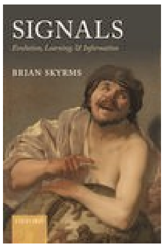

Signals: Evolution, Learning, and Information
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CHAPTER

12 12 Complex Signals and Compositionality

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Abstract

This chapter focuses on an earlier point in the evolution of signaling. It considers how one might come to have — in the most primitive way — a complex signal composed of simple signals. This is done with the smallest departure possible from signaling models that have been previously examined in this book.

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Humans are not restricted to one-word sentences, but rather can construct complex utterances whose content is a function of the content of their parts. This capability has sometimes been claimed to set man apart from beast. Such claims are somewhat overblown.[1] Birdsongs often string together in complex ways, and in some birds these are ways in which the content of the parts contributes to the content of the whole. Monkeys in the wild show some rudimentary steps in this direction. Domesticated apes, parrots, and dolphins have done more. Humans have gone much further down this road than other animals, but the use of complex signals is not unique to humans.

We try to understand the first step in this journey—the move from simple atomic signals to signals composed of parts. If one has little to communicate, simple signals may be perfectly adequate. But if one has a lot to say, complex signals introduce obvious economies. A lot can be communicated using combinations of a few basic parts. If it costs something to maintain a signal, there are obvious economies to be had by using complex signals. Martin Nowak and David Krakauer argue that complex signals may, in addition, increase the fidelity of
p. 146 information transmission, by preventing simple signals getting crowded together as the perceivable ↳ space of potential signals gets filled up.[2] By recombining parts, one can routinely construct new signals. Complex signals may make it easier to learn a signaling system, especially if the content of a complex signal is a function of the contents of its parts. Complex signals can facilitate information processing—as is evident from the development of formal logic. Complex signals can certainly be useful in many ways. It is not difficult to construct models where they confer an evolutionary advantage in a context where rich information exchange

is important. We can suppose that if we have them they will confer a Darwinian advantage. But how could they arise in the first place?

There are contributions to the literature that address this question. John Batali investigates the emergence of complex signals in populations of neural nets.[3] Simon Kirby extends the model in a small population of interacting artificial agents.[4] These models assume structured mental meanings that are meant to be conveyed by the sender in the signal string, and structured meanings that the receiver gets from interpreting the signal string, and a way to compare sender's meaning to speaker's meaning to determine success or failure.[5] Structured meanings like <John, loves, Mary> could, in principle, be conveyed by one-word signals, but systems of structured signals are observed to evolve.

These are important contributions to the problem. Here, however, I want to start at an earlier point in the evolution of signaling. I am interested in how one might come to have—in the most primitive way—a complex signal composed of simple signals. p. 147 ↳ And I would like to do this with the smallest departure possible from signaling models that have been previously examined in this book.

We have seen how a receiver can process different information from multiple senders. Multiple senders need not be different individuals, but could instead be the same individual at different times. A monkey who sees the grass move and sends the "leopard or snake" alarm call might run up a nearby tree and then be able to see that there is no leopard. It could then be able to send a signal to that effect. What is important is that there are separate pieces of information, not separate individuals sending them. The information processing problem faced by the receiver is exactly the same in both cases.

Let us revisit the *inventing the code* model from the last chapter. One sender observes whether the situation is up or down and sends the signal red or green. Another sender observes whether the state of the world is left or right and sends the signal yellow or blue. Interactions with a receiver who needs both pieces of information to make an optimal decision can lead to a complex signaling system. The receiver treats the juxtaposition of two signals as conjunction, which is simply to say that they are treated as two pieces of information to be integrated. In a community of individuals who are sometimes in one observational situation sometimes in another, this complex signaling system can become fixed.

If it is fixed, receivers have a fixed interpretation of pairs of signals. Suppose, for instance that the system is:

Red => Top

Green=> Bottom

Yellow=> Left

Blue => Right

In such a community, a sender who is well placed enough to observe that the state of the world is exactly <Bottom, Left> can communicate this by sending a complex signal consisting of green and yellow, in any order. This leads to a primitive signaling system p. 148 ↳ that exhibits a simple kind of *compositionality*. The information in a complex signal is a function of the information in its parts. It is not so far from integration of information from separate signals to the integration of information from separate parts of a complex signal.

The next stage in the development of compositionality is sensitivity to order.

This is the key that opens the door to richer compositionality: subject–predicate or operator–sentence. But sensitivity to temporal order is something many organisms have already developed in responding to perceptual signals. The efficient frog reacts differently to *first fly left*, *next fly center* than to perceptual signals in the opposite order.

More generally, we can say that temporal pattern recognition is a fundamental mechanism for anticipating the future. In the second stage of compositionality, this general-purpose mechanism is recruited to allow more complex signaling systems. We see beginnings of this process in bird calls.

Once we have sensitivity to order in complex signals, it is possible to have prototypes of sentential operators. Recall the “boom-boom” operator of Campbell's monkeys discussed in Chapter 2. The alarm call for a predator is prefaced by two low “boom” calls when the predator is distant and not an immediate danger. There is a basic signal, which is modified by what we would view as an operator. Much of the data on complex signals in the wild is quite recent. That is because investigators have looked for what isn't supposed to be there.

Some philosophers seem desperate to draw a line between humans and other animals—I have never understood why. However that may be, the line isn't here. We already find rudiments of compositionality in animal signaling, and once we have this then the evolutionary advantages of compositional signaling systems that have been noted in the literature can come into play. Why then, haven't lots of animals developed language? Perhaps they don't have that much to say. Their signaling systems are adequate to their needs.

Notes

1 As we have seen in Chapter 2.

2 See Nowak and Krakauer 1999.

3 Batali 1998.

4 Kirby 2000.

5 As Kirby 2007 succinctly puts it:

> Early models such as Batali 1998 and Kirby 2000 involved populations of individual computational agents. These agents were equipped with: explicit internal representations of their languages (e.g. grammars, connection weights, etc.); a set of meanings (provided by some world model) about which they wished to communicate; mechanisms for expressing signals for meanings using their linguistic representations; and algorithms for learning their language by observing meaning-signal pairs (e.g. grammar induction, back propagation, etc.).