Primer

Animal cognition

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When Descartes suggested that nonhuman animals are machines, he made formal a view widely taken for granted by most thinkers in the Western tradition. In the process, he conveniently supplied a rationale for the curious assumption that only humans have souls. (Swimming against the tide, Saint Jerome argued in the early 400s that certain animals might have small souls.)

Darwin's theory of evolution by natural selection licensed a new take on the problem: the difference between human and animal mentality was more likely to be one of degree. His enthusiastic followers began to discover that other species are very clever indeed. G.J. Romanes, in his *Animal Intelligence* (1882) found thought in virtually every creature from insects to mammals, but was especially impressed with primates.

By 1900, the flood of smart-animal stories reached flood stage. Theodore Roosevelt and the well-known writer John Burroughs took on what they called the Nature Fakers, who fudged the truth between fiction and fact. They mounted a blistering attack, for instance, on William Long's story of a woodcock that set its own broken leg using a cast made of mud. During the height of the debate came a gentle German schoolmaster and his famous pupil, Clever Hans. Hans, a Russian trotting horse, had learned the rudiments of addition and subtraction. He was known to read and spell, compute fractions and tell time, understand music and calculate dates. He tapped out most of his answers, but could also respond by pointing his nose.

Many notable experts observed Hans and questioned him with remarkable success, even in von Osten's absence. A panel formally appointed to investigate concluded that no trickery could be involved, but the members were quite reasonably worried that Hans was rather too clever. They engaged the psychologist Oskar Pfungst to study the horse further. Using a double-blind technique, Pfungst discovered that Hans was 'reading' the tension in his audience: when he reached the correct number of taps, the observers unwittingly relaxed.

Animals like Hans learn, but what does this ability to benefit from experience tell us about cognition? Does the learning involve understanding? Ivan Pavlov stumbled on the apparent key to this facet of the animal mind in 1903 in the course of his studies of digestion. He found that, once they had learned a predictive cue, dogs would begin salivating for food before it appeared. The dog innately recognizes food by an unconditioned stimulus, US (probably odor or taste), which immediately triggers an innate unconditioned response, UR (salivation): US$\rightarrow$UR. In time, a previously meaningless conditioning stimulus (CS), presented with or just before the US, comes to release the behavior: CS+US$\rightarrow$UR, then CS$\rightarrow$UR. For Hans, the relaxation of tension had been the CS. The learning is automatic: no comprehension is necessary.

In 1912, J.B. Watson proposed that all behavior — human or animal — is compounded of USs, their URs, and the automatic correlation process that we now call classical, or Pavlovian, conditioning. In Watson's view, we are the products of our conditioning, romantically imagining that we have independent thought. His school of psychology, Behaviorism, came to dominate the study of behavior in the United States for the next 60 years.

Watson's idea that novel behavior was created by chaining URs together was challenged two decades later by B.F. Skinner, who argued that humans and animals discover new ways of doing things by trial-and-error learning. The feedback from an innately defined goal allows an automatic correlation process to fine-tune the animal's efforts. This form of learning is 'operant conditioning'. Depending on the behavior studied, both Skinner and Watson are probably correct as far as either of these mechanisms applies.

Behaviorism, then, saw a difference in degree between humans and other animals, but in its ideological desire to rid the world of instinct, it considered all animals' minds to be essentially identical. Some were simply larger than others, ours being the biggest of all. Learning looked the same from top to bottom, limited only by sensory equipment and anatomy; universal rules of learning became the Holy Grail. At heart, then, Behaviorism ignored (and implicitly denied) natural selection's ability to create niche-specific minds designed to solve particular intellectual challenges.

Beginning about 1920, ethologists like Lorenz and Tinbergen started to generalize about innate behavior observed in the wild. They realized that animals generally respond to innate 'sign stimuli' — the USs of Behaviorism, though ethologists seem never to have realized this connection — with equally innate motor programs or 'fixed-action patterns' (the URs). The responsiveness of an animal to a particular sign stimulus depends on the specific drive associated with the behavior. Whereas Behaviorists generally used hunger or punishment as motivators, ethologists focussed on more natural and less extreme drives, like the ones associated with pairing, nest building, incubation, care of the young, and so on.

Ethologists saw in nature what they took to be a different kind of learning, subject to some degree of innate control. A key example is parental imprinting, in which a young animal learns to recognize its parents as individuals, distinct from other members of the species, a process triggered by a few sign stimuli. Other examples of learning also seemed to be innately guided: hunting wasps, for instance, memorize landmarks around the burrow entrance only as they leave; they concentrate on three-dimensional objects, and completely ignore a host of readily detected potential CSs. Like Behaviorists, most ethologists saw animals as machines; the two schools disagreed violently, however, on how these machines worked and the role of evolution in learning.

The Behaviorist world view of animals as mindless learning machines was shaken by four telling sets of studies. The first was Wolfgang Köhler's work on chimpanzees in 1915–17. Köhler reported numerous examples of spontaneous problem solving by his wild-caught animals, but an equally curious inability to focus on and perfect solutions. It is almost as though his chimps suffered from attention-deficit disorder. When Paul Schiller repeated this work on lab-reared chimpanzees in the late 1940s, he found that the crucial ingredient for problem solving was play: the animal must have had an opportunity to play with objects and discover their possibilities as tools before the problem was presented. Köhler's chimps had enjoyed weeks of exposure to the various boxes and sticks they later used to reach bananas. Schiller also discovered that, regardless of experience, chimpanzee expect boxes to stick to walls and remain balanced in any position the animal chooses to put them in.

The problem this work posed for Behaviorists was twofold: there is no reason for animals to play (no tangible reward), and no way for an animal designed along their lines to put together two or more experiences from other contexts to solve a novel problem. The next bombshell came from E.C. Tolman, who found exactly the same thing in rats — the official lab animal of Behaviorism. Tolman's rats fused two unreinforced experiences to solve a maze problem. In the late 1940s Tolman coined the term 'cognitive map' to describe this primitive ability to plan.

The third major shock came in 1966 when John Garcia discovered rapid food-avoidance conditioning. This kind of one-trial learning violates many of the rules of classical conditioning: the cues that can be learned are strictly limited, the association is not forgotten or reversible, and the UR can follow the CS+US experience by many hours. Suddenly the link between imprinting and classical conditioning became clear: learning can be controlled by instinct. Subsequent work revealed a host of such sensory biases in rats and pigeons, and then similar prejudices in operant conditioning in the same species. In most cases, these 'anomalies' seem to focus the animal's attention on the cues or body parts most likely to be relevant to the learning task at hand. Clearly natural selection should favor such biases if they tend to make the learning quicker and more reliable, and this is just the sort of innate guidance ethologists had been reporting for decades.

The final blow came in 1976 with David Olton's work on rats in eight-arm mazes. He showed that his animals create mental maps of the maze as they explore it, and can refer back to these unreinforced experiences days later. Indeed, a consistent pattern of having underestimated the mental powers of lab animals emerges from the studies that have followed. In one example, mice were allowed unreinforced inspection of an unbelievably complex maze, which required more than 1200 correct turns to solve efficiently. All mice, for no apparent reason, were running this path perfectly within three days. Or to take another case (discussed more later), pigeons were able to learn the concept of 'tree' faster than the distinction between two very different colors.

In the same year, a deeply subversive book by Donald Griffin appeared: *The Question of Animal Awareness*. For more than 60 years this topic had been off limits, and most of us had forgotten that there even was such a question. The response was mostly one of outrage and shock, but within a few years Griffin's continuing salvoes had generated considerable interest, reinspection and analysis of old data, and new experiments. By the time of his death in 2003, Griffin had created a vigorous new field of animal behavior — one which is now so crowded with evidence that some of us have begun to wonder if animals are not, once again, in danger of being thought too clever.

One of the problems endemic to research on animal cognition is the ability of natural selection to create behavior of astonishing complexity and suitability to a problem. For instance, so far as we know, all bird nests are built on the basis of innate instructions: a 'to-do' list specifying construction materials and methods. True, birds typically get better with experience, but an attempt to create a bird's nest by hand will convince anyone that the amount of trial-and-error learning needed to do the job even badly requires far too much valuable time in the breeding season.

So when an animal does something apparently clever, the first question to ask is whether this might be part of its natural repertoire. Is the intelligence genuine — an ability to create a novel solution in the mind — or is it a trick being played on an all-too-gullible audience of humans? The answer requires knowing the natural history of the species, and (ideally) what behaviors emerge spontaneously without experience.

Two examples illustrate this problem. Chimpanzees in the wild are sometimes seen using sticks or blades of grass to 'fish' termites from mounds, often with the young looking on. But our knowledge that lab-reared chimps spontaneously push long, thin objects (like pencils) into holes (such as electrical outlets) casts a new light on the likely origin of the behavior: the poking is spontaneous, and the food reward focuses the effort on mounds. Even the apparently attentive youngsters gathered round may only be learning where to experiment; this process, known as 'local enhancement', discredited most previously accepted examples of animal 'teaching'.

Or consider the famous case of cream robbing by blue tits in 1930s Britain. The birds learned to peel back the lids from unhomogenized milk left on doorsteps in the early morning hours, to consume the cream. While this was widely interpreted at the time as evidence of insight, a little knowledge of the natural history of blue tits suggests what really happened: These birds make their living peeling back tree bark to find and eat the fat-rich larvae of insects. So compulsive is this peeling behavior that hand-reared blue tits allowed to fly about indoors will strip the paper off walls in search of food. Peeling back the lid of the milk bottle is as likely to have been habit as genius; the subsequent spread of the behavior is probably an example of local enhancement.

One suggestion for measuring animal intelligence is to look at learning rates or memory capacity. But the numbers tell us that some animals must be smarter than humans at certain tasks. For instance, a human can remember perhaps a dozen places he has hidden food, whereas various caching birds regularly memorize hundreds or even thousands of locations. Or if we ask how many trials are needed to achieve an 80% success rate on a two-color discrimination task, we find that goldfish need 4 exposures, pigeons 10, rats 22, and five-month-old humans 28; honey bees require 2 trials. Clearly the idea that brain size and learning are correlated has no predictive value on these measures for these commonly tested species.

Or consider mental rotation, a component of human ‘intelligence’ tests — one on which men do substantially better than women. A look at the data reveals that the time required to decide if a particular figure is a rotation of another depends on the angle of rotation (up to 180°). Pigeons also recognize rotated figures, but their response time does not depend on angle; clearly the ability is hardwired in that species. Honey bees, too, can match rotated figures with little delay. Here again, we are faced with an apparent superiority of other species; clearly, some ‘cognitive’ abilities are wired in, and may even differ between the sexes of a single species.

Students of animal cognition must grapple with this question of what behaviors are really intelligent, knowing that what may be innate for us may require mental effort in another species, and vice versa. The ideal behavior for experimental purposes would be one that shows little evidence of species specialization — a behavior that is not part of the normal repertoire, but must be invented *de novo* to solve a novel problem. The behavior must also require something that goes beyond the mechanical operation of conditioning. There are several potential examples of thinking in animals that seem to meet these criteria, at least at first glance.

During concept formation, for example, an animal must generalize from specific instances to a list of features probabilistically associated with the concept in question. Consider a generic ‘tree’: it is usually green, with a central trunk, spreading branches, and so on. But in every case, we can think of exceptions. We recognize trees because we unconsciously come to know these association probabilities. Richard Herrnstein showed that lab-reared pigeons readily learn to recognize the concept of tree. That they did so after only 25 reinforced (concept-positive) and 25 unreinforced (concept-negative) slides is amazing: pigeons require many more trials to learn what seem to us much simpler distinctions.

The subsequent discovery that even honey bees spontaneously form concepts, however, has taken much of the force from this work. Edward Wasserman accounts for concept formation as an extension of classical conditioning, which is not unreasonable if we assume that the association probabilities — both negative and positive — of dozens of factors can be processed simultaneously. This is just what neural-net models assume, and here, finally, may be some reason to take them seriously. Selection should certainly have favored concept formation in many species; the fact that it is so widespread a feature suggests that animals may be programmed to look for more information than experimenters are in the habit of providing. If so, not only is concept formation not particularly cognitive, but we have been inadvertently making animals look stupid.

The route planning that Tolman uncovered and Olton made famous is another ability that may look more impressive than it is. Most of us can close our eyes and reconstruct the direction to an unseen target, or devise in our heads a novel and indirect route. So too, it would seem, can chimpanzees, dogs, rats and many birds. What is necessary is a knowledge of the surroundings, and useful landmarks to tell you where you are when the problem needs to be solved. But these abilities all map to a small area of the hippocampus in mammals, which suggests a piece of dedicated circuitry for this important class of behavior. Honey bees and hunting spiders are at least as good as many vertebrates. It is not hard to imagine a built-in program for making and using maps, while it is difficult to think of a way of disproving this alternative (or of some compelling reason natural selection would not have created such wiring).

Examples of apparent invention in nature bring us closer to animal intelligence: they are rare, but all the more remarkable (and less likely to be hard-wired). For instance, the practice of using bait to lure fish has been discovered by a handful of herons in widely separated parts of the globe. Bernd Heinrich hand-reared a group of ravens and then confronted them with a series of novel problems involving meat suspended from a branch by a piece of string. Initial attempts to snatch the meat on the wing were unsuccessful, and the birds eventually stopped trying. Later, with no preamble, one bird flew to the branch, reached down and pulled up the string, stepped on it, pulled up some more, and so on until it had the food.

Some (but not all) of the other birds subsequently solved the problem (apparently independently) in slightly different ways. This ability to devise a behavioral solution in the mind before applying the strategy in the real world — what I call mental trial-and-error — seems a key piece of evidence for thinking. If we know the natural history of the species and the past experience of the individuals, it is difficult to think of an explanation that does not involve understanding — and follow-up tests with stones and crossed strings seem to confirm this view for the ravens.

Another kind of behavior that seems to impress our species is abstract reasoning. When David Premack’s chimps solve problems involving proportions or cause-and-effect sequences, we sense something cognitively familiar. Premack notes that only chimps trained to use a token-based language could solve these problems. While any thinking or planning the ravens accomplished must have involved manipulating mental images, it is possible that having learned to use 'words' made reasoning easier for the chimps. If so, that would help explain why the parrots Irene Pepperberg trained to use words for objects and their properties seem so convincing — more so when observed in real time than when described on paper. Alex the parrot has just that degree of delay and hesitancy we associate with thinking. He can select an object with a novel combination of features in response to verbal questions, count and name the same/different features of a new pair of objects.

Language use is also of interest to cognitive ethology. But human language has enormous innate help in the form of drive, sign stimuli and brain organization. There is no reason to think parrots, sea lions, dolphins or chimpanzees enjoy any of these advantages; nevertheless, all four species can learn to decode (and in the case of chimps, encode) simple word-order sentences. This capacity to abstract cause-and-effect relationships may build on innate abilities to decipher how the world works, but that these animals can learn an alien language at all is deeply thought provoking.

While we may question the ultimate cognitive importance of language as more than a tool, certain spontaneous displays of human-like behavior seem easier to read. Perhaps the most impressive of these involve apparent self knowledge or self awareness. Most of us have seen birds attacking their reflection in windows, or dogs and cats ignoring their mirror images; they just don't seem to 'get it'. Dolphins, gorillas and chimpanzees, on the other hand, soon learn to treat the mirror (or video camera) as a tool for inspecting themselves (especially bodily orifices and unusual marks); particularly with cameras, the behavior is strikingly similar to that of humans in shopping malls. It is easy to interpret this behavior as showing self awareness, an ability we unquestioningly assume is cognitive; oddly enough, the pioneer of this approach, George Gallup, is not impressed.

Perhaps the most convincing cases of self awareness involve deceit. Lying seems to imply an understanding of the state of mind of another individual, a deliberate attempt to manipulate that creature based on acquired knowledge about him and what he knows, all in an effort to create a novel outcome. There is an endless series of anecdotes involving chimpanzees: singly unconvincing perhaps, but difficult to ignore when taken together. My favorite involves a low-ranking chimp named Dandy, studied by Frans de Waal. Dandy developed a number of ruses for fooling higher-ranking males in an effort to keep food for himself or copulate with females. Most seem obvious examples of intentional deceit — lying soon recognized for what it was by the other males.

Perhaps the best example of Dandy's devious mind involves an incident in which he discovered his 'special' female copulating with another low-ranking male: rather than throwing a fit (a typical response to aggravating or frustrating experiences), Dandy cold-bloodedly set off to bring a high-ranking male to see what was happening, and left it to this stooge to punish his rival. (With such machinations, involving forming coalitions followed by complex doublecrosses, Dandy rose to the top of his troop.)

Examples of animals apparently 'reading' the minds of their fellows are so far restricted to primates. Dorothy Cheney and Robert Seyfarth, for instance, have demonstrated that every member of a vervet troop understands the dominance rank and kinship bonds of every other member, and uses that information to guide behavior. On a much more restricted scale, however, even chickens evaluate their audience before deciding to produce alarm calls.

Perhaps the most even-handed thing that can be said about cognitive ethology is that it has made animals look smarter and humans dumber than either group formerly appeared. Individual opinion differs on where to draw the line on thinking, but it seems clear that much of what we once took to be cognitive and largely human now appears to be widespread and at least partially innate. The power of automatic learning (in humans as well as animals) is much greater than we had thought, while evolution seems to have smoothed the path to abilities once considered intellectually impressive.

Designing convincing tests requires knowing the natural history of a species, and the individual experience of each animal to be tested. Solving what are for the species and individual novel problems seems the best guide to animal thinking (and the most fruitful area of current research). The use of language or real-time TV images as tools, or guile as a strategy, are equally impressive windows into the animal mind, but this approach is limited to a narrow group of species — dolphins and apes. Niche challenges are especially critical in choosing animals for study and problems to offer: evolutionary necessity seems to have been the mother of cognitive invention; species that face frequent unpredictable challenges in nature are the ones in which a compensating ability to think and plan is most likely to have evolved.

Further reading

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