Thesis Title: Intrinsic Noise in Collective Dynamics

Jitesh Jhawar
Indian Institute of Science, Bengaluru

Synopsis

Animal groups exhibit many emergent properties that are a consequence of local interactions. Linking individual-level behaviour to group-level dynamics has been a question of fundamental interest from both biological and mathematical perspectives. However, most empirical studies have focussed on average behaviours ignoring stochasticity at the level of individuals. On the other hand, conclusions from theoretical models are often derived in the limit of infinite systems, in turn neglecting stochastic effects due to finite group sizes. In our study, we use a stochastic framework that accounts for intrinsic-noise in collective dynamics arising due to (a) inherently probabilistic interactions and (b) finite number of group members. We derive equations of group dynamics starting from individual-level probabilistic rules as well as from real data to understand the effects of such intrinsic noise and the mechanisms underlying collective behaviour.

First, using the chemical Langevin method, we analytically derive models (stochastic differential equations) for group dynamics for a variable m that describes the order/consensus within a group. We assume that organisms stochastically interact and choose between two/four directions. We find that simple pairwise interactions between individuals lead to intrinsic-noise that depends on the current state of the system (i.e. a multiplicative or state-dependent noise). Surprisingly, this noise creates a new ordered state that is absent in the deterministic analogue.

Next, focussing on small-to-intermediate sized groups (10-100), we empirically demonstrate intrinsic-noise induced schooling (polarized or highly coherent motion) in fish groups. The fewer the fish, the greater the intrinsic-noise and therefore the likelihood of alignment. Such empirical evidence is rare, and tightly constrains the possible underlying interactions between fish. Our model simulations indicate that fish align with each other one at a time, ruling out other complex higher-order interactions.

Further, we analyze the method to derive the group-level dynamical equation using simulated data from two different models of collective behaviour. In doing so we resolve important time-scale related issues with deriving the determinisitic and stochastic components of the mesoscopic description from the data.

Broadly, our results demonstrate that rather than simply obscuring otherwise deterministic dynamics, intrinsic-noise is fundamental to the characterisation of emergent collective behaviours, suggesting a need to re-appraise aspects of both collective motion and behavioural inference.