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PART A

The Nature of Communication

INTRODUCTION TO PART A

What is meant by communication? In summarizing a recent conference on (non-verbal) primate communication, Ploog and Melnechuk (1969) reported that some participants saw no differences between social behaviour and communicative behaviour, while others thought that a distinction 'ought to be possible'. Some workers prefer a broad definition, using communication to refer to the giving off by one organism of a signal which influences the behaviour of another (e.g. Frings and Frings, 1964), but others feel that this conceals fundamental differences of complexity between different phyletic levels (e.g. Tavolga, 1968). When there is difficulty in obtaining agreement over a dull matter of definition, one can be sure that unresolved conceptual issues lie concealed. The important goal then becomes, not the defining of the term, but specifying the sorts of distinctions which are useful. In the following chapter, MacKay, an information theorist, analyses various concepts often confused under the label of 'communication', and provides a framework which makes it possible to relate the different usages employed by other contributors. Thorpe, a biologist, takes up the matter of species differences in systems of communication: he compares species in the extent to which their communication systems possess the 'design features' of human language (Hockett and Altmann, 1968). This leads him to consider how far the complex communicatory abilities, which have recently been taught to chimpanzees, do, in fact, approach human language. In the third chapter, Lyons, a linguist, takes up in more detail the relations of non-verbal communication to verbal language, summarizes some of the basic principles involved in the study of language, and discusses current views on its evolution.

1. FORMAL ANALYSIS OF COMMUNICATIVE PROCESSES

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1. INTRODUCTION

Every field of science, old or new, is haunted by the perennial question: how can we avoid foreclosing empirical issues, and missing essential points of the situations we study, by our choice of conceptual apparatus and working distinctions? There is, of course, no static answer. A restless Athenian eagerness to run after 'some new thing' is generally counterproductive and damaging to scientific standards. On the other hand, especially in a new field, we must expect our concepts to need constant refinement, and must be alert for signs that something important is escaping us because our customary ways of looking at the phenomena have a significant 'blind spot'.

Given the enormous variety of ways in which animals and men can influence one another without relying on words as such, it is not easy to see how such a vast field can profitably be studied at all as a unity. Clearly, we need some way of abstracting formally what these diverse situations have in common, and of systematically comparing and contrasting the mechanisms at work in them. On the other hand, any formal description of something as familiar as communication runs the risk of seeming both pretentious and banal. Unless it is clear to what end we wish to formalize, the effort were better not made, or at least not made public! The purpose of this chapter is not, then, to offer an armament of neologisms for general use, still less to lay down the law in matters of definition; it is rather to consider what problems, if any, in the study of non-verbal communication create a need for analysis in other than commonsense terms, and what the prospects are of meeting that need without defining out of existence some of the questions we must be ready to ask.

2. WHAT COUNTS AS 'COMMUNICATION'?

At the outset we need some kind of convention, however arbitrary, to define what will count for our purposes as an instance of 'communication'. The etymological root of the term (*communicatio*) means *sharing* or *distributing*. Thus we can speak of 'communicating' rooms, and the Apostle (in the classical English of the Authorized Version) can admonish us to 'forget not to do good and to communicate'. In this general sense, *A* communicates with *B* if anything is shared between *A* and *B* or transferred from *A* to *B*.

For scientific purposes we need a more restricted usage if the term is not to become trivial. (Otherwise, the study of 'non-verbal communication' covers every interaction in the universe except the use of words!) For the purpose of the present symposium, we might agree to begin by restricting ourselves to interactions between organisms – though even here some communication engineers would be left out of step.

By them, communication is used loosely to mean the transmission of information regardless of its origin or destination. They will happily speak of a rock on a hillside as communicating with an observer, if sunlight reflected from the rock reaches his eyes. Worse still, the definition of a 'communication channel' in some mathematical textbooks does not even require a causal connection between the two points in question! Provided that the sequence of events at *A* shows some degree of correlation with a sequence at *B*, their authors are ready to define a 'channel capacity' between *A* and *B*, regardless of the possibility that the correlation is due to a third common cause, and not at all to any interactions between *A* and *B*.

Already we see that to speak of 'communication' between *A* and *B* can have a multiple ambiguity. As used by different people it may imply:

(*a*) mere *correlation between events* at *A* and *B*,
(*b*) any *causal interaction* between *A* and *B*,
(*c*) *transmission of information* between *A* and *B* regardless of the presence of a sender or recipient, and/or
(*d*) a particular kind of action by an organism *A* on another, *B*, or
(*e*) a transaction between organisms *A* and *B*.

Since we already have perfectly good terms (those I have italicized) for (*a*) to (*c*), we might perhaps agree to use them instead of 'communication' in those cases. But what of (*d*) and (*e*)? Are all actions by an organism upon another, or all transactions between organisms, instances of 'communication'? In one sense, no doubt, the answer could be affirmative. Organisms in interaction can hardly fail to *receive information* about one another; and it has often been emphasized that such information can be conveyed by inaction as much as by action. All behaviour is potentially *informative* – even non-behaviour. Our main question is whether for our purposes we need to draw any further distinctions. Is it good enough to say bluntly that therefore 'all behaviour is communication'; or do we need sharper conceptual tools?

It is my impression that when we in the present context speak of 'non-verbal communication' between *A* and *B* we do want to distinguish a certain class of non-verbal behaviour from others. Broadly speaking, our concern is with behavioural and structural features of *A* that affect the *internal organization* of behaviour – the control centre – in *B* and vice versa. We look upon the recipient as a system with a certain repertoire of possible modes of action, both internal and external, which must have some central 'organizing system' to set targets for, and control, the running selection from the repertoire which we call its behaviour. In higher organisms the organizing system, (which we shall discuss more fully in Section 6) must determine not only the behaviour of the moment, but also a vast complex of 'conditional readinesses for action' – what kind of behaviour *would* result *if* such and such circumstances arose. To be more specific, it must be able to adjust behaviour to take account of *facts*, acquire and preserve *skills*, and adjust the *priorities* of different possible courses of action.

What interests us here, then, is the kind of interaction between organisms in which signals from *A* influence this central organizing system – *B*'s internal representation of facts, skills or priorities. The ordinary 'Newtonian' effects of *A* on *B*, such as the mechanical vibrations of the body produced by a handshake, or even the réflex 'startle' response to a shout or a pinprick, are in a different and relatively uninteresting class. It is the 'informative', 'releasing', or 'coordinating' functions of behaviour and structure that raise the problems we want to solve. For our present purpose, an event is not communicative (in the relevant sense) unless it has some *internal organizing function* in a recipient. We shall take up this point also in Section 6.

This is a necessary condition – but is it sufficient? Here we reach the point where usages have tended to diverge. All would agree, for example, that a measly face can be *informative* to a qualified onlooker. But is it useful to speak of the sufferer himself (who may be unaware of it) as *communicating* this information? Is there no distinction to be made between the passive manifestation of a symptom and the deliberate (even if instinctive) production of words or non-verbal behaviour (including perhaps pointing to the spots) *calculated* to inform the observer? Again, shifts of gaze or posture may play a subtle part in coordinating the behaviour of two persons (Argyle, 1969); but may it not be useful to have different terms for those acts that are expressive of the originator's purpose and *perceived* or *interpreted* as such, and those that are not? For reasons to be elaborated in Sections 5 and 6, some of us interested in the internal organization of behaviour find such distinctions both operational and essential. Others concerned with purely external descriptions of behaviour may find the distinctions elusive and unnecessary for their purpose. This is understandable. But if we ourselves are to communicate without ambiguity, presumably some neutral terms will be needed which do not beg questions regarded by some of us at least as open.

Fortunately general terms are already available which leave room for most of the distinctions we want. *Signalling* is widely used as a neutral word for the activity of transmitting information, regardless of whether or not the activity is goal-directed, what impact if any it has on a recipient, or even whether the source is animate or not (we speak of 'signals from radio stars'). Its use would allow us to say, for example, that '*A* is signalling but not communicating' in circumstances where information is being transmitted from *A* but not affecting the organizing system of any recipient. Even here, care may be needed to preserve the distinction between signalling in a passive, impersonal sense – the sense in which a rock signals its presence by the light reflected from it – and signalling in the active, goal-directed sense of 'trying to communicate' – i.e. trying to establish a link with another agent – as when a mother calls 'dinner's ready' but the family is out of earshot. If this ambiguity proves serious, we may have to fall back on a still more neutral expression such as *emitting information*. *Control* can be used to denote regulative function by means of signals without either implying or denying that the regulation is consciously intended or consciously perceived. (We discuss the question of 'conscious intention' in Section 6.) *Coupling*, *interaction*, *correlation* are other terms with well-established functions that might with advantage take the place of 'communication' in appropriate contexts.

Similarly, it might help to sharpen our thinking if we were content to speak of structures or events as *symptomatic* or *informative* where one of those terms strictly and adequately describes their function, and allow the over-worked word 'communicative' to rest except when we are clear that it would add something both justifiable and essential.

3. THE TOOLS OF COMMUNICATION ENGINEERING

It is natural to ask how far the study of non-verbal 'communication' might be able to utilize the range of equipment and concepts already developed for the purposes of communication engineering. The answer, I think, depends very much on the kind of understanding we want, and on the extent to which we are prepared to adapt our questions to the tools that happen to be available.

(*a*) At the *taxonomic* level, the challenge has been to develop the equivalent of an 'Identikit' with which to classify the varieties of behaviour or structure that produce invariant (or rather, observationally indistinguishable) effects on the recipient of the resulting signals, and conversely. In the study of bird and mammal calls, for example, the sound spectrograph and its inverse the spectral synthesizer have played a valuable part in articulating the phenomena to be understood (Thorpe, 1967).

There are, of course, dangers in adopting the descriptive categories of the communication engineer, which can easily lead to biologically insensitive classifications. (Even with human speech sounds, for instance, the sound spectrograph can be notoriously ambiguous or misleading – see Fant, 1962; Lindblom, 1962.) There is perhaps a need here for the development of new automatic devices whose classifying categories are more biologically-oriented; but the work described by Thorpe and others in the present symposium shows that even the standard equipment used by communication engineers can be surprisingly effective.

(*b*) At the level of *mathematical* analysis rather less can be said for the quantitative tools developed in the past two decades under the name of Communication Theory. This may seem perplexing; a theory that purports to measure the traffic taking place between a sender and receiver separated by a communication channel might surely have been expected to throw useful light on the processes going on in the terminals themselves as well as in the channel? The reasons for the disappointment (by and large) of such hopes deserve detailed discussion in the following section. Meanwhile we may simply note that relatively little of the puzzlement actually felt by observers of animal communication has been of the right kind to be relieved by numerical answers to numerical questions. As we shall see, it is to a handful of qualitative concepts made precise by the theory, rather than to the great bulk of its mathematical formulae, that the study of non-verbal communication is likely to be most indebted in the immediate future.

(*c*) This brings us to the third level of understanding, that of *causal* analysis, at which engineering ideas have a crucial part to play. *How* do non-verbal signals elicit the response they do? What is going on inside the organisms concerned? What is the relation between the structure of a signal and the internal structure of the receiving organism, by virtue of which, presumably, the signal has the function it does? Answers to such questions can be sought in terms closely analogous to those of information-system engineering and the theory of automata; and the latter part of this chapter will be devoted largely to outlining the area of profitable contact between the two (though not to answering the questions themselves in any detail!).

4. THE MEASUREMENT OF INFORMATION-FLOW

The chief architect of the mathematical Theory of Communication, Claude Shannon, was at the time a communication engineer in Bell

Telephone Laboratories. Shannon (1948) is sometimes credited with having produced a mathematical definition of the concept of 'information', with the implication that if one now wants to use the word scientifically it must be strictly in the context of Shannon's theory. This impression is mistaken. As long ago as 1951, Shannon himself disclaimed any intention of defining 'information' *per se* (Shannon, 1951*a*). What he defined was one particular measure of '*amount-of-information*', which as we shall see was especially appropriate for assessing the capacity of a communication channel to transmit code-signals, but which was designed to be indifferent to the *information* that those code-signals might represent.

The concept of information itself is most readily defined operationally, in terms of what it does (MacKay, 1969). Subjectively, we say that an event provides us with information when it causes us to know or believe something that we did not know or believe before. In other words, information-about-X determines the form of our readiness-to-reckon-with-X in appropriate circumstances. Objectively, information is said to be transmitted from A to B when the form of an event or structure at B is determined by the form of one at A, regardless of the source of the necessary energy. For example, if a heavy machine in a factory is suddenly switched on to a power line, the resulting flick of the ammeters back in the power station provides 'information' to the attendant. We can speak of this as the 'transmission of information' from the factory to the power station, even though the direction of energy-flow was from the power station to the factory.

Thus the general notion common to both subjective and objective uses of 'information' is *that which determines form*. In order to make it precise, we have always to ask: the form of what? In the case of an organism 'receiving information', the answer must be in terms of those internal features of its organizing system that represent 'that which is the case' for the organism – in a general sense, its field of action – the 'world' it is prepared to reckon with. Information-for-an-organism is operationally definable as that which confirms or changes its internal representation of its world. (This clearly leaves open, as it should, the possibility that such information may be true, doubtful, false or even illusory.)

In this context, the communication engineer regards himself as a go-between whose job is to determine the form of certain events at a 'receiver' in obedience to instructions given by a 'sender'. Instead of *constructing* each form *ab initio* (for example, by tracing out each letter of the alphabet in a run of text), it is often economical for the engineer to keep a pre-fabricated range of standard forms (such as the letters in a teleprinter) at the receiving end and to *select* the forms required in response to the sender's instructions. The set of rules prescribing what must be selected in response to each possible signal is known as a *code system*. On this basis, the cost of transmission is measured by the number of basic instructions needed to define the total *selective operation* required – quite regardless of what it is that has been selected.

At this point non-mathematical readers may prefer to skip to the next section; but for our later discussion a few further details will be relevant. If we take as the basic instruction (and as our unit of cost) the answer to a simple two-valued question (yes/no, left/right, 1/0), then the most economical selection process (as in the game of '20 Questions') will be one in which each instruction halves the range of equally-likely possibilities. One out of two items can be identified in one step; one out of four, in two; one out of eight, in three; and so on. The cost (in this logical sense) of identifying one out of n equally likely possibilities is thus measurable by the logarithm of n to base 2, $\log_2 n$. Since the prior probability of each item will in this case be $p = 1/n$, we can write $\log_2 n$ as $\log_2 (1/p)$. This is defined as the *selective information content* of an identification whose probability was p. It is measured in 'bits' or binary digits.

Where some forms are selected much oftener than others, the average cost (in basic instructions or 'bits' per selection) is reduced if the more frequent items are encoded so that they can be selected in fewer steps than the less common ones. It was shown by Shannon (1948) that where the relative frequencies of selection are $p_1, p_2, \ldots, p_i, \ldots$, the minimum average (logical) cost per selection achievable by encoding in this way is $H = \Sigma p_i \log_2 (1/p_i)$ bits; i.e. the weighted mean of $\log_2 1/p_i$. This is the expression loosely referred to by some textbook writers as 'information'; but as Shannon emphasized, what it makes mathematically precise is not the concept of information at all, but only a particular *property* of information – its prior uncertainty or statistical unexpectedness.

The expression H has its maximum value (H_{max}) when all the probabilities p_i are equal – i.e. when all items in the repertoire are used equally often. ($1-H/H_{max}$) is known as the *redundancy* of the signalling process. It can be regarded as a measure of the extent to which the repertoire is under-utilized. Despite the pejorative flavour of the name, redundancy is of great value if signals are liable to distortion or corruption by 'noise', since it makes possible in principle the detection and correction of errors (Hamming, 1950). Our ability to detect misprints, for example, depends entirely on the redundancy of typical English text. Shannon (1948, 1951*b*) was able to show that in a strict sense a communication system's tolerance of transmission errors is directly proportional to the signalling redundancy.

5. COMMUNICATION THEORY IN BIOLOGY

The usefulness of Shannon's measures to people concerned with the economics of signalling systems is self-evident. What may be less obvious are the presuppositions that must be satisfied if they are to be applied in other contexts such as that of biological communication. At first sight it is all deceptively straightforward. An animal uses items from its repertoire of signals with different relative frequencies. By prolonged counting we can derive estimates for the probabilities (such as p_i) in Shannon's formula and compute an 'average selective-information-content' per item, H. So far, so good. But now, what does this mean? It means strictly that over a long run of items, an engineer who knew the probabilities (p_i) could specify the animal's behaviour by using a code sequence of about H basic instructions per item. The question is whether anything of biological interest is likely to correspond to or co-vary with this figure.

If the receiving animal's brain were organized to take account of relative frequencies on the same basis, then conceivably the brain might develop an optimal code-system whereby the items were identified 'economically' in the sense of Shannon's theory, and our estimate of H would then give some idea of the magnitude of the cerebral processing operation. But there are two snags. In the first place, for a biological system that *grows* its parts, the criteria of 'cost' may be very different from those used by the engineer. Logical economy and biological efficiency do not necessarily coincide. Large-scale parallel processing, for example, involving enormous numbers of signals per item, may be relatively cheap as a biological solution where it would be prohibitively costly in a wired automaton.

But more serious still is the problem of finding appropriate probabilities (p_i) for Shannon's formula. The whole computation presupposes a 'statistically stationary' situation: in other words, the relative frequencies must not change significantly as time goes on. But the behaviour patterns of greatest biological interest are often those that do change as communication proceeds; and if we confine ourselves to samples short enough to be 'stationary', we must then accept corresponding uncertainties in our estimates of the probabilities. Furthermore, the more labile the situation, the less confidence we can have that any probabilities we estimate are those reflected at a given time in the brain-state of the animal receiving the communication.

In short, any attempt to use Shannon's H as a measure of information-flow *between* organisms raises prior questions that are all too often unanswerable. As a measure of the variability or unexpectedness of behaviour for the scientific *observer*, H can, of course, have a precise significance; and the present symposium contains valid examples of its use as an overall statistical measure of the degree to which an organism's behaviour is coupled or correlated with that of another organism influenced by it. But unless one knows that the receiving organism has, so to say, a 'Shannon encoder' inside his head, one has no prior reason to regard H as a more biologically significant measure of the *information received* by that organism than, say, the total number or duration of the signals exchanged.

All this, however, does not mean that the engineering theory of communication can be ignored for biological purposes. On the contrary, since its basic notion is that of *selection from a repertoire*, it has an immediate link at the *qualitative* level with the characteristic habit of thought of the biologist. By viewing an organism as a system with a repertoire, and its environment as imposing a running pattern of demand for actions selected from this repertoire, we find ourselves talking essentially the same language as the communication engineer (MacKay, 1956, 1966). Terms such as 'redundancy', 'noise', and 'channel capacity' can be used quite rigorously to meet conceptual needs already recognized by biologists in the articulation of problems of behavioural organization. As we shall see in the next section, the related notions of 'feedback', 'feedforward' and 'evaluation of mismatch' have a still more direct (and long-recognized) application to the kinds of behaviour that most interest us in the present context. Finally, I hope it is now clear that ignorance of mathematical Communication Theory is no barrier to the use of 'information' in its ordinary sense, as long as we are not tempted to try to measure it. We are in much greater danger of bringing disrepute on our theorizing if we over-use the term 'communication' in such a way as to obscure necessary distinctions.

6. ORGANIZATION OF ACTION

The term 'action' in physical science has a very broad sense. When we speak, for example, of the action of frost upon rock, there is no implication that the frost is goal-directed, or governed to achieve a particular effect. In the present context, however, we are concerned with a more restricted usage. It is characteristic of organisms that they do act to achieve ends or maintain a required state.

Directed action by an organism is distinguished from mere undirected activity by an element of *evaluation*: a process whereby some indication of the current or predicted outcome is compared against some internal 'target criterion' so that certain kinds of discrepancy or 'mismatch' (those 'negatively valued') would evoke activity calculated to reduce that discrepancy (in the short or long term).