Emergent information use in mobile animals

Models, experiments and implications

Colin J. Torney

Department of Ecology & Evolutionary Biology, Princeton University
Department of Mathematics, University of Exeter

Introduction

Intelligence is often thought to be a property exhibited by individuals, however social groups also display *collective intelligence*, an emergent phenomenon in which simple behavioral responses and individual-level interaction lead to higher-level cognitive processes. In many scenarios the collective surpasses the capabilities of individuals in isolation and the group is far greater than the sum of its parts.

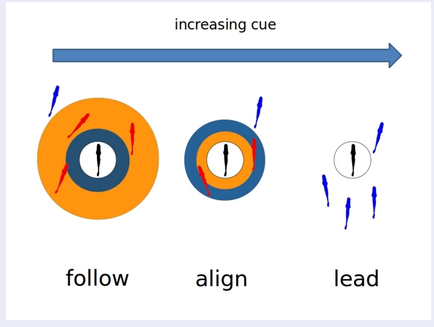
Examples abound in the natural world, from honey bees deciding between potential nest sites, to the efficient design of ant foraging networks, or the waves of information that travel through a fish school as a predator approaches.

We are now beginning to understand that emergence may also play a key role in navigation and movement, determining how animals effectively respond to the information in their environment.

Assessing the importance and the implications of emergence in this context will lead to a greater knowledge of how natural populations function and how they will respond to change.

Simulated Search

Locating the source of an advected chemical signal is a common challenge facing many living organisms. In turbulent or chaotic environments this task becomes very difficult. A simple method to solve this task can be found through social interaction, modified according to local conditions. Simulations show how obeying three rules can lead to an emergent search strategy [1].



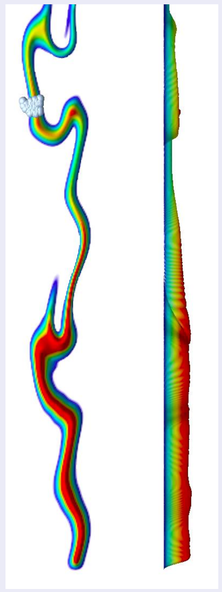
Firstly, a decrease in the level of the chemical signal results in social attraction; individuals are lost so they move toward their neighbors. A weakening signal results in moderate attraction and an alignment with neighbors. If the signal is getting stronger, interaction zones are reduced to zero. All neighbors are then ignored and the current direction is maintained.

Simulated Search

The model illustrates how simple social interactions can lead to behavior that produces an emergent group-level search. By modifying their behavior based on local conditions, independent (selfish) individuals enable the group to collectively act as a spatial gradient sensor that is able to track a chemical signal and locate its source.

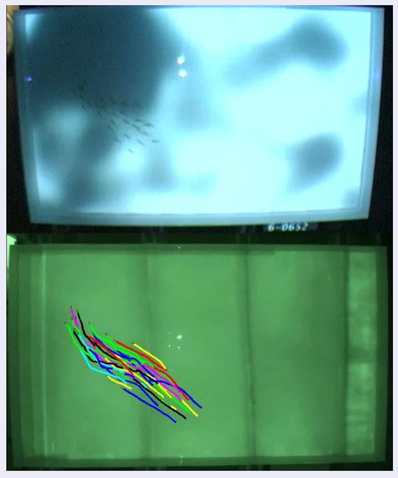
The nature of the context-dependent interaction mean leaders are dynamically changing and automatically selected. As these leaders are those that are experiencing increases in local concentration, group direction is toward the source.

The group successfully locates the source of the chemical signal and in doing so displays an awareness of the environment not present at the individual level.



An Experimental Test

In a recent experimental study [2] it was demonstrated how animal groups are able to sense complex environmental gradients through simple behavioral responses combined with social interaction.



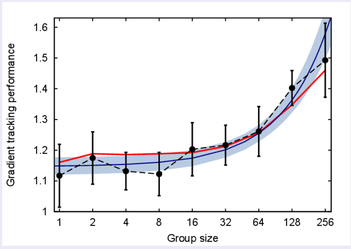
Robust collective sensing emerges at the group level from individuals modulating their speed in response to local, scalar, measures of environmental conditions, and through social interactions with others.

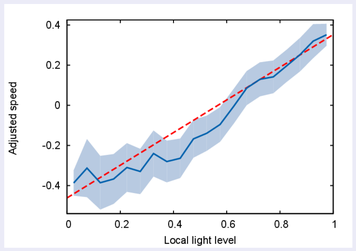
The experiment involved projecting dynamic light patterns onto the floor of a tank containing golden shiners, a small fresh water fish. As the fish have a natural preference for darker, shaded areas, this created a complex task for the animals to solve. By varying the size of the school, the role of emergence in their response to the environment could be assessed.

(See also NPR's Science Friday coverage)

An Experimental Test

Results show that as group size increases the effectiveness of the response to the environment dramatically improves. Data shown with error bars on the right.





By analysing trajectories a simple individual response is revealed; golden shiners slow down in areas they prefer (left). Adding this mechanism to a simulation of schooling fish in a virtual environment demonstrates that this behavior is all that is required. Simulation results are shown above (red line).

Implications : Migration & Dispersal

For many animals survival depends on being able to make the right decision. In the context of movement this means accurately determining when and where to go, by responding to the information contained in environmental cues. For social animal groups, emergence has the potential to enhance (or even enable) the processing of this information.

Beyond individual survival, there are also broader ecological implications. Processes such as migration and dispersal play a fundamental role in ecosystem function, coupling the dynamics of spatially distinct populations, determining ecological connectivity and transporting nutrients.

Key open questions in this area include

- How pervasive is emergent information use in nature?
- How does emergence affect larger scale ecological structure via long range animal movement?
- What influence does emergence have on the resilience of animal populations?

References

[1] C. J. Torney, Z. Neufeld, I. D. Couzin, *Proceedings of the National Academy of Sciences* **106**, 22055 (2009).

[2] A. Berdahl, C. J. Torney, C. C. Ioannou, J. J. Faria, I. D. Couzin, *Science* **339**, 574 (2013).