Frontier of Statistical Physics and Information Processing 2013

Statistical mechanics of flocks of birds

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The coordinated flight of bird flocks are a striking example of collective behaviour. The way flocks choose a common flight direction is reminiscent of models of ferromagnetism in which local interactions between spins lead to strong polarization at the macroscopic scale. Many theoretical studies have explored these ideas in the context of models of active matter. I will show how to make this analogy mathematically precise using field data. Using the maximum entropy principle, we learn effective equilibrium models of continuous spins (representing flight directions), formally equivalent to the Heisenberg model, directly from three dimensional flock reconstructions, with minimal assumptions. The range of interactions is inferred to be local in space, with a topological distance rule, and leads to long-range order. I will then show how the non-equilibrium behaviour of the system can also be learned from successive snapshots using the maximum entropy principle with temporal cross-correlations. This approach leads to a generalization of the Vicsek model, a common model of alignment by social forces, whose parameters can be learned from field data.