# Ants ordering ants to feed

David Waxman

**In a recent paper, M. Beekman and co-workers carried out experimental and theoretical investigations into the behaviour of a biological system consisting of a colony of Pharaoh's ants. By manipulating the colony, the foraging behaviour of the ants was, remarkably, shown to be capable of undergoing a transition between a disordered and an ordered state that was directly analogous to a phase transition in a physical system.**

As many biologists will tell you, biology is not physics, or even close to physics. Why is this? All biological organisms are made of atoms (or, if you prefer, even more fundamental entities, such as quarks and gluons), which are all undoubtedly governed by the laws of physics. The problem lies at the level of the richness of behaviour and organization exhibited by biological organisms; atoms are simple but life is not. Indeed, it is probably fair to say that it is unlikely, in the foreseeable future that any theoretical arguments, starting at the fundamental level of atoms, will come close to explaining the behaviour or organization of living organisms. However, physics is not completely barren of examples where (slightly) higher levels of organization arise from systems with very simple subcomponents.

### Organization in physics

I am thinking of what happens when a phase transition occurs; changing an external variable, such as the temperature, can result in a dramatic change in the organization of a system. For example, lowering the temperature of a piece of iron in a weak magnetic field can cause the iron to go from a non-magnetized state to a state of magnetization that will persist even in the absence of an external magnetic field. The very simple interactions between the atoms in the iron cause a dramatic change in their ordering as the temperature is lowered through a particular temperature that characterizes the iron. The atoms can, in this situation, be viewed as tiny magnets and, in the non-magnetized state, these are orientated completely at random, because the random fluctuations associated with temperature dominate the tendency of the atoms to organize themselves. The net effect is an overall cancellation of the individual atomic contributions to the magnetization of the iron. The block of iron then exhibits no magnetic properties. In a magnetized piece of iron at a lower temperature, the situation is very different. The tiny atomic magnets have directions that have become correlated so that the cancellation of their magnetic contributions no longer happens and the iron is magnetized. This area of phase transition physics has developed to a high level of sophistication since the 1970s, when the theoretical understanding of the phenomenon was firmly established.

### Phase transition in a biological system

In a recent paper [1], an enterprising team of biologists has reasoned that a similar phase-transition type of phenomenon can occur, not with inanimate entities such as atoms, but with living organisms. Here, the role of the atoms in physics has been played, in biology, by ants. The authors selected a species of ant (Pharoah's ants *Monomorium pharaonis*) that can be manipulated in similar ways to physical systems. The particular behavioural aspect of the ants under investigation was their foraging behaviour, where the ants interact with each other by laying or detecting a pheromone trail from the nest to a food source. A foraging ant that finds a source of food lays a trail of pheromone as it goes back to the nest. However, the pheromone trial is composed of volatile chemicals that evaporate in a short time (the paper quotes 10 min). Thus, if other ants from the nest do not discover the food source and reinforce the trail with additional quantities of pheromone, before the trail has evaporated, we have a situation that is analogous to the non-magnetized piece of iron. There are no correlations between the behaviour of the ants, no systematic ordering, and no detection of the food source by other ants with anything other than by random chance.

Beekman *et al.* proceeded to model mathematically the behaviour of the ants, and concluded that important parameters describing the behaviour of the ants were the total number of ants within a colony and the individual rate at which an ant was likely to find the food source. Their calculations suggest that if the individual rate of finding the food source is sufficiently high, an ordered behaviour – analogous to being magnetized – manifests itself, where a sustainable trail from the nest to the food source is maintained. When this rate is reduced and the number of ants in the nest was made smaller, two alternative modes of behaviour were suggested. One was a disorganized state with no systematic behaviour, and the alternative was one in which there was organization – with a sustainable trail from the nest to the food source. What ultimately determined which of the two behaviours was manifested was the initial situation of the nest. The authors described this as 'hysterisis', again using concepts taken from physics, and investigated this phenomenon with additional experimental manipulation of the ants. Hysterisis can be thought of as a sort of stickiness with which we are all familiar. Most thermostats exhibit this phenomenon, where the thermostat does not switch exactly at the temperature it is programmed to switch at. If the temperature is lowered from considerably above the programmed temperature, then the thermostat will not switch as the temperature reaches the programmed temperature, but at a slightly lower temperature. Conversely, when the temperature is raised from considerably below the programmed temperature, the thermostat will not switch until the temperature is slightly above the programmed temperature. The thermostat is designed, for practical reasons, to exhibit this behaviour. It is unclear that the hysteretic behaviour in the biological system – the ants – is an adaptive (i.e. equivalent to designed) behaviour, rather than an accidental outcome of the intrinsically non-linear

 0169-5347/02/$ – see front matter  PII: S0169-5347(02)02435-1

mathematics required to describe the system. It all depends on whether the effects seen in the experiments of the paper are often manifested in nature, and so are exposed to natural selection. A manifestation of the hysterisis reported in the paper was that at some point the behaviour of the ants jumped from one type of behaviour (disorganized) to the other type (organized), as conditions were manipulated. This is a form of self-organization in a biological system, which is the subject of a recent book in this area [2].

### Wider context

Let us briefly consider what these authors have done in wider context. They have manipulated a 'model' biological organism so that some of the behavioural phenomena that the organism can exhibit are explored. One of the reasons why physics has been so successful has been that it concentrates on simple fundamental systems, such as atoms (simple here is used in a relative context!). In physics, these fundamental systems are often studied in extremely pure samples, which allows elimination of extraneous complicating factors. The outcome has been that the properties of the fundamental systems manifest themselves cleanly and has been important in allowing their detailed theoretical modelling. It now becomes apparent that some biological organisms can be viewed as fundamental systems with some simplicity of behaviour, and there is the intriguing possibility, and indeed a good example in the paper discussed here, that a variety of these can be manipulated to illustrate their possible behaviours. Perhaps biology is now following a route taken in the past by physics and the two subjects might (or will) not be quite so different as has been previously supposed.


#### References

1 Beekman, M. *et al.* (2001) Phase transition between disordered and ordered foraging in Pharaoh's ants. *Proc. Natl. Acad. Sci. U. S. A.* 98, 9703–9706

2 Camazine, S. *et al.* (2001) *Self-Organization in Biological Systems*, Princeton University Press



**David Waxman**
Centre for the Study of Evolution, School of Biological Sciences, University of Sussex, Brighton, Sussex, UK BN1 9QG.
e-mail: D.Waxman@sussex.ac.uk


# The detection of neighbors by plants

Ragan M. Callaway

**Whether plants detect and respond to neighboring plants is crucial for a complete understanding of how plants interact with each other. If plants do not detect and respond to neighbors, interactions are determined by the way in which each species alters available resources and the passive responses of nearby plants. If plants do detect and respond to neighbors, interactions are not regulated by resource availability alone. Most reports of plants detecting and responding to neighbors have focused on avoidance, where either roots or shoots grow away from a detected neighbor. However, a recent paper by Gersani and colleagues has demonstrated that soybeans increase root growth in soil shared with conspecific competitors. Their findings shed light on a new ecological role for noncognitive behavior in plants.**

Plants can be passive organisms, capable only of responding to the 'raw materials' that they encounter, or they can transmit, receive and respond to nonresource signals that allow them to interact with other plants independently of resources [1]. As in animals, interactions stimulated by signals can have crucial ultimate importance for resource acquisition [2–4], but such communication can radically alter our understanding of how resources are acquired by plants and how plant communities are organized. Unraveling resource-driven and nonresource-driven interactions among plants has been hindered by methodological catch-22s and historical baggage [5]. The 1960s and 1970s were the zenith years of 'allelopathy', one example of a nonresource mechanism in which neighbors are chemically suppressed, and allelopathic explanations for community processes and patterns were common [6,7]. A broad acceptance of allelopathy was short-lived, in part because of a series of studies conducted in Californian chaparral. Initially, Muller and colleagues argued forcefully from laboratory experiments that airborne chemicals released by the leaves of some shrub species caused bare rings and open patches in California vegetation [8,9]. However, in an experiment with dire consequences for the future of nonresource interactions in general, it was shown that plants could thrive in bare rings around shrubs if herbivores were excluded [10]. The bias for nonresource mechanisms was rapidly replaced with a bias towards resource-driven mechanisms and doubt was cast on the existence of nonresource mechanisms, such as allelopathy, in general [5].

In a recent experiment, Gersani *et al.* [11] split the root systems of single plants to compare the growth and reproduction of soybean *Glycine max* plants with sole possession of growth space to that of others sharing space and resources with the root systems of a conspecific. Sharing individuals produced 85% more root mass than did nonsharing plants. Their demonstration that *G. max* can proliferate roots in response to the presence of other conspecific individuals is a substantial contribution to a newly developing body of literature that is reviving interest in nonresource mechanisms in plant interactions. This literature has shown that communication (i.e. the production, transmission and reception of signals) among plants can take several forms, including those among competitors' roots [4,12–14], pollen–stigma communication that promotes the germination and growth of pollen from unrelated neighbors and inhibiting pollen from close relatives [15], root–root chemical signals between parasites and hosts [16], oxidation of gases in smoke or acids from burned plants that cue germination of other species [17], wound-stimulated production of chemicals that induce defenses in unwounded conspecific and interspecific neighbors [18,19], and neighbor-altered light wavelength ratios that stimulate growth responses [20,21].

 0169-5347/02/$ – see front matter  PII: S0169-5347(02)02438-7