BILL O'LEARY/*THE WASHINGTON POST*

To prevent Shania the octopus from becoming bored, keepers at the National Aquarium in Washington, D.C., gave her a Mr. Potato Head filled with fish to snuggle. Researchers are now looking beyond behavior into the brain for signs of awareness in birds and invertebrates.

Humans wonder, anybody home?

Brain structure and circuitry offer clues to consciousness in nonmammals

By Susan Gaidos

One afternoon while participating in studies in a University of Oxford lab, Abel snatched a hook away from Betty, leaving her without a tool to complete a task. Spying a piece of straight wire nearby, she picked it up, bent one end into a hook and used it to finish the job. Nothing about this story was remarkable, except for the fact that Betty was a New Caledonian crow.

Betty isn't the only crow with such conceptual ingenuity. Nor are crows the only members of the animal kingdom to exhibit similar mental powers. Animals can do all sorts of clever things: Studies of chimpanzees, gorillas, dolphins and birds have found that some can add, subtract, create sentences, plan ahead or deceive others.

To carry out such tasks, these animals must be drawing on past experiences and then using them along with immediate perceptions to make sense of it all. In other words, some scientists would say, these animals are thinking consciously.

Many people (some scientists among them) would like to believe that consciousness sets the human mind apart from the rest of the animal kingdom. But whether in humans or other creatures, behavioral signs of cognizance all arise from the tangled interactions of neurons in the brain. So a growing number of scientists contend that animals with brain structures and neural circuitry similar to humans' might experience something like human awareness, even if a bit less sophisticated.

Still, everyone agrees that consciousness is one of science's great unsolved mysteries. Something goes on in the heads of people when they are seeing, thinking or feeling that does not occur during dreamless sleep. For two decades or so, researchers have been conducting studies to see what kinds of brain activity match up with those specific experiences.

Drawing on this information, scientists are now poised to explore the possible presence of consciousness in animals. Neurobiological information gleaned from studies of brain activity, together with studies of animal behavior, may help scientists identify various types of conscious states in animals, says neurobiologist David Edelman of the Neurosciences Institute in San Diego. He and collaborator Anil K. Seth outlined a framework for probing animal consciousness in the September *Trends in Neurosciences*.

"In many cases, we still know nothing about the brain areas that would control consciousness in a particular animal," Edelman says. "But we now have data in the human domain that suggests where to look and what to look for."

Past studies have shown that specific monkey brain structures do what they do in humans when the animals engage in certain activities, such as tracking objects in their visual field. "This raises the intriguing question whether conscious experience requires the specific structure of human or primate brains," biologist Donald Griffin wrote in *Animal Minds: Beyond Cognition to Consciousness* in 2001.

But today, Edelman says, most neuroscientists agree that consciousness probably correlates with the degree of complexity of the nervous system, not just a specific brain architecture. And studies are exploring self-awareness beyond monkeys and apes, even beyond mammals.

Recent studies of bird brains reveal that avian gray matter is more similar to mammalian brains than not — a fact that might explain why many kinds of birds are able to manufacture tools (*SN: 8/29/09, p. 5*), solve mathematical problems (*SN: 4/25/09, p. 15*) and communicate in ways that even some primates can't. And new work suggests that some invertebrates with wildly different brain structures, such as octopuses, have elaborate nervous systems and show high intelligence. They use tools, exhibit play behavior and have distinct personalities.

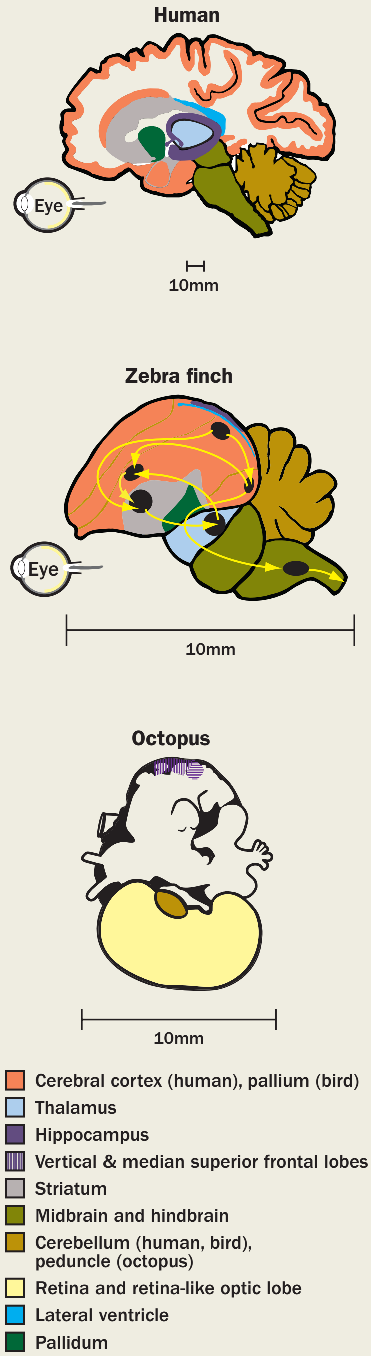
Studies designed to probe the conscious states of animals with various brain architectures may help scientists better understand the mechanisms underlying consciousnesses and how such levels of awareness evolved. John David Smith, a psychologist at the University at Buffalo of the State University of New York, says it's important to keep in mind that consciousness is not an all-or-nothing event. "It didn't just wink on like a fuse box in a house getting switched on," he says. "There are levels and gradations of the capacity, and I think we have to bear that in mind."

A consciousness loop

Everyone has an idea of what being conscious means, but nobody seems to be able to define it. In the 17th century, French philosopher and mathematician René Descartes declared that mind and body are separate, leaving the debate over the nature of consciousness to philosophers and theologians. Today scientists reject that notion, viewing

Brain-on-brain comparisons

In an effort to find signs of consciousness, scientists are identifying analogous structures (same coloring) among the brains of humans, birds, octopuses and other animals. The cortex, hippocampus and thalamus are believed to be involved in generating awareness. Once such structures are identified, researchers can look for similarities in neural circuitry (yellow arrows represent a vocal learning pathway in the zebra finch).



D. EDELMAN

consciousness as arising from the activity of neurons in the brain.

The late Francis Crick, who shared a Nobel Prize for the discovery of DNA's structure, helped pioneer studies on the neural basis of consciousness. Working with his longtime collaborator, neuroscientist Christof Koch of Caltech, Crick argued that consciousness is synonymous with awareness — all forms of awareness — and that only by examining neurons and their interactions could scientists accumulate the kind of empirical knowledge needed to create a scientific model of it.

Edelman likens conscious experiences to "scenes" in which sensations, perceptions, thoughts and feelings are unified into a picture of the world. Higher-order consciousness — the kind that humans have — may include context that helps shape the experience, such as inner dialog, implicit expectations and voluntary control of thought and action. Such high-level cognizance makes people aware that they are aware. Primary consciousness, on the other hand, requires no self-reflection but does require a neuronal circuit capable of combining attention and short-term memory, Edelman says.

"It's the ability to take in sensory information and form memories — whether those memories persist for tens of seconds or minutes — that allows one to interact in a meaningful way," Edelman says.

Scientists are working to identify the neurological mechanisms that knit sensory input and memory into a unified perception. One possible mechanism is a curious electrical rhythm in the brains of animals exposed to sensory stimuli. Known as gamma oscillations, the waves reflect the synchronous activity of large interconnected networks of neurons firing together roughly 40 times per second. This beat spreads across the brain and seems to be especially strong when animals are concentrating on a single object — such as they might when tracking the scent of their favorite prey.

More recent studies of human brain activity show that consciousness creates other frequencies of oscillation that can be detected using an electroencephalograph, or EEG. In 2005, Edelman and colleagues published a paper in *Consciousness and Cognition* outlining a series of studies showing that recordings taken during tasks such as memorization or problem solving reveal a circuit of neural activity running in loops between the thalamus, known to help control alertness, and the cerebral cortex, the brain's outer layer where sensory stimuli enter.

The presence of such activity is considered a correlate of human consciousness, rather than a direct measure, because "it's hard to know the exact instant a person is being conscious," Edelman says. "Still, 99 percent of the time if you're scanning a person and they're responding to something and they're aware of something, that signature appears reliably."

Such EEG patterns and cortical-thalamic interactions serve as a convenient reference point to probe for potential conscious states in other animals, he says. Birds, for example, don't have a cortex, but recent findings on the structure of avian brains do reveal a robust higher-processing center intricately wired to deal with information in a similar way.

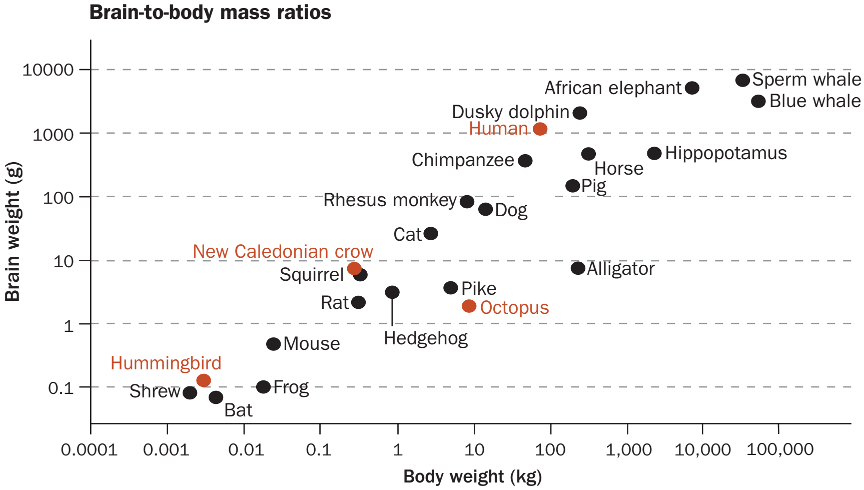
Singing in the brain

Bird brains have long had a bad rep, and until recently were considered to consist of one large basal ganglia forebrain and a few "primitive" structures. In 2005, Duke University neuroscientist Erich Jarvis showed this isn't the case at all. In reviewing the neuroanatomy of birds, he noted that there is a higher-processing center — similar to humans' cortical area — in the brains of all vertebrates, including birds, fish, reptiles and mammals. This area, critical for reasoning and remembering, is organized differently in birds and in mammals. In mammals, it appears as layered cells in the cortex, while in birds it is organized as clustered cells, Jarvis and colleagues pointed out in *Nature Reviews Neuroscience*.

Ann Butler, a neuroscientist at George Mason University in Fairfax, Va., says that before Jarvis' studies, many people thought the layering of cells, such as is found in the human cortex, was required to carry out complex behavior. Now scientists think that is not necessarily the case.

"For some reason, people think that because birds are far away from their genetic relationship to humans, that they're one of the last groups of animals in which you should look for consciousness," says Butler, who is working to identify neural features that may be capable of rendering consciousness in birds. "But I'm going to argue that they're probably one of the first."

Big brains and small brains Some scientists look to brain-to-body mass ratio as a sign of intelligence. Humans and dolphins have larger ratios, while the hippopotamus and blue whale have smaller brains than expected for their body size. New Caledonian crows beat out some mammals; octopuses, despite being invertebrates, rival some mammals.



SOURCE: GERHARD ROTH AND URSULA DICKE/*TRENDS IN COGNITIVE SCIENCES*, MAY 2005

Butler says Jarvis' studies explain why some birds, such as the famous African gray parrot Alex, can do things that were once thought specific to primates, such as recalling events from distinct times or places. In a survey of the literature on neuroanatomy and behavior in birds, published in October 2006 in *The Biological Bulletin*, Butler and her colleagues pointed to studies showing that birds can carry out sophisticated cognitive processes generally associated with mammals, including the ability to play games in which they intentionally deceive others or the ability to design and make tools.

"Studies show some birds will hide objects differently when another animal sees them hide it, suggesting that the bird who was hiding an object is aware of other animals' thought processes," she says. "In most people's minds, that can be defined as a conscious behavior."

Though scientists have yet to find evidence in birds of the cortical loops associated with conscious states in humans, Jarvis' studies have revealed at least one brain pathway with similarities to a pathway involved in human speech. His group found that in birds with vocal learning abilities — songbirds, parrots and hummingbirds — the brain structures for singing and learning to sing are embedded in areas controlling movement. Human brain structures for speech also lie adjacent to, and even within, areas that control movement.

Jarvis says the findings, reported in March 2008 in *PLoS ONE*, suggest that the brain pathways used for vocal learning evolved out of the same pathways that power limb and body movements. Because these brain areas serve a similar function in birds and humans, the areas may be a logical place to initiate neurobiological studies of consciousness in birds.

Invertebrates join big brain club

While birds and mammals share many neurological features, assessing conscious states in invertebrates, such as cuttlefish and octopuses, is more difficult. Unlike in mammals, where a large central brain is connected to a relatively small spinal cord, the octopus nervous system is divided into three parts. The two largest parts, the optic lobes for the eyes and the nervous system of the arms, sit outside the central brain capsule.

Alex, an African gray parrot who died in 2007, was the subject of 30 years of scientific study. He learned more than 100 words before his death and could distinguish colors and numbers.

MARK WILSON/*BOSTON GLOBE*/LANDOV

Despite this weird anatomy, octopuses share one brain trait with mammals and birds: They have a high brain-to-body mass ratio. Scientists have speculated that a bigger brain, when expressed as a percentage of body mass, may mean higher intelligence. And octopuses do seem to be one of the most intelligent invertebrates around. Studies show that they can easily learn and adapt new techniques for opening the shells of their favorite prey — clams and mussels — and can use clues to navigate through mazes.

Psychologist Jennifer Mather of the University of Lethbridge in Canada, who has studied octopuses for more than 35 years, says that the octopus brain is not just larger than that of most invertebrates, but also has areas dedicated to learning and memory. "That's the kind of thing we humans have," she says.

Although scientists have some general knowledge about cephalopod brain anatomy, they have limited knowledge about how it works, Edelman says. With Graziano Fiorito of the octopus behavioral biology laboratory at the Stazione Zoologica Anton Dohrn in Naples, Italy, Edelman is developing a recording system to collect EEG data and other brain signals as the creatures respond to visual cues.

"No matter how differently organized the brain is, there are fundamental properties — signaling, electrical activity, properties of certain kinds of neural networks — that are universally disposed across any animal who is able to have a conscious experience," Edelman says. "The trick, with the octopus, will be to figure out where to tap into those signals."

Considering how far removed cephalopods are, evolutionarily speaking, from mammals and birds, Edelman says studying these creatures may give researchers a broader perspective on consciousness.

"Cephalopods may be that one example of animals where we can show a true case of convergence, in the sense that conscious states may have appeared in these animals long before they appeared in mammals or in the birds," he says.

That consciousness could arise several times over the course of evolution, appearing in distant lineages with different brain structures, is not at all surprising, scientists say, considering such states seem to emerge in species facing similar social and physical challenges.

Butler adds that scientists need to use caution in limiting the study of consciousness only to animals with highly developed cognitive systems.

"You can't rule out consciousness where you don't have complex behavior," she says. "So what we need to do is identify a few places where it might be found, look to see what neural features there are, and then look to see if those are present across the board." ■

Susan Gaidos is a freelance science writer based in Maine.

Explore more

- D.B. Edelman and A.K. Seth. "Animal consciousness: a synthetic approach." *Trends in Neurosciences*. September 2009.