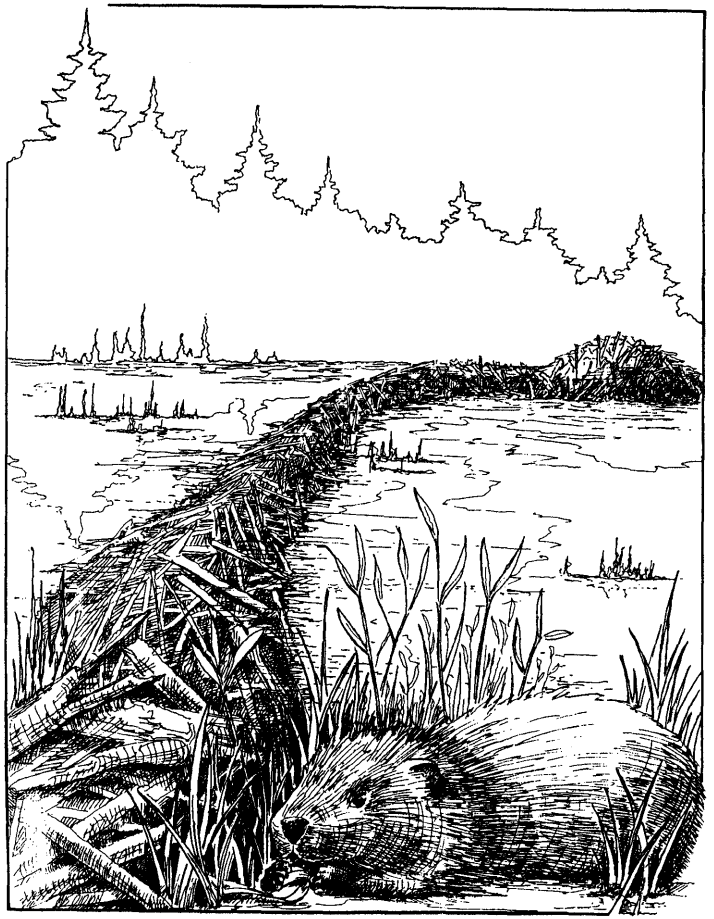


Figure 5.1 Beavers are well known for their "skill" in constructing lodges and dams from branches, mud, and other debris. However, the obvious analogy with human building activity is probably misleading. It is unlikely that beavers rely on an innate concept or blueprint of the structures they build. Instead, their building activity probably proceeds from an interplay among several mechanisms that may include: a genetically programmed sequence of behavior triggered by cues arising during construction, and stimulus-response behaviors that lead to self-organization through interactions among branches that are carried and moved about by the water currents and by the beavers themselves. The sound of water rushing over the dam or through holes in its structure is a key stimulus guiding certain aspects of the building behavior (Richard 1968, 1980). (Illustration by Mary Ellen Didion)

5

Why Self-Organization?

> It is all but impossible to conceive how any one colony member can oversee more than a minute fraction of the construction work or envision in its entirety the plan of such a finished product. Some of these nests require many worker lifetimes to complete, and each new addition must somehow be brought into a proper relationship with the previous parts.
>
> —Edward O. Wilson

Self-Organization Versus Alternatives

This chapter addresses the question: "Why is self-organization sometimes favored over other means of pattern formation in biological systems?"

Generally speaking, the rules in self-organizing systems can be quite economical in the physiological and behavioral machinery needed to implement them. They are more likely, therefore, to arise through evolutionary processes and more likely to carry smaller costs than more complicated rules. Thus, we expect evolution by natural selection to favor mechanisms based on self-organization whenever the alternative mechanisms—leaders, blueprints, recipes, and templates—are unworkable or costly to implement in terms of genetic coding. For a more telling answer, however, we must consider exactly why these alternatives are apt to work so poorly in particular circumstances.

Drawbacks of Alternatives

Why do biological systems often rely on interactions among their components rather than guidance from an external source to direct pattern-formation processes? We believe that the answers to such questions reflect the limited communication and cognitive abilities of individuals in a system; the problems of making and using blueprints; the need for components to flexibly coordinate their contributions to the desired pattern; and the lack of naturally occurring templates.

Central Authority

The quotation from E. O. Wilson points up the engrossing enigma of how large complicated nests of social insects such as hornets and fungus-growing termites are built. Certainly one of the major problems associated with having a complex system run by a central authority is that it requires both an effective communication network among individuals and sophisticated cognitive abilities by the central planner.

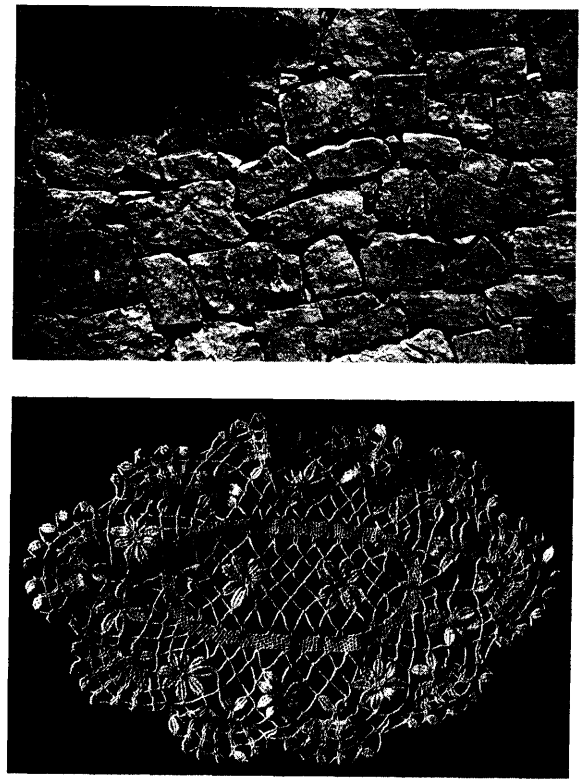
Consider what, in essence, is required for an animal group to be directed by a leader as it builds a particular pattern. For this to happen, the leader of the group must have thorough knowledge of the desired pattern, must be able to maintain a synoptic view of the emerging structure and to devise and communicate instructions to all the other group's members. Obviously, such centralized control by a leader places formidable, if not impossible, burdens of information acquisition, processing, and transmission on the leader, especially if the group is large and the pattern being built is far larger than any individual group member. Such is the case for our favorite example of group-level pattern formation—nest construction by a colony of *Macrotermes* termites—where group size can exceed a half million individuals and the construction is some ten million times more massive than any of its builders (Figures 18.1 and 18.2).

Even in smaller groups of animals such as beavers (Figure 5.1), extensive complex habitats may be modified over many generations. In such cases it is not at all surprising that natural selection has favored a decentralized, self-organizing approach to pattern formation rather than relying on the "direct intervention of some kind of 'little architect' or 'construction demon' " (Edelman 1984, p. 120).

Problems with Blueprints

The problems of information collection, processing, and dissemination by an omniscient and clever supervisor are avoided if each member of a group has a personal copy of a blueprint, either mental or external, indicating the pattern to be built. If the blueprints possessed by the group's members are similar, then all the individuals should work toward a common goal and the final pattern should be coherent. It seems clear, however, that blueprints are not a widespread mechanism for guiding pattern formation in groups, with the obvious exception of human groups (Figure 5.2). Why is this? Perhaps one important reason is that it would be extremely costly to encode genetically the vast quantity of information that would need to be expressed in a mental blueprint for a complex structure, such as a termite nest.

Perhaps, too, it would be extremely difficult to transform information that is ultimately stored in an individual's genes into a detailed mental blueprint during development. Finally, it also seems that a serious problem is associated



a

b

Figure 5.2 The regularity seen in man-made structures, such as these, seldom involves self-organized processes. Instead pattern generally arises by means of preconceived plans and the use of devices such as templates, recipes, and blueprints. (a) A wall whose component stones have been fit together precisely. (b) Intricate crochet work, the result of careful planning and the implementation of a step-by-step recipe.

with executing the information expressed in a blueprint, because a blueprint does not specify *how* something is to be built, only *what* is to be built. This means that a blueprint does not provide a complete set of instructions for building a structure. Any animal guided by a blueprint must be able to figure out the actual building operations needed to produce a structure, and this may be extremely difficult. The difficulty will be especially great if the pattern is large and complex and requires a specific sequence of stages in the pattern-formation process. Thus it seems that reliance on blueprints is generally impossible for

many animal groups, since this would require each group member to have an immense investment in genetically coded information and an unrealistically high level of mental sophistication.

Rigid Recipes Cannot Guide Flexible Building Behavior

Pattern-formation based on following a recipe circumvents the problem of instructions that are difficult to execute, for by its very nature a recipe provides step-by-step instructions for pattern-formation. It also skirts the problems associated with a leader, since it is inherently decentralized with each individual independently contributing to the pattern. Recipes, therefore, seem to be an excellent way to provide the instructions for pattern-formation. The instructions for structures built by single organisms, such as the cocoons of silkworm moths or the webs and egg cases of spiders (mentioned in Chapter 4), often take the form of a recipe.

A serious problem arises, however, when members of a group must use a recipe to work together to build a collective structure. Although the sequential instructions in a recipe are well-suited to a solitary builder, they are poorly suited to a group-building operation. A solitary builder such as a spider can be expected to encounter circumstances in a predictable sequence that would allow it reliably to execute its behavioral recipe. In contrast, an individual working within a collaborative group generally will not perform stereotyped sequences of building activities, since what it needs to do at each stage of building a pattern depends little on what it personally has done most recently. Rather, it depends primarily on what its fellow group members have recently accomplished. Thus individuals in a cooperative group need instructions that confer the extreme flexibility of behavior needed for coordinating the activities of many individuals. This need runs contrary to the basic nature of a recipe.

Templates Are Not Always Available

In most instances of pattern formation by biological systems the pattern is built from scratch in an environment that lacks anything remotely resembling a template for the pattern. Consider, for example, the example of pattern formation by a social insect colony—the air-conditioned termite mound (Figures 18.1 and 18.2). Mound construction starts underground and eventually extends above ground to form an impressive edifice, but in neither the subterranean nor the aerial construction phase are the termites guided by a three-dimensional template. As discussed in Chapter 18, however, one part of a termite mound's construction where a template may play a role is the building of the royal chamber, a thick-walled, bun-shaped cubicle completely enclosing the queen, and providing extra protection from intruders. The royal chamber's inner walls follow closely the contours of the queen's body, so it seems reasonable to hypothesize that the queen's body provides a template for chamber construction. Where such naturally occurring templates exist, they are expected to guide pattern-formation, but one suspects that such templates will prove very much the exception rather than the rule.

Summary

A reasonable suggestion is that pattern-formation by cooperative groups usually arises through self-organization rather than external guidance because the latter mechanisms generally are exceedingly difficult to implement. This seems especially true for pattern-formation by large groups. For large groups the high complexity and large scale of pattern-formation makes it virtually impossible for a leader to provide group members with detailed building instructions, leaves blueprints an insufficient source of instructions, renders fixed recipes of behavior inappropriate for the flexible building behavior that is required, and makes the occurrence of naturally occurring templates highly unlikely. Group-level pattern-formation through self-organization, in contrast, is based on rather simple instructions—which we perceive as rules of behavior—that are easily implemented by each member of the group.