# Order in groups

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Groups of living things – flocks of birds (Figure 1), shoals of fish, groups of motile cells, etc. have compelling similarities with liquid crystals. Comparable to the sort of ordering found in such living aggregations, in liquid crystals also elongated molecules spontaneously align themselves with one another for reasons of 'packing'. Probing this similarity raises some interesting questions. Can the physics of flocks describe the physics of liquid crystals? What laws of mathematics or physics govern this order and mass movement? As it turns out, some rather unexpected and extraordinary findings emerge when the organization in such groups is examined!

Narayan *et al.*[1] have described an experiment to study order in such systems. A system to mimic groups discussed above was created by cutting a copper wire ($d = 0.8$ mm) into rods (length $l = 4.6 \pm 0.16$ mm). The tips of each rod were tapered. A monolayer of these rods was placed in a closed cell of height 1 mm and circular cross-section diameter of 13 cm. To inject 'life' into the rods, the cell was mounted on a permanent magnet shaker and vibrated vertically (frequency of vibration $f = 200$ Hz and amplitude $A$ between 0.025 and 0.043 mm). Through frequent collisions with the floor and ceiling of the cell, the rods could gain kinetic energy. These collisions imparted or absorbed momentum in the horizontal direction. Collisions between particles also impelled horizontal motion by converting vertical motion into motion in the horizontal plane. As the two ends of an individual rod did not differ significantly, the collection as a whole could condense into what is known as the true 'nematic' phase. A 'nematic' phase is characterized by parallel orientation on average of the axes of the rods, with no sense of forward or back. Such an ordered state is not altered when the direction of one or more rods is reversed. According to Ramaswamy, 'The most familiar examples of flocks are of course of creatures whose head and tail are distinct. However, there is a simpler kind of order, in which the axes of the constituents are spontaneously aligned parallel to one another on average, but with fore-aft symmetry. Our experiment studied this state, known as a nematic liquid crystal because it is the simplest state with orientational order, and also because our theoretical work[2] predicted that it would display particularly bizarre behaviour.'

While the rods were being shaken, the arrangements assumed by the rods on the cell surface were digitally photographed at regular intervals. Contrary to what might be ordinarily expected, the remarkable observation was that the rods did not pack themselves in a relatively uniform manner over the surface of the cell (Figure 2). Rather, there were large and dynamic density fluctuations, with the rods closely packed in some areas of the cell and sparsely packed in other areas, and the areas themselves wandering across the cell. These inhomogeneities are referred to as 'giant number fluctuations'.

To examine the arrangement of the rods, subsystems of different sizes within the total cell area ranging in size from 0.1 $l$ by 0.1 $l$ to 12 $l$ by 12 $l$ ($l$ being the length of rod) were digitally photographed. The total number of rods was varied in the

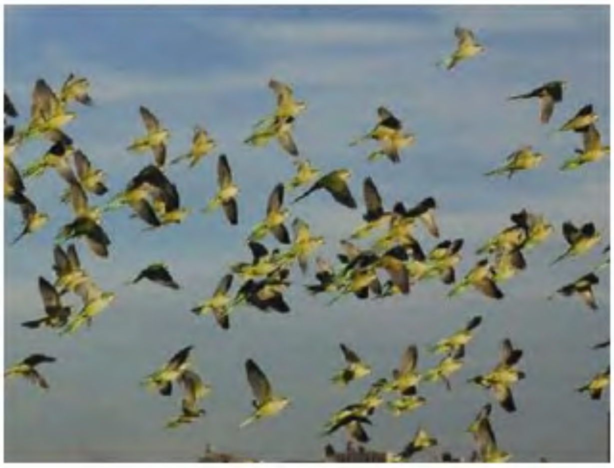

**Figure 1.** What rules does a bird in a flock follow? (Photo credit: Steve Baldwin, www.BrooklynParrots.com).

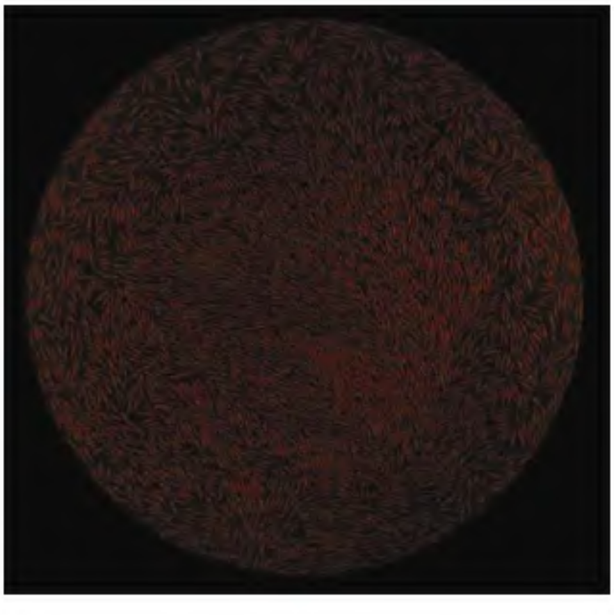

**Figure 2.** An arrangement assumed by the rods showing the giant number fluctuations.

**Figure 3.** Study of fish shoals agrees well with theoretical models predicting their behaviour (Photo credit: Peter M. Forster).

trials between 1500 and 2820. The area occupied by the particles divided by the surface area of the cell is the area fraction $\phi$, and this varied between 35 and 66%. From the photographs, the average $N$ and the standard deviation $\Delta N$ of the number of particles in each window was obtained. Where the conditions of the central limit theorem are satisfied, $\Delta N/\sqrt{N}$ should be a constant independent of $N$. However, it was seen that when the area fraction $\phi$ is large, $\Delta N/\sqrt{N}$ is not a constant. For big subsystems, the data showed giant fluctuations with $\Delta N$ growing more rapidly than $\sqrt{N}$ and consistent with proportionality to $N$. For smaller average number density, it was found that the nematic order was poorly developed and $\Delta N/\sqrt{N}$ was independent of $N$ as in thermal equilibrium systems.

The other significant finding was to do with the life span of each arrangement. How long did it take for either a sparsely populated region or a densely populated to travel from one location and form in another area? To figure this out, a subsystem of size $l$ by $l$ was scrutinized by taking images at a frame rate of 300 frames per second and a time series of particle number $N(t)$ obtained. From this, the temporal autocorrelation $C(t)$ of the density fluctuations was determined. It was found that $C(t)$ decayed logarithmically in time showing that the large density fluctuations were extremely long-lived.

These experimental results in fact substantiate earlier results from computer simulations[3] and confirm striking theoretical predictions[2] of such systems. Why do the rods not pack themselves uniformly across the surface of the cell? It turns out that such giant number fluctuations come about when particle motion is to happen in a particular direction. Particles move along their axes by first aligning themselves parallel to those in their immediate neighbourhood. In theoretical studies, imposing the condition on the particle that the movement happens along the particle axis in such a grouping was sufficient to produce giant number fluctuations. Intriguingly, when the rods did not have the ends etched, the nematic phase itself disappears and presumably as a consequence, the giant number fluctuations were not seen! Shape then has a significant effect on these groupings.

These findings have implications for studies on several natural systems. For instance, studies of extremely large fish shoals, stretching over several kilometres, (Figure 3) have shown that localized sampling of fish populations cannot be used to accurately estimate the size of the entire shoal[4]. As the authors conclude in their paper, 'The particles in our driven system do not communicate except by contact, have no sensing mechanisms, and are not influenced by the spatially varying pressures and incentives of a biological environment. This reinforces the view that, in living matter as well, simple, nonspecific interactions can give rise to large spatial inhomogeneity. Equally important, these effects offer a counterexample to the deeply held notion that density is a sharply defined quantity for a large system.'

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3. Chete, H., Ginelli, F. and Montagne, R., 2006.
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