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Vision and Body as Drivers of Topological Interactions in Collective Motion

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Abstract: Collective motion is a spectacular and common manifestation of collective behaviour. Striking examples include the flocking of birds, schooling of fish and swarming of insects. Theoretical investigation of collective motion is dominated by the standard complex systems approach of assuming point like particles interacting via repeated application of simple rules in a zonal fashion. This approach has been successful in producing tractable models which can visually reproduce the broad group level patterns found in nature and thus has become the standard in collective motion modelling. In 2008, a seminal study by Ballerini et al examined flocking starlings (*Sturnus vulgaris*) to determine if they apply local rules of interaction like those hypothesised within theoretical models and identified anisotropic (meaning direction dependent) structure of interactions between neighbours out to the sixth or seventh nearest neighbour. The data suggested that, contrary to the assumptions used by most models, starlings interacted in an anisotropic and topological (not based on metrical distance, but rather on the rank of nearest neighbours) fashion. Since then, various approaches to modelling topological and anisotropic interactions have been proposed which have mainly focused on changing the rules of social interaction between neighbours in some fashion to produce topological or anisotropic interactions.

The discovery of anisotropic and topological interactions in field studies suggests that vision and tactile forces are key drivers of collective motion, a hypothesis that has not yet been explored. To address this gap, we introduced physical constraints into a canonical model of collective motion (Couzin et al., 2002) in the following way. Instead of using points, we used solid, oval-shaped objects that cannot overlap. These objects could only interact with neighbouring objects they can "see" directly, where nothing is blocking the straight line between them (ray tracing). These restrictions provided the minimum ingredients for a visual and tactile force driven (thus naturally topological and anisotropic) implementation of the canonical model.

To examine how the introduction of physical constraints changed the canonical model's behaviour, we compared our modification of the canonical model to other topological modifications of the same model found in the literature, which included modifications based on limiting interactions to a single influential neighbour, to the N closest neighbours, or to neighbours forming a Voronoi tessellation around the focal particle (Mudaliar et al., 2022; Strandburg-Peshkin et al., 2013). We found that, in contrast to our modification which was able to reproduce the parameter space of the canonical model, the alternative topological modifications were not able to reproduce the emergent states of the canonical model and often fragmented into smaller subgroups, despite some alternative implementations interacting with more neighbours on average than could be seen by the solid body groups of our implementation (on average).

We performed a sensitivity test on the shape and size parameters of the solid body objects used in our modification and found that the emergent group state (swarm, mill or parallel motion) varied as we changed the shape or size of the solid body objects. After modifying our implementation so that the visual rays emerge from a pair of bi-focal eyes rather than the centre of the solid objects, we found that the emergent group state is also a function of eye position.

Our results suggest vision and tactile feedback carry key information in collective motion, which other topological approaches do not capture. Due to our modification requiring large numbers of intersection calculations for computing solid body and visual interactions, we have up to now only gained results for the two-dimensional case but are preparing further investigation into three-dimensions.

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