

Animal navigation

Ants march as they march

Mandyam V. Srinivasan

Behavioural biologists have long been intrigued by the strategies that animals use to find their way to a feeding site and return home. Hymenopterans, given their miniature brains, are particularly impressive navigators. Bees, wasps and certain species of ant rely heavily on vision for navigation and are very adept at using prominent landmarks, when available, as aids. The paper by Judd and Collett on page 710 of this issue¹ provides new insights into how landmarks are memorized and used.

Nearly 20 years ago, Wehner and R ber² and Cartwright and Collett³ suggested how an insect, when close to its goal, might make use of the surrounding landmarks to pinpoint that goal. Upon its first visit to the goal, the insect takes a 'snapshot' of the panorama as seen from the goal. On its subsequent visits the insect finds the goal by positioning itself so that the current image of the environment matches the stored snapshot. If the image of a particular landmark is smaller than in the memorized snapshot, the insect moves closer to that landmark to enlarge its image; if the image is larger, the insect moves away. In other words, the insect homes in on the goal by matching the current view to a 'retinotopically learned' image.

This strategy works well when the insect is in the vicinity of the goal, but runs into difficulties when the insect is far away. There,

the sizes and arrangement of the landmarks' images on the retina may be very different from what the insect experiences near the goal. Worse yet, at a remote location the insect is likely to be surrounded by a different set of landmarks, and those near the goal may not even be visible (Fig. 1). It has been speculated that navigation over long routes might be accomplished by acquiring a sequence of

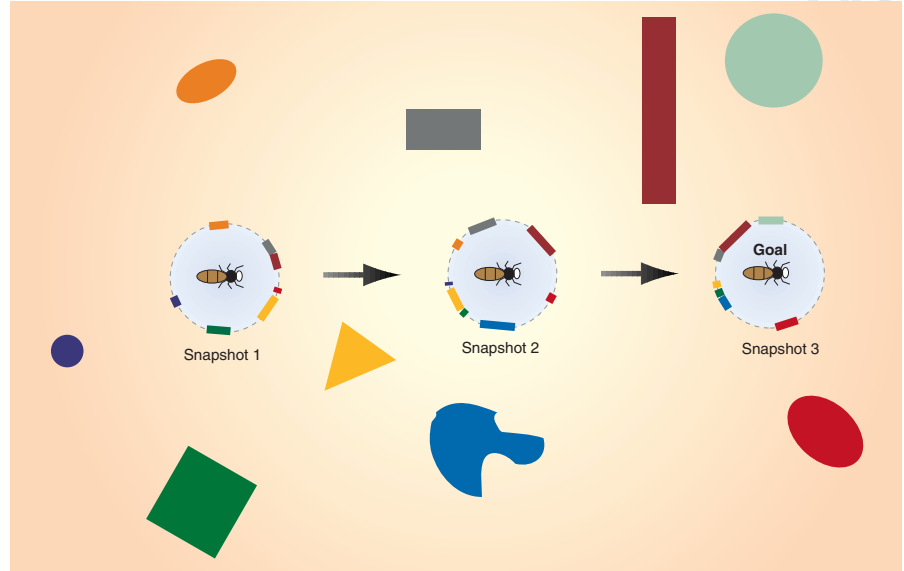


Figure 1 Illustration of how an ant might navigate to its goal (say, a food source) by using a sequence of 'snapshots' of the environment acquired during the learning phase after it first visited that goal. From their experiments, Judd and Collett¹ propose that the snapshots are acquired during so-called inspection runs — when, after leaving the goal for the first time, the ants frequently turn around and make short runs back towards it.

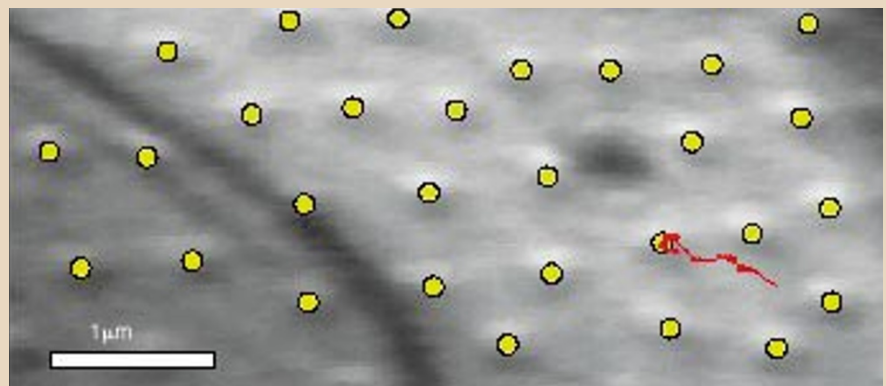
Superconductors

Cold cousin of the colloids

Some superconductors admit magnetic fields in thin flux lines, or vortices. Any electrical current exerts a force on the vortices, and if that force is enough to make them move, they dissipate energy. In other words, the vortices cause electrical resistance, even though the material around them remains superconducting.

The high-temperature superconductors are all of this type, and the misbehaviour of magnetic flux quanta severely limits their usefulness by reducing the maximum current and magnetic field that they can bear. The obvious way to solve this problem is to pin the vortices down: if they can't move, they can't waste energy.

Vortices are naturally pinned in place by defects in the materials, but weakly. To investigate this 'pinescape', in the hope of understanding how to make the pinning more effective, a Japanese group led by Akira Tonomura made high-resolution videos of vortex motion (a 'still' is shown here). Looking at a piece of niobium at 4.5 K with an electron microscope, they watched flux lines stagger from one



pinning site to another, propelled by a gradient in the magnetic field. The red thread marks such a path.

Watching these moving pictures, David Grier of the University of Chicago was reminded of Brownian motion in colloids, and realized that the depth of the pinning-site potential wells has the same randomizing effect as the thermal energy of colloid particles — or of any liquid particle. He and his colleagues have now adapted their data-analysis techniques to

the vortex movies, and use them to measure the strength of vortex-vortex interactions and the distribution of pinning potentials (C.-H. Sow *et al. Phys. Rev. Lett.* 80, 2693–2696; 1998). These numbers are already known for the simple low-temperature superconductor niobium, but the method could provide unique information about the more complicated high-temperature superconductors.

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snapshots on the journey, and steering the correct route by matching each snapshot in succession⁴.

Judd and Collett¹ now provide evidence that wood ants may indeed adopt such a strategy. They trained ants to find food behind a specific landmark, and video-filmed the ants' paths as they walked to the correct landmark and returned to their nest. Analysis of the paths revealed that the ants were operating not just on a single snapshot of the landmark, taken very close to the landmark where the food was located, but on a series of snapshots acquired at various points along the route.

How and when are the snapshots acquired? During the learning phase, ants leaving for home after collecting their food frequently turn back and make short runs towards the goal. Judd and Collett speculate that the snapshots may be acquired during these 'inspection' runs. The behaviour of learning ants leaving the feeding site is reminiscent, in some ways, of how bees 'turn back and look' when they leave a newly discovered feeder⁵, or how wasps departing from their nests inspect the environment in the nest's vicinity⁶. The precise function of these striking aerial manoeuvres remains a mystery, although there is some evidence that they may be used to extract information about the three-dimensional structure of the immediate environment^{5,6}.

In Judd and Collett's experiments, the ants did not have to deal with a visual environment that changed drastically as they proceeded from the nest to the food site. The food-bearing landmark acted as a beacon which guided them towards it, and produced a steadily growing image on the retina. For this task, therefore, the ants might well have managed with a single snapshot acquired at the goal. Nevertheless, the data indicate that they acquired not one, but a series of snapshots at different distances, and recalled them in the appropriate sequence. This finding reflects the potential capacity of the ant's navigational machinery to deal with visual environments such as that shown in Fig. 1, which are complex and rapidly changing, and which provide no beacon at which to aim.

One way in which a sequence of snapshots could be used in such circumstances would be to associate each snapshot with a vector which specifies how far and in what direction the ant should move to arrive at the location at which the next snapshot was acquired, as shown by the arrows in Fig. 1. Another strategy would be to dispense with the motion vectors and, instead, to acquire snapshots at closer intervals than those illustrated in the figure. If the rate of snapshot acquisition is sufficiently high, the insect could travel from each snapshot location to the next simply by recalling the next snapshot from memory and moving so as to

match the viewed scene to it. This second possibility is supported by Judd and Collett's observation that the wood ants acquire snapshots more frequently when the image of the environment changes rapidly.

Do insects use 'photographic' representations for tasks other than navigation? One would surmise that a miniature brain with restricted memory capacity would favour compact, non-photographic representations whenever feasible. Bees seem to learn certain properties of flowers, for instance the spatial arrangement of the colours, in a photographic way⁷. But they also seem to learn other attributes of the same flowers — such as the dominant orientation of the constituent contours, and the radial or bilateral symmetry of the shape — in an abstract fashion^{8–10}, and recognize these general attributes in other objects that they have never previously encountered.

Future research will sort out the extent to which insects can be described as photographers taking snapshots, or as abstract artists capturing the essence of what they see. In the

meantime, it is interesting to note that engineers have independently discovered the 'snapshot principle' and are applying it to the design of algorithms for autonomously navigating robots¹¹. □

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Plant extinction

Frondless ferns lie low to survive

Peter D. Moore

Why do we write to the newspapers to record the first cuckoo of spring, yet never the last cuckoo of the summer? The answer, of course, is that we cannot be sure that it was the last cuckoo until time has proved us correct. In the same way, it is difficult to be sure when we have witnessed an extinction — particularly in the case of a plant. When a plant disappears from a locality, there is always the possibility that it will emerge from some obscure and unobserved dormancy, perhaps decades later, to the predictable delight of conservationists. This has recently happened with a fern that was thought to be extinct over eastern Britain and through most of continental Europe. The story of the resurrection of the Killarney fern (*Trichomanes speciosum*) is reported by Rumsey, Jermy and Sheffield¹ in *Watsonia*, the journal of the Botanical Society of the British Isles.

The Killarney fern is particularly beautiful, with delicate, bottle-green, translucent fronds (Fig. 1, left; overleaf). It grows in deep shade, often in dark, wet, rocky ravines in oceanic locations. Obsessive Victorian fern-hunters collected this fern, and some of their specimens still survive in captivity a century later². But, by the mid-nineteenth century, it had already been lost over much of its former range. Writing in 1867, the Victorian pteridologist E. J. Lowe recorded³ that the Killarney fern had grown in abundance near Bingley in Yorkshire in 1758, but had

been reduced to one root by 1782. The sporophyte generation, which bears the conspicuous fronds that carry the spore-bearing structures, is now known from only a few localities in western parts of Britain and Ireland (including Killarney), Brittany, western Iberia and some of the Atlantic islands, including Cape Verde, the Canaries, the Azores and Madeira.

Ferns have a complex life cycle, involving a free-living, independent stage with a haploid constitution — the gametophyte. In the case of the Killarney fern, the gametophyte is perennial, and structurally very distinctive. It is filamentous, rhizoidal and highly branched, forming a green mat over the surface of wet rocks (Fig. 1, right). The gametophyte bears not only the sexual organs, but also asexual gemmae that can break off and form new gametophyte plants. These features help to identify the gametophyte of *Trichomanes*.

The gametophyte generation of most ferns is a short-lived, flat plate of cells, the sole function of which is to bear the sexual organs. But in certain genera, such as *Trichomanes*, it can form an independent and persistent plant that is more tolerant of desiccation and frost than are the sporophytes⁴. Moreover, in some North American species, gametophytes have been found in locations that are geographically isolated from populations of the sporophyte.

Over the past few years, there has been an intensive search to see whether the Killarney