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H. S. Terrace

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Animal cognition: thinking without language

By H. S. Terrace

Department of Psychology, Columbia University, New York, New York 10027, *U.S.A.*

Recent attempts to teach apes rudimentary grammatical skills have produced negative results. The basic obstacle appears to be at the level of the individual symbol which, for apes, functions only as a demand. Evidence is lacking that apes can use symbols as names, that is, as a means of simply transmitting information. Even though non-human animals lack linguistic competence, much evidence has recently accumulated that a variety of animals can represent particular features of their environment. What then is the non-verbal nature of animal representations? This question will be discussed with reference to the following findings of studies of serial learning by pigeons. While learning to produce a particular sequence of four elements (colours), pigeons also acquire knowledge about the relation between non-adjacent elements and about the ordinal position of a particular element. Learning to produce a particular sequence also facilitates the discrimination of that sequence from other sequences.

1. Introduction

The existence of human thought is self-evident. Whether animals think is more difficult to determine. Unlike human beings, animals cannot speak about their thoughts. The only evidence that animals think is indirect evidence which must be gleaned from their behaviour.

Scientists and laymen approach such evidence with deep-seated and contradictory attitudes. One point of view, usually attributed to Descartes, regards animals as unthinking mechanical beasts. Behaviour is elicited automatically by stimuli that originate in the animal's internal or external environments. However complex or elaborate the animal's behaviour, it can always be reduced to some configuration of reflexes in which thought plays no role. Descartes also argued that an animal, no matter how intelligent, lacked the capacity to learn language, the vehicle of human thought.

Darwin's theory of evolution acknowledges the possibility that animals can think. In comparing man and animals, Darwin argued that it is just as logical to say that the human mind evolved from animal minds as to say that human anatomical and physiological structures evolved from their animal counterparts.

Until recently, there has been little concrete basis for choosing between the contradictory positions of Descartes and Darwin. During the past two decades, however, students of animal behaviour have provided two important answers to the venerable question 'can an animal think?'. For the first time, ample evidence is available of the existence of animal thought (see, for example, Hulse *et al.* 1978; Roitblat *et al.* 1984. There is considerable agreement that apes, considered by many psychologists to be man's most intelligent relatives, are unable to master the basic features of human language (Premack 1979; Savage-Rumbaugh *et al.* 1980*a*; Terrace *et al.* 1979). That state of affairs raises a fascinating question that can be asked of animals in general: 'what is the non-linguistic medium of animal thought?'.

This question poses obvious problems of definition regarding thought and language. In a later section of this paper, I will review some examples of cognitive processes in animals and indicate why any definition of animal cognition must concern itself with representations of previous experiences that an animal can generate to solve some current problem. That is, to argue that an animal thinks is to have evidence that, in the absence of an external stimulus, an animal learns to represent to itself some feature of a prior experience that will serve as a cue for an appropriate choice of response (cf. Hunter 1913; Terrace 1984*a*). For the moment, I will focus on language and try to justify my claim that it is absent in animals. Once we understand what is absent, we will, at the very least, see the importance of developing non-linguistic models of animal cognition.

2. Original goals of ape language projects

Though linguists, philosophers, psycholinguists and psychologists have yet to agree on a rigorous definition of language that encompasses its many complexities, there is general agreement that the most distinctive feature of human languages is the provision they make for creating new meanings by combining arbitrary words into sentences according to arbitrary grammatical rules. In contrast to the fixed character of various forms of animal communication, the meaning of a word is arbitrary. A sentence characteristically expresses a semantic proposition through words and phrases, each bearing a well-defined but nevertheless arbitrary relation to one another (for example, in some languages actions can precede objects; in others, actions follow objects).

Our ability to create and comprehend novel sentences has prompted many linguists (for example, Chomsky 1966) to argue that human grammatical competence is innate and species-specific. It was in this neo-Cartesian Zeitgeist that the various recent ape language projects were started (see, for example, Gardner & Gardner 1969; Premack 1971). Accordingly, it was not surprising that a general goal of those projects was the demonstration of grammatical competence in apes. As we shall later see, that goal took too much for granted regarding an ape's non-grammatical linguistic competence and stimulated the various ape language projects to set goals for themselves that were unrealistically ambitious. It is only recently that researchers in this area have redirected their efforts toward more productive lines of inquiry (for example, Savage-Rumbaugh *et al.* 1983).

The initial results of the various ape-language projects produced exciting evidence of an ape's ability to create sentences. (See Ristau & Robbins 1982 for a thorough summary of the literature on attempts to teach language to apes.) For example, in an early diary report, the Gardners noted that Washoe used her signs 'in strings of two or more...in 29 different two-sign combinations and four different combinations of three signs'. That report prompted Brown to comment 'It was rather as if a seismometer left on the moon had started to tap out "S–O–S"' (Brown 1970, p. 211). Indeed, Brown compared Washoe's sequences of signs to the early sentences of a child, in particular, with respect to their structural meanings (for example, agent–action, agent–object, action–object, and so on).

Other projects reported similar combinations of two or more symbols. Sarah produced strings of plastic chips such as MARY GIVE SARAH APPLE (Premack 1976). Rumbaugh *et al.* (1973) taught a juvenile female chimpanzee named Lana to use an artificial language of 'lexigrams'. Each lexigram was constructed by superimposing an arbitrary geometric configuration on one of six coloured backgrounds. After learning to use individual lexigrams, Lana was taught to produce sequences such as PLEASE MACHINE GIVE M & M. Subsequently, Patterson (1978) reported that Koko, a young female gorilla she taught to use American Sign Language (A.S.L) produced many combinations of two or more signs.

The imitative and non-spontaneous nature of an ape's signing

By 1980, it became apparent that the evidence purporting to show that an ape could create a sentence could be explained without any reference to grammatical competence. Terrace (1979; Terrace *et al.* 1979) analysed approximately 20000 combinations of two or more signs made by a young chimpanzee (Nim) who, like Washoe, had been reared by his human surrogate parents in an environment in which A.S.L. was the major medium of communication. Superficially, many of Nim's combinations appeared to be generated by simple finite-state grammatical rules (for example, MORE + X; transitive verb + me or Nim, etc.). However, a frame-by-frame analysis of videotapes of Nim's signing with his teachers revealed that Nim responded mainly to the urgings of his teacher to sign and that much of what he signed was a full or partial imitation of his teacher's prior utterance. Thus, unlike a child at stage 1 of language acquisition (cf. Brown 1973; Bloom *et al.* 1976, Nim's signing was mostly non-spontaneous and imitative. Analyses of the available films of other signing apes revealed similar patterns of non-spontaneous and imitative discourse (for example, Washoe signing with the Gardners and her other teachers, and Koko signing with Patterson).

The conclusions of project Nim were criticized by other investigators attempting to teach an ape to use sign language on various methodological grounds (for example, Gardner 1981; Patterson 1981). However, none of those investigators have revealed enough of their own procedures to allow one to evaluate the significance of their criticisms of project Nim (Terrace *et al.* 1981; Terrace 1982). Of greater interest is the fact that Terrace's conclusions have yet to be countered with positive evidence. Specifically, no discourse analysis of an ape's signing (as obtained from unedited videotape or film records) has been presented which shows that an ape's utterances are spontaneous and that they are not whole or partial imitations of the teacher's most recently signed utterance.

Rote sequences versus sentences

Different considerations led to a rejection of the view that Sarah's and Lana's sequences were sentences. After analysing a corpus of approximately 14000 of Lana's combinations that were collected by a computer, Thompson & Church (1980) concluded that those combinations could be accounted for almost completely by two non-grammatical processes; conditional discrimination and paired-associate learning. Which of six stock sentences occurred could be predicted by the circumstances under which Lana would try to obtain some incentive. For example, if the object was in view in the machine, the stock sequence would be of the form PLEASE MACHINE GIVE X or PLEASE MACHINE GIVE PIECE OF X. If there was no object in view, the appropriate sequence would be PLEASE PUT INTO MACHINE X. If an experimenter was present, the stock sequence would be of the form PLEASE Y GIVE X. In addition, Lana learned paired associates, each consisting of a particular lexigram and a particular incentive (for example, apple, music, banana, chocolate, and so on). These lexigrams were inserted in the appropriate position (usually the last) of the stock sentence.†

Further evidence of the non-sentential nature of Lana's (and Sarah's) sequences were produced by studies demonstrating that pigeons could be trained to respond in an arbitrary sequence to four simultaneously presented coloured lights (red, green, yellow and blue) whose positions was changed from trial to trial (Straub *et al.* 1979; Terrace 1984*b*). Mention of a pigeon's sequence-learning ability is not to imply that a pigeon could approach a chimpanzee's ability to learn various conditional discriminations which specify which arbitrary sequence is to be emitted in which context. Nor is it meant to imply that a pigeon could master even a single sequence as rapidly as could a chimpanzee. Indeed, there is strong evidence to the contrary (Pate & Rumbaugh 1983). There is also no reason to assume that pigeons and chimpanzees use similar strategies in learning to produce a sequence.

There considerations should not, however, detract from the fact that, in each case, what was learned was a rote sequence. It would be just as erroneous to interpret a rote sequence of pecks to the colours, red, green, yellow and blue (in that order) as a sentence meaning PLEASE MACHINE GIVE GRAIN as it would be to interpret the sequence that a person produces while operating a cash machine as a sentence meaning PLEASE MACHINE GIVE CASH. In sum, a rote sequence, however that sequence might be trained, is not necessarily a sentence.

What do the words of an ape's vocabulary mean?

In a searching review of their own work and that of other projects, Savage-Rumbaugh *et al.* (1980*a*) not only doubted the validity of evidence purporting to show that apes can produce and comprehend sentences but also doubted whether, at the level of individual elements of their vocabularies, the apes studied by any project used those elements as actual words (Lana included).

By questioning the lexical status of an ape's use of signs, of A.S.L., of plastic chips or of lexigrams, Savage-Rumbaugh *et al.* identified a basic problem of interpretation that is common to all of the projects that sought to demonstrate that apes could master simple features of human languages. Indeed a strong case can be made for the hypothesis that the deceptively simple ability to use a symbol as a name required a cognitive advance in the evolution of human intelligence that was at least as significant as the advance(s) that led to grammatical competence.

The development of a child's vocabulary: the behaviourist view

Thanks, in large part, to a preoccupation with the emergence of grammatical competence in children, developmental psycholinguistics have paid relatively little attention to the *process* of lexical acquisition *per se*. It is, of course, true that ample information is available regarding the kinds of words children learn and at what rate they do so (for example, Brown 1956; Clark

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† The validity of Thompson & Church's 'stock sentence plus paired associate' hypothesis was questioned by Pate & Rumbaugh 1983 in their analysis of Lana's later productions. Pate & Rumbaugh concluded that, given the variety of the stock sentences and the paired associates that would be needed to account for Lana's well-formed sentences, it would seem reasonable to postulate that they were constructed by a more complex (but unspecified) set of rules. That conclusion seems premature for a variety of reasons. Of the 881 sentences that were analysed only 512 (58.1 %) were well-formed. Further, many of the sequences were quite similar to one another and variation of a particular sequence appeared to be synonymous, for example, JUICE NAME THIS, JUICE NAME THIS IN CUP, JUICE NAME THIS THAT'S IN CUP IN ROOM, etc. Given the constant context, longer sequences do not appear to add any additional information and may have resulted from the experimenter's implicit encouragement to produce long sequences (cf. Terrace 1979).

1973; Nelson 1973). However, it was widely assumed by most psychologists, at least implicitly, that some version of a 'behaviourist' explanation of vocabulary growth would suffice to explain how children learned their initial vocabulary.

At first glance this might seem to be a reasonable state of affairs since there is general agreement that, unlike sentences, words are learned individually. Accordingly, why not invoke principles of associative learning to account for vocabularly acquisition? On this view, a child associates the speech of a parent with primary reinforcers such as physical contact, food, or the removal of distressful stimulation. As a consequence, the parent's vocalizations become reinforcing.

At the same time, the child's vocalizations are presumed to be reinforced directly, either by the parent providing a primary reinforcer, by the parent's attention or by the parent's vocalization. Initially, virtually any instance of an infant's babbling is reinforced. As the infant becomes older, the parent shapes her vocabulary to approximate adult sounds. In addition, those infant's vocalizations that resemble parent's speech are self-reinforcing. Gradually, the frequency of the infant's vocalizations that resemble sounds uttered by a parent increases while the frequency of those sounds which differ from the sounds uttered by the parent decreases (for example, Mowrer 1954; Winitz 1969).

Naming versus paired-associate learning

At best, the behaviorist view of vocabulary acquisition is an explanation of paired-associate learning: learning to use an arbitrary symbol as a means towards the end of obtaining some reinforcer in the presence of a particular stimulus. What is missing from the behaviourist view is the speaker's intention in using a word. Saying something and meaning what you say are obviously two different kinds of response. In most human discourse, a speaker who utters a name expects the listener to interpret the speaker's utterance as the referent for a jointly perceived object. It should therefore come as no surprise that the function of much of a child's initial vocabulary of names is to inform another person, usually a parent, that the child has noticed something (Halliday 1975; MacNamara 1982). In many instances, the child refers to the object in question spontaneously, with obvious delight, and shows no interest in obtaining the object. The child appears to not only enjoy sharing information with her parent but to also derive intrinsic pleasure from the sheer act of naming. As I will argue later, these aspects of uttering a name have not been observed in apes and there is reason to doubt whether the most intensive training programme imaginable could produce an ape who would approximate a child's natural ability to refer to objects as an end in itself.†

How children learn to use language

An obvious truism about language learning is that it draws upon certain kinds of non-linguistic knowledge. For example, before learning to speak, an infant acquires a repertoire of instrumental behavior that allows her to manipulate or approach various objects. An infant also learns how to engage in various kinds of social interaction with her parents, for example,

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† Other deficiencies of the behaviourist view of word acquisition can be found in studies showing that there is little evidence that the sounds an infant emits are truly imitative of the parent's sounds (see, for example, Winitz & Irwin 1958) and that, in many instances, a child's initial utterances function as names rather than as requests (for example, Nelson 1973). Discussions of these and other observations that cannot be accommodated by a behaviourist account of language development can be found in various recent accounts of the growth of a child's vocabulary (for example, Bloom & Lahey 1978; Nelson 1973).

being able to look where the parent is looking or pointing.† Eventually, the child learns to point at things that she would like her parent to notice. In short, the infant first masters a social and conceptual world onto which she can later map various kinds of linguistic expression.

The rapidly expanding literature on the pre-linguistic development of the child makes clear that, for whatever reason, or reasons, naming emerges from the highly structed interactions between an infant and her parents. Especially relevant are interactions in which the parent is able to direct the infants's attention to particular objects. For example, at the age of roughly four months, a parent can direct an infant's attention to an object simply by looking at it. Subsequently, the parent can accomplish the same end by pointing to an object. Often the parent will comment about the object while pointing to it or moving it towards the infant. By placing stress on the spoken name of the object to which the parent seeks to direct the infant's attention, the infant comes to discover that a stressed vocalization is a signal that there is 'something to look at'. Likewise, highly ritualized games whereby an object is made to disappear and later reappear (typically, with distinctive vocal accompaniments) also facilitates a parent's control over an infant's attention. As the infant gets older, her contribution to these interactions increases. At first she may only point to an object in response to the parent's pointing or vocalizing. Subsequently, the child may utter non-standard vocalizations while looking or pointing at the object presented by the parent. Eventually, the child learns to repeat the object's name as provided by the parent, while the child and the parent jointly attend to that object (see Bruner (1983) for summaries of such studies).

During the course of a long series of object-oriented interactions with her parents, an infant not only learns to direct her attention to objects that are presented by her parent but she also learns that her response to such objects, whether pointing, babbling or saying the actual name of the object, is recognized by the parent as a sign that she has noticed the object. In short, the infant learns that her response to an object has much in common with her parent's response to the same object. In that sense, the child learns the conventions of reference, first non-verbally and subsequently at a verbal level.

Can referring be taught?

In a provocative discussion of how children learn to name objects, MacNamara (1982) concludes that referring to an object (the act of communicating that one's attention is directed to a particular object) is not learned. Instead he regards referring as a 'primitive of cognitive psychology' (MacNamara 1982, p. 190). What is learned is reference: the conventions of using symbols and words that do the work of referring.

Verification of MacNamara's view of learning names awaits much further research, his painstaking marshalling of empirical and logical arguments notwithstanding. It is of interest, however, to consider the extent to which learning theory can account for a child's ability first, to understand that her parent is referring to a particular object and, subsequently, to master pre-verbal techniques for directing her parent's attention to a particular object. As commonplace as such skills may seem, it is not obvious how one can teach them. To argue that referential behaviour is shaped begs the question of what rudimentary forms of referential behaviour can be used as a point of departure for the shaping process. To acknowledge that such a rudimentary

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† It is clearly more generally accurate to invoke shared attention than shared looking in describing pre-linguistic origins of reference. For example, 'looking' would be inappropriate as a description of how a blind child responds to particular objects. Nevertheless, blind children develop a sense of the focus of their parents' attention and readily learn to refer to the act of engaging someone else's attention with verbalisms such as 'look' (Landau & Gleitman 1983).

form exists, is to agree with MacNamara that the act of referring is a given. At best, principles of learning might be invoked to characterize how a parent adds to the variety and complexity of situations in which referring occurs.

The function of symbols for chimpanzees and children

The hypothesis that the act of referring is a given and that it is also a necessary precursor of naming provides an important basis for comparing symbol use by children and chimpanzees. Like children, chimpanzees appear to show evidence of object-recognition soon after birth. It is also quite easy to direct their attention to a particular object by looking at it, by pointing to it or by moving it into the chimpanzee's line of sight. Though their reactions to objects have not been subjected to systematic study, informal observations suggest that their main reaction is acquisitive (Terrace 1979). When confronted with an object, familiar or otherwise, an infant ape will make soft reflexive hooting noises and either reach for the object or try to approach it. Typically, the object is explored orally and manually. However, beyond such explorations there is no evidence that suggests that an infant ape is interested in communicating, to another ape or to its human surrogate parent, the fact that it has noticed an object, as an end in itself. To be sure, chimpanzees will communicate with one another about food locations (cf. Menzel 1979) or about objects of prey (cf. Telecki 1973). It is, however, important to recognize that such communication is in the service of some concrete end and is not intended simply to inform a companion that something has been noticed.

The absence of natural referential skills that are independent of concrete ends makes all the more remarkable the kinds of symbol use that an ape can master. For example, recent studies have shown that chimpanzees are capable of learning symbolic concepts such as generic terms that apply to symbols for particular foods and tools (Savage-Rumbaugh *et al.* 1980*b*). They have also shown some rudimentary intentional communication in highly structured play situations (Savage-Rumbaugh *et al.* 1983).

Naming as a precursor of syntax

It is beyond the scope of this paper to speculate when in the evolution of human intelligence infants were able to relax their acquisitive reactions to objects and simply indicate to a parent that they noticed an object. Whatever the origin of that kind of reaction, it clearly exerted a significant influence on the evolution of language. Foremost, it provided a psychological basis for activities between an infant and her parent for engaging in activities based upon their joint perception of an object. As we have seen, such activities are important precursors of reference to objects and events with names.

If a child hadn't developed the ability to use a name to register what she saw and if the sole function of her speech was to demand things, it is hard to see why she would combine words according to a grammatical rule. Since a single word should suffice as a demand or as a warning of some danger, the child would have no need to learn to speak syntactically. Obviously, the same argument applies to apes and indicates why it was premature to have expected that an ape might master even the most primitive grammatical rules.

In theory, one could, of course, argue that a highly structured system of demands might require syntactic rules, for example, a request for the red plum from the far tree, as opposed to the green apple under the near bush, and so on. Such a state of affairs is implausible for a variety of reasons. To the extent that such specific desires occur in the natural world, they could be dealt with by eye–gaze, pointing, facial expressions, some combination thereof, or by a process of elimination of alternative incentives. Thus, it is not clear what natural function a hypothetical demand system of such complexity might serve. Further, any attempt to teach such skills in a laboratory environment would seem to tax the ability of any known primate other than man.

A different state of affairs exists in those situations in which there is a desire simply to transmit information about a relationship between one object or action and another, or about some attribute of an object or about past or future events. In these instances, a single word would not suffice. Hence, the functional value of syntax.

Representations as evidence of animal thinking

For reasons far more elementary than those advanced by the contemporary neo-Cartesian school of linguistics, we have seen that Descartes was correct in denying that animal lack the capacity to learn a human language. However, Descartes' contention that animals cannot think was based as much on their inability to master a language as it was on his view that their behaviour consisted of nothing more than a mechanical system of reflexes. That view in particular became the creed of 20th century behaviourists (for example, Pavlov 1927; Guthrie 1952; Hull 1943; Skinner 1938). It is, of course, true that behaviourist developed models of reflexes (and their combination) that were more elaborate than the model suggested by Descartes, particularly in the case of learned behaviour. It should also be obvious that their models assumed a more realistic view of the nervous system than was available to Descartes. However, like Descartes, modern behaviourists saw no need to appeal to cognitive structures that intervened between a stimulus and a response so long as their models of conditioned behaviour could predict reliably the occurrence of a particular response.

An important tension in the modern study of behaviour is one that resulted from a tug of war between behaviourists and cognitively oriented psychologists as to validity of instances of animal behaviour that were purported to be exceptions to reflex models of behaviour. The significance of such exceptions was recognized more than 70 years ago by Hunter, an early behaviourist, who observed that:

> '...if comparative psychology is to postulate a representative fact,...it is necessary that the stimulus represented be absent at the moment of response. If it is not absent, the reaction may be stated in sensory-motor terms' (Hunter 1913, p. 21).

By stipulating that '...the stimulus represented be absent at the moment of the response', Hunter argued that the only cue available to the organism was one that it generated as some representation of the absent stimulus. That representation functions just as an exteroceptive stimulus might in evoking appropriate behaviour.†

To grasp fully Hunter's view of an animal's ability to use a self-generated representation of some feature of its environment, it is important to ask why he did not see any need to argue for representation in those instances in which a stimulus reliably precedes a response. Why not,

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† In the various types of delayed response apparatus that Hunter devised to study representation in animals, he took pains to rule out particular postures or orientations of the organism as mediators between the stimulus and the response recorded by the experimenter. Hunter correctly rejected, as representations, kinesthetic feedback from such mediators because they could be construed as members of a covert chain of stimuli and responses. Overall, Hunter found very little evidence that animals could represent features of their environment in ways that could not be explained in S–R terms.

for example, appeal to representations of a conditioned stimulus or of an unconditioned stimulus in a typical conditioning experiment?† Hunter's answer was the logic of parsimony. Like Skinner and other behaviourists, Hunter noted that our ability to predict or to explain behaviour is not enhanced by appealing to a representation of a stimulus if that stimulus is available when the organism responds.

This is not to say that, somehow, an animal doesn't store memories of its experience. Quite obviously it must if it is able to react to a stimulus at time 2 in a manner similar to its reaction to that stimulus at time 1. It is, however, necessary to distinguish between an organism's ability to generate, or at least to maintain, a representation of some previously experienced stimulus that is present when the response in question occurs and its ability to respond when that stimulus is absent.

More so than any other type of study, recent experiments on animal memory provide compelling evidence that animals form representations. In each case the subject is required to recall certain features of one or more events and, in the absence of those events, to use that information as a basis for performing some response.

Learned sequences of responses: the traditional view

Of particular interest are experiments involving integrated sequences or responses. Though behaviour typically occurs in integrated sequences, learning theorists have concerned themselves mainly with principles of conditioning as they bear on individual repetitive responses such as bar-presses and key-pecks and how such responses are influenced by the presence of a particular cue or the value of a particular schedule of reinforcement. Integrated sequences of response are regarded as 'chains' of discrete responses (cf. Skinner 1938; Hull 1943; Guthrie 1952; Spence 1956; Logan 1960). This model of behavior, which derives from Sherrington's (1906) formulation of chains of reflexes, assumes that the stimulus consequences of one response function as a cue for the next response. On this view, an organism who learns a sequence of responses has simply learned to respond appropriately to a series of successively presented stimuli, and nothing more. For example, a rat that learns to run through a maze need not have any knowledge of the plan of the maze. At first choice point, it makes a response appropriate to S_1; the response, R_1, is followed by the appearance of S_2, and so on.

The literature on chaining in animals consists almost entirely of experiments in which the subject encounters, one at a time, the stimuli that occasion successive responses and the manipulanda for responding instrumentally to those stimuli. In a maze, for example, a rat progresses through a sequence of choice points. Each choice point can function as a unique discriminative stimulus for the next response. In operant conditioning chambers, the acts of a rat pressing a bar or of a pigeon pecking a key have been conceptualized as a sequence of responses (approach, postural shifts, turning the head, etc.), each of which produces a new discriminative stimulus (Skinner 1938; Skinner 1953; Keller & Schoenfeld 1950). Common to each of these examples is an organizational plan whereby a particular response results in the elimination of one discriminative stimulus and the presentation of a new one. In turn, the presentation of each new discriminative stimulus provides an opportunity to make a response that could not have occurred earlier.

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† It is immaterial, for this argument, whether the representation is of the CS, the US, the UR, or of some S–S or S–R connection. The form of the representation is less critical than the fact that some type of representation exists.

3. RESPONSE SEQUENCES THAT TRADITIONAL CHAINING THEORY CANNOT EXPLAIN

The radial maze

Olton's experiments on a rat's behaviour in a radial maze provide an important departure from traditional maze studies. Consider a radial maze in which eight runways radiate from a common start point. Olton & Samuelson (1976) and Olton (1978; 1979) demonstrated that rats can remember which of the runways they entered while searching for food. In the basic paradigm, each runway was identical and was baited with equal amounts of food that could not be seen from the entrance to the runway. The variable of interest was how many runways were entered before all the food was consumed. After a few days in the maze, Olton's rats, on the average, re-entered less than one ally per trial.

To appreciate the performance of Olton's rats, let us identify each of the arms of a radial maze by a number, from 1 to 8. On one trial, the rat's sequence of arm entries might be 3-7-2-1-5-4-6-8; on another, it might be 6-1-5-7-3-8-4-2; and so on. Thus, it is impossible to predict the rat's sequence on one trial from the sequence followed on previous trails. This poses an interesting question. How does the rat remember which arms it has already visited?

One possibility is that, as the rat enters or leaves an arm, it lays down some kind of trail that it can detect when it returns to the entrance of that arm. This explanation was ruled out by the results of a number of subsequent experiments. In one instance a highly odorous substance was used to mask presumed olfactory cues. In another, the olfactory nerve was cut. Neither procedure impaired the rat's efficient performance. In another clever variation of the basic training procedure, the rat was confined on the centre platform after it made a few choices. The arms of the maze were rotated some arbitrary distance, say, 90°. The rat then visited arms that now occupied the *position* of previously unvisited arms, even though, because of the rotation, it had, in fact visited some of them before. Taken together, these observations show that the rat's choices cannot be attributed to any particular external cue. In that sense, they are not conditioned responses to some feature of the environment.

A rat's ability to create and use a map of food locations is clear evidence that, while foraging, it is not simply making a series of mindless responses, each triggered by some environmental cue. But however remarkable this ability may seem, it sheds no light on an animal's ability to learn *particular* sequences. Young children, for example, find it easy to learn all kinds of arbitrary sequences by rote, such as nursery rhymes or telephone numbers.

Serial learning in the pigeon

Those kind of sequences, which also resemble the rote sequences chimpanzees were trained to perform to obtain some reward (for example, MARY GIVE SARAH FOOD), were studies in a series of experiments in which pigeons served as subjects. The procedure used to train these sequences differed significantly from conventional chaining paradigms. Such paradigms do *not* require the organism to memorize the sequence that defines a particular chain. For example, in learning to run through a typical maze, a rat has only to learn what to do at various choice points. Since each choice point is discriminable, the rat's task can be characterized as learning to solve a set of discrimination problems in which the discriminative stimuli are encountered successively.

In contrast to the traditional successive-chaining paradigm, in which discriminative stimuli and the opportunity to make a particular response are encountered one at a time, a simultaneous chaining paradigm presents, at the same time, all of the stimuli and all of the manipulanda for each response. Another essential feature of the simultaneous-chaining paradigm is that it provides no differential step-by-step feedback following each response. In contrast, a conventional successive-chaining paradigm ensures that each correct response produces feedback that typically results in the automatic replacement of the current discriminative stimulus by the next one.

In the first studies to employ a simultaneous chaining paradigm (Terrace *et al.* 1977; Straub *et al.* 1979), pigeons were trained to learn a 'list' of coloured lights. Each trial presented an array of four colours (A, B, C, D) each randomly positioned on different response keys. To obtain food reinforcement, the pigeon had to respond to each array by pecking in the sequence A-B-C-D regardless of how those colours were positioned on the response keys. For example, on one trial the left–right arrangement of the colours might be B, C, A, D; on the next trial it might be D, B, C, A. In each case access to food was provided if and only if the pigeon pecked the keys in the order A-B-C-D. If the subject made an error the array was turned off and a new array was presented during the next trial. With the exception of the response to the last colour (which was followed by reinforcement), no differential feedback was provided following correct responses.

Pigeons learned to perform the A-B-C-D sequence on the arrays on which they were trained at levels of accuracy that exceeded 70%. No decrement in performance was observed even when the colours A, B, C, and D were configured in novel arrays (cf. figure 1). This showed that the pigeon had not simply mastered a set of rotely learned response sequences to the arrays used during training. Thus, the only basis the pigeon had for choosing a particular colour is its representation of what colour it just pecked and what colour should next be pecked.

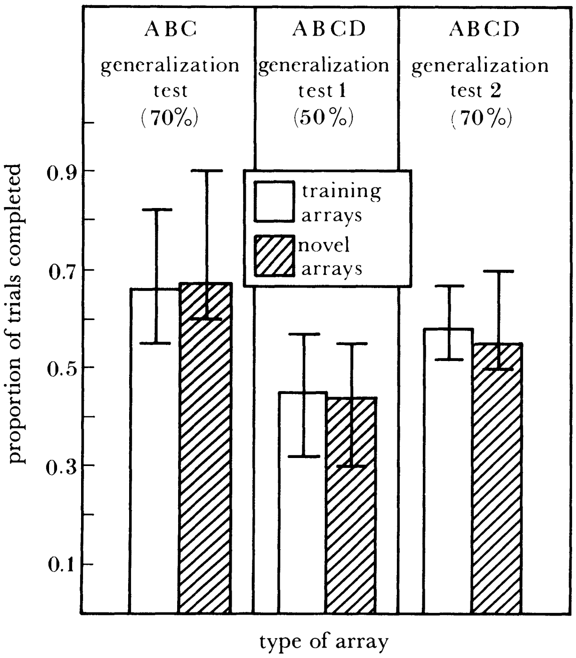

FIGURE 1. Average proportion of training and novel arrays computed during A-B-C generalization test at 70% accuracy level (left-hand panel) and during the A-B-C-D generalization tests at 50% (middle panel) and 70% accuracy levels (right-hand panel). See Straub & Terrace (1981) for further details.

A pigeon's ability to form a representation of the sequence was also demonstrated by its accurate performance on 'sub-sets' of the original sequence (for example, B and D, A and D, C and D, and so on). On arrays presenting B and D (in which the required sequence was B-D), the pigeon had neither the advantage of the normal starting colour nor, having pecked B, the advantage of an adjacent element. Just the same, accuracy of performance was as great on arrays requiring the sequence B-D as it was on arrays requiring the sequence A-B.

Another study showed that the ordinal position of the middle element *per se* controlled performance on three-element sequences of coloured elements (Terrace 1984*b*). Following acquisition of the sequence A-B-C, training commenced on one of three new 'lists' of elements. All of the lists consisted of one old element, B, the middle colour of the original list, and two new elements, X and Y, a white vertical line and a white diamond (on black backgrounds), respectively. For one group, B retained its original position in the new sequence: X-B-Y. For both of the other groups, the position of B was shifted (with respect to A-B-C training). One group was trained on the sequence X-Y-B; the other on the sequence B-X-Y.

As shown in figure 2, the subjects trained on the sequence in which B retained its original position (X-B-Y) learned that sequence more rapidly than the subjects trained on the sequences in which the position of B was changed (X-Y-B and B-X-Y). Conversely, it took longer to acquire the sequences in which the ordinal position of B was changed (X-Y-B and B-X-Y) than it did to acquire the original A-B-C sequence. These results show that in addition to mastering a three-element sequence of colours, pigeons also acquired knowledge about the ordinal position of the second element. That knowledge adds to the complexity of the representation that would be needed to account for performance on simultaneous chaining.

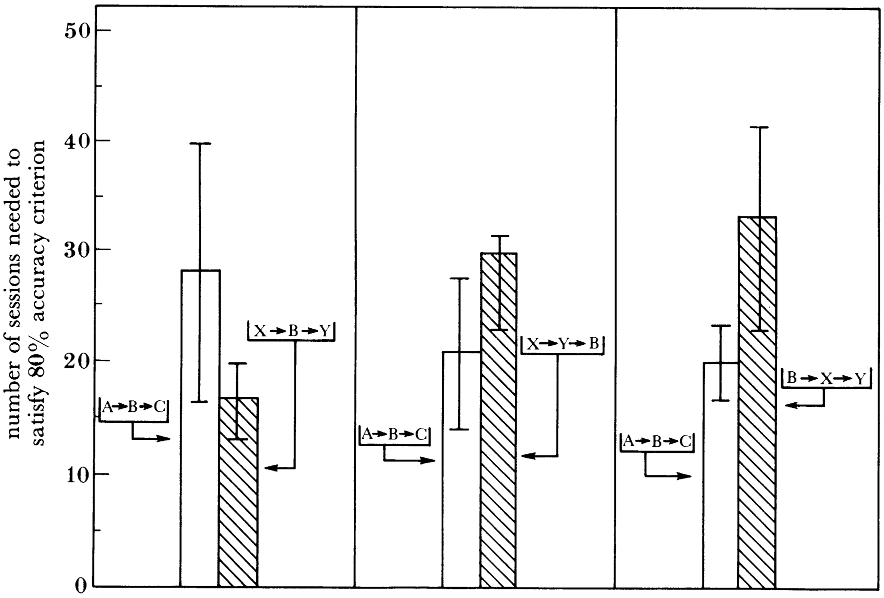

FIGURE 2. Number of sessions needed to acquire X-B-Y, X-Y-B and B-X-Y sequences following training on the simultaneous chain A-B-C.

Yet another consequence of learning to produces a sequence is positive transfer to sequence recognition. In a study recently completed in my laboratory, sequence recognition was trained by a 'yes–no' paradigm. On half of the trials the sequence A-B-C was presented on a single key. On the remaining trials sequences of the elements A, B, and C were presented in other orders. Following each type of sequence, 'test' stimuli were presented on keys to the left and the right of the key on which the sequence was shown. Food reward was provided for pecks to the left hand key following A-B-C sequences and to the right key following non A-B-C sequences (see Dopkins *et al.* (1983); Weisman *et al.* (1980), for similar procedures for training sequence discriminations).

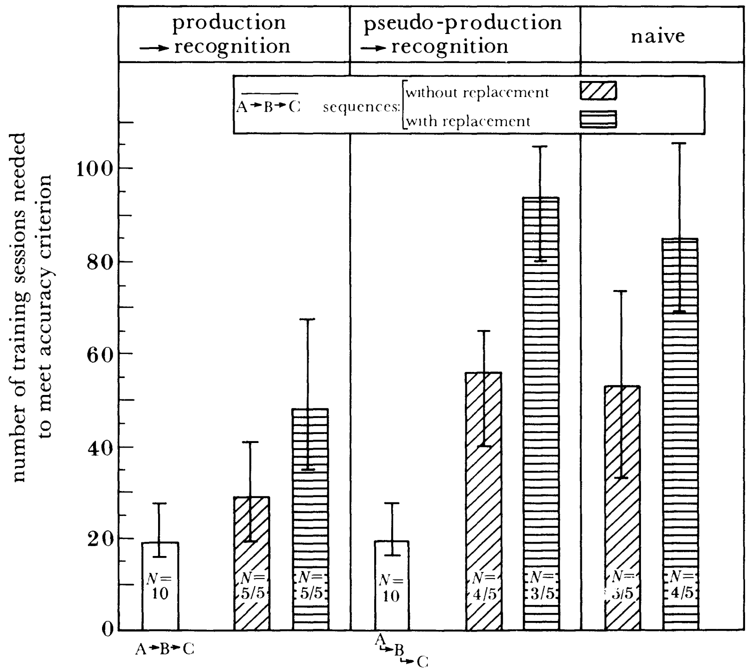

Figure 3. Number of sessions to acquire discrimination between the elements A, B and C as presented in A-B-C sequences (left-hand panel), the pseudo-production of A-B-C sequences (middle panel) and in the case of naive subjects (right-hand panel).

The acquisition of sequence discrimination was studied under three conditions. One group of pigeons first learned to produce an A-B-C sequence under the simultaneous chaining procedure described earlier. A second group was given the same amount of training on a successive training procedure in which the elements A, B and C were presented one at a time. (A peck to A produced B and turned off A, a peak to B produced C and turned off B, and a peck to C turned off C and produced food reward.) The third group had no experience with the elements A, B, and C before sequence discrimination training. As shown in figure 3, the first group learned to discriminate the A-B-C from the non A-B-C sequences much more rapidly than the subjects of the other two groups. Thus, the representation that a pigeon acquires when learning to *produce* a sequence facilitates learning to *discriminate* the sequence from other sequences containing the same elements.

4. Difference between human and animal representations

Though our knowledge of animal representations is embarrassingly meagre, we can be fairly confident that animal representations differ from those generated by human beings in two important respects. Most studies of human memory use verbal stimuli. Even when non-verbal stimuli are used, memory may be facilitated by verbal mnemonics and control processes. In the absence of such mnemonics and control processes, it seems foolhardy to assume that animals rehearse stimuli verbally or that there is much overlap between animal and human encoding processes. It also seems clear that cognitive processes in animals may be more limited by biological constraints than their human counterparts.

In the radial maze, for example, an important basis of the rat's ability to avoid previously visited alleys is an unlearned 'win–shift' strategy that it follows when searching for food. While a win-shift strategy is not sufficient to explain the highly efficient performance of Olton's rats, it appears to be a necessary condition. This becomes evident when comparing the radial-maze performance of pigeons, who are 'win–stay' organisms, with that of rats. Pigeons appear to be considerably less efficient than rats in avoiding previously visited alleys (Bond *et al.* 1981). Given the pigeons's ability to home, it seems more plausible to attribute their poor performance in the radial maze to it's 'win–stay' tendency than to a poorer ability to represent spatial locations.

Putting aside the contribution of a win–shift strategy, it is unclear that the rat's ability to perform efficiently a radial maze has very much in common with such superficially similar human abilities as remembering elements of arbitrary lists, for example, which of a group of people have yet to be called, which errands have yet to be performed, and so on. At present, we have no basis for assuming that a rat's ability to keep track of alleys that it has visited could generalize to tasks that require other responses (for example, bar-pressing) or to the many kinds of arbitrary non-spatial tasks that language makes possible in the case of humans.

Virtually all of the examples of representation in animals described earlier warrant similar caution when it comes to extrapolating to human cognitive processes. For example, both Herrnstein and Lea have noted that the processes used by pigeons to form concepts may differ considerably from those used by human subjects (Herrnstein & deVilliers 1980; Lea & Harrison 1978; Morgan *et al.* 1976. In the case of a pigeon's ability to represent a group of elements in performing a serial learning task, it is unlikely that their representations of these elements has much in common with human representations of serially ordered elements. Both involve representation and both involve sequences. There is, however, good reason to assume that, unlike the pigeon, human subjects encode each element of the sequence verbally.

These, and other problems suggested by recent demonstrations of animal cognition, leaves us with a baffling but fundamental question. Now that there are strong grounds to dispute Descartes' contention that animals lack the ability to think, it is appropriate to determine just how an animal does think. In particular, how does an animal think without language? Learning the answer to that question will provide an important biological benchmark against which to assess the evolution of human thought.

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