Part IV

COGNITIVE ETHOLOGY

Communication and Cognition: Is Information the Connection?

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Among cognitive ethologists, communication is widely supposed to be a good area for comparing animal minds (e.g., Cheney & Seyfarth 1990; Griffin 1991, and other contributions to Ristau 1991). There is, however, considerable controversy about how to define or characterize communication. We will not survey these attempts in this paper (see Philips & Austad 1990). Rather, we focus on conceptions of communication as *transfer of information from signaler to receiver*. In conjunction with descriptions of human cognition in information processing terms, this conception encourages the idea that communication provides a '"window" on animal thoughts' (Griffin 1991, p.3). The first step in getting beyond this metaphor is to identify possible relationships between information and cognition. This paper attempts that first step.

1. Philosophy of Information

The relationship between information and cognition is not a new topic to philosophers, particularly since Dretske's (1981) book. Thus, philosophers might reasonably be expected to contribute to the methodological foundations of cognitive ethology. There are, however, more reasons for philosophers to become engaged in this project than the desire to help set someone else's house in order. We will mention three.

Philosophy of Mind. If human mental states are intentional it is reasonable to ask whether intentionality is found in other species. Information and intentionality are closely related concepts; information is always about something, and "aboutness" is one common characterization of intentionality. Studying the connection between information and cognition in non-human animals may help to naturalize intentionality.

Philosophy of Cognitive Science. Philosophers concentrating on psychology, artificial intelligence, and linguistics may benefit from the evolutionary emphasis of cognitive ethology. This emphasis forces one to consider cognitive systems embedded in a physical and social environment, since this is where selective pressures arise. One way to characterize this embedding is in terms of information flow, but a thorough understanding of the concept of information is needed before it can be said whether this is an appropriate characterization.

Philosophy of Science. Different sciences have different explanatory goals. They may require different theoretical structures to accomplish those goals. There may,

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then, be no single concept of information of equal use to different cognitive sciences. (Stich (1992) comes to a similar conclusion with respect to the notion of mental representation.) The ethological notion of information should be compatible with its counterparts in other sciences, and all these notions should be similar to one another in ways which make it reasonable to call them all 'information'. Compatibility and feature sharing are weaker requirements than identity or reducibility: such relationships are of interest for understanding relationships between scientific theories.

2. The Biology of Communication

The social interactions of some nonhuman animals are frequently accompanied by complex vocal exchanges which biologists regard as communicative. (Our focus on *vocal* communication is not intended to deny the existence or importance of other forms of communication.) Until quite recently, it was claimed that the vocalizations of nonhumans correspond to changes in emotion and provide information only about the internal states of signalers. More recently, research on a wide variety of nonhuman primates and some birds has been used to argue that some communicative signals are referential, meaning that they convey information about states of affairs external to the signalers (e.g., Seyfarth, Cheney & Marler 1980; Gouzoules et al. 1984; Macedonia 1991). Proponents of the referential view typically allow that signals might convey information both about the signaler's internal state and about external referents but insist that available evidence supports attribution of the complex cognitive processes they believe are required for referential signaling (e.g., Cheney & Seyfarth 1990). We will refer to this debate as the Emotion/Reference (E/R) debate. Most recently, Marler (1992) has argued for combining emotional and referential accounts of communication.

At stake in the E/R debate are comparative judgments about animal communication systems and the cognitive mechanisms presumed to underlie them. Additionally, investigation of non-human primate vocalizations is often explicitly directed at finding evolutionary precursors for human language. Human language is usually presumed to include referential signals. Confirmation of this feature in an animal communication system could provide important clues about the evolution of human language. The E/R debate thus provides a good case study of the potential for using communication as a window to cognition.

Among biologists the term 'information' is widely employed but rarely analyzed. For example, in a recent article reviewing the intentionality of animal communication, Hauser & Nelson (1991) use 'information' in over half of the paragraphs in the article but do not give an explicit account of their use of the term. Thus, they take for granted a shared conception of information with their readers. Unfortunately, the term 'information' is ubiquitous but by no means commonly understood. Some accounts of information presuppose the attribution of mental states, others presuppose only relatively simple input/output capabilities. Clearly, if communication-as-information-transfer is to provide a window to animal minds, it is necessary to decide just how 'information' should be understood in this phrase.

Among those engaged in the E/R debate, there has been some attention to the notion of information being used. For example, Smith (1990) describes information as 'a property of entities and events that renders them, within limits, predictable'. Smith does not formalize the idea of predictability, but it appears to be closely related to the idea of reducing uncertainty that underlies the mathematical theory of information developed by Shannon & Weaver (1949) (see section 4 below). In contrast, Wiley (1983) and Krebs & Dawkins (1984) claim that the proper notion of information for describing animal communication is not Shannon & Weaver's (SW); instead they claim that a semantic notion of information is required. In a related context, Dennett (1983/1987) endorses this distinction and claims that despite Dretske's (1981) attempt to extend SW into a theory of semantic information, an appropriate notion of semantic information is 'as yet imprecisely described' (1987 p. 240). The same is true ten years later.

It is far beyond the scope of this paper to say what the prospects are for developing a precise account of semantic information. Nevertheless, it is possible to describe three different approaches in enough detail to support the purpose of this paper, which is to investigate how attention to SW and three alternative approaches to the notion of information clarifies certain aspects of the debate about animal communication and cognition. Specifically we will discuss the consequences of each approach for experimental design and interpretation, and for assessing the significance of the E/R debate itself. Our goal is not to argue for the adoption of any particular analysis of information. Neither have we attempted an exhaustive survey of theories of information. Rather, the point is to illustrate how careful attention to this concept reveals hidden assumptions and apparent confusions in the E/R debate.

3. Animal Communication—An Example

To make the ensuing discussion of the E/R debate concrete, we will focus on recent studies into the behavior of rhesus monkeys discovering food (Hauser & Marler, in press, a,b). When individuals find food, they often give one of five acoustically distinct vocalizations. This section contains a brief summary of the most pertinent results. Three of the vocalizations are given *only* in the context of finding and eating rare and highly preferred food such as coconut. We will refer to these as "FS calls" (for food-specific). In over 2000 hours of observation, these FS calls were never heard in anything but a food context. The other two calls are given to food (primarily chow) and in non-food contexts as well. We will refer to these as "NFS calls" for non-food-specific calls. Some of the acoustic variation between different FS calls may be associated with differences in food quality.

During natural and experimentally-manipulated encounters with chow and coconut, hungry animals called at higher rates than satiated animals and independently of hunger level, females gave more food-associated calls than males. Although call rate varied as a function of hunger level and sex, call type did not. That is, males and females produced all of the food-associated calls and the primary factor influencing the type of call used was food quality.

When individuals hear food-associated calls, they frequently approach the caller. Individuals producing FS calls are approached more frequently, and apparently more rapidly, than individuals producing NFS calls. Under natural conditions, call rate covaries with the caller's level of excitement. Nonetheless, callers were approached whether they called at high or low rates.

Under experimental conditions, 45% of all individuals who found food announced their discoveries by producing food-associated calls whereas the remaining animals were silent. There were no notable differences between the individuals or experimental conditions which would explain the vocal behavior of the subjects tested. Females called more than males, but not all females called. Animals at the top of the dominance hierarchy did not call more than those at the bottom. Hungry animals called at higher rates than those who were relatively satiated, but level of hunger was not a good predictor of the probability of producing at least one food-associated call. If these factors fail to explain the vocal behavior of discoverers, what does? The answer may lie in the discoverer's initial response to seeing food and the subsequent response by conspecifics to seeing the discoverer with food. In all trials, discoverers first scanned the immediate area and then called, approached the food and scanned some more, or began eating. The scanning behavior suggests that the discoverer was attempting to identify those who were in visual range of the food source. In 90% of all trials, discoverers were detected by at least one other group member. Interestingly, silent discoverers were chased and attacked significantly more often than vocal discoverers and such targeted aggression was directed at both high and low ranking individuals. An important consequence of targeted aggression was that silent discoverers obtained less food than their vocal counterparts, but silent discoverers who were not detected at the food source, obtained more food than both vocal and silent discoverers who were detected. Thus, these data suggest that discoverers first assess the composition of their audience through active scanning. Identifying the audience provides a foundation upon which discoverers can assess potential beneficiaries (i.e., those who might profit from hearing the call) and potential aggressors.

4. Mathematical Information Theory

With the rhesus monkey example in mind, we will now consider Shannon & Weaver's (1949) mathematical information theory. We will not provide a thorough introduction to the theory here (see Dretske 1981, chapter 1). For our purposes, it is sufficient to say that SW uses a statistical measure of the relationship between events at one end of a communication channel and the events at the other end of the channel to provide a measure of the amount of information carried by the channel and the efficiency of the channel. The theory does not give any explicit account of what individual signals are about (i.e., their content or meaning). Instead, the operative notion is that of reducing uncertainty. If the reception of a signal reduces the receiver's uncertainty about the events at a source, then information has been transmitted from the source to the receiver. Very different physical mechanisms can serve as channels for information transmission.

SW is attractive because it is mathematically rigorous. Within its framework, the E/R debate can be characterized as about the reliability of correlations of signals to events in the environment. If a signal is reliably correlated to some feature of the environment, then it reduces uncertainty about that feature and can be viewed as a source of information about the feature. This may seem to provide a notion of content since it helps to characterize what a given signal is about. It is, however, too weak a notion of content to be of use in understanding the cognitive processes of communicators. For receivers, change in uncertainty can result in many ways. In the rhesus monkeys, receivers approach FS callers. This is presumably adaptive behavior since individuals who approach are likely to find food. Whether this behavior is mediated by a cognitive expectation of food in receivers or by some other mechanism is undetermined by the evidence from approaches. Ants follow pheromone trails and thereby increase their chances of finding food. If the chances of an ant finding food at the end of a pheromone trail are the same as the chances of a monkey finding food at the site of a particular vocalization, both are equally good information channels according to SW, regardless of differences in cognitive sophistication, and regardless of whether the ants or the monkeys have a cognitive expectation of finding food. Similar considerations apply to cognition in the signaler. The efficiency of the channel need not depend on whether the food-associated calls are the result of an emotional response to food or a different process. If emotional responses are reliably correlated with the presence of food, then the signals produced by emotional responders can be just as informative about food as signals produced by other mechanisms. An emotive account may seem unlikely because one would expect that objects other than food would produce the same emotional state (especially if emotion is viewed simply as level of arousal on a linear scale). But more sophisticated emotive accounts can be developed to handle this.

SW theory is not entirely indifferent to mechanisms. Signals will typically provide information about the proximal mechanisms of their production. However, the point of juxtaposing the food signals of ants and monkeys is to show that the theory is indifferent to mechanisms where information about more distal events is concerned. Proponents of the referential view of vocalizations stress the reliability of the correlation between external referent and signal, as for example we did above when reporting that FS calls are produced *only* in the presence of food. Those who are opposed to attributing referential signaling on the grounds that it presupposes complex cognitive abilities are clearly mistaken if the operative notion of information is SW. Just as clearly, communication understood within this framework cannot be taken as a window on the mental lives of animals.

SW cannot answer certain questions about cognition for another reason; it is indifferent to what Dretske (1981) calls nested information. According to his account, a piece of information B is nested in another piece of information A if pr(B/A) = 1. For example, suppose some signal carries the information that monkey chow is present. Chow is a human artifact. Hence the signal also carries the information that an artifact is present. Presumably there is a cognitive difference between knowing there is monkey chow and knowing there are artifacts. Unmodified, SW cannot account for this difference in informational terms, since any signal carrying the information that there is monkey chow carries the information there is an artifact. For reasons like this, many people believe that SW is not sufficient to provide an adequate account of communication and that some notion of semantic information is required. In the next section we discuss Dretske's (1981) attempt to extend SW in this direction.

5. Information Flow and Semantic Content

We will focus on two features of Dretske's extension of information theory that provide perspective for the E/R debate. The first feature, mentioned above, is his attempt to develop a notion of semantic content and use it to draw a distinction between cognitive information systems and other information systems. The second feature is the idea that the informational content of a signal is relative to what the receiver knows.

Semantic Content. Dretske describes the semantic content of a signal or structure as the most specific piece of information encoded in the signal or structure—i.e. that piece of information in which all other information carried by the signal is nested. On Dretske's view digitalization is a necessary condition for cognition. By digitalization, he means that the cognitive structures activated by a given signal have as their semantic content something less specific than the semantic content of the original signal. On his account, only one piece of information can be the most specific carried by a signal or structure so the semantic content is unique. An example may help here. Monkey A's FS call might contain the information that *A has discovered food.* Nested in this piece of information is the information that *food is present.* Her discovery of food (D) entails the presence of food (F), so pr(F/D) = 1. If listener B's cognitive structures discard the information about the specific caller (and any other more specific information), then B's cognitive system has digitized the information that food is present.

If Dretske is right, digitalization is necessary for cognition but not sufficient. Black and white television sets discard more specific information (i.e. about colors) available in the electromagnetic signals they receive, but even Dretske wants to deny that televisions are cognitive. Although it provides only a necessary condition for cognition, it is helpful to attempt to apply Dretske's notion of semantic content to the E/R debate. On this view, discovering the semantic content of the monkeys' signals requires us to find out how the monkeys treat these signals perceptually. In human language, information about speaker's sex or identity is often available from spoken utterances. Having heard about Ross Perot's reentry to the 1992 presidential race from Connie Chung or Ted Koppel you may later be unable to remember who you heard it from. Information about identity available from newscasters' utterances is discarded. In treating A's FS calls similarly to B's FS calls a monkey similarly discards specific information about the caller which may be available from the call.

On this model, the E/R debate comes down to a question of whether organisms classify the signals according to information they may contain about the emotional level of the signaler, whether they classify signals according to the information they provide about the external environment, or some combination of the two. This question is about mechanisms of reception, in contrast to SW which downplays the significance of mechanisms. On Dretske's account, the dispute between protagonists in the E/R debate appears more substantial since there is a clear question about whether receivers classify signals according to the emotional level of signalers.

Semantic information in Dretske's sense is necessary but not sufficient for cognition or mind. Thus, regarding animal communication as transfer of semantic information, in this sense, does not fully explain how the study of communication provides a window on animal minds. We could identify signals with semantic content that would tell us nothing about minds. Dretske's account of cognition does not end at semantic information however. Specifically, he proposes that cognitive structures are semantic structures that have an "executive function", that is, they are active in causing a system to respond to its surroundings (1981, p. 198). It follows from this conception that semantic communication provides evidence about minds only if we are able to determine that the communicators have internal states with the right kind of informational and executive features. Thus, it seems, we would have to determine first that animals have minds before we could use their communication to tell us about those minds. Consequently, Dretske's account is limited in its ability to cash out Griffin's metaphor.

Receiver-relative information. Dretske stipulates that a signal S provides the information that F to receiver R, if pr(F/S&K) = 1 where K is what R knows. Suppose, for example, that members of a hypothetical group of monkeys give a specific FS call only in the presence of highly preferred foods, but that individual preferences result in different FS-call patterns. Monkey A might use a particular FS call only for coconut, but monkey B might use the same FS call both for coconut and banana. A hearer who knows about the general role of these FS calls will receive the information that *a preferred food has been found* on hearing A's call, but to another hearer who knows about A's particular preferences, A's call will convey the more specific information that *coconut has been found.*

Receiver-relativity helps to clarify an aspect of the metaphor of communication as a window by which ethologists may peer into animal minds. If receiver-relativity is correct, communication does not provide a perfectly transparent window into animal minds since one must first have some idea of what an individual knows before determining what information a given signal conveys to that individual. Thus it is necessary to know something about an animal's mind in order to use its reaction to communicative signals to make further inferences about its mind. Does this result in hopeless circularity? We think not. Communication is not the only source of evidence about the contents of animal minds. Data from studies of both communicative and non-communicative behavior provide mutual constraints on theories of animal minds.

The notion of receiver-relative information can be used to help design experimental tests of hypotheses in the E/R debate. Suppose (in our hypothetical group of monkeys) one has evidence of the food preferences of individual monkeys (e.g., that A prefers coconut over chow but is indifferent between banana and chow, and that B prefers coconut and bananas equally over chow). One could create an experimental situation where a third animal, C, is simultaneously presented with FS calls from A and B from different directions. In the absence of other reasons C might have for approaching one animal, the hypothesis that the FS call conveys information about emotional state but not food type predicts that C would not show any preference for moving towards A rather than B or vice versa. If, subject to appropriate controls (including C's own food preferences), C consistently heads in the direction of one caller rather than the other, one has evidence that the FS calls of A and B convey information about food type to C and that C knows about the food preferences of A and B. Viewing information as receiver-relative helps fix the appropriate controls. For example, by using an animal from a different group than either A or B as the focal animal one could control for C's knowledge of the preferences of A and B and thereby control for the informational content of the signals. (One would also have to control for preexisting social bonds between the animals by varying the social rank and genetic relatedness of A, B, and C.)

The E/R debate is often framed as a question about the specific information conveyed by particular signals. The receiver-relative conception of information indicates that this question may be badly posed if it presupposes that the information carried by a given signal is the same for all receivers of that signal. If receivers differ in their knowledge, then the very same signal might carry information only about emotions to one receiver but carry additional information about external referents to another. The focus on individual differences implied by this approach raises a tricky methodological problem for ethologists. The problem is to devise experiments that are sensitive to individual differences yet meet the requirement of producing statistically significant results. This is especially acute for ethologists working on mammals who typically are faced with small sample sizes anyway.

6. A Biofunctional Account of Informational Content

The next approach to information turns to biology rather than probability theory for its foundation. To determine the informational content of a signal why not ask what its biological function is? Ruth Millikan (1984) tries to build a theory of content which follows this suggestion. We will focus on her account in this section although she is not the only philosopher to take such an approach. Dretske (1981) also makes use of biofunctional notions to help flesh out the account of cognition introduced above. (See Millikan (1990) for an explicit comparison of her view to Dretske's.)

On Millikan's view, the informational content of a signal derives from the way such signals feature in "Normal" explanations of the survival of ancestral organisms that used them. "Normal" in Millikan's usage does not refer to statistical frequency, but to causal efficacy. A signal will be about food if the fact that it (often enough) corresponded to the presence of food is part of the explanation of why using the signal provided an adaptive benefit to the ancestors of organisms who presently use the signal.

In application to the E/R debate, Millikan's notion of information seems to favor referential interpretations over emotion-based interpretations of vocalizations in most circumstances. This is because it is unlikely that signal correspondence to emotional levels would provide any adaptive benefits *except* insofar as emotional levels in turn correspond either to environmental features or to the future behavior of the signaler. In other words, even if the signals are correlated to callers' emotional levels, this in itself is unlikely to have adaptive significance for the monkeys.

Consider Millikan's account applied to the rhesus monkeys. Both FS calls and NFS calls are produced in the presence of food. Suppose the ancestors of the present rhesus monkeys responded to similar calls and as a result were more likely to find and eat food, thus more likely to be healthy, hence more likely to pass the genes for signaling and responding to the next generation. Then it is appropriate to say that a biological function of these signals is to correspond to the presence of available food, and hence that the signals are about food. This is so, even if the behavior of signalers is mediated by emotion.

This approach can also be used to make more fine-grained distinctions in content. A key question is what explains the *diversity* of vocalizations in these monkeys (i.e., why are there three different FS calls)? If different signals get different adaptive explanations, then we can use these explanations to specify the contents of the vocalizations in a fine-grained manner. Assume there is a correspondence between the type of FS call and the nutritional value of the food and that an adaptive explanation for the use of a particular FS call makes reference to the high nutritional value of the food. Then, it would be appropriate to say that the information carried by this particular FS call is that *highly nutritious foods are available*, whereas different FS calls may carry other information about food.

This account of information provides a valuable perspective, but it seems to be too weak to explain the relationship of information to cognition. Like SW, Millikan's account is too indifferent to underlying mechanisms to provide a means of getting from communication to minds. Her account is historical in the sense that a signal's content depends not on present characteristics of signalers or receivers, but on the historical process of selection that explains how the present organisms inherited their capacity for signaling and allows us to say what the signals are for. Applying her account of content, some interactions between trees can have content attributed to them. For example, African acacia trees appear to increase tannin production in their leaves in response to predation by kudu antelope to a level that can kill the antelope. In addition to this primary response, acacias release ethylene into the air causing downwind acacias up to 50 yards away to step up their tannin production within 5 to 10 minutes. The apparent adaptive significance of ethylene release has led at least one science journalist to call it an 'alarm system' (Hughes 1990). Assuming that the full explanation of ethylene release will refer to predation by kudus, this ethylene can be said to carry the information that kudus are eating leaves. Assuming that trees do not have minds, if, under Millikan's theory, trees can be said to communicate, then it is not obvious how analysis of communication provides for straightforward inferences about minds.

Millikan's theory is useful for ethologists insofar as it provides a framework which can be used to help formulate hypotheses (Bekoff & Allen 1992). Its utility in this respect however seems to us to fall short of explaining Griffin's metaphor. One who is convinced that the best account of information that is likely to be forthcoming is based on notions of biological function might just say so much the worse for the metaphor. In the final section, however, we will sketch a conception of information which we believe is capable of fleshing out the metaphor and, at the same time, providing a framework for empirical investigation.

7. The Strong Information Approach

Underlying the E/R debate is a question about mechanisms of production and comprehension that none of the foregoing conceptions of information can adequately address. Consider the rhesus monkeys. One would like to know not just whether their calls are reliably correlated with food, not just whether the monkeys, or their ancestors, gained any adaptive benefit in virtue of the calls sometimes corresponding to the presence of food, but whether such correlations play any role in the mental lives of the monkeys themselves. We believe that this question can be answered without lapsing into gross anthropomorphism.

Grant, for the sake of discussion, that rhesus FS calls normally convey semantic information about the availability of food to the monkeys according either to a probabilisitic account such as Dretske's or to a biofunctional account like Millikan's (your choice). Call this the "weak information content" of these signals for the monkeys. We have argued in the earlier sections of this paper that weak information content does not distinguish genuine cognitive systems from other complex systems (such as television sets or trees). As a working definition for strong information content, we propose the following:

Signals of type *S* have strong information content *C* for organism *O* just in case

(i) tokens of *S* have weak information content *C* for *O*;

(ii) other structures can have the weak information content for *O* that *a token of S has occurred despite the absence of the conditions described by C*; and

(iii) other structures can have the weak information content for *O* that *no token of S has occurred despite the presence of the conditions described by C*.

This is a definition schema in the sense that it yields a different definition of strong information content depending on which account of weak content is selected. Intuitively, the idea is this: for the weak content of a signal to count as strong content for an organism, that organism must be able to treat the signal as an independent indicator of the conditions where it is normally (or Normally) produced—in ethological terminology, the 'species-typical environment'. For example, according to this definition human vocalizations (typically) convey strong information about sex of a speaker. Although we can be fooled by males speaking falsetto, we are also capable of recognizing the mismatch between perceived sex of the speaker and the speaker's actual sex. In contrast, acacia trees are utterly incapable of distinguishing ethylene molecules produced as a result of (e.g.) artificial damage to leaves from those produced as a result of foraging kudus. Consequently, for acacia trees the ethylene molecules fail to carry information in the strong sense about kudus. We do not have the space to explore the concept of strong information in any detail. The definition that we propose seems, however, to account for several intuitions about the difference between mindless information processors and cases where mental properties are plausibly attributed. Prima facie, then, it provides a way of connecting communication to minds in the way suggested by the window metaphor.

Now let us return to the E/R debate and consider it as a discussion about the *strong* informational content of animal signals. In particular, consider the rhesus monkeys. Do their calls convey strong information about emotional response, about food, both, or neither? The strong information approach suggests that we should look for evidence which shows that monkeys are sensitive not just to the signals but to the potential independence of the signals and their production conditions. In section 3 we described how monkeys who discover food scan their immediate surroundings and produce a call if they see another group member. This suggests (but by no means guarantees) that signalers are sensitive to the independence of the presence of food from the production of the call. We also described the cost to animals detected with food after not signaling. Once again, this suggests that the potential receivers are sensitive to the independence of signals from the condition of food being present. Although neither piece of evidence is conclusive, we think the examples illustrate the promise of using the concept of strong information content to help analyze the rich empirical evidence on animal communication. We are, therefore, optimistic about the prospects for a sound non-anthropomorphic methodology for cognitive ethological study of communication.

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