Reviews
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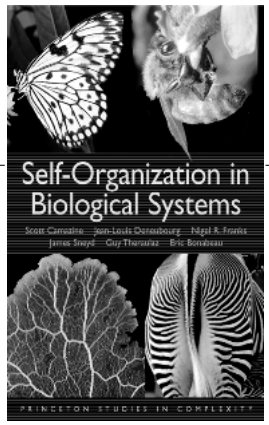
Self-organized Behavior: Case Studies

Who could believe an ant in theory?
A giraffe in blueprint?
Ten thousand doctors of what's possible
Could reason half the jungle out of being.

John Ciardi

Fish schools are incredible things. They snake through the water like a single entity, turning in unison, waves of activity flashing across the shoal. However, their group-level behavior is not encoded within each individual, nor is there a leader or small group of individuals directing the movement of the school. It is instead a process whereby individual fish react to movements of their immediate neighbors and, as a result of such local interactions, the group-level pattern of activity arises spontaneously. This is an example of biological self-organization.



SELF-ORGANIZATION IN BIOLOGICAL SYSTEMS
by S. Camazine, J.L. Deneubourg, N.R. Franks, J. Sneyd, G. Theraulaz, and E. Bonabeau, [Princeton Studies in Complexity], Princeton University Press, Princeton, 2001 538 pp, $65 (US hardcover)

In their recent addition to the Princeton Studies in Complexity series, Scott Camazine and colleagues detail other examples of biological self-organized behavior. They focus on the organismal level, that is, group-level behaviors arising from interactions among multiple individuals, and also structures—such as nests—that are constructed in a self-organized manner from multiple builders. All this is encompassed in their definition of self-organization: "a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern."

Self-organization is not a new subject; physicists have studied it for many years. But, this is probably the first book to deal exclusively with such a process in biological systems, at least at the organismal level. Biological self-organization uses many of the same fundamental mechanisms and ideas as physical self-organization, but this book will likely appeal to a broader audience. It will also hopefully make the study of self-organization more inclusive and with any luck will stimulate and inspire a new generation of students.

The book is split into two main sections: a general introduction followed by a group of thirteen in-depth case studies. For me, this first introductory section is by far the most important new contribution to the subject. It is in these seven short synthetic chapters that we are briefed as to what self-organization is, what it is not, how it works, and how it can be studied. The core proposal is that we find in nature five fundamental pattern formation mechanisms. Self-organization is one; blueprints, recipes, well-informed leaders, and templates are the others. Presumably in an attempt to make the differences among these mechanisms crystal clear, examples from human activities are given, for example, carpenters building a house from a blueprint and cooks following a recipe. Unfortunately, although followed by a section entitled "biological examples of alternatives to self-organization," I believe the authors have strayed too far toward simplicity. In particular, they define a template as "a full-size guide or mold that specifies the final pattern and strongly steers the pat-

tern-formation process," citing examples such as a seamstress's paper pattern, candle molds, and cookie cutters. In short, they imply that the final pattern is a copy, the same size and shape as the original template.

To me, and I suspect to the authors too, it is clear that within the class "templates" should be included gradients. Although gradients such as temperature and chemical concentrations steer the pattern-formation process, they are not necessarily the same size and shape as the resulting pattern. One example might be a flock of seabirds standing on the shore, each of whom faces into the wind to avoid ruffling its feathers. There is a group-level polarity, the pattern, but, unlike the fish school, it arises from each individual reacting not to its neighbors but solely to wind direction, the gradient; and, of course the final pattern is not the same "size and shape" as the wind. In a sense, this is a minor criticism, as most of the book concerns self-organization. However, the authors are at pains to stress that in nature, probably very few completely pure self-organization systems exist; that is, there are few situations where no other pattern formation mechanism plays a role in the system. Many examples may result from interplay of components from two or more of these five fundamental mechanisms, and where these occur in the case studies, they are highlighted.

As for the case studies, four chapters concern a variety of taxa—slime molds and bacteria, bark beetles, fireflies, and fish—whereas the other nine chapters focus exclusively on social insects. This predominance partly reflects the authors' particular expertise, but this is largely because self-organization is widely employed in many larger insect societies and because colonies can readily be studied in the lab and field. Basically, this is where most biological self-organization research has been directed. Each chapter is arranged in a similar manner. First, the natural history of the phenomenon is described. Then the adaptive significance of the pattern is discussed, and importantly, this is followed by arguments as to why we can rule out the other four alternatives to self-organization. Finally, a model whose assumptions are derived directly from the biology is detailed (occasionally with pseudocode). As a bonus to students and teachers alike, in some cases these models are complemented with illustrative StarLogo or Pascal simulations on the book's own website: http://beelab.cas.psu.edu/organization.

One chapter did strike me as a little unusual in a series of case studies of self-organization, and that was a chapter on qualitative stigmergy. The reason why it seemed odd is that the authors do not regard is as self-organization. Qualitative stigmergy, a mechanism that coordinates individuals through work-in-progress, has a counterpart, quantitative stigmergy, which *is* involved in many of the self-organized examples. (Although the two mechanisms are very similar, only quantitative stigmergy may generate positive feedback, a "key ingredient" of self-organization.) The authors tout this chapter as a useful comparison to the others, which in some sense is true. However, consider a sentence from a different chapter: "[the model] is based upon an alternative to self-organization that is not easily classified as one of the mechanisms described in Chapter 4 (leader, blueprint, recipe and template)" (p. 467). Taken together, readers may start to question whether the issue of these five fundamental pattern formation mechanisms is as clear-cut as the authors make out. Certainly with some examples using a combination of two or more mechanisms, the boundaries among these five mechanisms must be fuzzy.

My overriding impression of the book is that it is very honest. It does not hype the subject; it highlights that many patterns may be self-organization acting in concert with other mechanisms and that much self-organization research is, at this stage, plausibility arguments. That is, one may derive the possible proximate mechanisms from empirical research and then plug those mechanisms into a model. Just because the global pattern may match the pattern observed in nature, it is never *proof* that those are the proximate mechanisms at work. All that has been shown is that those mechanisms are "necessary and sufficient" to generate the global pattern. (In fact, the quote in the previous paragraph comes from a section where they showed that two very different models, one self-organized and one not, both produced the same global pattern, a point well made and for which the authors should be commended.) Only critical tests, such as perturbation experiments—both in nature and in the models—will help establish "beyond all reasonable doubt" that those are the correct proximate mechanisms. Unfortunately, most research in this field stops short of such rigorous methods.

The book is an important contribution to biology and to complex systems research more generally and is certainly an enthralling subject. Why, though, is it so fascinating? As the authors put it so well: "one of our fascinations with self-organization is its ability to create complexity from simplicity with remarkable economy." Don't believe me? Go ask a fish!

Reviewed by Carl Anderson, postdoctoral researcher in the Zoology Institute, Regensburg University, Germany.