Similar emergent states in swarming animals and thermophoretic colloids

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Bird flocks, insect swarms and fish shoals resemble fluids made up of many individuals where the controlling interactions are social rather than physical in character [1]. Some progress has been made reverse-engineering candidates for these interactions that are local in space, either in a metric-based [2] or topological sense [3,4]. A question that has been largely overlooked is whether the interactions should be expected to be local at all. We discuss the evidence for them having a non-local character and, furthermore, that there is a natural choice for this that is consistent with the cognitive limitations of a bird's vision. This leads us to propose a non-local *hybrid-projection* model. This has the physically satisfying feature that it involves an unusually small number of control parameters, when compared with other swarming models. We study the global character of the flocks that emerge from this model and their various phenotypes. Most significantly, an emergent state arises in which the probability that a typical bird can see out (sky) in any direction divided by the probability that its view is blocked by other bird(s) is O(1). We refer to this as *marginally opaque*, see Fig 1. We present experimental data on bird flocks that confirm this prediction and discuss how these models may naturally be associated with evolutionary fitness, as well as being physiologically plausible.

Finally we report on recent work on systems of thermophoretic colloids that are heated by an external light source, extending on [5]. We show that these systems can undergo first order transitions from compact to disperse states as the light intensity is varied. Intriguingly, we find that the same state of marginal opacity emerges: no compact state with a density below marginal opacity is stable. This reveals an unexpected similarity between social and thermodynamic swarms.

Figure 1: The centre panel is an image of a real flock of Starlings. It is *marginally opaque*. The left and right panels show the same image artificially doctored so as to resemble states that would have a very low (<<1) or a very high (≈1) opacity, respectively.

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