When we think of mind reading, most people imagine the abilities of a magician, an evil genius, or an alien life form. In fact, we perform mind reading everyday. For example, as you are reading this book, maybe you are on the subway, and there are no open seats, so you are standing. The train pitches and sways, and from the corner of your eye you notice that a nearby passenger starts to gather up his belongings. You check around for other passengers who might also be eyeing the seat and note that you are the only one who seems to have noticed. So without drawing too much attention to yourself, you move in closer. When the passenger gets up, you quickly swoop in and grab the seat. You can now continue reading this book in comfort.

In carrying out this simple strategic move for a seat, you have performed several acts of mind reading. Neuroscientists call mind reading of this sort “Theory of Mind” (abbreviated ToM, also sometimes called “intentional stance,” “social cognition,” “cognitive empathy,” “mind attribution,” and “mentalizing”). ToM is a cognitive ability that is only a theory insofar as it is a best guess about another person’s mental states (that is, desires, beliefs, knowledge) and an understanding that these mental states might be different from your own. As in the example above, we use this theory to understand other people’s motivations, anticipate their ac-
tions, and modify our own behaviors accordingly. We perform ToM mental tasks constantly and often reflexively, without conscious awareness.

Consider, for example, the Heider-Simmel illusion. An animated film shows a large rectangle, a big triangle, a small triangle, and a small circle moving around a page. When asked to describe what the film is about, most people will ascribe thoughts, feelings, and emotions to the two triangles and the circle and construct a scenario explaining interactions among them—for example, the small triangle is annoying, the big triangle is a bully, the circle is a dreamer.

Although most of us perform mind attributions easily and reflexively, as with many of our cognitive abilities, we are not born with ToM. Rather, children begin to demonstrate such abilities starting around age four. As children incorporate ToM into their play behavior, they will typically attribute desires, beliefs, and knowledge to dolls and figurines. As ToM abilities become increasingly more sophisticated, children begin to use their newly acquired abilities for joking and pranking. If you spend any time with children, you may have been the victim of the classic shoulder tap prank (where the child reaches around your back and taps you on the opposite shoulder, causing you to look the wrong way); the prank requires that the child understand that your knowledge of the source of the tap is different from the child’s own.

Most of what we know about the brain mechanisms that enable ToM comes from studies in humans. Brain imaging studies of human subjects have consistently correlated performance of ToM tasks with activity in two brain regions: the right temporoparietal junction and the dorsomedial prefrontal cortex. It is not surprising that these brain regions are also activated when viewing the Heider-Simmel illusion described above.

Many scientists have held that ToM abilities are restricted to humans. Anyone with pets, especially dogs, would be incredulous at this assertion because so much of the behavior exhibited by these companion animals seems to meet the criteria for having a ToM. There are three theoretical problems for scientists wanting to formally claim that animals have this attribute.

First, as we’ve already discussed, reflexive mind attribution is difficult to turn off, even when we know the objects (such as circles, triangles, dolls, or figurines) are incapable of desires, beliefs, or knowledge. Thus
when objects are not objects at all, but rather living, breathing, companions, it is hard to know whether we see feelings, emotions, and thoughts in our pets because they really have them or because our brains are wired to believe that they have them.

The second problem for scientists who want to argue that animals have a ToM is how to demonstrate it to a skeptic. For example, we might be tempted to say that a dog brings you his leash when he wants to be taken out because he anticipates that your inability to find it will delay departure and that this is an effective way to communicate to you his desire to go out. On the other hand, a skeptic might argue that this behavior is just an elaborate sequence of actions that the dog has learned to produce the desired outcome and that you are just a fancy kind of robot that he must include in the sequence.

The third problem for animal ToM is that in terms of brain anatomy, only humans are thought to be equipped with the required brain regions (the aforementioned temporoparietal junction and the dorsomedial prefrontal cortex) implicated in ToM. Although studies in monkeys have revealed that another region, called the superior temporal sulcus, may correspond to the temporoparietal junction in humans, the dorsomedial prefrontal cortex is proportionally much larger in humans, even when compared to our closest primate relatives. This is because during the course of evolution, the human brain, and especially the cerebral cortex (the folded outer surface that contains both the temporoparietal junction and the dorsomedial prefrontal cortex), underwent a massive expansion, both in relative size and in number of neurons.

So how might we begin to tackle the scientific problem of whether animals have ToM? Let us begin with how it is demonstrated in humans. The vast majority of studies use some variant of the Sally-Ann False Belief task. In this instance, the subject is presented with a vignette consisting of two characters, Sally and Ann. Sally has a ball and places it into her basket and then leaves the room. Ann then removes the ball from Sally’s basket and places it into her own. Then Sally returns, and the subject is asked a series of questions: (1) Who is Ann? (2) Who is Sally? (3) Where is the ball? (4) Where does Sally think the ball is? A typically developing child, starting at around age four, will correctly answer all four questions.

When tested on the Sally-Ann False Belief Task, children with autism spectrum disorder will give the same answer for both questions (3) and
(4) because these children are unable to distinguish between their own and Sally’s knowledge of the location of the ball. These ToM impairments in autism spectrum disorder are not due to diminished intelligence because they are evident even in high-functioning autistics, and conversely, Down’s syndrome patients, even those with severe intellectual disability, show no ToM deficits.  

The cause of autism is overwhelmingly genetic. To date, mutations in over 750 genes have been associated with causing autism, and future studies will likely reveal many more. While it is still unknown how each of these gene disruptions produces the symptoms of autism, most of these genes are also found in animals. Since these genes are required for ToM abilities in humans (that is, mutations lead to ToM deficits in autism), they may also be important for ToM-like functions in other animals. If so, we would say that the genes found in humans and other animals are homologues because they encode the same function (ToM) across evolutionarily related species.

In fact, it is unlikely that ToM abilities in humans emerged spontaneously. Instead, they probably evolved from existing cognitive abilities. Researchers agree that many of the foundational capacities of ToM are also exhibited by a number of other animals, including dolphins, some primates, and scrub jays. For example, dolphins recognize themselves in mirrors and are able to differentiate between individual members of their social group. Because the ability to attribute mindfulness to others requires being able to differentiate between self and other, these abilities are said to be foundational capacities of ToM.

We humans mainly use ToM in a social context; therefore most researchers believe that this cognitive function evolved in response to the selection pressures imposed by social living.  

By this reasoning, ToM-like abilities might only be observed in species that live socially (for example, humans, most primates, dolphins, and wolves).

Nevertheless, we can imagine that the ability of a predator to catch its prey would be greatly enhanced if the predator were to attribute mindfulness to the prey. This idea raises the interesting possibility that predatory rather than social selection pressures could have shaped the evolution of ToM. If so, ToM-like abilities would be much older (in terms of evolutionary time) than has previously been supposed since hunting almost certainly evolved earlier than social living.
Supporting this latter view, the recently rediscovered larger Pacific striped octopus exhibits a unique hunting behavior that suggests that these animals might have ToM-like cognitive abilities. When hunting shrimp, this octopus uses what appears to be a variant of the shoulder-tap prank. Having identified its prey, the octopus assumes a dark-colored skin pattern and then very slowly extends one of its dorsal arms, arching it above and around the shrimp. When the octopus is in position, it lowers the tip of its extended dorsal arm behind the shrimp and taps it on its pleomere (the posterior portion of the shrimp’s body), causing the shrimp to leap forward into the octopus’s other seven arms.

The larger Pacific striped octopus is one of a handful of known social species of octopus (the vast majority of the three hundred or so members of the order Octopoda are solitary and cannibalistic). Nevertheless, in the example described above, this octopus’s ToM-like behavior is used in a predatory setting. Furthermore, the ToM-like hunting strategy is also used by this octopus’s asocial sister species, Octopus chierchiae. Anthropomorphic descriptions notwithstanding, the hunting strategy used by Octopus chierchiae to catch shrimp is reminiscent of the ruse of the man at the movies, yawning and stretching in order to get an arm around his date. Taken together, these observations support the hypothesis that, at least in octopuses (yes, octopuses, not octopi), predatory rather than social selection pressures molded the emergence of ToM-like behaviors.

Although the similarity of the larger Pacific striped octopus’s hunting strategy to the shoulder-tap prank may merely represent an especially convincing Heider-Simmel illusion, this animal is able to modify its strategy in a context-specific way, suggesting that it has true ToM. For example, if the prey’s view is obstructed (for example, when the octopus is hunting hermit crabs, whose shells cover them from behind), this octopus uses a direct pounce strategy rather than the pleomere tap strategy, suggesting that it knows the difference between a prey that can see its predator and one that does not, and it acts accordingly. Although these observations may not convince a skeptic, they do suggest that the octopus is employing a flexible cognitive strategy rather than just an elaborate set of learned routines.

Still the problem of brain anatomy remains: the octopus brain is nothing like a human brain. It doesn’t have any of the cortical regions
suggested to underlie ToM or even, for that matter, a cerebral cortex. Nevertheless, the degree of encephalization and neuronal expansion seen in octopuses sets this species apart from other invertebrates. Indeed, the nervous system of the octopus, thought to be the most intelligent invertebrate, is comprised of approximately half a billion neurons, more than six times the number in a mouse brain. Additionally, like humans, dolphins, and elephants, octopuses have a brain with a folded surface, ostensibly to pack in more neurons in a confined space, in contrast to the smooth-surfaced brains of other cephalopods, mice, rats, and marmosets. Thus although octopuses don’t have cortical regions associated with ToM, they have an exceptionally large brain capacity and may have evolved to solve the problem of ToM using different anatomical strategies.

Perhaps the most effective way to determine whether octopuses have ToM would be to show that the same genes that are necessary for this attribute in humans are also necessary for ToM-like behaviors in octopuses. Experiments to test this possibility are under way in my lab. In the meantime, it is interesting to note that octopuses have gene homologues for at least two of the genes most centrally implicated in autism. Although it may seem far-fetched to suppose that these genes may encode ToM in octopuses, there is in fact precedence for this type of so-called deep homology. For example, the invertebrate compound eye is anatomically very different from the vertebrate camera eye, and vertebrate and invertebrate lineages diverged from each other long before the evolution of either type of eye. Nevertheless, the Pax6 gene, found in vertebrates and invertebrates, is required for the formation of both types of eye. Most recently, a set of genes has been described that controls language in both humans and African grey parrots, despite anatomical differences in brain organization between humans and birds and the absence of a common ancestor that shares the language trait. If manipulation of genes implicated in autism impairs ToM-like hunting behaviors in octopuses, such a finding would provide a novel example of deep homology. Moreover, because it would mean that octopuses are able to use the same genes as humans to encode ToM-like behaviors, even though their brains are organized totally differently, such a finding would suggest that it is the genes, rather than the specific brain circuit arrangements, that confer complex brain function across species.
NOTES

1. F. Heider and M. Simmel, “An Experimental Study of Apparent Behavior,” *American Journal of Psychology* 57 (1944): 243–259. To see how you would respond to the illusion, try it out for yourself on one of the videos of the Heider-Simmel illusion available on the Internet, such as https://www.youtube.com/watch?v=8FIEZXMUM2I.


