United by noise: Randomness helps swarms stay together

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Devastating consequences

During plagues, desert locusts can migrate over or into parts of 60 countries, covering more than 20% of the total land surface of the earth and affecting the livelihoods of 10% of the world's population.

A typical swarm can be up to one kilometre wide, up to three kilometres long and a quarter of a million locusts strong. Each of these locusts can eat up to their own weight (2g) in food every day.

Strategies to understand the formation and cohesion of locust swarms are therefore of great importance.

Experimental setup

Groups of (between 5 and 100) locust nymphs were placed in a ring-shaped arena (see Fig 1 (a)) and their movements recorded [2]. Low density (~20 individuals) groups aligned and marched in one direction around the ring for up to 3 hours, before spontaneously switching direction in the space of only a few minutes.

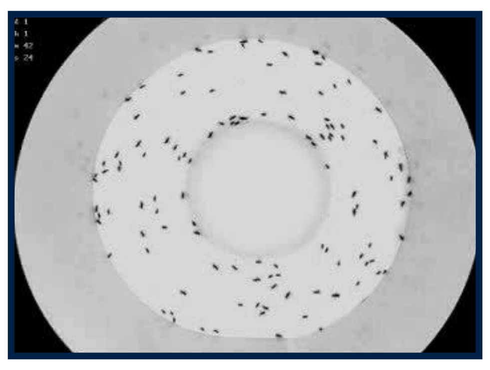

Fig. 1 (a): The ring-shaped experimental arena (from above).

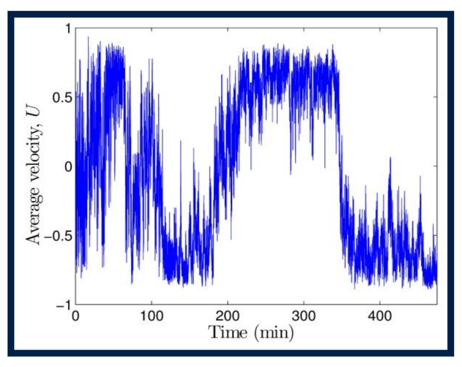

Fig. 1 (b): Average velocity, *U*, of 30 locusts over 8 hours.

The group property of average velocity, *U*, characterises the locusts switching behaviour. $|U| \sim 1$ indicates the locusts are aligned and marching in the same direction. Fig. 1 (b) gives an example of spontaneous switching.

The switching rate can be thought of as a measure of swarm stability: larger, more stable groups switch less often than smaller more volatile groups.

Our model

In order to investigate the locusts' behaviour we construct a 'self-propelled particle' model. Consider *N* 'particles' each representing a locust. Each particle adjusts its movement according to the behaviour of its neighbours within a radius, *R*. Particle *i*'s behaviour is described by its position, $x_i(t)$, and velocity, $u_i(t)$. Our particles move on a one-dimensional domain with periodic boundary conditions (representing the ring-shaped arena, see Fig. 2). At each time step, each particle uses a function of the measured velocity of its neighbours as its new velocity. Noise is added to mimic the uncertainty in the measurements and/or their implementation.

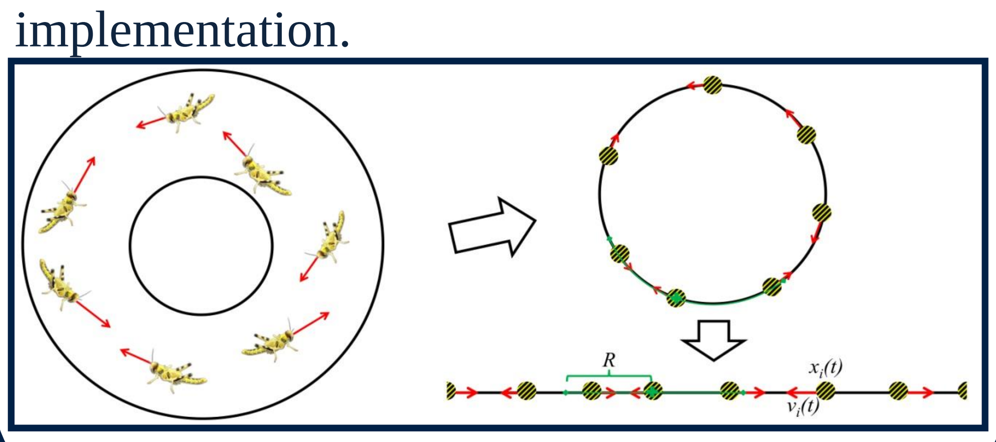

Fig. 2: A schematic justification of the one-dimensional model for locusts moving in the ring.

Model switching

Our model is capable of replicating the group-level property of density-dependent stochastic switching found in the experiments [1] (see Fig 3).

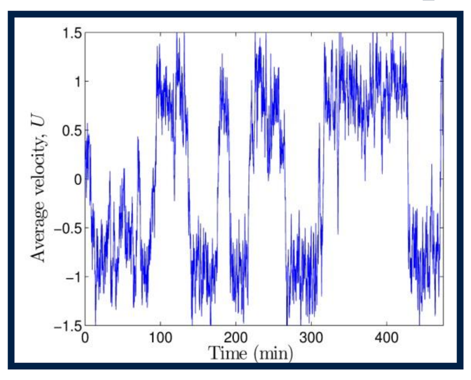

Fig. 3: Average velocity, *U*, of 30 simulated locusts looks qualitatively similar to the experimental switching behaviour (*cf.* Fig. 1 (b)).

Effective SDE for *U*

Switching behaviour of this type can also be reproduced using an appropriate Stochastic Differential Equation (SDE). In order to compare our model to the data directly, we assume that there are effective SDEs for the average velocity of the locusts, *U*, for both the data and the model. We developed a technique [1,3] which employs short bursts of simulation/data in order to estimate these coefficients for a discrete range of values of *U*. We then compared these coefficients in order to determine the validity our model.

Refining our model

Upon finding that the diffusion coefficient of our model did not match that of the data we altered the original model (see Fig. 4). Now, when our simulated locusts find themselves unaligned with their neighbours they increase the randomness in their motion. This effect propagates through to the corresponding SDE, changing the noise term from additive to multiplicative. The agreement between the coefficients of the data and the revised model is clear (Fig. 4).

Comparing coefficients

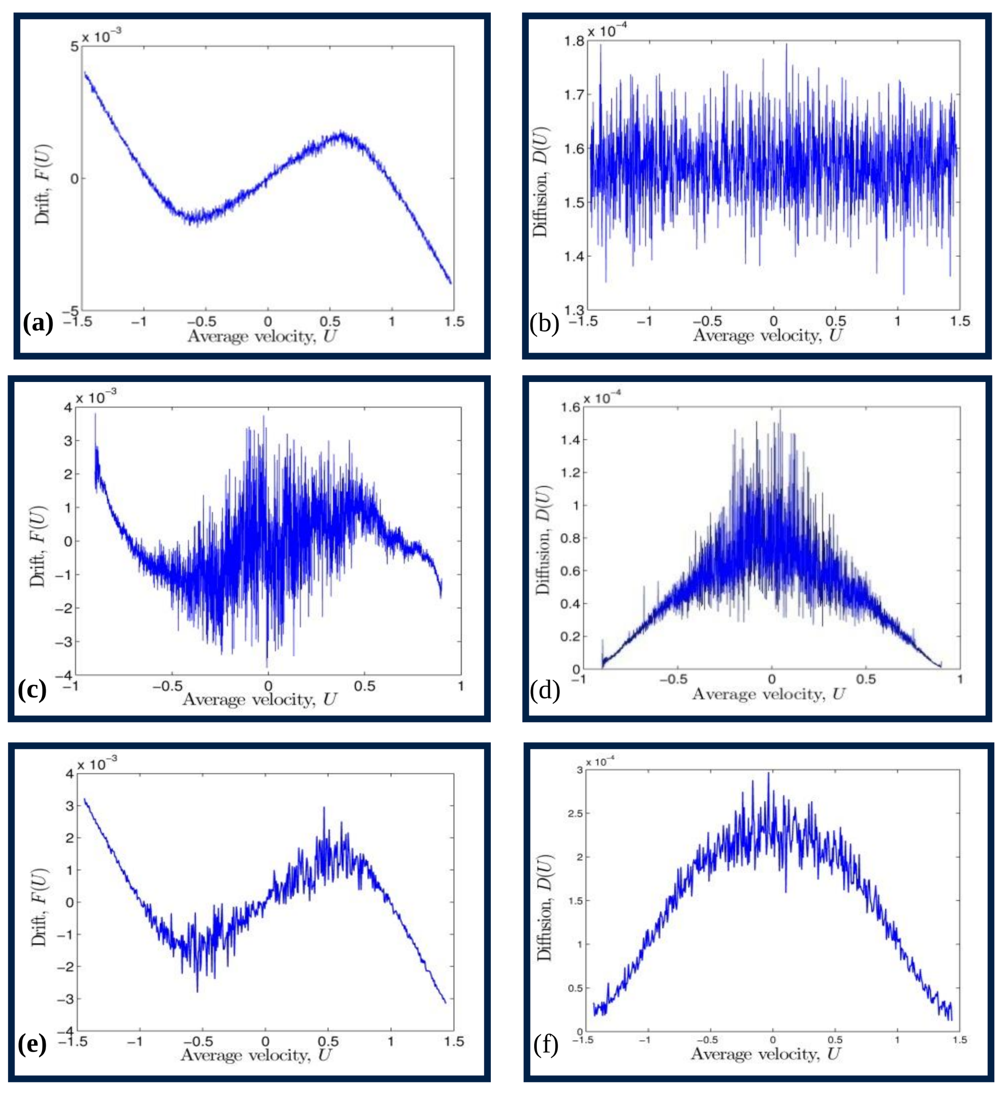

Fig. 4: Drift and diffusion coefficients of underlying SDEs for our original model (a-b), the experimental data (c-d) and our refined model (e-f). All drift coefficients are roughly cubic with varying degrees of noise. The quadratic shape of the experimental diffusion coefficient (d) is matched qualitatively by that of our refined model (f) but not by the uniform diffusion coefficient of our original model (b).

Implications for locusts

Based on a comparison with experimental data we inferred a revised interaction rule in our individual-based model. This revision indicates that locusts increase the noisiness of their motion when their perceived local alignment is smaller. This local effect gives rise to a global phenomenon: locust groups remain aligned for longer than in the previous model [1]. **Counterintuitively, this indicates that increasing the randomness of their motion may aid locust swarm stability.** Stability may be selected for in an evolutionary scenario since it allows the locusts to remain in a coherent group for longer periods, potentially increasing harvesting efficiency and reducing predation.

Cannibalism

Fig. 5: Cannibalism in locusts.

The best way for locusts to get protein and salt into their diet is to eat other locusts [4]. Experiments have revealed that an individual's sides are most vulnerable to cannibalistic attack [5].

This may provide a rationalization for the observation of increased individual randomness in response to a loss of alignment at the group level: given the risk of exposing the rear of the abdomen to oncoming insects, there may be selection pressure on an individual to minimize the time spent in the disordered phase.

Managing locust plagues

Our model suggests that, reducing cannibalism by providing alternative, protein- and salt-rich food sources may reduce cohesion and marching motivation in locust swarms, potentially leading to their eventual break-up. Our model also suggests locusts are extremely susceptible to noise and explains why strategies which increase the overall randomness of a swarm (e.g. flying aeroplanes low overhead) are increasingly being employed in an attempt to disorient and disperse swarms.

References

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[2] Buhl *et al.*, Science 312, pp. 1402-1406 (2006).

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[4] Simpson *et al.*, PNAS 103(11), pp. 4152-4156 (2006).

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