25th International Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July 2023
mssanz.org.au/modsim2023

Individual measures for heterogeneous collective motion

Andrei V. Zvezdin[a], Mitchell C. Welch [a] and Timothy M. Schaerf [a]

[a]*School of Science and Technology, University of New England, Armidale, Australia*

Email: azvezdin@myune.edu.au

Abstract: Insect swarms, fish schools and bird flocks are familiar everyday examples of collective motion. How these groups synchronize despite being made up of vastly different individuals is a fascinating question. Classical modeling of collective motion assumes homogenous individuals interacting locally to produce group-level patterns which are then classified via summary measures, usually called order parameters, such as the degree of alignment or rotation of the group. Empirical and theoretical work have pointed to the importance of individual differences (heterogeneity) driving collective behaviour. To investigate how individual differences drive collective motion, we need to understand how the different members contribute to the emergent collective motion phenomena. For this we need to shift the focus from the group to the individual and either introduce new measures or generalize the group level order parameters to the individual level.

We investigated the following measures for studying heterogeneous groups: 1) the individual state (cycling, directed, random or composite trajectories) derived from applying alignment and milling order parameters to an individual's track; 2) the individual fluidity defined as the amount of movement relative to the group centroid over a fixed period; 3) the dichotomy defined as the local difference in heading between a focal individual and its neighbours and 4) the number of neighbours an individual sees or interacts with. Using a canonical zonal (repulsion, orientation, attraction) constant speed self propelled particle model we applied the above measures to homogenous and heterogeneous groups comprised of two distinct behavioural class types to investigate key questions of multi-stability, self-sorting and state transitions. We investigated these questions in the context of hysteresis as it is a natural measure of multi-stability and the tendency of a collective motion system to exhibit a form of collective memory where current emergent group behaviour is influenced by the recent history of the system. We produced hysteresis loops for heterogeneous groups by keeping one subgroup fixed while varying the other's orientation parameter. Using motion rugs to visualize our results we found high levels of distance based self-sorting, particularly during transitions between collective movement states. We also found that groups containing subgroups representing swarming or parallel behavioural types tended to resist hysteresis, and often self sorting as well, stabilizing the group at particular collective motion states. Fig 1 illustrates some of the concepts.

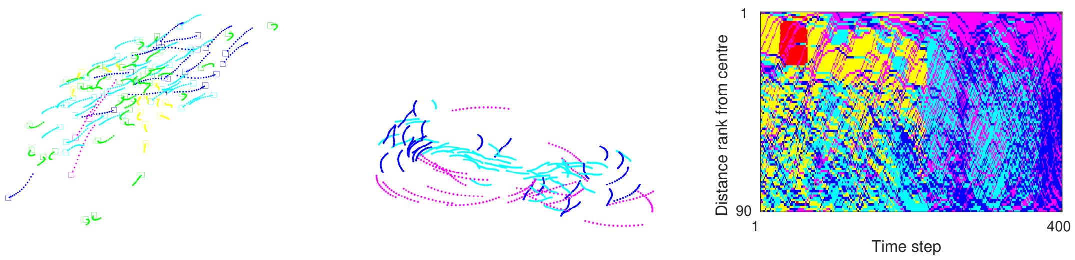

Fig 1: An illustration of the methods and concepts for the case of a simulated homogenous group of 90 particles transitioning from a parallel to a milling state and the fluidity measure applied to the above. Left: the local fluidity measure of a parallel group, lines indicate movement relative to centroid while color shows extent of past movement (see colorbar, 1 = most solid, 6 = most fluid). Here highly fluid individuals instigate a transition. Centre: group fluidity 10 seconds later. Right: to interpret our measures at a global level, we used motion rugs, each row of this graph corresponds from top to bottom with the nearest to farthest individual from the group centre at a given time, with each column corresponding to increasing sample times from left to right. Colours on the graph correspond to the individual fluidity measure, 400 simulation time steps of the transition are shown.

Keywords: *Collective motion, heterogeneity, individual measures, motion rugs, self propelled particle models*