Collective motion and consensus decision-making in social animal groups

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Collective motion usually refers to the coordinated motion exhibited by groups of social animals and its a beautiful example of self-organization in natural far-from-equilibrium systems. It is observed in a broad range of living systems, from bacterial colonies to the spectacular form of wildebeest herds crossing deserts in Africa, huge fish schools running away coordinately from predators, and even in human crowds.

Real animals percieve a broad variety of social and environmental stimuli and, probably, perform complex stochastic decision-making processes to eventually coordinate their behavior, since coordination and cooperation are often crucial to their survival and reproductive success. Despite the rich ethological diversity, the ubiquity of collective behavior in very disparate systems suggests the existence of some underlying principles that transcends the peculiarities of individual animals and species.

As statistical physicists, our current understanding of collective animal behavior is thus largely based on models that, quite often, consider self-propelled identical agents that obey similar interaction rules. Indeed, statistical models, such as the celebrated Vicsek model, have shown that simple rules for local interaction among individuals can generate coordinated behavior like that found in natural systems. Using these models, or more coarse-grained descriptions, physicist have established several analogies between collective motion and more traditional physics disciplines such as collective phenomena, phase transitions and rheology.

Following this statistical physics approach, we will first discuss some modeling results where we apply common statistical physics techniques to characterize collective motion in social animal systems. Then, since our research group is currently working to validate some of our modeling hypothesis and results by using empirical data obtained from the observation of schools of black neon tetra swimming in a lab tank, we will also discuss some empirical results along with our modeling efforts to describe the collective behavior of real fish schools.

Social relationships, for instance, characterize the interactions that occur within social species and may have an important impact on collective animal motion. By incorporating interactions mediated by an empirically motivated scale-free topology that represents a heterogeneous pattern of social contacts, we observe thatthe degree of order of the model is strongly affected by network heterogeneity.

We also examine avalanching behavior (behavioral cascades) in the collective motion of groups where a single individual has a long range orientational contagion effect over the rest ofindividuals. Behavioral changes at the individual level, which may by transmitted to the group, are well documented in the literature and can trigger intermittent avalanche-like behavior. The results obtained appear to be in qualitative agreement with experimental results characterizing collective motion in schooling fish (see Fig. 1). Yet, more empirical data are needed to obtain a better understanding of the reorientations patterns in confined systems.

Speed acts as a modulator of collective ordering, which makes sense from an adaptive perspective. Responding to speed variations requires minimum perception and cognitive abilities, and it functions as a mechanism to transfer information fast and efficiently. We find that individual fish speeds, compatible with a burst-and-coast behavior, are synchronized at the global level, resulting in a quasi-periodic oscillation pattern of speed over time. Changes in global polarization are positively correlated with changes in average speed with a characteristic time lag, and both quantities tend to oscillate with the same effective period.

Collective motion implies collective decision-making, a process which occurs daily in the lives of many group living animals. Understanding how consensus is reached, understanding who, if any, has any influence and the mechanisms by which information and preferences are integrated, poses a fundamental challenge in this research field. We finally discuss modeling results of consensus decision-making to understand the effects of animal interdependencies for the case of information pooling. Some of these results are also studied experimentally in a swarm of kilobots, mini-robots that are able to detect each other and exchange simple messages within a given distance, especially well suited to study the process of collective decision making.

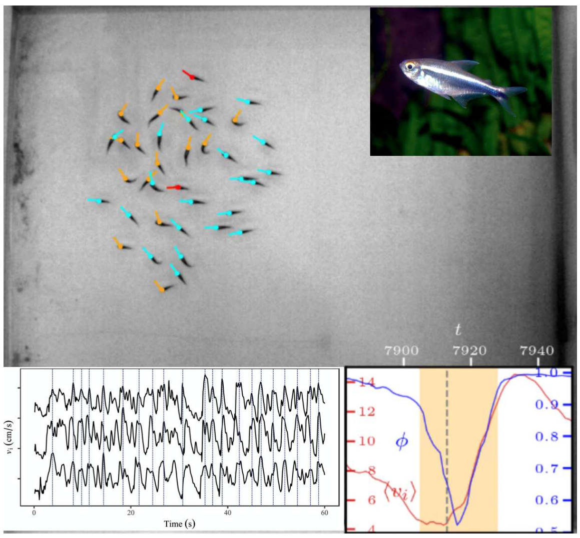

Fig. 1. School of 40 black neon tetra in a laboratory tank. Bottom insets: Fish speed in time. Average speed (red line) and polarization (blue line) in the course of an avalanche.