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Data-driven models of collective motion derived directly from force maps

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Abstract: Throughout nature, animals exhibit remarkable feats of coordinated collective motion, such as the murmurations of starlings, the shoaling of fish, the swarming of insects and krill, and the movement of human crowds. Model-based theory, supported by observation and analysis of the movement of multiple species, posits that such collective motion is driven by three relatively simple *rules of interaction*: that individuals adjust their velocity to avoid collision with near neighbours, to align their motion with neighbours at intermediate distances, and to move toward neighbours farther afield to avoid separation from a group (Ward and Webster 2016).

This talk is devoted to the development of a species-specific discrete-time individual based model of collective motion, where the rules of interaction that govern the model are inferred directly from the movement data of real animals, rather than being defined algorithmically or via differential equations from theoretical principles. The focal species for this work will be X-ray tetras (*Pristella maxillaris*) based on extant collective movement data from laboratory aquaria, but the broad approach will be applicable to many species. The locomotion rules, including a tendency to adjust to a preferred movement speed and social rules of interaction, will be inferred via force mapping. Force mapping was one of the first techniques used to infer collective motion interactions directly from experimental data (Katz et al. 2011, Herbert-Read et al. 2011). The method uses coordinate geometry and numerical derivatives to determine how individuals adjust the components of their velocity on average as a function of the relative coordinates and velocity of neighbouring group members, and the coordinates of boundaries. Previous data-driven models of collective motion have assumed convenient mathematical functions for the interaction rules, with the parameters determined via best-fit (Escobedo et al. 2020), but the approach here reduces the assumptions to just the relevant independent variables.

I will examine how well the data driven models can mimic the observed motions of the real animals, including individual trajectories, measures of locomotion, local density of neighbours and patterns of group movement examined via collective order parameters. The viability of the direct use of force maps as a model's rules of interaction will be discussed; although force mapping has been shown to be able to capture the qualitative form of interaction rules in previous work, the method is also susceptible to errors induced by varying group size and group-level patterns of motion (Mudaliar and Schaerf 2020, Mudaliar and Schaerf 2023).

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