Mouvements collectifs des oiseaux : quelques perspectives

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Institut Jacques Monod – 5 avril 2011

Starlings in the sky of Rome

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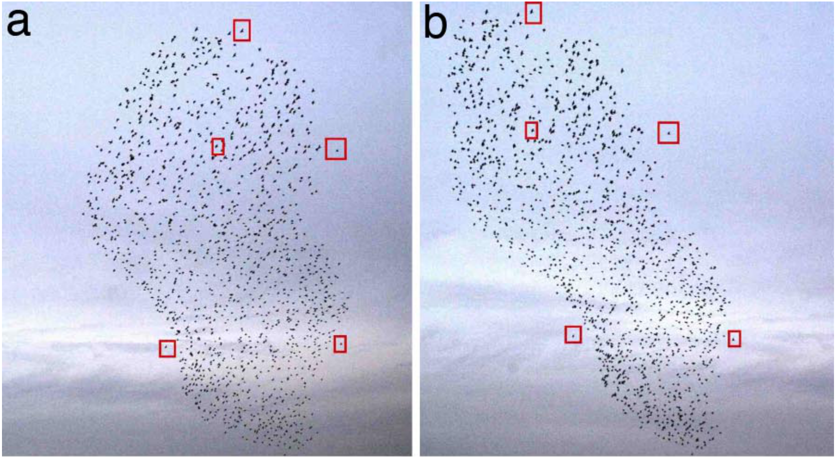
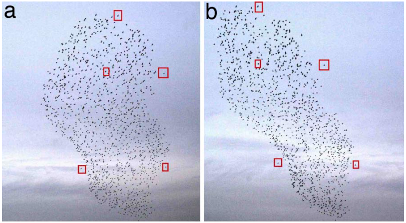
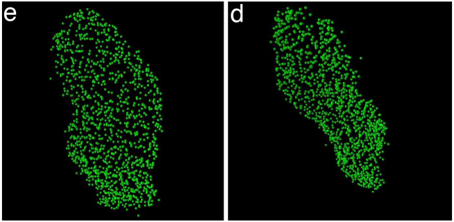


Starlings in the sky of Rome



← same time, different perspective

3D reconstruction →



[Michele Ballerini, Nicola Cabibbo, Raphaël Candelier, **Andrea Cavagna**, Evaristo Cisbani, **Irene Giardina**, Vivien Lecomte, Andrea Orlandi, Giorgio Parisi, Andrea Procaccini, Massimiliano Viale and Vladimir Zdravkovic, PNAS **105** 1232 (2008)]

Physical point of view

Features

- Dissipation (energy is spent flying)
- No leader (local dynamics)
- Fluctuations

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Vicsek model

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- Birds align with their neighbours ($\leftarrow$ local interact.)
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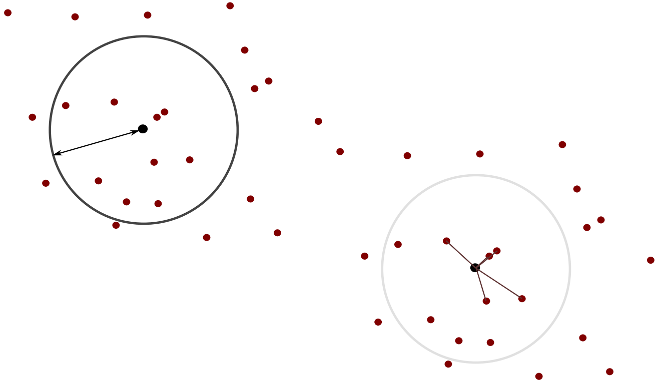
Who are your neighbours?

Metric interaction

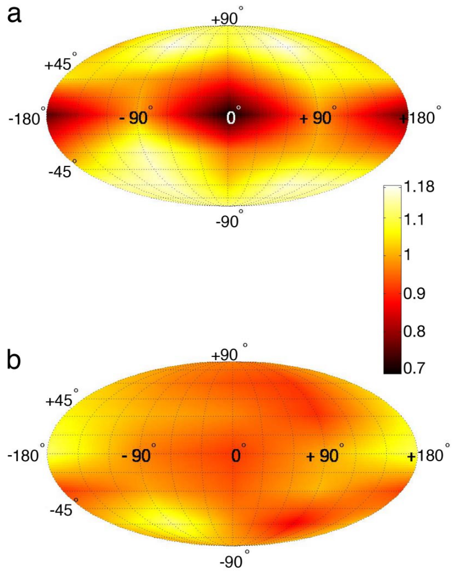
Birds inside a sphere of fixed radius



Topological interaction

Fixed number of closest neighbors

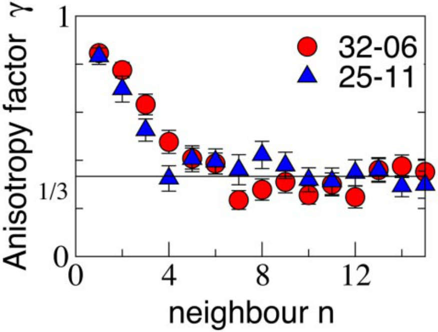
Short/long distance correlations



Correlation map at close range

Correlation map at large range

Counting while flying



anisotropy γ becomes isotropic @
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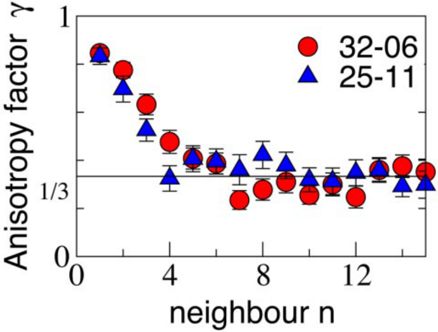


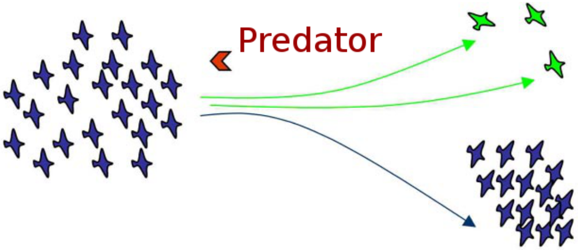
anisotropy γ becomes isotropic @
characteristic distance r_c
characteristic neighbour number n_c

Among flocks of different densities
n_c stays constant while r_c varies
$\rightarrow$ *this characterises the topological interaction*

$$n_c = 6.5 \pm 0.9$$

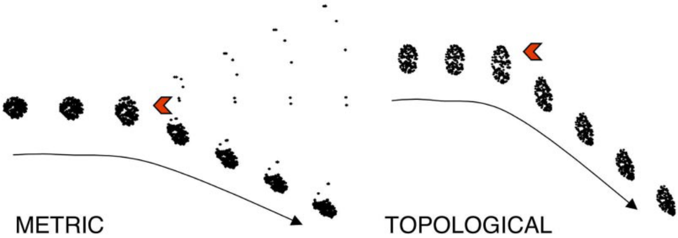
Numerical experiment

Settings



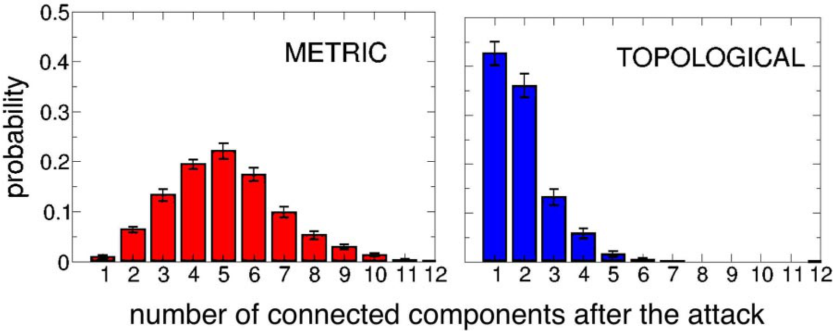
Numerical experiment

Successive snapshots



Numerical experiment

Quantifying the robustness



Perspectives

IEEE Transactions on Automatic Control, **48** 6 (2003)

Coordination of Groups of Mobile Autonomous Agents Using Nearest Neighbor Rules

Ali Jadbabaie, Jie Lin, and A. Stephen Morse, *Fellow, IEEE*

Questions

- Convergence to a stable flow?
- Dependence on the initial condition?
- One bird (or ‘agent’) is directed: does the flock follow?

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Approach

- Dynamical network of interacting birds.
- Results of ergodic matrix theory.

  $\rightarrow$ Solved in some cases (gentle initial condition, metric interaction).

arXiv:1107.0604 (PNAS 2012)

Statistical mechanics for natural flocks of birds

William Bialek[a], Andrea Cavagna[b,c], Irene Giardina[b,c,1], Thierry Mora[d], Edmondo Silvestri[b,c], Massimiliano Viale[b,c], and Aleksandra M Walczak[e]

Interactions among neighboring birds in a flock cause an alignment of their flight directions. We show that the minimally structured (**maximum entropy**) model consistent with these local correlations correctly predicts the propagation of order throughout entire flocks of starlings, with **no free parameters**. These models are mathematically equivalent to the Heisenberg model of magnetism, and define an “energy” for each configuration of flight directions in the flock. Comparing flocks of different densities, the range of interactions that contribute to the energy involves a fixed number of (**topological**) neighbors, rather than a fixed (**metric**) spatial range. Comparing flocks of different sizes, the model correctly accounts for the observed scale invariance of long ranged correlations among the fluctuations in flight direction.

J. Phys. A: Math. Theor. **42** 445001 (2009)

Hydrodynamic equations for self-propelled particles: microscopic derivation and stability analysis

Eric Bertin[1,2], Michel Droz[2] and Guillaume Grégoire[3]

Considering a gas of self-propelled particles with binary interactions, we derive the **hydrodynamic equations** governing the density and velocity fields from the microscopic dynamics, in the framework of the associated Boltzmann equation. Explicit expressions for the transport coefficients are given, as a function of the microscopic parameters of the model. We show that the homogeneous state with zero hydrodynamic velocity is **unstable above a critical density** (which depends on the microscopic parameters), signalling the onset of a collective motion. Comparison with numerical simulations on a standard model of self- propelled particles shows that the phase diagram we obtain is robust. [...] We find **solitary wave solutions** of the hydrodynamic equations, quite similar to the stripes reported in direct numerical simulations of self-propelled particles.

Generalized Navier-Stockes equation: ($\mathbf{w} = \rho\mathbf{v}$ = momentum field)

$$\frac{\partial \mathbf{w}}{\partial t} + \gamma(\mathbf{w}\cdot\nabla)\mathbf{w} = -\frac{v_0^2}{2}\nabla\rho + \frac{\kappa}{2}\nabla\mathbf{w}^2 + (\mu - \xi\mathbf{w}^2)\mathbf{w} + \nu\nabla^2\mathbf{w} - \kappa(\nabla\cdot\mathbf{w})\mathbf{w} + 2\nu'\nabla\rho\cdot\mathbf{M} - \nu'(\nabla\cdot\mathbf{w})\nabla\rho,$$

Correspondence btw micro- and macro-scopic parameters:

$$\nu = \frac{v_0^2}{4}\left[\lambda\left(1 - \mathrm{e}^{-2\sigma_0^2}\right) + \frac{16}{3\pi}d_0 v_0\rho\left(\frac{7}{5} + \mathrm{e}^{-2\sigma^2}\right)\right]^{-1},$$

$$\gamma = \frac{16\nu d_0}{\pi v_0}\left(\frac{16}{15} + 2\,\mathrm{e}^{-2\sigma^2} - \mathrm{e}^{-\sigma^2/2}\right),$$

$$\kappa = \frac{16\nu d_0}{\pi v_0}\left(\frac{4}{15} + 2\,\mathrm{e}^{-2\sigma^2} + \mathrm{e}^{-\sigma^2/2}\right),$$

$$\mu = \frac{8}{\pi}d_0 v_0\rho\left(\mathrm{e}^{-\sigma^2/2} - \frac{2}{3}\right) - \lambda\left(1 - \mathrm{e}^{-\sigma_0^2/2}\right),$$

$$\xi = \frac{256\nu d_0^2}{\pi^2 v_0^2}\left(\mathrm{e}^{-\sigma^2/2} - \frac{2}{5}\right)\left(\frac{1}{3} + \mathrm{e}^{-2\sigma^2}\right).$$

Waiting for *The birds 3D*