ANIMAL

Reasoning in Animals

A mounting body of evidence suggests that a number of species can infer concepts, formulate plans and employ simple logic in solving problems

by James L. Gould and Carol Grant Gould

COURTESY OF THE MUSEUM OF MODERN ART, NEW YORK

The ability to think and plan is taken by many of us to be the hallmark of the human mind. Reason, which makes thinking possible, is often said to be uniquely human and thus sets us apart from the beasts. In the past two decades, however, this comfortable assumption of intellectual superiority has come under increasingly skeptical scrutiny. Most researchers now at least entertain the once heretical possibility that some animals can indeed think. At the same time, several of the apparent mental triumphs of our species—language, for instance—have turned out to owe as much to innate programming as to raw cognitive power.

This reversal of fortune for the status of human intellectual uniqueness follows nearly a century of academic neglect. The most devastating and long-lasting blow to the idea of animal intelligence stemmed from the 1904 incident of Clever Hans the horse. Oskar Pfungst, the researcher who unraveled the mystery of an animal that seemed as intelligent as many humans, described the situation vividly: “At last the thing so long sought for was apparently found: a horse that could solve arithmetical problems—an animal, which thanks to long training, mastered not merely rudiments, but seemingly arrived at

***The Dream,* by Henri Rousseau**

a power of abstract thought which surpassed, by far, the highest expectation of the greatest enthusiast." Hans could also read and understand spoken German.

After expert groups had tested the horse (often in the absence of his owner, Mr. von Osten) and agreed that no trickery could be involved, Pfungst undertook to study the animal in detail. After many months, he discovered the true source of Hans's cleverness: the animal watched for slight involuntary cues that invariably arose from his audience as he approached the correct number of taps of his hoof.

The consequence of a mere horse having "tricked" the philosophical establishment was a wholesale retreat from work on animal thinking: before the incident, it had been common to attribute reason and thought to animals. British comparative psychologist George J. Romanes, in his 1888 book *Animal Intelligence,* set the bar so low that even shellfish could be said to be rational, as when "we find, for instance, that an oyster profits by individual experience, or is able to perceive new relations and suitably to act upon the result of its perceptions." In short, Romanes felt that if instinct is not at work, reason must be.

As a result of the Clever Hans incident, however, the behaviorist school of psychology came to dominate experiments on animal behavior in the English-speaking world. This reactionary perspective denied the existence of instinct, consciousness, thought and free will not only in animals but in humans as well. As the founder of behaviorism, American psychologist John B. Watson, put it in 1912 (in characteristically uncompromising terms), "Consciousness is neither a definite nor a usable concept.... [B]elief in the existence of consciousness goes back to the ancient days of superstition and magic."

For Watson, all human and animal behavior was the result of conditioning—even breathing and the circulation of the blood. From his perspective, humans do not really think, although they may form "verbal habits"—highly rational ones—with proper training. In the absence of words, Watson believed, animals could not possibly think. Species-specific behaviors—nest building by birds, for instance—were a result of the particular anatomy of a species, the habitat into which it was born and the experiences individuals typically underwent as they grew up.

And contrary to Romanes's view, the behaviorist felt that even learning can be mindlessly automatic, requiring no comprehension on the part of the "student." Classical conditioning simply associates an innate stimulus-response reflex with a novel stimulus. Thus, it is possible to teach a dog that a bell or a flashing light means food. The other form of learning in the behaviorist worldview—operant conditioning—merely requires animals to discover by trial and error which of their movements are rewarded and to use these data to fashion novel behavior patterns. No understanding is needed in either case. Even the subsequent discovery of species-specific learning programs (learning that is initiated and controlled by instinct) did little to alter this passive-learning-machine view of animals, although it did deliver a fatal blow to behaviorism itself [see "Learning by Instinct," by James L. Gould and Peter Marler; SCIENTIFIC AMERICAN, January 1987].

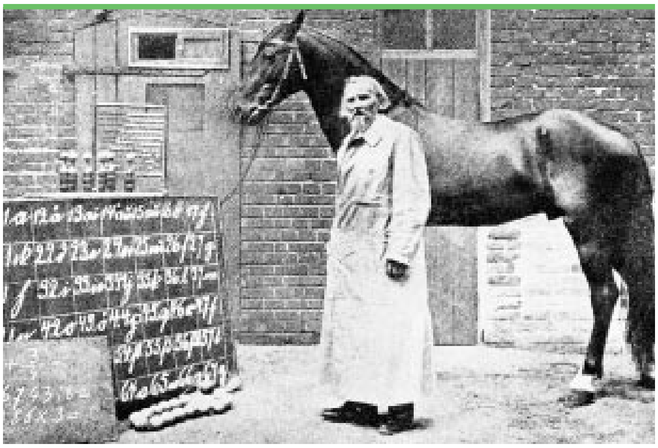
The pervasive behaviorist taboo against investigating whether animals can think, however, has persisted. Only the publication of Donald R. Griffin's highly provocative and controversial 1976 book, *The Question of Animal Awareness,* has begun to erode it. Like most of our colleagues trained in the "don't ask, don't tell" intellectual atmosphere of the first three quarters of the century, we were astonished at first that anyone would risk raising this academically dangerous issue—least of all someone with Griffin's distinguished scientific credentials. His 1984 *Animal Thinking* and 1992 *Animal Minds* have widened the scope of his assault on conventional wisdom, but the shocked outrage in academia seems to have subsided into a civilized mixture of skepticism and interest. Maybe, after all, some animals might sometimes formulate simple plans. But how can we know?

What Criteria for Thought?

The kinds of behavior that Romanes found convincing no longer seem very persuasive. For instance, the highly complex nest-building routines in birds and insects are known to be largely or entirely innate: individuals reared in isolation will nonetheless select appropriate nest sites, gather suitable material and fashion it into the kind of nest that wild-reared individuals of the species create. True, nest building often improves with practice and site selection benefits from experience, but the basic elements of the behavior are in place before the animal sets to work. Indeed, it is possible that the kinds of complex adaptive behavior that so impress us are just the types of behavior that *must* be innate, simply because they would be impossible to learn from scratch.

And as the behaviorists showed, learning can be automatic, too. In fact, conditioning seems to involve an innate and complex weighing of probabilities—computing the chance that a particular stimulus predicts the prompt appearance of an innate cue versus the chance it does not. Although it is possible that a duckling imprinting on its parents understands what it is doing and why, the behavior of a young bird following a toy train that was presented during the animal's critical period does not suggest any necessary comprehension. Thus, learning to modify behavior in the face of experience is not by itself clear evidence of thinking.

Similarly, the frequently cited cases of apparent insight in animals, such as the outbreak of cream-robbing behavior among blue tits in England in the 1930s, may not mean what they seem to mean. When unhomogenized milk was delivered to the doorstep early each morning, a layer of cream would rise to the top of the glass bottles. Blue tits, British cousins of the chickadee, would remove the foil cap and sample the cream before the bottles were taken in. The inviting idea that some cagey



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MR. VON OSTEN AND CLEVER HANS, his horse, stunned the world in the 1900s with the claim that Hans could do arithmetic, spell and even understand German. Hans was actually responding to subtle cues of the people observing him.

bird had figured out this ploy and taught it to its friends ignores the natural history of the species: tits make their living peeling bark off trees to find insect larvae. So compulsive is their need to peel that hand-reared tits often strip the wallpaper from their owners' rooms in a presumably unrewarded search for insects. Perhaps the first blue tit to harvest cream from a milk bottle was outstandingly stupid rather than amazingly bright, having mistaken a bottle for a tree trunk.

Another common example is termite fishing among chimpanzees. Some adult chimps strip long twigs of leaves and insert them into the holes in termite mounds. When they withdraw the twig, they eat the termites that cling to it. Photographs frequently show a younger chimp appearing to study the behavior before trying it. But observations of lab-born chimpanzees reveal that chimps in general are obsessed with putting long, thin objects into holes—pencils into electrical outlets, for instance. As with the blue tits, the behavior seems to be innate, and only knowing the proper place to perform it need be conditioned.

Early Hints of Thinking

To infer that an animal can think, therefore, enough must be known about the natural history and innate behavioral propensities of the species, as well as the individual history of the animal in question, to be able to exclude both instinct and conditioning as the source of a novel behavior. Before the current rebirth of interest in animal thinking, a few controversial studies suggested that animals might be able to plan actions in advance. They guide much of the experimental thinking that continues today.

In 1914 German psychologist Wolfgang Köhler was working at a primate research center on the Canary Islands. He presented his captive chimps with novel problems; often the pattern of solution suggested insight rather than trial and error. For instance, when Köhler first hung a bunch of bananas out of reach, the chimpanzee being observed made a few useless leaps, then went off to a corner and "sulked." But in time he looked back at the bananas, then around the large outdoor enclosure at the various objects he had to play with, back to the bananas, back to one specific toy (a box), then ran directly to the box, dragged it under the fruit, climbed on top, leaped up and grabbed the prize.

In other variations the bananas were mounted higher, and the same pattern of seemingly sudden insight appeared, whether it involved stacking boxes, joining sticks to make a pole long enough to knock down the fruit or using a single stick from atop one box. Criticisms of Köhler's work focused on two important points: the prior experience of these wild-caught animals was unknown (so they might be remembering a solution they had learned in the wild), and lab-reared chimps spontaneously pile boxes (which they then climb and use as jumping platforms) and also fit sticks together to make poles.

Well-controlled planning tests that avoided these problems were performed by Edward C. Tolman of the University of California at Berkeley in the 1940s. He would allow a rat to explore an experimental maze with no differential reinforcement—a T-maze, for example, with the same food reward at the end of each arm—but something the animal did not need to learn, and had not been trained to learn, would be different at each end. In one instance, the left arm ended in a dark, narrow box, whereas the right arm terminated in a wide, white box. (Rats inherently prefer dark, narrow boxes.) On another day the rat was taken to a different room, placed in a dark, narrow box and electroshocked. On a subsequent day the rat was returned to the original maze. Conditioning theory predicts that the rat, not having been trained to any behavior in the maze, would explore at random. Alternatively, it might have learned the location of the innately preferred dark, narrow box. The rat, however, went directly to the right end of the maze and its white box.


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PROBLEM SOLVING IN CHIMPS, in this case, stacking boxes to reach bananas, was first documented by Wolfgang Köhler around the time of World War I.

The rat, Tolman concluded, had used two independent and apparently unrelated experiences to form a plan on the third day. He called this plan a "cognitive map." Applying this perspective to Köhler's chimps, even if they had previously played with boxes and sticks in another context, to move the box under the bananas without any apparent trial and error would require enough insight to link the knowledge of what could be done with boxes to information on the desirability of bananas. In the absence of trial-and-error conditioning, the chimps had to conceive and execute a simple plan. This, at its most basic level, is evidence of animal thought.

Skeptics, however, found elaborate explanations for Tolman's results. For instance, one critic countered that rats are afraid of mazes; hence, removal of the rat from the maze when it reached one of the end boxes was actually a reward that triggered learning. When returned to the maze, the rat knew its best chance of a reward (escape) was to go to the box it had been taken from before. By chance, that was the white box.

Cognitive Maps

Although there is good evidence for cognitive maps in creatures as phylogenetically remote as honeybees and jumping spiders, work on animal thinking has centered on birds and primates. One important line of evidence is the apparent ability of some animals to form concepts. The remarkable abilities of Alex the parrot, studied by Irene M. Pepperberg of the University of Arizona, provide one clear example (see her article on page 60). Another, involving pigeons, was pioneered by the late Richard J. Herrnstein of Harvard University (perhaps now better known as the co-author of *The Bell Curve*). His technique was to provide lab-reared pigeons with a carousel of slides, half with some example of the class of target objects—trees, perhaps, or fish or oak leaves. The birds were then rewarded with food for pecking at any slide that contained, say, a tree. Learning was slow until the birds appeared to figure out what the rewarded slides had in common. Under some conditions, the pigeons would resort to memorizing the full rewarded set of slides, revealing an astonishing ability to recall hundreds of pictures. In most cases, however, they caught on to the common feature, demonstrating their knowledge by responding correctly to an entirely new set of slides.

Because of the huge range of variation among possible examples, a concept such as "tree" is difficult to formulate. There is no list of necessary and sufficient features, because we (and pigeons) recognize trees both with and without leaves, with and without central trunks, with and without substantial side branching, close up and far away, isolated or in dense stands, with standard green or ornamental reddish leaves, and so on. For humans (and presumably for birds), a concept includes a list of properties that have individually predictive probabilities: leaves are highly correlated, for instance, whereas long, thin extensions have a lower (but still positive) association value. A tree is any object that has a sufficient "score" of individual properties—one high enough to exclude telephone poles and television antennas. Many philosophers used to accept concept formation as proof of thought; with the data on pigeons in hand, some have backed away from that criterion.

Many birds formulate and use mental maps of their home area. The ability to devise a novel route to get from one familiar location to another is often taken as a literal example of a cognitive map. Whereas many, perhaps most, birds have local-area maps, few are as spectacular as those of the African honeyguide, which makes its living feeding on the larvae and wax of bees.

The honeyguide has formed a symbiotic relationship with both honey badgers (powerful, intelligent animals that are very fond of honey) and humans. The bird locates a potential hive opener—badger or human—and attempts to "recruit" it through highly visible and audible displays. One of the two most common signals it uses is an onomatopoeic call that resembles the sound of tearing bark. Having engaged the attention of a suitable helper, the honeyguide makes short flights in the approximate direction of its target and calls again; if the helper fails to follow, the bird returns and tries again, perhaps with a shorter flight and louder calls this time. Once at the nest (which is generally a quarter- to a half-mile away), the honeyguide waits while the badger or human it has led there breaks open the hive. The bird moves in for the larvae and wax after the hive opener has left.

Numerous experiments have shown that honeyguides know the location of several hives and usually guide their accomplices to the nearest one—generally, by as direct a route as the landscape allows. In one of the most interesting experiments, the human "helper" followed the bird but insisted on walking steadily past the tree containing the hive. The honeyguide would first attempt to draw the person back to the tree; next the bird would change tactics and try to lead the human on to another hive in the approximate direction of travel. The seemingly inescapable conclusion is that honeyguides know the location of many colonies over a fairly wide area.

J. MARKHAM *Bruce Coleman Inc.*

CREAM-ROBBING BEHAVIOR of blue tits, an outbreak of which occurred in 1930s Britain, was probably not as ingenious as it first seemed: the birds naturally peel bark off trees in search of insect larvae.

Distracting Predators and Getting Food

Flexibility in the use of innate alternatives may also be evidence for simple thinking. Two groups of ground-nesting birds, killdeers and plovers, have a variety of distraction ruses that are used to lure potential predators away from their eggs. Each display begins with the bird leaving the nest and moving inconspicuously to a location well away from its eggs. The set of possible performances ranges from simply calling from a highly visible spot to the complex feigning of a broken wing. There is even a highly realistic rodent-imitation ploy in which the bird scoots through the underbrush rustling provocatively and uttering mouselike squeaks. Each species also has a separate "startle" display designed to keep harmless animals such as deer from stumbling into the nest.

Anecdotal reports have suggested that the decision to leave the nest to perform a display, as well as which display to employ, are suited to the degree of predator threat. A fox heading directly toward the nest, for example, is more likely to get the high-intensity broken-wing performance. Carolyn Ristau of Columbia University put this reported ability to gauge threats to a test by having distinctively dressed humans walk in straight lines near plover nests. Some were told to scan the ground carefully, apparently searching for nests, whereas others were instructed to pay no attention to the ground. As time went on, the plovers began to discriminate between the potential hunters and the seemingly harmless humans: they did not even bother to leave the nest for the latter group but performed elaborate distraction displays for the former. Some degree of understanding seems evident in this ability to judge which innate response to select.

Two well-studied cases of unusual foraging behavior in birds also suggest an ability to plan. One involves green herons, birds that capture fish using several (presumably inborn) approaches. In addition, occasional herons have been observed bait fishing. They toss a morsel of food or a small twig into the water, and when a curious fish rises to investigate, the bird grabs it. Bait fishing has been observed in a few widely scattered spots in the U.S. and in a park in Japan. It appears on its own, seems (except once in Japan) not to spread to other birds and then vanishes. Given the high success rate of the technique, and yet the rarity of its use, it is improbable that bait fishing is genetically programmed; most likely the trick has been independently invented by many different herons.

A more controlled study on the ontogeny of novel foraging techniques was performed by Bernd Heinrich of the University of Vermont. He maintained five hand-reared ravens in a flight enclosure and thus knew just what kinds of learning opportunities had been available to the birds. He tested them with pieces of meat hung by strings from perches. The strings were far too long to allow a raven on the perch to simply reach down and grab the meat. The birds attempted to capture the food in midair by flying up to it, but it was secured too well for this approach to work. After repeated failed attempts, the ravens, like Köhler's chimps, ignored the food.

Six hours after the test began, one raven suddenly solved the problem: it reached down, pulled up as much string as it could manage, trapped this length of string in a pile between its foot and the perch, reached down again, trapped the next length of string under its claws and so on until it had hauled the meat up to the perch. Again, as with Köhler's chimps, there was no period of trial and error.

After several days, a second raven solved the problem. Even though it had had ample opportunity to observe the first bird's repeated successes, this individual pulled up the string, then stepped along the perch, arraying the string in a line rather than a pile. It trapped the string under a foot, reached down and moved over again and again until the string was stretched out along the perch and the meat was within reach. Other birds' solutions of the problem involved looping the string onto the perch. One bird never discovered how to obtain the meat; interestingly, this was also the one individual that never learned that flying away with the tied-down meat led to a nasty jerk when the food reached the end of its tether.


GERRY ELLIS *ENP Images*

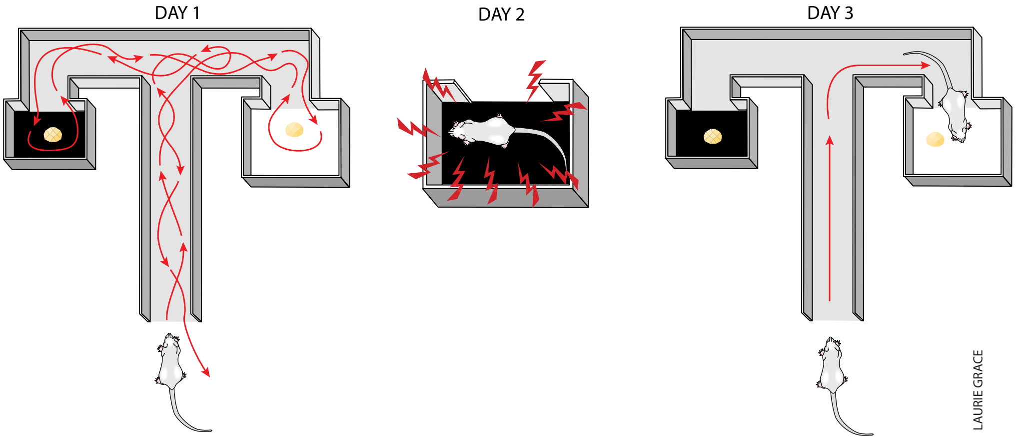
TERMITE FISHING by chimpanzees is accomplished by inserting a stripped twig into a termite mound and then eating the insects that cling to it. As with blue tits, however, the behavior seems innate, and only knowing the proper place to perform it needs to be conditioned.

Learning and Play

It may seem surprising that the ravens did not seem to learn from one another but instead appeared to solve the problem independently. In fact, there is very little evidence for observational learning outside of primates. Most (some would say all) of what researchers have initially assumed was observational acquisition of a technique has turned out to be "local enhancement": learning where other animals congregate, not how they harvest what they find there. Bottle opening in blue tits spread quickly because the birds learned from others *where* cream was to be found and had been born with the technique for peeling back the lid.

As longtime cat and dog enthusiasts, we were originally as dubious as many readers probably are of the idea that animals rarely, if ever, learn to copy behavior. A cat, for instance, that

FORMING A FUTURE PLAN, or a "cognitive map," was demonstrated in rats in the 1940s. On the first day, rats were allowed to explore a maze that terminated with food in a narrow, dark box and in a wide, light box (rats prefer dark boxes). On the next day, the rats were taken to a dark box and electroshocked. On the third day, the rats navigated to the light box, indicating that the rats used two unrelated experiences to form a plan for the third day.



LAURIE GRACE

NOVEL FORAGING TECHNIQUE can develop in animals. Green herons have been seen to toss food or twigs into the water as bait to attract fish to the surface (left)*. In a con-*

PHOTOGRAPHS BY ROBERT F. SISSON *National Geographic Society*

reaches for a doorknob apparently to obtain help in getting out seems to be imitating part of the human behavior associated with door opening. In fact, however, vertical stretches are part of the innate solicitation behavior of felines. What the cat may have had the insight to do is perform the solicitation at the door when it wants to go out. This example, like so many others of ostensible copying, is a clever application of an innate or conditioned behavior in a novel location via local enhancement.

About the only possible exception to the local-enhancement theory outside of primates comes from work on octopuses. In one test done in 1992, an untrained octopus on one side of a glass partition was allowed to view a trained octopus on the other side choose between two objects that differed in color. Later, when provided with the same choice, the observing octopus selected the same-colored object as the "teacher" animal had about 10 times as often. In other, more demanding experiments, the observer octopus watched while a trained octopus in the adjoining compartment opened a container holding food. When tested, the "student" could open a similar container (using the same technique) much sooner than an untrained peer. These findings, however, are still preliminary; researchers have had difficulty in verifying them fully.

One behavior that intelligent animals appear to share is play, defined as performing seemingly pointless but energetic behaviors that human observers consider (introspectively) playful. Octopuses, for instance, jet at floating objects. Parrots will swim (they prefer the backstroke) and make snowballs. Dolphins and whales leap high in the air for no obvious reason and engage objects on the surface. Ravens will toss rocks to one another in midair—it looks to be a game of catch—and repeatedly slide down snowbanks. And primates are famous for their antics—hanging upside down from a limb over a stream to splash water noisily or covering their eyes with broad leaves to play blindman's buff high overhead in trees. Although we cannot know what is going on in the minds of these creatures, even the most hardened observer must wonder if these are not intelligent but bored animals injecting some excitement into their lives.

Evidence for Primate Thinking

One important aspect of logic is the ability to recognize and act on relations between objects and individuals. Perhaps the first well-documented example of how much animals know about one another came from the work of Robert M. Seyfarth and Dorothy L. Cheney, now at the University of Pennsylvania, on vervet monkeys in Africa [see "Meaning and Mind in Monkeys," by Robert M. Seyfarth and Dorothy L. Cheney; Scientific American, December 1992]. Dominance interactions had already suggested that each monkey understood the position of every other vervet in the troop hierarchy. Seyfarth and Cheney performed numerous ingenious experiments to investigate what individual vervets knew. They discovered that the monkeys also kept track of each infant's mother and her social status. When the researchers played recordings they had made of various infants' distress calls, the infant's mother would look in the direction of the hidden loudspeaker, while all the other females would look at the mother.

The logical operations that support the behavior specific to individual vervets are essential to the social calculus of the group. Studies by Frans B. M. de Waal of Yerkes Regional Primate Research Center and Emory University on the intricate social maneuvering that goes on in captive chimpanzee troops show how this kind of knowledge can be exploited. More dramatic, however, are his descriptions of the chimpanzees' use of deceit, which had been reported from the wild by the naturalist Jane Goodall.

The master of dissimulation in one of de Waal's troops was a (then) low-ranking male named Dandy. Usually alpha males do not permit other males to mate with females. Dandy and his special female friend would meet as if by chance behind rocks or brush. The simultaneous disappearance of a female and a low-ranking male usually provokes suspicion in alphas, but Dandy and his date would choose cover that hid only their lower bodies. They would mate while pretending to forage, and the female would suppress the shrieks that accompany typical chimpanzee intercourse.

Dandy also took advantage of distractions to mate or would even create them himself, as when he once rushed to the front of the enclosure and began screaming at the passing humans. The alphas hurried to see what was going on, and Dandy slipped away in the confusion. Another time Dandy observed a low-ranking male courting his own special female. Instead of throwing a tantrum—the usual response to this kind of affront—Dandy fetched the nearest alpha and allowed him to deal decisively with the transgressor.

BERND HEINRICH

trolled study, ravens had to figure out how to retrieve a piece of meat dangling on a string from the perch (right). *Most developed unique ways to pull up the string.*

These and many other instances of Dandy's expert use of social logic imply an ability to think and plan—even scheme—at an impressive level. Combined with other extensive observations of chimpanzees in both the wild and more controlled seminatural enclosures, these examples strongly implicate an evolutionary continuity in the ability to analyze situations and imagine solutions. Without words, the mental operations involved may be of necessity pictorial; language doubtless permits our species to contrive far more elaborate plans, not to mention fantasies and self-delusions.

Humans in Perspective

Language has played a dominant role in discussions about thinking and consciousness. Some philosophers go so far as to assert that language is uniquely and essentially human, a creation of a conscious intellect, a tool necessary to planning and thought. The discovery of symbolic languages in animals ranging from vervets to honeybees has been sobering; the almost overwhelming evidence for nonverbal planning has further blunted the authority of such sweeping generalizations. But nothing has been as deflating to the human self-image as the discovery that consonant recognition, language processing and even grammar are largely innate [see "The Perception of Speech in Early Infancy," by Peter D. Eimas; SCIENTIFIC AMERICAN, January 1985; "Creole Languages," by Derek Bickerton; SCIENTIFIC AMERICAN, July 1983; and "Specializations of the Human Brain," by Norman Geschwind; SCIENTIFIC AMERICAN, September 1979].

Our uniqueness as a species, it would seem, depends on a genetic specialization not obviously more elaborate than the one that confers the power of echolocation on bats. But language empowers what already appears to be a phylogenetically widespread ability to reason and plan with an evolutionarily new capacity for elaboration, communication and coordination that has catapulted our species into a position of astonishing intellectual potential. When we look at the fascinating fauna with which we share the planet, we should recall that but for the fickle logic of evolution, our species would be just another variety of conniving, inarticulate primates. SA

About the Authors

CLARE H. GOULD

JAMES L. GOULD and CAROL GRANT GOULD have co-authored many articles and books on animal behavior. James Gould became interested in animal behavior in the 1960s, when he was a young draftee at a U.S. military base in Germany. Spending his off-duty hours in the library, he one day picked up a copy of *King Solomon's Ring,* by Konrad Lorenz, the Austrian ethologist perhaps best known for his studies on imprinting in birds. When Gould returned to college at the California Institute of Technology, he signed up for a course in animal behavior. He went on to get his Ph.D., studying learning in honeybees with Donald R. Griffin at the Rockefeller University. Although he enjoys working on animal cognition, Gould doesn't recommend cutting one's academic teeth on such a controversial problem. "Studying animal intelligence is no longer tantamount to professional suicide, but it used to be," he says. As a professor of ecology and evolutionary biology at Princeton University, Gould is now studying how females choose their mates—particularly among guppies, mollies and other tropical fish.

Carol Grant Gould got her Ph.D. in Victorian literature from New York University and often joins Jim in the field, whether tracking birds in upstate New York or watching whales in Argentina. "When you're married to a field biologist, you have to become a biologist by association if you ever want to see your spouse," she says. "Fortunately, learning biology, like studying literature, opens fascinating new windows on life." Carol is a science writer by profession and teaches English at a private high school in Princeton, N.J. Besides writing projects, they have also collaborated to produce two kids and enjoy biking, canoeing and hanging out in Princeton.