Danger! Danger! American crows chase a bald eagle, which is an innate behavior.

Into the Minds of Birds

A new brain-scanning method offers a window into the brains of birds, which have emerged as the surprising stars of many animal cognition studies

BIRD 7, AN AMERICAN CROW BLACK OF feather, beak, and eye, stood unmoving behind the bars of the cage, his right eye fixed on me. Outside the bars, with a mask covering my face, I sat unmoving, looking back at him. In my outstretched hands lay the corpse of a dead crow. For a full minute, Bird 7 stared at me and the cadaver. In the wild with his fellows, he likely would have also cawed, scolded, and mobbed me, perceiving me as a threat because of my association with a dead crow. As a lone captive, he merely studied my masked face. "Focus on one of his eyes and count the number of times he blinks," John Marzluff, the wildlife biologist behind this experiment at the University of Washington, Seattle, had instructed me. Blinks are a simple measure of a bird's nervousness, and in that minute, I counted 29. Relaxed birds average 36 blinks per minute, a statistically significant difference. Looking at me made Bird 7 nervous.

When the minute was up, Marzluff and graduate student Kaeli Swift moved in. They slipped a hood over the crow's head while an anesthesiologist stepped forward to sedate him. Marzluff then gently strapped Bird 7 onto the examining tray of a positron emission tomography (PET) scanner. For the next 15 minutes, a radiologist captured images of the crow's brain—specifically, those areas that had been activated when Bird 7 stared at me. Before the test, the scientists had injected the crow with a radioactive tracer that metabolizes so slowly that it would highlight the brain's synaptic activity in the past 15 minutes. Thus, the scan would reveal what scientists had seldom witnessed: the brain of a wild bird in the act of thinking about—or processing—a real-life, threatening event.

"We're seeing that the crows' brains are cognitively flexible," Marzluff explained later as we looked at Bird 7's scan and those of 23 other crows, all wild-caught. Different types of threats—a predator like a red-tailed hawk, or my masked face—elicit the same staring behavior but involve different kinds of processing in the brain, Marzluff, lead author Donna J. Cross, and colleagues report in this week's issue of the *Proceedings of the Royal Society B*. When looking at me holding a dead crow—but not when looking at a hawk—Bird 7 activated its hippocampus and cerebellum, regions involved in learning and memory. "Even though their outward reaction appears to be the same, their mental processing of these threats is very different," Marzluff said. "The crow wasn't just responding to a danger when he was watching you. He was learning the features of your masked face. That's why we think his hippocampus was activated."

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Podcast interview with author Virginia Morell (http://scim.ag/pod_6141).

While Marzluff emphasizes that the PET scanning is a "first try" at glimpsing bird brains in the act of working, it is already being hailed as a powerful new tool for studying avian cognition. "This is pioneering avian cognition neuroscience," says Russell Gray, an evolutionary biologist at the University of Auckland in New Zealand. "They're showing us what's going on inside the crows' heads. There's a lot more cognitive processing that's much more finely tuned than we would think by observing the birds' outward behavior. It means that if you only judge animals by the way they behave, you could be mistaken."

Gray and others hope that the scans will spur an already-booming field. Being able to tell what parts of the brain are active in an animal's response might offer clues to when—or if—it is "thinking," rather than simply responding to a stimulus. Thus, the scans have the potential to illuminate a long-term debate over animal capabilities. On one side are researchers who consider animals' stereotypical behaviors as evidence of mental inflexibility. On the other are those who suspect that animals have more complex thought processes, but who struggle to prove it. The scans "may help close the divide," says Corina Logan, a comparative cognition scientist at the University of California, Santa Barbara.

But not everyone is persuaded that brain scans will change views. "This kind of comparative behavioral neuroscience is definitely worthwhile," says Sara J. Shettleworth, a professor emerita of psychology at the University of Toronto in Canada and self-described "killjoy" when it comes to animal smarts. But "it is not a substitute for behavioral tests" of mental abilities.

Feathered apes?

A decade ago, researchers might have been surprised that scientists would bother studying the minds of birds so intensely. Members of the avian family were once dismissed as "bird brains" and regarded as mentally simple. They were thought to lack a cerebral cortex, the area in the mammalian brain where higher cognitive functioning takes place.

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Then, in 2004, an international team of neurobiologists and ornithologists reported that the brains of birds have structures, including an advanced forebrain, that are analogous with those of mammals. Even before that study, some comparative cognition researchers had demonstrated that some birds—especially parrots, crows, and jays—behaved in ways that suggested sophisticated cognitive skills (*Science*, 23 June 2006, p. 1734; 23 February 2007, p. 1074). The 2004 report "provided the neural evidence. It showed that there was real brain power behind what these labs were revealing, and helped convince skeptical people," says Logan, who entered the field partly because of that paper. "Now bird cognition is hot."

Indeed, over the past decade, the field has gathered momentum, producing a stream of papers. Researchers have detailed sophisticated memories in ravens and jays; tool-manufacturing and reasoning abilities in crows; and complex social skills in many species, especially corvids and parrots. Corvids are the most studied. "The range of behaviors—from counting to caching—that corvids do and are surprisingly good at, just shows how flexible and diverse they are," says Nicola Clayton, a comparative psychologist at the University of Cambridge in the United Kingdom. She and Nathan Emery of Queen Mary, University of London termed corvids "feathered apes" because they have many of the talents celebrated in the great apes, from toolmaking to social networking (*Science*, 10 December 2004, p. 1903). Some corvids even surpassed apes on tests designed to reveal things such as the ability to recognize that others have intentions.

But not everyone is convinced by these claims of advanced cognition in birds. Some researchers argued that those behaviors could be explained by simpler cognitive processes such as associative learning. The same arguments seem to play out over study after study (*Science*, 2 March 2012, p. 1036). "The two sides keep doing what they've always been doing," says Elske van der Vaart, a postdoctoral theoretical biologist at the University of Groningen in the Netherlands. "One side says it's found some new mental ability in an animal, and the other says that's still not enough proof."

Why might birds have evolved a rich repertoire of mental abilities? Thomas Bugnyar, a cognitive psychologist at the University of Vienna, suggests that it may be a result of living complex social lives—the same theory proposed as the driving force behind the evolution of primate cognition. "We're trying to see how well the social intelligence hypothesis fits with nonmammalian species, and corvids in particular," explains Bugnyar, who recently published a summary of his team's studies in *Comparative Cognition & Behavior Reviews*. American crows, for instance, have complex social lives that might shape their evolution: They mate for life; have extended families; communicate in complex vocalizations; and travel, forage, and roost in large social groups. If similar social pressures drove both avian and primate intelligence, it would be a stunning example of convergent evolution.

But there are key differences between the evolutionary pressures that likely led to the social smarts of ravens and mammals, Bugnyar notes, beginning with their most basic social bond. "In mammals, it is the mother-infant bond, but in birds it is the partner relationship, the pair-bond. It is a bond that develops through learning," he said, citing work that he reported in *Current Biology* in 2007. Clayton agrees that despite the similarities between some of our skills and those of birds, they don't experience the world as we do. That's why they're so useful to study—if one can figure out how.

Bird "folk physics"

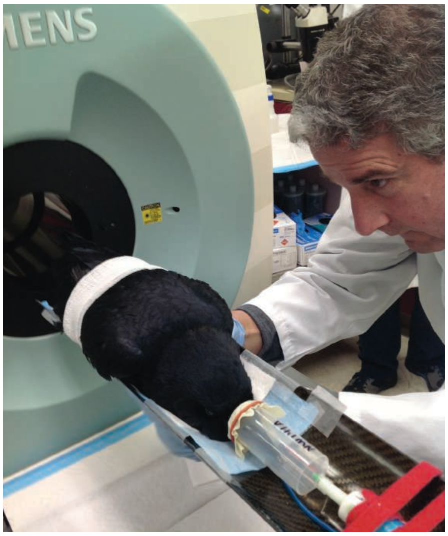
Behavioral experiments that try to explore just what's behind a bird's actions are often tortuously complex, as researchers try to come up with protocols to test how birds process their world. Many experiments examine tool use and manufacture and the manipulation of objects to get a treat. Researchers say that such experiments offer clues to the "folk physics" of animals—how they perceive the mechanical world. "Physical tasks are appealing because they are more likely to reveal the precise cognitive operations an animal makes to solve a problem," says Alex Kacelnik, a behavioral ecologist at the University of Oxford in the United Kingdom.

His group, led by Alice Auersperg at the University of Vienna, last year reported that a captive Goffin's cockatoo, Figaro, can spontaneously invent, make, and modify tools. The bird picked up a twig from the floor of the aviary, snipped off the side branches, and cut it to the right length to rake a nut into his cage.

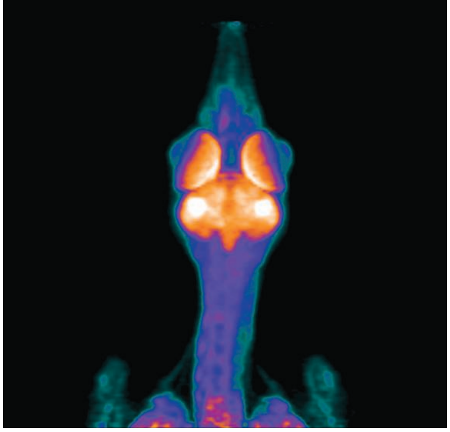
That sounds like a dramatic, spontaneous invention out of whole cloth. But did Figaro have a mental image of a finished rake and take all these steps toward that image?

If so, no one has proved it yet. It may be that the bird learned through a series of intermediate, exploratory steps.

Just this week, the same team reported in *PLOS ONE* that other captive cockatoos were able to learn to unlock a series of



Thinking with crows. After a crow has looked at a masked person holding a dead crow (*left*), scientists ready him for a PET scan.



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five locks to get a treat, suggesting that the birds can learn sequential steps without extra rewards. The birds also succeeded when the locks were presented in a different sequence, showing that they could consider each step independently. "It's a kind of ratchet mechanism—little steps—that leads them toward a solution," Kacelnik says.

The lockbox experiment shows stepwise progress, but the mechanism behind the birds' abilities to create tools and manipulate objects remains a mystery, says Alex Taylor, an evolutionary biologist at the University of Auckland. "These are impressive performances, but it is difficult to know exactly what cognition is being used; what is going on in the bird's mind."

Indeed, the same question—whether the birds imagined a full-blown solution or proceeded in small steps—inspired Taylor and Gray to further explore New Caledonian crows' ability to use "insight" to solve a problem. Although not well-defined, insight is considered a kind of instantaneous problem-solving skill—the aha! moment.

New Caledonian crows are one of a few species of birds, including ravens, African gray parrots, and keas, that can get a treat dangling out of reach from a vertical string that's suspended from a perch. The birds all use the same stepwise method: They pull up the string with their beak, then step on that segment with their feet, freeing their beak to pull up more string, and so on, until they reach the treat. But what goes on in their minds when they do this?

Some have argued that the birds mentally imagine the result of repeatedly pulling on the string—that the food will be within reach—and so are working toward that final goal. But others suggest that the birds may simply be responding to a feedback loop, and that the rising food acts as a reinforcement that keeps them pulling and stepping.

Taylor tested the two hypotheses by slightly changing the setup for 11 wild New Caledonian crows, in work reported in the *Proceedings of the Royal Society B* in 2012. Instead of dropping the string from a perch, he arranged it in two separate coils on a table. Both ropes had meat at their ends; but one rope was broken into two pieces, so if a bird pulled, the meat on the end would not move. Most of the birds pulled the continuous rope rather than the broken one, but only one did so enough times to get the food. The others stopped after a couple tugs, or didn't bother to pull at all, Taylor reported. He suggests that—at least in this case—the birds are indeed responding to the results of each step, rather than imagining the end result.

But what are they thinking? To get a treat, crows can pull strings (*top*), and cockatoos can craft tools and open five locks (*middle and bottom*), but just how they solve these problems is a mystery.

CREDITS (TOP TO BOTTOM): BRENNA KNAEBE; ALICE AUERSPERG (2)

Marzluff points out that the birds had enough understanding of the test to pull the connected string, not the broken one. "I think they just didn't get the experiment; it doesn't mean that they don't have insight."

Inside a crow's head

These differences of interpretation are why researchers are so excited about the idea of viewing the brain at work. Marzluff already knew, for example, that crows are extremely attentive and have excellent memories. They pay attention to the dead body of another crow, cawing and mobbing when they see one, and they don't forget the faces of people who threaten them, Marzluff reported in 2010 in *Animal Behaviour*. In 2006, wearing identical Halloween cavemen masks, he and his students captured seven crows on campus, tagged, and released them. Later, when the researchers donned their masks again and walked around campus, the banded crows scolded them; they ignored people wearing a Dick Cheney mask. To this day, campus crows (even those that the cavemen never handled) harass Marzluff if he wears the caveman mask. That's why lab workers wear masks when working with crows—so they won't be mobbed later.

Last year in a study in the *Proceedings of the National Academy of Sciences*, using his brain-scanning technique for the first time, Marzluff examined the neural circuitry active when crows scan and remember masked faces. Now, the new study shows that the parts of the brain active when viewing a predator that crows innately fear (a hawk) is different from those that are active when a crow learns and memorizes the face of a threatening person they've not seen before. This method "should vastly improve our understanding of how animals interface, interpret, and internalize information," says Teresa Iglesias, a behavioral ecologist at the Australian National University in Canberra, who has studied mobbing in Western scrub jays.

"It's a technical and conceptual breakthrough," agrees Erich Jarvis, a neural anatomist at Duke University in Durham, North Carolina, "the first study that I am aware of that asks cognitive questions about fear and memory in the avian brain using in vivo imaging." But he cautions that Marzluff's team may be "too quickly explaining the results in purely cognitive terms." More basic brain functions—sensory processing and activation of nerves that move muscles—might also explain some of the differences in the scans.

Even if the first run of the method isn't foolproof, Gray, Logan, and others are excited about combining it with their behavioral experiments for clues on just what is going on in a bird's mind—the brass ring for cognition researchers. Taylor and Gray would like to try the string-pulling tests with Marzluff's scanning technique, to see what areas of the brain are involved. Because some crows are better than others at solving the vertical string-pulling test—and certain songbird species can do it only after being trained—the researchers hypothesize that there may be key differences in the birds' brains, both within and between species.

Of course, there are some things we'll never know, such as just what the crows thought about their 2-week visit to Marzluff's lab. Earlier this month, however, Marzluff spotted Bird 7, identified by his band. He's back in the area where he'd been trapped, "is doing fine, is territorial, and is the king of the valley," Marzluff reports. Maybe the crow had learned something, too, because this time, he was smart enough to evade the scientists' trap while making off with the bait—a dozen hard boiled eggs.

–VIRGINIA MORELL

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