FLUIDDYNAMICS

Flows like smoke and honey

Observe wafting cigarette smoke, and you are watching some complex physics: close to the lit end, the smoke rises smoothly; farther away, it unfurls into swirls. This second type of behaviour is an example of chaotic, turbulent flow, the course of which — because of the huge number of interacting particles involved — cannot be precisely predicted.

Denis Bernard *et al.* instead perform numerical simulations of turbulent flow (*Nature Phys.* 2, 124–128; 2006). Surprisingly, they find a connection between two-dimensional turbulence and a simpler, hitherto unrelated

phenomenon — that of critical percolation.

Percolation describes the flow of a fluid through a porous material, such as honey seeping through beeswax. In a honeycomb, percolation reaches a critical threshold at which half the cells are filled with honey and the probability that a row of honey-filled cells spans the whole layer is not zero (although it might be infinitesimally small). At criticality, the filled and empty clusters of cells assume a 'fractal' pattern that follows a principle known as conformal invariance: as long as the angles don't change,

magnifying different sections of the pattern by different amounts results in a pattern that is indistinguishable from the original.

The principle is demonstrated in this image of Bernard and colleagues' turbulent flow. Here, connected clusters of vortices rotating in one direction are coloured and those rotating in

the other are black; the resulting pattern is indistinguishable on small and large scales. The authors calculate a fractal 'dimension', a measure of the degree to which the pattern seems to fill space as one looks at ever finer scales. The value they find, $4/3$, corresponds exactly to that found in the distribution of a fluid such as honey at the critical percolation threshold.

The discovery of this link could open the field of turbulence to the full theoretical artillery of conformal mapping, a technique that is central to a whole range of physical theories, such as string theory, besides critical percolation. But more work is required to smoke out the exact extent to which these ideas can be applied.

May Chiao

stocks are available by mail, each with TG-1 expressed in a different tissue, neuroanatomical structure or subgroup of neurons.

Nowadays, TG-1 usually encodes GAL4, a gene regulator that can be used specifically to turn on a second transgene ('TG-2') only in the requisite tissues or cell types. TG-2 will be a particular gene variant or mutation of interest, and it will have genetics such that it can be transferred into or out of a fly's genome via simple genetic crosses³. So it is now possible, by mail order and simple fly breeding, to express almost any interesting gene in an infinite variety of tissues or cells (Fig. 1). TG-2 can encode a gene product that identifies the selected neurons by dye or fluorescence, or it can be a protein that kills them, blocks transmission from them or overstimulates them. If TG-2 makes a protein that fluoresces in response to markers of neuronal activity such as elevated calcium or membrane voltage changes, then one can watch the neurons in action^{4,5}.

Liu *et al.*¹ used this method to dissect minutely the circuits involved in learning visual patterns. In their behavioural assay⁶, the fly faces a choice between two visual figures (for example, upright and inverted T shapes) and is punished by mild heating when it turns to one of them. Not surprisingly, the fly ends up facing the other figure; more surprisingly, it remembers to face the second figure in a subsequent test without heat reinforcement⁷.

Learning in *Drosophila* depends substantially on the Rutabaga enzyme. This enzyme is a calcium-calmodulin-dependent adenylyl cyclase⁸ that could be a molecular site for the convergence of signals from the cued stimulus and the reinforcement. Different types of learning require Rutabaga in different areas of the brain. Odour-discrimination learning, for instance, requires the enzyme found in brain structures called the mushroom bodies⁹. What Liu *et al.* show is that to learn specific visual

patterns, a fly must have Rutabaga in a brain region known as the central complex. They used mutant flies that lacked Rutabaga, and then switched Rutabaga on in a selection of specific patterns using the system above, and tested to see which flies remembered the visual cues. Strikingly, discrimination between different features — the angular orientation of a bar or its vertical position on the fly's retinal field — requires Rutabaga in different sets of central-complex neurons, which project to different layers of the 'fan-shaped body' (FB), a substructure of the central complex (Fig. 2). Those neurons that use Rutabaga to store vertical elevation extend into FB layer 5; those that encode contour orientation project to FB layer 1.

How does this work advance the field? Memory has been plausibly localized to small groups of neurons before, in *Aplysia*, but that was memory simply to increase or decrease

the strength of an innate reflex — gill withdrawal after electric shock. Liu *et al.* localize memories much richer in information about higher-order visual properties — memories that presumably require the cells' integration into finely tuned circuits. Can we understand the circuits? Probably not for a while. The neuroanatomy of the central complex has been systematically studied, and several stereotyped classes of neuron have been categorized and mapped there¹⁰. The organization of the central complex is repetitive and regular, but fiendishly intricate. Understanding how the circuitry encodes angular orientation, for example, will require either new methods or clever, and lucky, anatomical insight.

A more tractable question is: how does Rutabaga bring about changes in the appropriate central-complex cells to encode the memories, and what are the relevant changes? If the changes are structural, there are methods that will pinpoint them¹¹. Finding electrical changes in the cells is a knottier problem, because the central-complex cells are small and located deep inside the fly brain. Clues may come from other mutants deficient in learning, work on *Aplysia*, or studies of larger, more superficial cells in the *Drosophila* brain⁵. What Liu *et al.* make very clear is that genetic trickery has converted *Drosophila* from one of the worst organisms for functional neuroanatomy to one of the better ones. Indeed, for localizing individual, complex memories it may be the best.

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Figure 2 | Pinpointing visual memories. The pictures show brain sections of flies, with the fan-shaped body (FB) outlined in yellow. In the cells coloured white, the Rutabaga enzyme was needed to learn the visual cues shown on the left. Liu *et al.*¹ show that the ability to learn the horizontal elevation of a cue requires Rutabaga in a different set of FB neurons than does the ability to learn a diagonal cue. The involvement of the white-stained cells seen elsewhere in the brain was ruled out by other experiments. (Adapted from Liu *et al.*¹.)

1. Liu, G. *et al.* *Nature* **439**, 551–556 (2006).
2. O'Kane, C. J. & Gehring, W. *Proc. Natl. Acad. Sci. USA* **84**, 9123–9127 (1987).
3. Brand, A. H. & Perrimon, N. *Development* **118**, 401–415 (1993).