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Communication as a transfer of information: measurement, mechanism and meaning

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4.1 Introduction

No one seems ever to have doubted that animals can communicate with each other. The evidence for communication has always seemed obvious – responses by one individual to the actions of another. In his extended discussions of animal behaviour, Darwin for instance took communication by animals for granted. Although he cited many reports of animals' responses to each other, he never made them the subject of his studies. Instead, he focused on evidence for continuity between humans and non-human animals in the evolution of mental processes. In *The Descent of Man, and Selection in Relation to Sex* (1871), he made an extended case that animals express many of the same emotions that humans do, even such mental activities as deceit, revenge, humour, deliberation and reason. In *The Expression of the Emotions in Man and Animals* (1873), he elaborated on phylogenetic continuity in the expression of many emotions – although not all of those he had mentioned previously. Furthermore, his principle of antithesis, that contrasting emotions tended to be associated with contrasting actions, suggested that animals' actions evolved by natural selection to promote communication.

The basic components of communication are now widely recognised – signaller, signal and receiver. To confirm that communication has occurred, it is thus necessary to show that one individual has produced a signal – a pattern of stimulation – to which another individual has responded. Experimental investigation of this process began with the use of simple models by early ethologists such as Niko Tinbergen (1951). In recent decades, presentations of audio and

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video recordings and even robotic models have resulted in extensive experimental analysis of communication by animals.

Yet Darwin's principal claim remains controversial. Is there continuity between mental processes of humans and those of other animals? Even if the differences prove to be qualitative, can we measure the magnitude of the differences? As Darwin recognised, one of the central issues in these controversies is communication. What do animals communicate? And how much do they communicate? These questions are often phrased in terms of information. What information is communicated by animals? And how much?

This chapter addresses these questions in four steps. First, it reviews the concept of information in communication and thereby concludes that all communication must involve a transmission of information. Second, it considers, but rejects, the argument that information and manipulation are incompatible. Third, it argues that the transfer of information depends on mental processes of categorisation and association. Fourth, it addresses the issue of information about mental states of other individuals and ourselves. It concludes with an element of necessary ignorance.

4.2 Communication as a transfer of information

It is probably not a coincidence that the three components of communication – signaller, receiver and signal – were first identified in the decades following the invention and deployment of the telegraph. De Saussure's (1916 [1959]) diagram takes the telegraph as a metaphor for human language, and Ogden and Richards (1923) elaborate the model by emphasising the mental processes of the signaller and receiver. Linguists and philosophers now use these models routinely in their discussions of communication.

Further advances in engineering and the widespread adoption of telephones and electromagnetic radiation for human communication eventually led to competition for communication. How many radio stations could simultaneously operate in one area? How many conversations could simultaneously use one telephone line? Investigation of these practical issues revealed that communication had limits. To understand these limits, it was apparent that communication had to be measured. Shannon's (1948, 1963) pioneering contribution was to propose a measure of information and then to use it to demonstrate mathematically that the properties of the connection between signaller and receiver – the channel – imposed a limit on the amount of information that could be transmitted in any period of time.

Shannon's measure of information in a set of i signals (H_o) equals $\sum p_i \ln p_i$, with p_i being the probability of the ith signal. As Shannon explains, this particular expression is the simplest one possible that can satisfy our intuitive requirements for a measure of the amount of communication. This measure (H_o) is the number of binary decisions required to specify which signal in a message is next, or in other words to specify the occurrence of any one signal. It is thus the uncertainty in predicting the occurrence of any one signal. An informative message would have high uncertainty about the occurrence of any one signal (it would require many binary decisions to specify each signal's occurrence). Frequent use of just a few signals conveys less information than would many less frequent signals. An infrequent signal increases the amount of information in a message more than does a frequent signal.

A set of signals could consist of a sequence of signals in time or an arrangement of signals in space. Shannon's measure applies to both cases. In either case, identifying a set of signals often requires some method for segmenting the temporal or spatial continuity of an animal's actions into components. As Shannon shows, this segmentation is not necessary, because his conclusions still apply in the limit of continuously varying signals and responses. Nevertheless most attempts to measure information require segmentation of animals' actions into sets of signals and responses.

The concept of information as a measure of the degree of uncertainty in a pattern of signals contrasts with the usual concept of information as the degree of certainty a receiver acquires from signals. Shannon's definition of information thus seems contrary to any definition that others might accept as intuitively appropriate. The issue is whether information is a property of the structure of signals or of the state of the receiver.

The problems arising from the segmentation of actions and the nature of information have both resulted in distortions in how biologists think about information. Both have resulted in premature rejections of information in animal communication. The remainder of this section discusses the first of these issues, the segmentation of signals and responses. Subsequent sections take up the second issue, the receiver's state of mind.

The problem of segmentation arose during attempts to measure the amount of information in animals' displays. At the time it seemed that such measures would allow comparisons of communication by different species or different modalities. Attempts to measure the information in the displays of rhesus macaques and fiddler crabs (Altmann, 1965; Hazlett & Bossert, 1965) consisted of identifying a set of distinct actions and then estimating the probability of each in particular contexts. Ethologists had become accustomed to describing ethograms, discrete categories of actions for each species. Measuring the information in displays was just one of a number of ways that ethograms could be used to quantify behaviour. It became apparent, however, that any measure of information depended on how the observer chose to segment the animals' actions. In some cases, such as the songs and stereotyped displays of some birds, actions seem relatively invariant and discrete, although only in a few cases has variation actually been measured (Wiley, 1973). As a rule, however, animals' displays, including those of monkeys and crabs, consist of variable and intergrading actions. When an observer segments these variable displays into discrete categories, the number of categories and their boundaries have unknown relevance for the animals involved. As a result, measuring the amount of information in animal displays seems arbitrary, and comparisons of different species seem fruitless. Only a few studies have followed these precedents (Dingle, 1969; Steinberg & Conant, 1974).

The problem of segmentation is not insurmountable, however. The problem lies not with segmentation of animals' actions in itself but with identifying a segmentation relevant to the species under investigation, rather than one imposed by a human observer. Behavioural and neurophysiological experiments can determine how individuals classify stimulation. Yet we often do not know as much as we should.

Consider recognition of conspecific individuals. Many experiments have shown that animals respond to signals from their own species but not from others, and that they respond to signals from particular individuals but not others (Falls, 1982; Wiley & Wiley, 1977; Godard & Wiley, 1995). Recognition of young by parental birds provides a good example. Beecher and his students, for instance, have shown that adult cliff swallows recognise their own young while they are still in the nest, whereas adult barn swallows do not (Beecher *et al.*, 1986). When nestling barn swallows were experimentally exchanged between nests, parents responded to nestlings from another nest just as much as to those of their own. In contrast, parent cliff swallows did not feed others' young under any conditions. Playbacks of nestlings' calls confirmed this difference between the two species in parental recognition of young. Furthermore, the calls of nestling cliff swallows vary more among individuals than those of barn swallows, as expected if they encode more information about individual identity. Because the nests of cliff swallows are clustered in dense colonies, while those of barn swallows are dispersed, only among cliff swallows might parents or young occasionally enter the wrong nest. Since cliff swallows build flask-shaped nests of mud, so the young inside are in nearly complete darkness, it makes sense that the nestlings' vocalisations have evolved to promote parental recognition.

Although parent cliff swallows recognise their own young at least collectively, it is not known whether or not they can go a step farther to recognise each of their young individually. Individual recognition of this sort would require that parents respond to each offspring in a distinctive way. Current experiments indicate only that parents distinguish familiar nestlings' calls from unfamiliar ones.

These classic experiments demonstrate two important points. First, animal communication does convey information, in this case the identity of offspring, and, moreover, the analogous signals of two different species can differ in the amount of information conveyed. Second, even in species for which transmission of information has been demonstrated, it is a more difficult task to determine how much information this is. In particular, we do not know whether parents recognise their young collectively or each one individually. The difference is between a binary discrimination (between categories of their own young and all others) and a more complex discrimination (between as many as six individual young). In this case the units of classification (individual organisms) are clear, and we understand something about how swallows of different species classify these units, but there remain open questions about the complexity of this classification.

Even when units of classification are apparent, actual signals and responses themselves are likely to vary continuously or at least in complex ways. This complexity makes it difficult to measure the amount of information in signals. Beecher and colleagues (Beecher *et al*., 1989; Medvin *et al*., 1993) have estimated the potential amount of information in the vocalisations of nestling barn and cliff swallows by measuring variation in many different features of frequency and timing and then reducing this variation to a set of independent principal components. They could then use the standard deviations of these principal components to estimate the potential amount of information, in binary units, that these vocalisations contain. This estimate is an upper limit for the amount of information transmitted from signaller to receiver. To determine the actual amount of information transferred would require experiments to document the association between variation in signals and variation in responses.

Haldane and Spurway (1954) had earlier used similar procedures to determine the amount of information transmitted by the waggle dances of honeybees. Variation in the directions of honeybees' foraging flights provided an estimate of the amount of directional information that foraging bees obtained from waggle dances. Error in the mean direction of foraging flights provided an estimate of the amount of information in the dances themselves. Haldane and Spurway concluded that the dances appeared to contain two to three bits of information more than the accompanying foragers received. Recent measurements have shown that variation in the directions of the dances themselves depends on the distance or nature (food or nest site) of the target (Towne & Gould, 1988; Weidenmüller & Seeley, 1999; Tanner & Visscher, 2010). Similar procedures have been used to estimate the amount of information in the odour trails of ants (Wilson, 1962).

These cases show that determining the amount of information in animal signals must clear some technical hurdles (Pfeifer, 2006, but they also indicate that this process is important if we wish to understand the complexity of animal communication. As discussed below, understanding the categorisation of stimulation by animals is critical for any understanding of the evolution of communication.

4.3 Manipulation versus information

Prior to the development of rigorous thinking about the evolution of cooperation, it had always seemed that communication was an example of cooperation. Signallers provided information that receivers used. In *The Behavior of Communicating* (1980), Smith took this point for granted. He identified the 'message' of a signal as the association between a signaller's action and its current state (its neural and physiological state, including its disposition to act in particular ways and its perception of its environment). Thus the message of a signal might be that the signaller is likely to fight if attacked, that it has just seen a predator approaching, that it is in excellent physical condition, or that it is a particular species or individual. Marler (1961) had earlier discussed the ways in which signals are associated with states of signallers. Smith then identified the 'meaning' of a signal as the association between the signal and the receiver's responses. He made the important point that signals with the same message could have different meanings for receivers, as a result of differences in a receiver's context and state. Much of Smith's own work focused on determining the associations between the signals produced by birds and their contexts and states.

Although these early analyses assumed that communication had mutual advantages for signaller and receiver, they nevertheless emphasised two undeniable features of communication. Signals include information only by virtue of their associations with the states (including contexts) of signallers. They transmit information only by virtue of their associations with the responses of receivers.

Rejecting the assumptions that communication is necessarily mutually beneficial to the participants, Dawkins and Krebs (1978; Krebs & Dawkins, 1984) argued that signals instead evolve by natural selection to manipulate receivers to respond in ways that provide advantages for the signaller, regardless of any advantages for the receiver. This position, however, raised the question of why receivers should respond to signals in ways that were disadvantageous for them. A possible answer is that signallers exploit sensory biases of receivers, in other words constraints on the way receivers respond to signals (Guilford & Dawkins, 1991; Arak & Enquist, 1993; Endler & Basolo, 1998; Ryan, 1998). Such constraints might occur when receivers have evolved to respond to particular signals in another context. For instance, if females respond to particular signals in finding food or shelter, a signal mimicking these signals might stimulate a female to respond to a male when she otherwise would not. Alternatively receivers might respond to exaggerated signals not normally produced by signallers, examples of supernormal stimuli, as a result of the retention of ancestral constraints on their nervous systems or as a result of peak shift in learning (Hogan, Kruijt & Frijlink, 1975; Lynn, Cnaani & Papaj, 2005; ten Cate & Rowe, 2007). Both of these proposals assume that receivers have not yet evolved more discriminating responses to sensory input.

A revision of this position came when Grafen (1990) emphasised that receivers must on average receive benefits from their responses, otherwise natural selection would tend to eliminate those responses. As a rule receivers should respond only to signals that convey information about (are associated with some feature of) the signaller that is useful to the receiver. Grafen attempted to confirm Zahavi's (1977; restated in a 1997 book) proposal that the cost of a signal guarantees its honesty, because for one reason or another the cost is too great for a deceptive signaller to bear. Searcy and Nowicki (2005), in their review of the evolution of communication, confirmed the three relevant points in this theory of honest signalling: (1) to qualify as signals, actions must at least occasionally evoke responses from receivers; (2) receivers must on average benefit from their responses; and (3) signals must convey information about signallers in ways related to their costs. For instance, females respond to signals associated with high-quality mates, and these signals have higher costs than those associated with low-quality mates. Searcy and Nowicki identify many examples of animal communication that meet these criteria.

These conditions for honest communication are close to the position that Smith advocated earlier, with the addition of a stipulation that signals are honest on average. The message of a signal is its association with the state of the signaller. Receivers on average benefit from their responses. Communication is on average honest and thus normally advantageous for both signaller and receiver. This revised position leaves open the possibility for manipulation, which occurs when signallers can take advantage of receivers by mimicking a signal that would in other contexts evoke a response beneficial to the receiver or when receivers can take advantage of signallers by eavesdropping on signals that would in other contexts evoke responses beneficial to the signaller. In all such cases receivers and signallers benefit on average from communication, although on infrequent occasions they are manipulated to their disadvantage.

Numerous such cases of manipulation are now known. For instance, birds occasionally give false alarms for predators in order to gain access to food that is otherwise monopolised by more dominant individuals (Møller, 1988), and some primates practise deception routinely (Whiten & Byrne, 1988; Cheney & Seyfarth, 1991; Mitchell & Anderson, 1997). It is now apparent that signals must, as a result of natural selection, evoke responses that have advantages for both signaller and receiver, at least on average. Manipulation is thus the exception that proves the rule (Wiley, 1994).

Recent discussions of the role of information in animal communication emphasise one aspect of these conclusions or another but are not actually in conflict (Owings & Morton, 1998; Rendall *et al.*, 2009; Seyfarth *et al.*, 2010). Signals do convey information about the signaller, and yet sometimes signals are manipulative. Everybody can agree that communication has three basic components: signals include information (about the signaller or its situation), receivers respond (overtly or covertly, with high or low probability), and both signallers and receivers benefit on average.

These conclusions do not resolve all problems raised by information in signals. Most people feel that the information in signals is more than a correlation with the internal or external state of the signaller. Instead, most people feel that information is about something – about something the signaller perceives or thinks. De Saussure (1916 [1959]) emphasised the relationship between a signal and the signaller's mind, and Ogden and Richards (1923) added an external referent to make a triangular relationship – signal, mind and referent – necessary to understand the 'meaning of meaning'. In the following sections, I pursue an engineering approach to information in order to address the 'meaning of meaning'.

4.4 Communication as categorisation and association

So far I have used the term 'signal' loosely. Engineers in fact never seem much concerned with a definition of a signal, although ethologists have perennially wrestled with a definition. Maynard Smith and Harper (2003), like Grafen (1990) previously, emphasised that a signal must have evolved for the purpose of evoking a response. They maintain that the condition of evolution distinguishes signals from 'cues', which include inanimate sources of stimulation that influence animals' behaviour. They also distinguish two kinds of signals – indices and handicaps – based on whether or not a signal is reliable because it cannot be faked or has excessive costs. All signals have costs, but handicaps have 'strategic costs', costs in excess of 'efficacy costs' which are those 'needed to transmit the information unambiguously' (Maynard Smith & Harper, 2003, p. 7).

Shannon and Weaver (1963) defined ambiguity as the uncertainty in responses to a given signal (as opposed to equivocation, uncertainty in signals for a given response). Ambiguity and equivocation are the two components of noise in any system of communication. Ambiguity is a relationship between a signal and responses, not a property of a signal. In the real world, as Shannon realised, there is no communication without noise – no communication without ambiguity. Communication can have more or less ambiguity (and equivocation), more or less efficacy, if you will, but there is no transition between efficacious and 'strategic' communication, as Maynard Smith and Harper maintain. All the costs of an evolved signal contribute to efficacy, to reducing ambiguity by evoking an appropriate response.

Instead I have proposed a definition of a signal that does not require an antecedent understanding of its evolution (Wiley, 1994). A signal is any pattern of energy or matter that evokes a response without providing all of the power for that response. For instance, if a tree falls, shoving someone out of the way is not communication (the shove is not a signal because it provides sufficient energy to effect the movement of the recipient). A shout, "Heads up!", on the other hand, is a signal, provided the receiver sometimes responds, for instance by jumping out of the way. By this definition, the sound of the cracking trunk is also a signal, so that, if the hearer jumps away, communication has also occurred.

Two points need clarification. First, a system of communication includes many such instances of signals, not just one. It is characterised by probabilities, not isolated instances. Communication occurs even if on some occasions the recipient does not move. Second, although this definition includes inanimate sources of signals (which Maynard Smith and Harper and others would term cues), there is no essential distinction between these and signals from animate sources. However, animate sources can evolve, which raises the possibility that the properties of signals become optimised for communication, as Darwin's principle of antithesis had suggested. Because a signal does not provide all of the power for a response, the receiver must perceive a signal and provide some, often most, of the power for the response. The signal of course must provide enough power to affect the receiver's sensory organs.

A receiver thus must have a nervous system (or some other feature of its physiology), which perceives a signal and then associates it with a response, and a musculoskeletal system (or in some organisms just a muscular system), which produces the response. The engineering equivalents are transducers, gates (switches) and amplifiers. The definition of a signal thus also defines a receiver – a mechanism with transducer, gate and amplifier.

Second, this definition makes it clear that the receiver is in control of communication. A receiver is a decision-making mechanism. It categorises impinging stimulation into perceived signals and associates perceived signals with responses. Animate receivers can evolve and thus optimise responses to a signal. As I have discussed elsewhere (Wiley, 1994, 2006) and as Grafen (1990) had previously recognised, such receivers should in all cases benefit on average from their responses to signals. They should evolve to minimise responses to unreliable or deceptive signals. In communication there is always the possibility of some deception or error, but unless responses to signals provide some benefit on average to a receiver, receivers should evolve to cease responding altogether.

Instead of pursuing questions about the evolution of communication, I want to emphasise here the decision-making property of receivers. One of their essential properties is categorising the stream of incoming stimulation. This is the process often called segmentation, by which discrete objects or units are identified in the continuous flood of stimulation. It is the basis of perception – a relationship between the properties of stimulation and the properties of the sensory components of the receiver's nervous system (the sense organs and higher sensory centres of the nervous system). The examples of recognition of conspecifics above are clear cases of the categorisation of sensory input. In fact, all communication involves such categorisation.

Furthermore, a receiver must associate perceived categories of stimulation (signals) with responses. As Sherrington (1906) long ago emphasised, one important function of all nervous systems is to associate each perceived category of stimulation with a particular response or suite of responses. The motor components of the nervous system, which control the musculoskeletal system, become the 'final common pathway'. Categorisation of stimulation and association of the resulting categories with responses are the two fundamental properties of an animate receiver – and indeed of any nervous system.

The process of categorising stimulation raises a question about the perceptual demarcations of categories. In general terms the rules for demarcation could be learned or innate. By innate, I mean developing in the absence of sufficient external information to specify the resulting rule. For instance, the striate cortex of mammals includes cells that develop into stripe detectors that respond only to strips of light in particular orientations at particular locations in the animal's visual field. It is now well known that these cells develop before birth in the absence of any exposure to patterns of light such as stripes (Hubel & Wiesel, 1963). Their development requires only environmental conditions sufficient for normal development of the brain in general. After the eyes open, the further development of these cells depends on subsequent environmental conditions, both general (exposure to light regardless of pattern) and specific (exposure to particular patterns of light, such as predominantly horizontal or predominantly vertical stripes). Nevertheless, under normal conditions for brain development, these cells develop initially to detect specific features without exposure to patterns of light.

Songbirds learn features of their songs, but they begin the process of learning with innate predispositions to attend to certain patterns of sound (in some cases, components of conspecific songs) or to sounds in certain situations (Marler, 1984; Marler & Peters, 1988). Without these initial (innate) predispositions, it is hard to imagine how a naïve bird could identify in the flood of incoming stimulation what it is that it should learn.

The importance of predispositions for learning had previously been emphasised by Lorenz (1966). Chomsky (1959, 1986) made the same point about the development of language in human children. Much earlier, Kant (1793 [1961]) had elaborated his philosophy from similar arguments for innate categories in all rational thought. Association without predisposition leads to chaos. With predispositions, association can produce the extraordinary complexity of animal and human behaviour, much if not most of which is communication in one form or another.

The expanded brain of humans no doubt allows greater complexity in categorisation and association. Quantitative increase in components can, in some sense, lead to qualitative differences in performance. Of course, recognising a qualitative difference is itself a form of categorisation. Humans are perhaps predisposed to recognise categories of human and non-human animals. So caution should temper any conclusion that human and non-human brains differ categorically.

4.5 Communication of states of mind

If the nervous systems of organisms, their brains in particular, are mechanisms for categorising stimulation and for associating the resulting categories with responses, are they sufficient to produce minds? Whether brains are sufficient explanations of minds is, of course, an old question in philosophy – perhaps, in one form or another, the only question. If an organism's mind is sufficiently explained by its brain, then the minds of other organisms are revealed by their behaviour. This position, I suggest, is the essence of behaviourism (Morris, 1955; Bennett, 1976) (perhaps philosophical behaviourism is a better label, to distinguish it from psychological behaviourism). What a stimulus means to me, for instance, is entirely equivalent to how it changes my behaviour. The change might not be immediate or overt. In addition, because so much of behaviour is communication in one form or another, we should accept probabilistic changes in behaviour as meaning. Two signals would have different meanings if they evoked different probability distributions of responses, covert or overt, immediate or eventual.

With this point of view, a 'theory of mind' would consist of an ability to predict, at least probabilistically, other individuals' responses to stimulation (signals). Humans obviously can manage this feat. As was long ago pointed out to me, we would not dare to drive home if we could not predict other people's behaviour. It is also obvious that all animals can predict the behaviour of other individuals, at least probabilistically, and respond appropriately. This behavioural point of view thus implies that all animals have 'theories of mind'. Just as animals differ in complexity of associative learning, so their 'theories of mind' differ in complexity.

Mind, however, is not obviously equivalent to brain. This nagging reservation arises particularly when I consider my own mind. Sometime in the future neurophysiologists might be able to specify the precise state of every cell in my brain at a particular time. It might, for instance, become possible to specify exactly which neurons are activated when I see a particular tree or when I imagine the concept of treeness. Nevertheless, these neurons, it is easy to suppose, might not *be* my image of a tree nor my concept of a tree. The issue is whether observations of another organism's brain or behaviour are, or are not, enough to characterise its mind. Such thoughts raise many issues, but at the core of these issues are self-awareness and intention.

Evidence for self-awareness, it is often assumed, can come from reactions to mirrors. When an animal or human directs responses to its own body while viewing itself in a mirror, it seems that it must have an awareness of itself (Gallup, 1970, 2011; De Veer & Van den Bos, 1999). This ability, however, develops as a result of experience with mirrors. Humans without such experience are baffled by mirrors. Indeed, even photographs and recordings confuse people who lack experience of seeing or hearing themselves. Learning that visual images in a mirror can be associated with actions directed toward one's own body requires mastery of a chain of contingencies. It requires a complexity of learning that is evidently beyond the abilities of most animals. Yet it is not clear that the process differs qualitatively from other examples of associative learning. Furthermore, anyone who has tried using mirrors to view the back of the head, or, worse still, to direct actions there, becomes quickly disabused of any conclusion that self-awareness is equivalent to mastery of mirrors.

Normally our sense of self-awareness comes from introspection, just as does our sense of treeness or a particular tree. It is probable that association is important for this introspective self-awareness. We might associate all of our responses to sensory input with a common agent, in other words, our self. Once again, it might become possible, sometime in the future, to predict when a person is self-aware by determining the state of neurons in the brain, but making this connection would depend on the person's own report of self-awareness. Thus it is not clear that a description of neurons can ever be equivalent to self-awareness. Even one-to-one mapping of behaviour and brain might not guarantee existential equivalence of mind and brain.

I am trying to choose my words carefully here so as not to take a position that mind is, or is not, brain. The preceding arguments suggest that currently there is no indisputable evidence for or against either position. At least to my mind, if I may say so, it is not utterly obvious that mind is brain, nor that it is not. Nevertheless, a discussion of information in communication must include attention to the state of mind often thought to be crucial for human communication – intention.

Intentions (in the sense of preconceptions of actions) are often assumed to distinguish human communication from that of animals. When communicating, I intend to modify the recipient's mind, at least in some minimal way. When speaking of a tree, for instance, I intend for the listener to acquire an image of a tree somewhat like my own. As Wittgenstein (1968) has famously emphasised, this process requires that we have developed similar rules for using signals, or, Shannon (1948) would say, for encoding and decoding signals. We must both associate the word 'tree' with a mental image such as 'generalised tree'. These rules are just as important when our intention is to deceive. Intentions are the basis for much human morality and justice. It has also been proposed that adopting an 'intentional stance' (Dennett, 1987) facilitates communication or indeed all interactions with animate and perhaps even inanimate objects. What produces intentions? And how do we recognise them in others?

By introspection, my intentions seem connected to my awareness of my self as an agent. As described previously, this awareness might arise as a result of an association of my responses. It is thus a second-order association. Particular sensory inputs become associated with certain responses. Then these sensory–motor associations become associated with each other to produce a sense of agency. It is the patterns in my behaviour as a sentient and responsive organism that generate my sense of my self as an agent (so it appears to me on introspection). Can someone else study my intentions by studying my brain and behaviour? It is not clear that they can, because, just as with self-awareness, verification of my intentions requires my introspection.

If my intentions are a result of introspection, to pursue this argument, my willingness to attribute them to others must depend on empathy. I can of course, with enough study, predict the behaviour of others, in a probabilistic way, as discussed above. Yet, if mind is not behaviour, attributing mental states such as self-awareness and intentions can only occur by empathy. Empathy is attribution of mental states based on a sense of similarity between oneself and another. The more similar another person is to me, for instance in behaviour, the easier it is to empathise. Empathy can be extended to non-human animals, on the same basis, and even to plants and inanimate objects. To the extent that my automobile responds predictably to my input and my careful attention, I can empathise with it. It might well help me to communicate with my automobile to take an intentional stance and to empathise with it. The personification of many objects and features of the environment by peoples of many cultures could well have the same basis.

The two contrasting possibilities, that mind is brain or that it is not, thus lead to two contrasting views of information in communication. The first possibility leads to probabilistic predictions of behaviour, based on associations of contexts with responses. The second leads to introspection and empathy. If attributing states of mind to other organisms is equivalent to predicting their behaviour, then I regard all animals (as well as people) as having states of mind, and all as having theories of mind that allow them to respond to other individuals in appropriate ways. If attributing states of mind is not equivalent to predicting behaviour, then animals (and indeed other people or even machines) have states of mind depending on my ability to empathise with them.

I want to stress once again that I take no position on this polarity. It is not clear to me whether it will be possible, sometime in the future, to reduce my introspective sense of self-awareness, intention and meaning to the states of the neurons in my brain or to complexities in my behaviour. Thus it is also not clear to me that I can identify these states of mind in other individuals by studying their brains or behaviour. It is an uncertainty I can live with, however. I conditionally accept that mind is brain and proceed to analyse how animals communicate, how they categorise other individuals and their environment, how they associate sensory input with responses, how complicated these processes can be. Attributing states of mind, self-awareness and intentions to other humans is a necessary feature of our moral and legal systems. Attributing these states to other people, to non-human organisms and to inanimate objects is often an amusing diversion and might also help me to interact with them fruitfully. Insofar as I do anything more than predict or anticipate their behaviour, however, I engage in empathy.

To summarise, this discussion has led to three conclusions. (1) Communication consists of transmission of information from one individual to another. (2) If mind is behaviour, then all organisms communicate states of mind. (3) If it is not, then no communication transmits states of mind.

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