Recent experiments show that these birds use logic to solve problems and that some of their abilities approach or even surpass those of the great apes

BY BERND HEINRICH AND THOMAS BUGNYAR

A trapper in the north woods observes a common raven (*Corvus corax*) roll over on its back with its feet in the air next to a beaver carcass on the snow. A biologist laboriously climbs a cliff to band raven nestlings, and the birds' parents rain down loose rocks from above. A lone raven clamors loudly near a remote cabin, alerting a man next to it to look up and see a hidden cougar that is about to spring on him.

Each of these three people presumed to know what the ravens were up to. The trapper thought the raven was playing possum, pretending it had been poisoned to keep other ravens away so it could have the beaver carcass to itself. The biologist thought the raven pair was deliberately trying to hit him with rocks so he would go away. The man at the remote cabin thought the raven had alerted him to save his life.

These various hypotheses cannot be discounted, but most of us who have become intimate with ravens might offer other, more likely explanations. Ravens are perhaps the most playful of all birds, and they regularly roll on their back apparently for the fun of it. They often hammer the substrate in anger, wherever they may be perched, when a predator is near their nest. And they are known to lead carnivores to potential prey they cannot overpower themselves, so the bird may have been leading the cougar to the man.

Raven anecdotes are legion, and many suggest the birds are clever, but stories do not provide proof of diabolical cleverness. Even more straightforwardly sophisticated behavior by ravens—such as their habit of carving a block of suet into chunks to carry off manageable portions, their precise stacking of crackers to allow them to fly away with the whole stack, their manipulation of two doughnuts so they can carry both at the same time, and their making of false food caches that mislead raiders—does not prove that the birds are able to consciously contemplate alternative actions and choose the most appropriate ones.

Mere observations, after all, cannot rule out other possibilities, such as instinct or learning to perform specific actions by rote. Indeed, until the 1990s, probably only one careful scientific test implied logical reasoning in ravens of the type we take for granted in humans. This was a set of experiments published in 1943 by Otto Koehler of the former Zoological Institute of Konigsberg. He demonstrated that his 10-year-old pet raven, Jakob, could count up to seven by training

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Just How Smart Are Ravens?

TO GET A TREAT suspended on a string tied to the perch, a raven has to follow a precise sequence of steps—reach down and grasp the string, pull up on it, put the pulled-up string on the perch, step on it with enough pressure to hold it there, let go of the string, and repeat the process. Some mature ravens studied the situation for several minutes and then performed the entire procedure on their first try—a sign they used logic.

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it to retrieve food from under one of several vessels with various numbers of spots on the lid. But studies undertaken in the past few years, mostly by the two of us, have finally offered some hard proof that ravens are indeed intelligent, in that they are able to use logic to solve problems. What is more, we found, to our astonishment, that they can even distinguish one individual from another. In that way, too, they are much like humans; we could not form societies (except those akin to insects') without this ability.

Proof of Problem Solving

RAVENS ARE NOT the only birds generally reputed to be smart. In the past two decades a virtual avalanche of studies have revealed that certain of their corvid relatives (which include the smaller crows, as well as jays, magpies and nutcrackers) possess surprising and sophisticated mental capacities. In some species, these abilities appear to be on par with, or exceed, those of the great apes. For example, nutcrackers have phenomenal memories that encompass thousands of food cache locations, a capacity that would challenge most humans. The New Caledonia crow (*Corvus moneduloides*) has been shown to fashion tools out of parts of pandanus leaves and to use them to extract grubs from crevices in wood. What has not been known, though, is to what extent such remarkable feats involve innate blind programming versus rote learning and memory (through past trial and error) versus reasoning (choosing from alternatives that are represented in the mind and evaluated).

The two of us have devised experiments to try to distinguish the role and the relative importance of those possibilities. In the first of these tests, we confronted individual ravens with food hanging on a string. To get the treat, they had to reach down from a perch, grasp the string in the bill, pull up on the string, place the loop of pulled-up string onto the perch, step on the string and apply the appropriate pressure to prevent slippage, then let go of the string and reach down again, repeating this sequence six or more times in a row.

We found that at least some grown-up birds would examine the situation for minutes on end and then perform this multistep procedure on their first try in as little as 30 seconds, without any preliminary efforts at trial and error. In classical "shaping" of behavior in laboratory animals, the steps in a desired behavioral sequence are typically rewarded with food, whereas false steps are punished with electric shock. The links in the sequence are established presumably without the animal needing to understand how a single one of them contributes to the overall outcome. Our animals, however, would not have encountered this task in the wild and therefore could not have learned how to do it in the past by trial and error. Hence, the simplest suggestion is that they imagined possibilities and figured out what steps to take.

Passing the test did require maturation. Young birds (a month or two past fledging) are unable to perform this complex behavior. And year-old birds require on average six minutes to solve the puzzle, during which they overtly test various possibilities (such as flying at the food, trying to rip off the string, pecking the string, or yanking and twisting it).

No one step in the pull-up sequence was rewarded with food; the raven had to accomplish the whole lengthy sequence in order to eat. One might argue, however, that each step is "mentally" rewarded and therefore reinforced simply because the food comes nearer and that the animal does not necessarily know that each step in the sequence brings it closer to its goal. But that explanation does not hold water. If each step were acquired by trial-and-error learning, it would require numerous trials, and the entire pull-up sequence would probably take months of train-

Overview/*Raven Intelligence*

- Although the clever behavior of ravens convinces most people that the birds are intelligent, it does not prove that they can consciously contemplate alternatives and choose the best one.
- The authors set out in search of such proof by devising a series of experiments that involved pulling up meat on a string and hiding food from competitors.
- They found that ravens can use logic to solve problems and that they can distinguish individuals (both humans and other ravens) and attribute knowledge to them.

ing. But this is not what happened. The birds acted as if they knew what they were doing.

We could only know that they knew, however, if they behaved according to certain predictions. If the ravens knew what they were doing, for example, then they should also know what they had done. They should know, for instance, that after they had pulled up the treat on the string, it was still attached to the perch. To find out if they understood, we shooed them away from the perch after they had pulled up meat. If they dropped the meat, we figured they knew it was attached to the perch; if they flew off with it (and had it ripped out of their bills), they did not know. Most dropped it, even though they always flew off with meat that had string attached to it but that was laid (and not tied) onto the perch.

Knowing requires few or no trials, whereas trial-and-error learning requires no logic. And so we sought still another test to find out if the birds might have solved the challenge of meat pull-ups by random movements that happened to be rewarding but that were unsupported by logic. This time we confronted naive birds with the same physical choices but with what we hoped would be, to them, an illogical situation, namely, a looped string that had to be pulled *down* to make the food come up.

Under this situation, the ravens were still interested in the food; they investigated the setup and pecked and yanked on the string, thus making it at times come a little closer. They soon gave up, however, and none learned to access the food even though the same pull/step/release sequences that quickly delivered the food before *could* have provided it again. We believe, therefore, that the direct pull-up was mastered quickly and sometimes almost "instantly" only because it was supported by logic. Apparently ravens have the ability to test actions in their minds and project the outcomes of those actions. That capacity is probably lacking or present only to a limited extent in most animals—and for a good adaptive reason.

The Benefits of Intelligence

BY SOME PROCESS that still remains one of the great unsolved mysteries of biology, exquisitely precise behaviors can be genetically programmed in animals with brains no larger than a pinhead. Consider, for example, a wasp that makes paper expertly from the time it is born, that fashions a nest of precise architecture with that paper, while another wasp uses mud to make a mortar nest of a very different but also very specific shape. Similarly, birds of each species are programmed to make precisely predetermined nests. All barn swallows build a shelf nest from mud that hardens when it dries. Cliff swallows construct ovenlike nests, also out of mud but with a small round entrance hole.

CONFRONTED with having to pull *down* on a string to pull food up, inexperienced ravens (those who had not mastered pulling food up on a string) seemed to decide that pulling down to make something move up was illogical and soon gave up. (The wire mesh prevented the birds from pulling up on the string.)

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None of the most intricate of these behaviors is learned, nor do the behaviors depend on thinking (although learning and thinking can modify some genetically programmed behavior). Thinking and logic can be notoriously unreliable and can lead to much mayhem, as we all well know. The big question, then, is why, if behavior can be so precisely preprogrammed, some animals (ourselves, for example) are consigned to muddling. Why are they not endowed as most animals are to "do it right," except perhaps after experiencing the many things that can go disastrously wrong?

The usual answer is that such animals evolved in a complex and unpredictable environment in which prewired responses were inappropriate. If the animal can identify individuals, and it lives among others that can in turn identify it as a separate entity, then the environment for each of them is indeed complex. Social life among most animals that do identify individuals is thus often cited as the driving force for the evolution of intelligence: in such a context the ability to predict the responses of others, who constitute the main relevant feature of the environment, becomes extremely valuable. We were therefore led to consider the ravens' social environment to try to understand why they, more than many other animals, would have benefited from becoming intelligent.

The Natural Environment of the Raven

MUCH OF THE RAVENS' natural history suggests that they had to evolve to cope with ever changing short-term circumstances. These birds are basically opportunists that do some hunting but have specialized to live off the food other animals kill. The predators that provide them with food, however, are unpredictable and can also kill them. Lengthy conditioning through trial and error would appear to be fatally costly, because the first mistake could cost the birds their life, and a totally programmed response to an unpredictable carnivore could be equally dangerous.

The way they compete for food with other ravens also requires coping with ever changing circumstances. Territorial pairs of ravens attempt to monopolize food bonanzas, and members of the large population of juveniles and nonbreeders mount a counterstrategy of recruiting flock mates that then overpower the territorial defenders. Significantly, however, the same behavior that gains the crowd access to the food, as well as diluting the danger by their numbers, intensifies the competition for the resource.

Food bonanzas are not only provided by carnivores, they are often quickly consumed by them. It pays the attending ravens to get an early start in the feeding cycle, preferably next to the carnivores while they are still eating. To do that, the birds need to be able to predict the predator's behavior, such as whether or when the animal might attack, how far it can jump, and how it may be distracted. Some of that knowledge needs to be in place before the raven is distracted by feeding, because in that context practice could be deadly.

Indeed, the birds acquire practice more safely early in their lives. Juvenile birds, when undistracted by feeding, routinely "test" the reactions of large animals such as wolves and other carnivores by interacting with them, usually by landing nearby and then nipping them from the rear. It is unlikely that such behavior is tactically deliberate. More likely it is a form of "play," defined in the considerable scientific literature on the subject as a behavior that has no immediately discernible function but that commonly has an ultimate function, one that is not consciously intended but that proves useful anyway.

Even youngsters recognize that nipping carnivores is dangerous (they display fear when they do it), and thus they must be wired to engage in such activity because the risky play ultimately aids survival—presumably by giving them experience in gauging how much they can get away with around their carnivore companions. By such provocation they soon learn which animals to trust and the distances required for safety. Conversely, their nearly constant presence around the carnivores accustoms the larger animals to the birds, and they gradually learn to ignore them. But getting along with dangerous carnivores is only a means to the end of getting access to a rich supply of food.

The often short time that a food bonanza lasts (deer carcasses in the Maine woods, for example, are consumed in a day or two) places a premium on hauling the food away first and eating it later. Like other corvids, ravens cache food for later use. At a contested carcass, they busily haul off one load of meat after another and hide it by burying it and camouflaging it with debris so that it is totally removed from view. Also, like many other corvids, ravens memorize the exact locations of their numerous caches and usually retrieve them within hours or days. Yet unlike most food-caching birds, ravens carefully observe the caching behavior of competitors, and they memorize the precise locations not only of the caches that they make themselves but also of those they see others make.

THE AUTHORS

BERND HEINRICH and *THOMAS BUGNYAR* share a fascination with the intellectual abilities of ravens; they investigated the birds together when Bugnyar was a research associate at the University of Vermont, where Heinrich has been a professor of biology since 1980. Heinrich received his Ph.D. from the University of California, Los Angeles, and spent 10 years in the department of entomology at U.C. Berkeley before going to Vermont. He is the author of several well-known books, including *Ravens in Winter* (Simon and Schuster, 1989) and *Mind of the Raven* (HarperCollins, 1999), which will be reissued in a new edition this summer. This is his seventh article for *Scientific American*. Bugnyar received his Ph.D. from the University of Vienna for work that he did with ravens at the Konrad Lorenz Research Station in Grünau, Austria. He is now a lecturer in the school of psychology at St. Andrews University in Scotland.

JIM BRANDENBURG *Minden Pictures*

Playing with and Hiding Food

REALIZING THAT PLAY with predators apparently helps ravens learn how to size up situations and act accordingly, we decided to test whether play really did help young birds gain the ability to adjust their behavior flexibly. Caching behavior offered a promising field for this inquiry, and a large aviary we had designed to simulate natural conditions of trees and ground cover provided a convenient setting for the experiments.

We found, as we had seen before, that ravens actively avoid one another while caching. They prefer to do their hiding in private, or they use trees or rocks to block the view from others. Cache owners also attempt to chase off potential pilferers. And we discovered that these caching skills originate from innate play responses that provoke their protagonists to react and that then permit learning of the appropriate responses. This testing and learning process starts among the siblings shortly after they leave the nest and begin to follow their parents, learning to identify the

MATURE RAVENS, which have a wingspan of 1.25 meters and weigh about 1.25 kilograms, move in on an animal recently brought down by wolves in Yellowstone National Park. The playful behavior of young ravens, the authors suggest, teaches them how to get along with much larger carnivores, on whom they depend for much of their food.

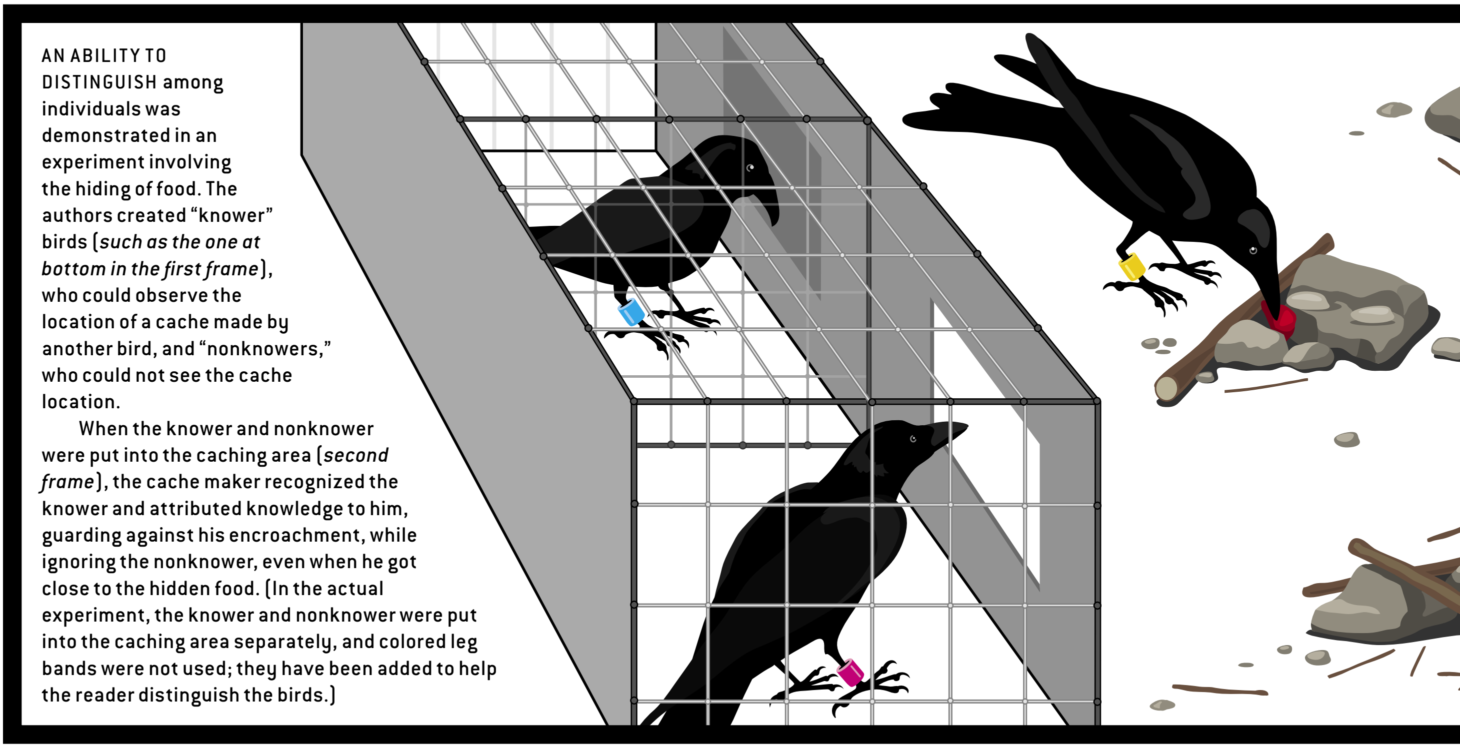
great variety of small food objects, such as insects and fruits.

Young ravens in the nest and several days out of it manipulate all sorts of objects with their bills, and like the tail tweaking of wolves, such behavior is defined as play because it brings no proximate advantages, yet it requires the expenditure of time and energy or the taking of risks. In essence, these objects are "toys." In experiments with a brood of tame ravens, one of us acted as parent and daily led the birds around. The juveniles kept themselves busy picking up twigs, leaves, flowers, pinecones, pebbles, cigarette butts, coins and other objects we had "seeded" on the ground. Within days the young ravens largely ignored the inedible items and eagerly sought out the edible. Their playful object manipulation gave them the experience of learning about their environment. Because the ravens normally would still have been fed by their parents at that time, they could afford the apparently useless behavior, whose benefit would only become manifest later.

While the young birds are learning to distinguish the edible from the inedible, they simultaneously increase and shape their caching skills. At first they indiscriminately tuck some of the items that catch their attention up against other objects. Later they shove them partially out of view into crevices, and by a month or two the still-dependent young cover cached objects with debris. Because these young ravens ordinarily cache in front of their siblings and parents, with whom they travel for several months after fledging, the siblings often recover the hidden items. We wondered whether the playful caching of the inedible items helps them gain the ability to predict others' behavior so that they can successfully hide and defend their valuable food items later on.

One problem with tests of whether early experience ultimately affects adult behavior is that it is difficult to control the experience that any one bird might have. We noticed, however, that the birds also watched *us* and retrieved "caches" of food that we, their surrogate parents and companions, hid from them. And we could control our behavior! For an experiment, we therefore designated one person as a "thief" who always stole the cached objects that the young birds hid in apparent play, whereas a second person consistently examined the birds' object caches but never retrieved any of them. In the test situation, we provided the then more mature ravens with food rather than inedible objects. This time the same two people, either the thief or the nonthief, stood by and only observed the birds' behavior without interfering.

Confronted with the potential thief, the ravens significantly delayed the time until they cached their food (as if they were waiting for a time when the thief was not looking), and they retrieved those caches that they did make when he walked near them. In contrast, the previously benign person who had not stolen cached objects did not elicit delays in stowing food, and the birds ignored him when he went near one of their caches. This experiment thus showed not only that the birds improve their food-caching skills after experiencing others' raiding their object caches but that they distinguish individuals (in this case, humans).



AN ABILITY TO DISTINGUISH among individuals was demonstrated in an experiment involving the hiding of food. The authors created "knower" birds (*such as the one at bottom in the first frame*), who could observe the location of a cache made by another bird, and "nonknowers," who could not see the cache location.

When the knower and nonknower were put into the caching area (*second frame*), the cache maker recognized the knower and attributed knowledge to him, guarding against his encroachment, while ignoring the nonknower, even when he got close to the hidden food. (In the actual experiment, the knower and nonknower were put into the caching area separately, and colored leg bands were not used; they have been added to help the reader distinguish the birds.)

Discriminating "Knowers"

WILD RAVENS in the field commonly feed in crowds, as we have described, and spend much of their time busily caching food for later use. In this situation, it would be almost impossible for any one bird to chase off every other bird that happened to wander near one of its often dozens of caches. Yet adult ravens greatly reduce the possibility of having competitors see them make their caches or having to chase others away who might be potential raiders by scattering their valuable hoards over an area of many square kilometers. In the confines of our aviary, though, it is often not possible for an individual to escape the watchful eye of competitors, and such a situation gave us the opportunity to determine experimentally whether the birds are able to discriminate among raven competitors based on what the competitors could potentially know, just as they had discriminated among different humans.

In this series of tests, we capitalized on our knowledge that ravens distinguish one another (as well as others of another species—namely, us) as individuals. We created "knower" birds—those that had observed the locations of a given bird's caches—versus "nonknowers"—those that could not have observed the cache locations. We then paired the cache maker with these different competitors, much as we had in the experiments to examine the responses of young birds to thieves and nonthieves. In this case, however, the experimental setup called for a modification of the aviary.

One large compartment of the aviary served as the caching arena. We separated a smaller compartment from this area with an opaque wall. In the wall we made a small viewing window and placed a perch in front of it, on which a bird could land and look through wire screening to observe the caching bird in the main compartment. Next to the viewing compartment a similar compartment also contained a bird, but in this case the viewing window was occluded by a curtain. Thus, two birds had the same aural access to a caching bird, but only one had visual access.

Both the birds in the small compartments would soon (within five minutes) be allowed into the caching area to search for food. They were therefore motivated to watch the cacher. Indeed, the knower bird normally perched to try to watch the cacher, and the nonknower in the curtained compartment tried to lift the curtain to watch (we found we had to secure the curtain so it could not be lifted). After the cacher had made three caches, we removed it from the large compartment and five minutes later let it back in to retrieve its hidden stores. It was allowed to retrieve either in private or in the presence of the knower or of the nonknower. (Both these potential thieves were of subordinate status to the cacher so that they would not extinguish its responses defending its hoard.)

Cachers typically retrieve their food when robbery seems imminent, and indeed the experiments showed that they retrieved significantly more of their caches when they were paired with knowers than with nonknowers or when they were alone. Furthermore, when a knower came within two meters of the camouflaged food, the cache maker chased it away, whereas he ignored nonknowers. We speculated that the cachers remembered which birds had watched them make any particular cache and later discriminated against them, as though attributing knowledge

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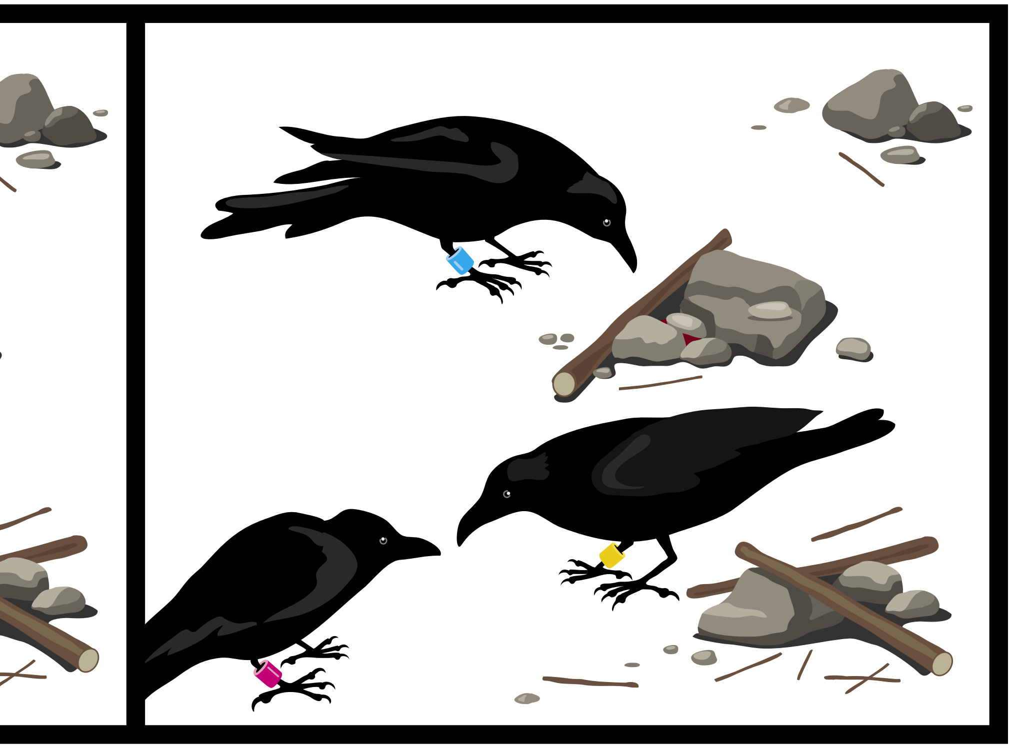

to those that watched. They apparently anticipated the watcher's intentions and guarded against his expected raiding behavior. But the knowers also guarded against the defensive behavior of the cache makers: they did not go directly to the caches in their presence but waited until they were at some distance. The results of these experiments suggest the attribution of knowledge and the anticipation of a response.

In another version of the same experiment, we tried to control for the possibility that the apparent knowers had been inadvertently providing some subtle cues that the cache defenders could read, rather than that the cache defenders actually knew that the knowers had seen them. So we had a human, who would stand by passively, make the caches. As we predicted from the results of the first experiments, knowers rushed to pilfer the human-made cache if they were paired with another knower. On the other hand, when paired with an ignorant *dominant* competitor (who would attack the raider to get the cache), they delayed, by 10 times on average, the duration before they approached the cache, waiting until the dominant raven was occupied at a distance. These results do not totally exclude the possibility that the knowers provide some subtle unknown cues that the cache raiders may use, but such cueing is unlikely, and the findings strongly suggest that the birds engage in amazingly sophisticated behavior based on an ability either to interpret or to anticipate the actions of others.

What Are Ravens Thinking?

THE STUDY OF mental states of animals who cannot report their thoughts to us is beset with difficulties. Indeed, we do not know and perhaps can never know what goes on in the mind of another animal or even other individuals of our own species. Yet invoking Occam's razor and accepting the simplest explanation, as is traditional in science, we can conclude that our experiments provide a consistent affirmation that ravens use some kind of mental representation to guide their actions. The results of the string-pull experiments indicate the use of logic. And the pilfer and antipilfer tactics suggest that ravens judge their competitors on the basis of what they remember them paying attention to. They then attribute to the competitors the capacity of knowing, and they integrate that knowledge together with dominance status into strategic decisions for making and retrieving caches.

Learning occurs, but it alone cannot account for all of the observed behavior, because the behavior is exhibited very fast, almost immediately, without any trials and errors. We speculate that the birds start from an innate framework of prewired, playlike behavior, which generates the experience that is a prerequisite for learning. Learning may later translate to conscious awareness—that is, an ability to use logic—that would be useful in the highly unpredictable context of a social milieu with competitors and predators and that can then be transferred to any other novel context, such as pulling food up on a string.

We do not know how unusual the ravens' kind of ability is in nonhumans. But we suspect that although it may not be rare, it would generally be narrowed to specific kinds of tasks, because the underlying instincts and learning tendencies that are tailored to the animals' environment vary greatly. In the raven, however, it may be more general than in most. We think so because no other bird we know of is as playful as the raven and consequently exposes itself to such a variety of contingencies. These tendencies may have allowed it to become the most widely naturally distributed bird in the world, inhabiting the same continents as humans and being at home in as many diverse habitats. SA

MORE TO EXPLORE

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