. Cavagna, E. Cisbani, I. Giardina, V. Lecomte, A. Orlandi, G. Parisi, A. Procaccini, et al. Interaction ruling animal collective behavior depends on topological rather than metric distance: Evidence from a field study. *Proceedings of the National Academy of Sciences*, 105(4):1232, 2008.

[2] I.D. Couzin, J. Krause, R. James, G.D. Ruxton, and N.R. Franks. Collective memory and spatial sorting in animal groups. *Journal of Theoretical Biology*, 218(1):1–11, 2002.

[3] Y.X. Li, R. Lukeman, and L. Edelstein-Keshet. Minimal mechanisms for school formation in self-propelled particles. *Physica D: Nonlinear Phenomena*, 237(5):699–720, 2008.

[4] T. Vicsek, A. Czirok, E. Ben-Jacob, I. Cohen, and O. Shochet. Novel type of phase transition in a system of self-driven particles. *Physical Review Letters*, 75(6):1226–1229, 1995.

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