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THE MIND OF ORGANISMS: SOME ISSUES ABOUT ANIMAL COGNITION

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*Sense sure you have,
Else could you not have motion.*
Hamlet, III, 4

INTRODUCTION

The study of animal behavior and intelligence has a fairly long tradition, starting with Romanes naive mentalism. With a few noble exceptions, like Tolman and Köhler, psychological research on animals has been dominated by the behaviorist paradigm, and only in the last fifteen years has there been a substantial growth of interest in the analysis of cognitive processes in animals. This renewed impetus towards a cognitive approach, as opposed to a strict behaviorist perspective, resulted from both internal problems and external influences: on the one hand, there were difficulties in explaining all instances of behavior within the traditional S-R approach; on the other, mental concepts were gaining a new scientific respectability, thanks to the development of human cognitive psychology and artificial intelligence.

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In the late sixties, the powerful influence of behaviorism on animal psychology began to decrease, as a consequence of a variety of empirical data, which proved difficult to explain, or even contradicted the fundamental assumptions of S-R theories. Phenomena such as autoshaping, selective attention, conditioned learning of taste aversions, and preferential learning of some responses showed that the traditional laws of learning were inadequate to explain every conceivable case of learned behavior, in humans as well as in other animal species.

While learning theory continued to evolve in response to empirical challenges, trying to accommodate all the new findings within the classical conception through *ad hoc* adjustments of the accepted laws, a growing number of comparative psychologists felt that the basic assumptions of behaviorism needed to be re-examined.

Along this line, a number of studies questioned the universality of the S-R laws of behavior at both the intra- and the interspecific level, focusing on the relevance of biological factors in controlling behavior. This area of study stimulated debate on biological constraints and adaptive specializations in learning (Bolles, 1970; Hinde & Stevenson-Hinde, 1973; Rozin & Kalat, 1971; Seligman, 1970; Shettleworth, 1972), promoting concern for functional approaches to the study of learning (Hollis, 1984; Staddon, 1983).

A different line of research has attempted to apply the tools of human cognitive psychology to the study of animal behavior. In recent years, a number of systematic attempts have been made to explore this possibility in a comparative frame of reference. This is the case for comparative analyses of short and long term memory (Van der Wall, 1982; Grant, Brewster, & Stierhoff, 1983; Vaughan & Green, 1984; Roberts & Van Veldhuizen, 1985), studies of cognitive maps (O'Keefe & Nadel, 1978; Gaffan & Gowling, 1984; Gould, 1984, 1986), works on categorization and concept formation (Herrnstein, 1984, 1990; Lea, 1984), studies on linguistic abilities of different species (Ristau & Robbins, 1982; Herman, 1986; Schusterman & Gisiner, 1988; Pepperberg, 1991), and research on natural communication systems in animals (Snowdon, 1987). Although not yet conclusive, the results of these studies are beginning to take a coherent shape, providing important information for answering questions about the evolution of cognition, and suggesting new and stimulating directions for future research. It is with this approach that we are concerned here.

This paper is neither a review of all relevant work in animal cognition, nor a complete, detailed survey of the theoretical stands taken by researchers in the field: even though the discipline is still young, a similar endeavor would require at least a book size work. Our aim is rather to present, analyze and discuss the basic assumptions of animal cognition, focusing on those aspects that appear to be central today, and will presumably continue to be so in the near future. The questions are: What

do those who study animal cognition intend to achieve? And why? And how?

In Section 1, we state the main goals of those who study animal cognition, and argue that this discipline has an intrinsically comparative nature. In Section 2, we delineate some classical objections to cognitivism, show that they have been overcome by present day methodology, and introduce the notion of representation as the basic element of cognition. In Section 3, we introduce the view of representations as mental states, i.e., states endowed with content; an alternative perspective, based on the notions of form and formal manipulation, is presented in Section 4. Finally, in Section 5 we draw some conclusions.

1. THE WHY AND THE WHAT OF ANIMAL COGNITION

*What a piece of work is a man!
how noble in reason! how infinite
in faculty [. . .]! The beauty of the
world, the paragon of animals!*

Hamlet, II, 2

While the study of human cognition arose as a clear-cut break with the behaviorist paradigm, animal cognition, partly due to the nature of the available data, necessarily maintains a certain degree of continuity with the traditional methods. The cognitive approach brings to the comparative psychologist a further set of tools for the formulation of theoretical models of animal intelligence. In the words of Roitblat, Bever, and Terrace (1984),

Animal cognition is concerned with explaining animal behavior on the basis of cognitive states and processes, as well as on the basis of observable variables such as stimuli and responses. (p. 1)

Whatever position one may adopt towards cognitive states and processes, it is clear that the main reason for attributing cognition to animals is that we, as humans, do experience a mental life. While such an attribution is in agreement with a unitary and evolutionary view of organisms, it introduces an element of anthropomorphism, which has often motivated suspicion or rejection by scientists. However, animal cognition does not imply a straightforward transfer to animals of models of human thought, which would indeed be unjustified; rather, it is to be taken as a source of possible explanatory hypotheses about the unobservable determinants of animal behavior, which are then to be tested through a strict empirical methodology. It is expected that by careful experimental control the anthropomorphic component of cognitive models can be made harmless—as harmless as the anthropomorphic component of concepts like force and energy in classical physics.

Given that the prototype of cognition is, by definition, human thought, animal cognition appears to be an intrinsically comparative study of intelligence: the direction of comparison goes from humans to animals, then back again to humans. In fact, even though the fundamental concepts of the cognitive approach originate in human psychology, we expect that they will be substantially enriched and refined through the attempt to apply them to other species. Although the physical continuity between humans and the other species was accepted more than one century ago, the problem of the continuity of mental capabilities has not yet been satisfactorily solved.

But what are the fundamental concepts of a comparative study of cognition? As Roitblat says (1987),

Comparative cognition is the study of the mind of organisms and the ways in which those minds produce adaptive behaviors. It is an approach to understanding behavior that emphasizes what animals know and how they use that information in guiding their behavior. Comparative cognition seeks to understand how animals acquire, process, store, and use knowledge about their world. (p. xii)

As already remarked, cognition is concerned with explaining behavior not only through observable variables like stimuli and responses, but also on the basis of cognitive states and processes, which are not directly observable. Apparently, the goal has not changed since the time of Romanes. But what sounds similar need not be the same. There is no room in contemporary "cognitivism" for naive anthropomorphism; as we shall argue in the next section, the criticisms made to Romanes' easygoing approach are not pertinent any more.

There are basically two orders of considerations that motivate a cognitive approach to the study of animal behavior. The first one, as we have already suggested, arises from the limitations of behaviorism, and views cognitive concepts as hypothetical constructs that might provide better explanations of empirical data. From this standpoint, cognitive science does not differ from any other natural science, in that it postulates unobservable entities to explain the regularities of observable phenomena. Such entities are justified when they provide economical and general interpretations of complex findings, and produce predictions that are experimentally testable.

But comparative cognition has also a completely independent motivation, which is often overshadowed by the previous one. As regards the human species, cognition is not so much an explanatory construct as a plain matter of fact: mental states are part of subjective reality before entering the theoretician's tool kit. But the mind is a very complex biological entity, and Darwin teaches us that any such thing stands in need of an evolutionary explanation: Where does cognition come from?

How did it evolve? Is *Homo sapiens* the only cognitive organism on the earth?

So, there are two sides to cognition: it is a tool for understanding behavior, but also a phenomenon to be understood in its own right; and we believe that a comparative approach should be concerned with both issues.

At this point, a number of questions arise. Are there real methodological problems with the use of mental notions in natural science? If not, what makes the mental different from the nonmental? How can mental processes be described? And then: What is the adaptive value of cognition? Are there species-specific differences in mental processes?

In the following sections, we shall consider possible answers to some of these questions.

2. NATURAL SCIENCE AND THE CONCEPT OF MIND

Behaviorism emerged as a reaction to the fuzzy, prescientific use of mental terminology in “internal eye” psychology. Mental concepts were regarded to be incompatible with the materialistic stand required by a mature scientific discipline, and were viewed as uneconomical and superfluous in a science of behavior. Moreover, mental explanations were considered to be unfalsifiable, in that it was always possible to find one that fitted any experimental data.

As documented in the scientific literature (Sober, 1983), the revival of a science of the mind was made possible by the overcoming of these objections. Here we shall run quickly through this matter, focusing on a few points which are particularly relevant for our goals.

A first objection to the use of mental concepts in science was that mental processes are not physical. A similar assumption is certainly part and parcel of the Cartesian doctrine, but it is by no means a necessary corollary of the concept of mind. As remarked by Place back in 1956, it is perfectly sound to assume that typical mental features, like consciousness, are features of neurophysiological processes: the mind need not be less physical than any other process studied in natural science. In talking about the mind we must be very careful, because in ordinary language the terms “physical” and “mental” are opposite; it is therefore up to natural science to construe the notion of mental process so that it is a special kind of physical process.

When we accept this assumption, we might be tempted to get completely rid of any notion of mind and to consider only neurophysiological phenomena. In fact, this position is advocated by the so-called “eliminativists,” like Churchland (1981). The main problem with this approach is that it fails to identify the characteristic properties of the mental. Given that mental processes are neurophysiological, not all neurophys-

iological processes need to be mental; but how can we find out which ones are, if we do not have an independent theory of the mind? As remarked by Sober (1983), there is a big difference between explaining the mental, and explaining it away.

It is important to note that leaving the neural level to deal with mental states does not force us to analyze the subjective quality of conscious experience. Phenomenological issues, put forward by Griffin as the core of cognitive enquiry (1978, 1981, 1984), pose problems far beyond the present possibilities of experimental research. But, as we shall see in the following sections, cognitive science has developed concepts and methods to deal with the mind from an objective, rather than subjective, standpoint.

The goal is therefore to build an independent theory of mental processes, by putting forward a number of hypothetical constructs for the explanation of behavior from an objective standpoint. As stressed by Chomsky (1959), there is no special problem in postulating unobservable entities in scientific theories; almost any science deals with hypothetical entities that can only be inferred from observable events.

A frequent objection to the use of mental explanations is based on the well-known Morgan's canon (1894), stating that:

. . . in no case may we interpret an action as the outcome of the exercise of a higher psychical activity, if it can be interpreted as the outcome of one which stands lower in the psychological scale. (p. 53)

However, in 1903 Morgan himself added that:

. . . the canon by no means excludes the interpretation of a particular activity in terms of the higher processes, if we already have independent evidence of the occurrence of these higher processes in the animal under observation. (p. 59)

Again we have a situation common to many sciences. A general theory, accounting for a whole set of phenomena through higher level concepts, is preferable to a theory that explains the same phenomena by lower level processes, but requires several *ad hoc* adjustments to encompass all of them. In fact, one of the goals of the study of comparative cognition is to provide general explanations of a wide range of observable behaviors.

Perhaps a more severe objection, put forward by Skinner (1964), is that mental explanations can always be made to fit any experimental finding, thus dooming mental theories to be unfalsifiable. In fact, this appears to be an actual risk for cognitive theories, that have a very complex equipment of unobservable entities. Therefore, comparative cognition must take great care to avoid falling into this trap. This point will be considered in the following sections.

To summarize, the cognitive approach is based on two fundamental assumptions. The first assumption is that cognitive processes are physical

and biological, in that they are fully realized in the nervous system of the organism. The second one is that cognitive processes can be described at an abstract level, making no reference either to the specific quality of the subjective experience of the organism, or to the processes taking place at the neural level.

It has been argued that to keep the concept of mind in a scientific context it is necessary: (i) to identify and define instances of mind, and to establish a set of procedures and empirical markers with some degree of consistency; (ii) to show that the concept of mind will serve to more efficiently integrate and organize existing information; (iii) to demonstrate that the formulation permits the derivation of specific, testable predictions about the presence or absence of mind and its influences on behavior (Gallup, 1982). These recommendations are, however, very general and contain neither reliable nor simple formulas for deciding if and when we should use cognitive terms when dealing with animals.

In fact, in order to explain behavior, many contemporary comparative psychologists use a mass of technical terms that have an intrinsic cognitive connotation, even if they are not always defined in a precise way. A list of such terms includes cognitive map, perception, memory, concept, representation, expectation, rule, goal, behavior plan, linguistic ability, and intelligence.

Although these terms cover a wide range of different ideas, they share the common underlying notion of representation, which, therefore, qualifies as the central concept of cognitive theories. In fact, two different views of representations have been adopted in animal cognition. The first approach, presented in the next section, regards representations as mental states, defined by a mode and a content, both involved in causing behavior. Typical mental states are beliefs and desires about objects, facts and events in the environment. According to the second perspective, known as information processing psychology (Section 4), representations code information about the environment, and their ability to mediate between stimuli and responses relies upon transformations performed by computational processes, which are sensitive to their formal structure.

3. THE SEMANTIC MIND

A possible approach, which is gaining favor especially within cognitive ethology, is to regard representations as particular types of internal states, such as beliefs and desires, that can be held by organisms. In analytic philosophy, such states are called mental or intentional, and their characteristic property is that they are about objects and states of affairs in the outside world: for example, a belief is always the belief that something is the case, and a desire is the desire that something be the case. It is important to note that the term "intentional," here, does not mean voluntary or purposive as in everyday English; following a tradition started

by Brentano and Husserl, and continued by a number of contemporary philosophers of mind, it just means about something, and, therefore, has a broader sense. What we call "intentions" in everyday language is just one possible form of intentionality.

When representations are regarded as mental states, their essential feature is content. Representations have a content, in that they represent something: objects of the external world, relationships among objects, facts, events, etc. In other words, representations hold a semantic relationship with the environment.

Mental states are made up not only by a content, but also by a mode (Searle, 1983). Examples of modes are: to believe that, to desire that, to see that, to intend to, to fear that, etc. Note that, in terms that should be more familiar to comparative psychologists, holding a belief is nothing more than possessing certain information about the environment, while a desire is just a goal or a purpose. Two different mental states may have distinct modes, while sharing the same content. For example, the belief that one's offspring is safe and the desire that one's offspring be safe are two distinct mental states, with equal content and different modes.

The idea of a semantic relationship between representations and reality originates in human conscious experience: for example, the experience we have when we see something is that there are real objects out there, showing certain properties and relationships. In fact, consciousness is taken as the central issue in the study of cognition by Griffin (1978, 1981, 1984), who defines cognitive ethology as the study of the mental experiences of animals.

Even if one accepts that representations presuppose conscious experience, it is not the subjective quality of the experience itself that is under investigation. In fact, such a subjective quality is impossible to assess: how could we possibly know what it is like to be a bat? (Nagel, 1974) Fortunately, the aim of a scientific study of the minds of other animals is not to find out what it is like to be a certain type of animal, but rather to clarify how mental states cause observable behavior. In order for mental states to have an explanatory role, their power to produce behavior has to be a function of their constitutive features, i.e., their content and mode. But content and mode can be defined without trying to make the actual quality of experience explicit. Consider for example the perception of colors. The ability of an animal to discriminate objects of different colors, plus the presence of cones in the retina, would be considered as sufficient evidence that the animal has color vision. Even if we have no idea of the exact nature of the experience of the animal when it is looking at a red triangle, we can take colors into account when describing the content of the animal's visual perceptions.

A characteristic property of mental states, like beliefs and desires, is that they exhibit a logic. For example, keeping in mind the definitions of belief and desire given above, from the belief that there is an intruder near the nest, and the belief that intruders are dangerous for the offspring,

follows the belief that the offspring is in danger. The attribution of logical capacities to animals may appear as a piece of unjustified anthropomorphism. But this is not necessarily the case, as simple logic does not require high level abilities, like that of reflecting upon one's own beliefs and concepts, which might well be specific to the human species. As Griffin (1991) reminds us, complex phenomena like self-awareness and thinking about the process of thinking itself are by no means necessary components of cognition: in fact, to think that they are so would be the real anthropocentric mistake.

The view of representations as mental states, which is traditional in analytic philosophy, is far less accepted in cognitive science. One common criticism is that notions like belief and desire are metaphoric and, while used in everyday "folk psychology," have little to share with real science (Stich, 1983). However, the work of philosophers like Dennett (1987) and Searle (1983) and pioneering research in animal cognition show that mental states, and in particular beliefs and desires, can be employed as useful explanatory tools and undergo rigorous scientific investigation.

The fact that "belief" and "desire" are part of the folk vocabulary used to describe everyday behavior does not mean that the same terms cannot be used technically. It is inevitable for a science of the mind to have some overlap with everyday language. Similarly, linguists use terms like "sentence" and "name" in a strictly technical way, and nobody thinks that they are producing "folk linguistics"; the same is true for such terms of physics like "force" and "energy." Furthermore, terms like "belief" and "desire" are by no means metaphors. The ascription of mental states to an organism, in order to explain its behavior, is meant to be literal, not metaphoric, in that it is assumed to describe—at a high level of abstraction—a real physical state of the organism. Once more, there is no difference with respect to other sciences: to say that a body moves under the action of gravitational force is a literal statement, not a metaphoric one, even if the notion of force is a theoretical construct.

Clearly, before beliefs and desires can be used to explain behavior, we need a general theory of mental states. Here we shall consider two different approaches: Dennett's intentional stance and Searle's biological naturalism.

In the field of animal cognition, the best known approach to intentional explanation of behavior is that proposed by Dennett (1987), under the name "intentional stance." Essentially, the intentional stance is the standpoint of the scientist who seeks to explain behavior as a rational consequence of beliefs and desires ascribed to the organism.

The role of rationality is to dictate how beliefs and desires interact in determining behavior: it is assumed that an organism acts in order to fulfill its desires on the basis of its beliefs. As Dickinson says (1988),

In general, I assume that an intentional account of behavior is justified if that behavior can be shown to be dependent on, in the sense of being

a rational consequence of, a set of beliefs and desires about the world.
(p. 307)

It is essential that the explanations in terms of mental states are not simply *post hoc* reconstructions. As remarked by Bennett (1991), the belief-desire-behavior triangle is, so to speak, an equation with two unknowns: one can always find many different belief-desire pairs that explain any given behavior. Therefore, we need some criterion to attribute beliefs and desires in advance, in order to predict a forthcoming response; the validity of the attribution will then be tested by observing the behavior actually occurring.

Of course, it is not possible to give a list of observable features that are necessary and sufficient for an organism to entertain a specific belief. However, as holding a belief means to possess certain information about the environment, we can try to attribute certain beliefs to an animal when they can be the result of its learning history and of its present situation, given the characteristics of its sensory apparatus.

With desires we face a similar problem. From a functional standpoint, desires act like motivational states in producing behavior. They differ from simple motivations in that, having a content, they can combine with beliefs, thus determining in a flexible way a response that fits the situation as represented by the organism. Therefore, when we attribute a desire we must take into account both the basic motivational states that the animal is assumed to have, and the possibility that it combines with the animal's beliefs.

An example of this methodology can be found in Dickinson's experiments on intentional behavior in rats (1988). In one of these studies, hungry rats were trained to pull a chain in order to obtain sucrose solution, and to press a lever to obtain food pellets. By changing the motivational state from hunger to thirst, it was found that the rats preferred pulling the chain to obtain sucrose solution, provided that they had previous, independent experience of the different effects of sucrose solution and food pellets on the state of thirst. These results can be accounted for in terms of rats holding beliefs and desires (Figure 1), the content of which is directly determined by the experimental conditions in the following way:

As regards desires, the motivational states of hunger and thirst were produced experimentally, via food and water deprivation. Furthermore, the experimental procedure allowed the rats to learn the value of both food pellets and sucrose solution in relieving hunger, and of sucrose solution in relieving thirst. Therefore, we are justified in attributing to hungry rats the desire for either food pellets or sucrose solution, and to thirsty rats the desire for sucrose solution only.

As regards beliefs, the experimental procedure was designed to let the rats acquire the information that pressing the level caused the delivery

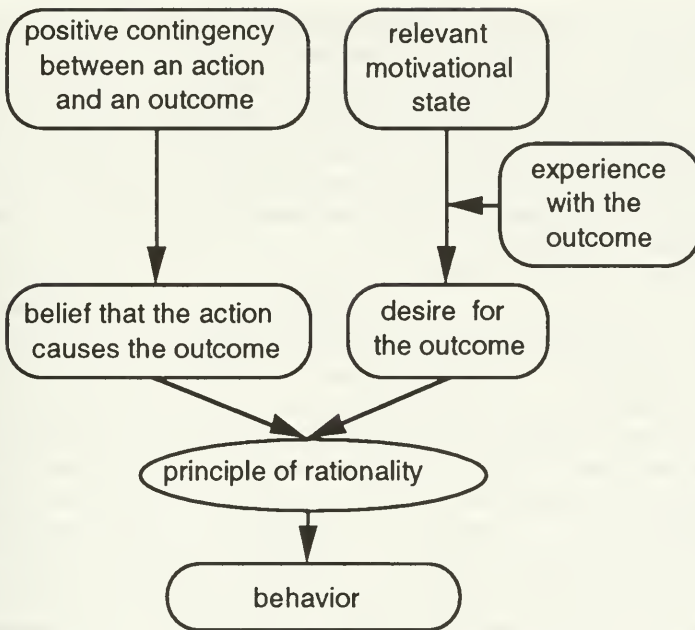


FIGURE 1. An experimental application of the intentional stance.

of food pellets, and pulling the chain caused the delivery of sucrose solution.

Having thus attributed beliefs and desires to the animals, the principle of rationality leads us to predict that thirsty rats will try to fulfill their desire to get sucrose solution by pulling the chain. This prediction was confirmed by the observed behavior.

This experiment deserves a few words of comment. First, it is remarkable that even simple instrumental behavior supports an intentional account; however, as stressed by Dickinson himself, particular care is required in designing experiments in order to evaluate competing mechanistic and intentional explanations. Second, one should not expect that representations spring up by themselves in the animal's mind; sufficient experience with the relevant aspects of the world is crucial to support the content of both beliefs and desires. For example, in the reported study previous experience with the effects of the reinforcers was essential to turn the pure motivational states into actual desires.

The intentional stance is by no means confined to laboratory experiments; in fact, it has more often been adopted in cognitively oriented field research (Ristau, 1991). Indeed, we think that a number of results reported in the literature are suitable for an intentional interpretation; this seems to be the case also for simple organisms, like honeybees.

In a series of extremely intriguing experiments on honeybee cognition,

Gould and Gould (1988) showed that the bees' ability to use their maps of the territory apparently goes beyond simple navigation. It was observed that dance attenders were not recruited by dances indicating that flowers were located in an adjacent lake, whereas they were recruited normally by dances indicating an equally distant location along the shoreline. A possible interpretation proposed by Gould and Gould was that the location in the middle of the lake must, in a sense, have "sounded unplausible" to the bees.

This interpretation could be easily cast into intentional terms. Given the nature of the motivational state of bees, we can assume that all bees ready to leave the hive hold a comparable desire to reach the flowers. What inhibits the recruitment appears to be the belief that no flowers are to be found in the middle of lakes.

As observed by Gould and Gould, it is not easy to imagine what kind of selective pressure might have promoted the ability to discard, on the basis of an individually constructed map, the information obtained from the dancers. In fact, there is no experimental evidence, and no theoretical reason as well, supporting lying and deceit in honeybees. This problem is related to the more general question of what might be the adaptive value of cognitive processes. At the present stage, it is only possible to attempt a few speculations. On the one hand, the ability to disbelieve a message when it clashes with previously acquired information has an adaptive value not only in case of deception, but also if messages are prone to errors. On the other hand, it is possible that such an ability has no value of its own, but is a consequence of selective pressure toward the more general capacity to hold beliefs about the environment.

From a methodological point of view, Dennett's intentional stance is an instrumentalist position, in that it is neutral with respect to such issues as the real nature of mental states, their experiential correlates, and their relationship with the actual causes of behavior. The instrumental nature of the intentional stance becomes especially clear if one considers the role of the principle of rationality. Principles of this kind are common in science. For example, predictions of the fate of physical systems can be based on the principle of minimum energy: if a spherical body is allowed to move freely in a concave container, sooner or later it will stand still at the bottom of the container, having reached a state of minimum energy in the gravitational field. The minimum energy principle thus allows one to predict the final equilibrium state in a synthetic way, without bothering about how the state is reached. This kind of physical explanation is clearly not causal, because there is no assumption that a "tendency to minimum energy" is acting on the body. However, this does not rule out the possibility of explaining the same phenomenon causally, which can be done by taking gravitational force and friction explicitly into account. In fact, the minimum energy principle can be derived from the basic laws of physics: its use does not imply that one

gives up the assumption that all physical phenomena have a causal explanation.

On the basis of these considerations, it is natural to wonder whether we can replace the principle of rationality with a causal account. According to Bennett (1991), intentional explanations are noncausal: they should be regarded as simple, synthetic tools for making predictions about behavior; causality only makes sense at the neural level. A substantially different standpoint is taken by Searle (1983), who argues that mental states are not only explicative tools, but rather real states endowed with causal power.

According to Searle, intentional states are a particular kind of physical state of the nervous systems, and as such can cause other intentional states and, eventually, behavioral responses. What characterizes intentional causation with respect to classical physical causation is that there must be a certain kind of relationship between mode and content of the causally related intentional states. For example, thirst may cause an intentional act of drinking because thirst involves a desire to drink, which is satisfied by the act of drinking itself. This kind of explanation is coherent with the traditional requirements of natural science. Rationality appears to be an emergent property of intentional causation, and the principle of rationality is therefore a derived law, like that of minimum energy.

Between Dennett's instrumentalism and Searle's realism there is indeed a profound philosophical difference. But this does not necessarily imply a comparable difference in the explanation of behavioral data. Beliefs and desires, whether considered as instrumental attributions or as descriptions of real physical states of an organism, lead to the same predictions about the organism's behavior. At the present state of cognitive science, the question of which of the two approaches should be adopted is a matter of personal philosophical position, and cannot be settled on the basis of observable data.

However, beyond strictly philosophical matters, Searle's work on intentionally presents many ideas that might prove important for developing a general theory of cognition. In particular, two points are worth discussing here.

The first is that although scientists can only describe the content of mental states through language, such contents need not be realized in linguistic form in the mind. Language is necessary for us to describe the representations held by other organisms, but it is not necessary in order for representations to be realized in the brain. When we say that an animal perceives an intruder, we do not mean that the animal entertains a mental sentence like "There is an intruder in front of me"; rather we mean that the animal is in a neural state related to the world in a way that an external observer can describe by the reported sentence.

The second important point is that allowing for representations in the

mind does not mean that every process going on in the brain is representational. Rather, representations presuppose a rich repertoire of non-representational capacities as a necessary background. Let us consider Sober's example (1983) of a dog, Fido, recovering a bone previously hidden under a tree. Fido's behavior can be accounted for in terms of the belief that there is a bone under the tree and the desire to get the bone. Therefore, we assume that its mental states contain representations of a bone and a tree. Such representations are possible because Fido is able to discriminate bones and trees from other types of objects. However, its ability to discriminate bones and trees, which is a necessary precondition for holding representations about bones and trees, is not itself based on representations.

Searle's idea is that without a rich repertoire of such nonrepresentative capacities, that he calls the Background, we cannot even start to form representations about the world. After being able to recognize stones, tables and the "on" relationship between two objects, we can entertain the thought that a particular stone is on a given table. But the ability to recognize a stone is not itself based on beliefs about stones.

When we attribute to Fido the belief that a bone is buried under the tree, we give for granted that it is able to recognize a bone. As Sober remarks, the use of the term "bone" in describing Fido's belief does not imply that we attribute to it our knowledge of bones, e.g., that bones are part of an animal's skeleton, that they can be used to make a tasty broth, etc. Fido's representations must be considered to be relative to its Background, not to our Background and general knowledge.

This kind of species relativism is extended by Millikan (1986) to the very notions of belief and desire. In commenting on Gould and Gould's researches on honeybee cognition, she says that:

... it is unlikely that there is any distinction *within* the performing bee to correspond to the distinction between belief and desire—unlikely that the bee either believes or desires anything in the human way. (p. 72)

Perhaps it is not necessary to go this far. As we have already said, it is not the experiential quality of beliefs and desires that matters, but rather their role in causing behavior. Fido does not possess the same information we have about the world, but certainly it has some information; the content of its beliefs will be "doggyish," but they are beliefs after all.

The standpoint just outlined suggests that representations are the tip of a nonrepresentation iceberg. It follows that cognitive science has two concerns: first, the role of representations in producing behavior, which we have discussed in the present section; second, the nonrepresentative process that generate representations. We shall come back to this point in the next section, devoted to the paradigm of information processing psychology.

4. THE COMPUTING MIND

When dealing with representations, it is traditional to distinguish between content and form. While issues about content have been extensively investigated in philosophy, cognitive psychologists have devoted their attention mainly to form.

The role of form is a central concern of information processing psychology (IPP), which regards mental processes as a flow of information through a number of cognitive subsystems. A pioneering effort in this direction is Broadbent's model of memory (1958). It is assumed that in any subsystem information is coded in a suitable way, and that cognitive processes can be regarded as transformations acting on coded information. As remarked by Yoerg and Kamil (1991),

The task of the cognitive psychologist from an information processing perspective is to determine the nature and organization of the processes which transform, encode, represent, and use information from the external (or internal) world to produce behavior. (p. 279)

Possibly the main reason for the success of IPP has been the availability of rigorous mathematical tools derived from information theory (Shannon, 1948). A further impetus came from computer science, and in particular from artificial intelligence. According to Newell and Simon (1978), any intelligent system, either natural or artificial, is a physical symbol system, i.e., a physical system whose states are symbolic structures, and whose processes are computations performed on such structures. In a physical symbol system, symbolic structures play the role of representations; however, computations are sensitive only to the form of representations, not to their content.

This version of IPP is substantially equivalent to the philosophical position originally put forward by Putnam in 1962 under the name of functionalism, and developed in a series of papers reprinted in *Mind, language and reality* (1975). According to this view, the brain is to be regarded as a digital computer executing a specific program. The resulting computations transform the stimuli (input) into behavior (output), through a series of intermediate steps. Mental states are simply states occurring in the computations carried out by the brain according to the program. Therefore, for any given organism the goal of psychology is to determine the program executed by its brain. It is important to note, however, that Putnam has not completely changed his philosophical position (1988), reaching the conclusion that functionalism cannot shed any light on the structure and activity of the mind.

Functionalism has become a popular approach to cognition for a number of reasons. As it reduces intelligence to computations carried on by a machine, it is clearly a materialistic approach. The brain is viewed as just one possible kind of machine able to carry on the required computations; functional models are abstract and independent of the neu-

rophysiology of the brain, and, therefore, the present lack of knowledge about brain processes does not bear on cognitive modeling.

From the point of view of animal cognition, the main virtue of functionalism is perhaps that it does not presuppose any kind of subjective experience. Consciousness, if present, is an epiphenomenon, in that it does not contribute in any way to the computational process.

A typical controversy in IPP is whether particular cognitive processes exploit pictorial or symbolic representations, i.e., whether the information is coded as a sort of mental image or rather in a sentence-like form. Questions of this kind may be addressed either at the competence or at the performance level (Airenti & Colombetti, 1991). In the former case, the relevant variable is whether the subject is or is not able to perform a certain task; in the latter, the focus is on variables like the time required to produce a response.

An example of competence oriented research on the nature of representations is provided by the work on category discrimination by pigeons carried on by Pearce (1988). In a number of experiments, Pearce has shown that pigeons learn to discriminate visual stimuli consisting of several bars on the basis of their absolute height, but find it very difficult to discriminate on the basis of the same/different height relationship. Referring to Premack's claim (1983) that the ability to rely on relationships between stimuli is the mark of symbolic representation, Pearce interprets the results of his study as showing that pigeons store visual information in pictorial rather than symbolic form.

Also, performance data have been invoked to support hypotheses about the form of representations. An interesting and well-known kind of experiment studies the ability to recognize different rotations of an image. Shepard and Metzler (1971) showed that the time employed by human subjects to recognize an image as the rotation of another one was proportional to the angle of rotation. This result strongly suggests that such images are represented in pictorial form. A similar set of experiments was carried out by Hollard and Delius (1982) using the same apparatus, task and stimuli on both pigeons and humans. The performance of the two species turned out to be remarkably different. As in the Shepard and Metzler study, the latency of response by humans increased with increasing amount of rotation. On the contrary, the response produced by pigeons did not depend on the rotation angle. The conclusion drawn by the authors was that pigeons and humans use different representational systems.

It is clear from the preceding examples that the aim of IPP is to study how information is encoded by organisms, and to analyze the transformations that operate on such coded representations. However, we think that the very notion of mental transformation is somewhat problematic. Consider for example Gould's researches on the visual perception by honeybees, which are regarded by their author to "shed some light on the nature of the mental transformations honeybees are capable of, though

not as yet on how these transformations are made.” (1990, p. 87) In particular, Gould showed that a bee trained to discriminate between two vertically oriented artificial flowers can recognize their right-left mirror image as similar to, even if different from, the original pattern; on the contrary, bees do not exhibit the same ability when confronted with an up-down reversal of the flower.

These results are easy to explain if one assumes that the bee's representation of the flower is pictorial: the representation has to undergo a mental transformation that is analogous to the physical transformation of the stimulus pattern. Gould's findings are then explained by assuming that bees' images can undergo vertical, but not horizontal, mirror transformations. To account for the same results in terms of symbolic representations would be much more difficult, even if not impossible.

However, it is important to stress that within IPP there seems to be an implicit assumption that representations necessarily have either pictorial or symbolic form. But where does this assumption come from? Clearly from the human use of pictures and of language for representing objects or state of affairs. But pictures and words are external carriers of representations, and they do not immediately warrant the assumption that mental representations must be of either kind. Mental representations are not external, and there is no reason to assume that they should mimic some object of our experience.

A similar problem has already arisen in other scientific disciplines. In Newton's times, the assumption that light was made of particles accounted for a number of optical phenomena; however, in the nineteenth century it was discovered that light often behaved as a wave in an elastic medium, in a way that was incompatible with the corpuscular hypothesis. This contradiction remained unsolved until it was accepted that light did not need to have either a corpuscular or an oscillatory nature: it could be something different. The point is that both particles and waves are objects of our everyday experience; but the microscopic structure of light is beyond our direct acquaintance, and so required completely new tools to be described.

Possibly, in cognitive science we are facing a similar situation; maybe mental representations are not like pictures or sentences: they are something else. A concrete example of what they could be like is provided by a recent approach to mental modeling known as neural networks (Rumelhart & McClelland, 1986). Neural networks are mathematical models inspired by the structure of the nervous system: they consist of a large set of units connected by excitatory or inhibitory links of variable strength. Such networks encode information through the strengths associated to the links, and represented as numerical “weights,” in a way that is neither pictorial nor symbolic. It is conceivable that a model of this kind may account for Gould's data without resorting to any notion of transformation of representations.

It should be clear by now that contemporary research in animal cog-

dition is following two distinct paths: in general, interpretations in terms of mental states are not integrated with IPP models. This may sound surprising, if one considers that functionalism was first conceived in order to provide a computational basis for concepts like belief and desire (Putnam, 1988, p. 73). But, in fact, the development of IPP has been largely independent of philosophical concerns—and, after all, philosophy has often overlooked the problems of applied research. We think, however, that it is now time to see whether the two approaches can be successfully and usefully merged.

One of the studies considered in the previous section can provide an example of how mental states could be related to information processing. Let us go back to Gould and Gould's finding that honeybees are not recruited by dances indicating that flowers are located in the middle of a lake. We have already suggested an interpretation of this result in terms of beliefs and desires. It is crucial to our interpretation that the bees' representation of the home range can be viewed as a set of beliefs. But where do these beliefs come from?

In general, there is the possibility that a belief is derived from more fundamental ones: recall the example of the belief that the offspring is in danger, which could be derived from the previous beliefs that there is an intruder near the nest, and that intruders are dangerous for the offspring. But then, we are left with the problem of explaining where the previous beliefs come from. It is clear that we cannot assume that all beliefs derive from more basic ones, lest we should face an infinite regression.

When a belief is not derived from more fundamental ones, it has to be the product of some basic Background capacity—to adopt Searle's terminology. Going back to the bees' representation of the home range, it is reasonable to assume that it is the product of a basic ability to represent the spatial structure of the environment. Therefore, while the representation of the home range can be regarded as an intentional state, it has to be the result of a more fundamental, nonrepresentative process.

The problem now is how to explain such a capacity. It seems to us that the real explanation can be given only at the neurophysiological level (Airenti & Colombetti, 1990). But IPP can offer us a possible description of the process that highlights important properties: for example, Gould (1984) presents evidence that the bee's representation of the home range appears to work more like a pictorial map rather than like a series of snapshots of key points along the route.

To conclude, we would like to point out that the IPP approach to the study of animal cognition has at least two main merits. The first is that it allowed scientists to deal with mental features in a very concrete way, helping them to overcome a deeply rooted reluctance. The second, and more important, is that its models are suggestive and have a strong heuristic value: many interesting aspects of animal behavior would not

have been investigated without an information processing frame of reference. However, it should be kept in mind that interpreting mental processes as computations is a metaphor, even if one with a great heuristic power, and not a literal explanation. In fact, there seems to be no reason to assume that the processes going on in the nervous system of organisms are more computational than those occurring, say, in the growth of a plant or in a chemical reaction.

5. SUMMARY

In this paper, a number of issues related to animal cognition have been discussed. In particular, we have argued that:

- (1) As it is formulated today, the notion of mind does not commit to the existence of nonphysical entities, and can be investigated within a rigorous scientific framework.
- (2) Mental processes can be described at an abstract level, with no appeal either to the quality of subjective experience or to neurophysiological processes.
- (3) There are cases in which the behavior of organisms is amenable to an explanation in terms of mental states, i.e., states endowed with content about the external world. However, the existence of mental states presupposes a rich repertoire of nonrepresentative capacities.
- (4) Even if for nonhuman animals mental states are hypothetical constructs, in the case of humans their existence is a plain matter of fact, and the challenge for comparative psychology is to establish their evolution.
- (5) Explanations of behavior in terms of mental states might well be causal in nature as it is traditional in the natural sciences.
- (6) Information processing psychology describes neurophysiological processes in terms of computational analogues. Basic concepts such as mental transformations depend heavily on the tools chosen to describe computations.
- (7) It is time to pursue an integration of the approaches based on mental states and on information processing. A promising meeting point could be provided by the nonrepresentative capacities underlying mental states.

While most of these points clearly have an intrinsic philosophical relevance, the standard of judgment for the success of the study of animal cognition can only be that of the empirical sciences. A survey of the state of the art reveals that much progress has been made in this direction, both by field research and by laboratory work exploiting traditional conditioning procedures.

The comparison of different species appears to be particularly impor-

tant. By considering also species not closely related to humans it is easier to overcome the danger of projecting the contents of our minds onto the experimental nonhuman animals. Furthermore, studying different species in their natural environment allows for the investigation of the adaptive value of cognition.

While it is generally accepted that cognition emerges from the activity of the nervous system, we do not know how complex this system must be to implement mental processes. It is certainly more intriguing to find evidence of cognitive processes in honeybees than in apes, and this emphasizes the utility of investigating even simple organisms.

Since the late seventies, the term cognitive science came to denote an interdisciplinary effort to understand cognition. Up to now, the disciplines officially pertaining to cognitive science are human cognitive psychology, philosophy of mind, neuroscience, artificial intelligence, linguistics, and cognitive ethology. We believe that it is time for animal cognition to be considered a component of cognitive science in its own right. To reach an integrated view of cognition, both developmental and evolutionary aspects are essential. Animal cognition contributes to the former, and is indeed crucial for the latter. Moreover, by studying cognitive processes in an ethological perspective, research on animals may shed light on the coupling between a cognitive system and its environment, thus introducing into cognitive science an ecological component that is still lacking.

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