# animal eyes®

## *Presented by Museum of Vision*

An educational program of The Foundation of the American Academy of Ophthalmology

The Foundation of the American Academy of Ophthalmology
Advancing Lifelong Ophthalmic Education

National Science Foundation

## *Contents*





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# Introduction

The animal kingdom is full of amazing eyes. Come discover eyes that look like yours, and eyes that are wildly different. Join scientists on their exciting quest to understand how animals actually see.

Vision is an integral part of our lives. Even though we rely on it, many of us know very little about how we see. Because vision is so important to us, scientists have studied it more than any other sense. The Museum of Vision created the *Animal Eyes*® exhibit and educational materials to share important discoveries about vision—a sense that is precious to ourselves as well as many animals.

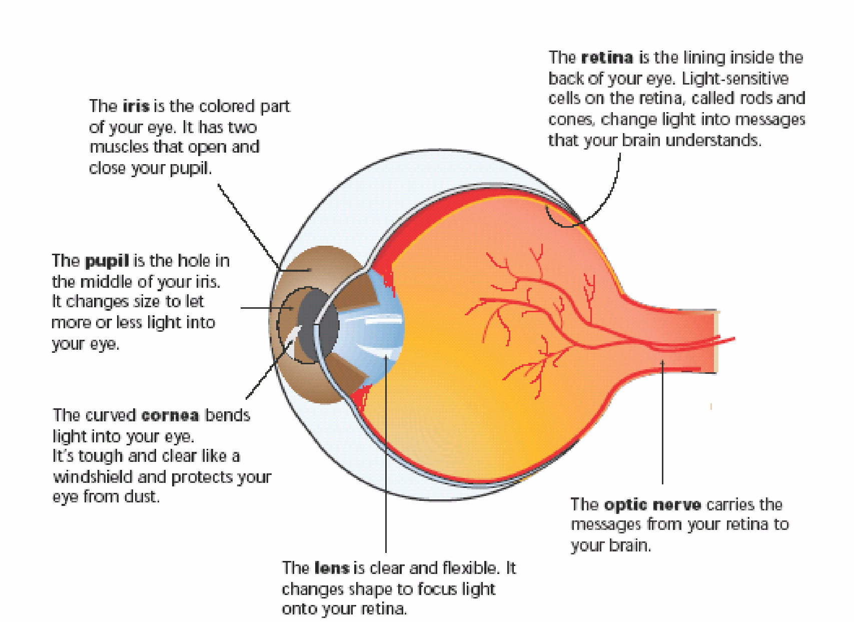
The *Animal Eyes*® exhibit was organized by the Museum of Vision, an educational program of The Foundation of the American Academy of Ophthalmology, with generous support from the National Science Foundation and LensCrafters.

# *How Does the Human Eye Work?*

Vision is a complex sense. The eyes are the entry to a multilayered visual system that processes millions of bits of information every second.

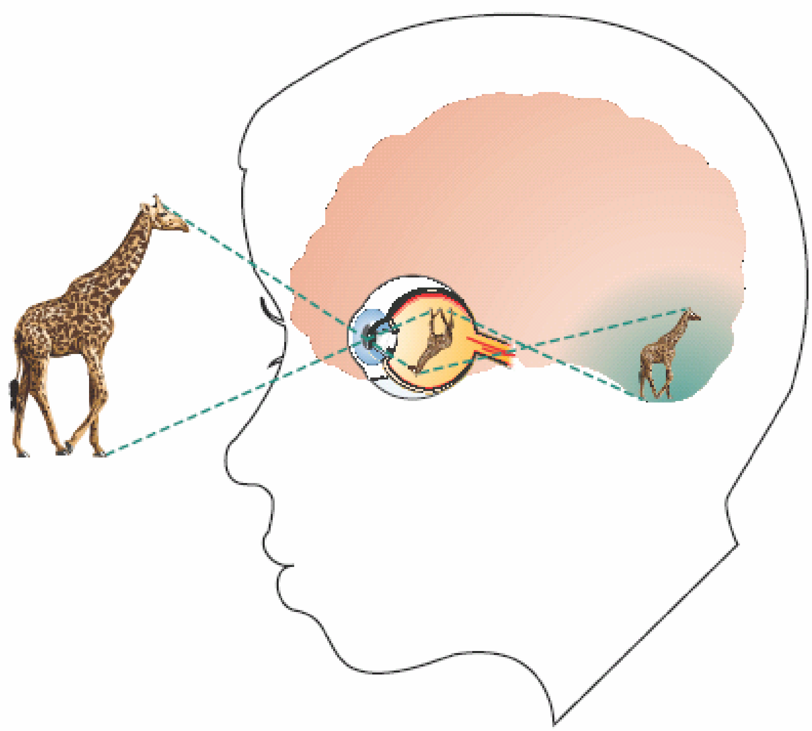
In order for us to see, light rays must be bent or "refracted" so that they can focus directly on our retina, the nerve layer that lines the back of the eye. The curved cornea bends light into your eye and the lens changes shape to bring things into focus. Once the light reaches the retina it's picked up by millions of photoreceptors called cones and rods that convert the light waves into information including color, shape and motion. The information from the cones and rods are then sent to the brain via the optic nerve. The retina is actually brain tissue so it begins coding visual information, a process which is finished in the brain, allowing us to recognize objects, people and places.

The place where your optic nerve joins the retina is called your blind spot. There are no light-sensitive cells in this area, so this part of the retina can't see. Most of the time you don't notice your blind spot, because the blind spot from one eye doesn't line up with the blind spot from the other eye. Your brain fills in the blind spots with what it thinks should be there based on what information it receives.



# How Does the Human Eye Work?

- First, light bounces off objects all around you and enters your eye.
- Then the light passes through your pupil and lens to the retina at the back of your eye.
- In the retina, the light makes an upside-down and backwards picture.
- The retina contains light-sensitive cells (called rods and cones) that change the picture into messages that your brain understands.
- The optic nerve carries these messages to your brain.
- Finally, your brain reads the messages and tells you what you're looking at.

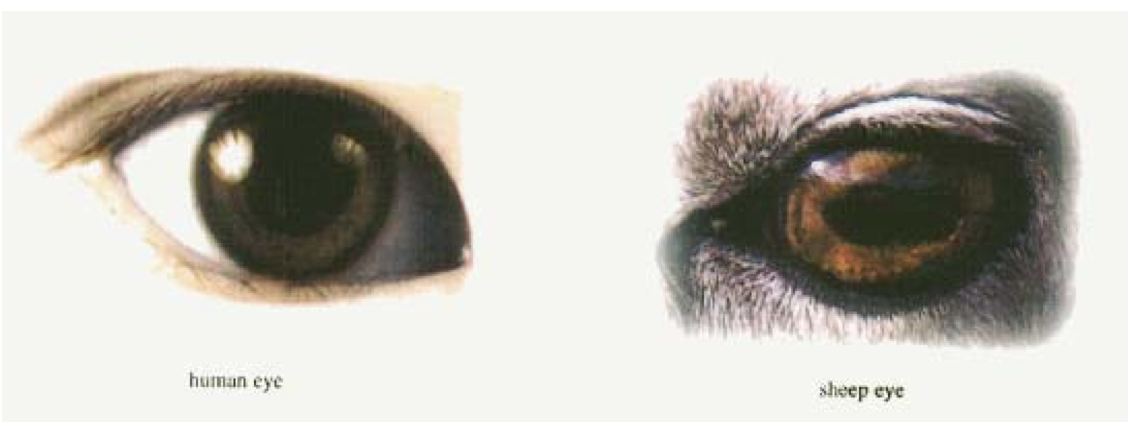


# How Are Human Eyes Different from Animal Eyes?

Medical researchers often look at the animal kingdom to help them learn more about body parts such as the eye. It is thought that by comparing the anatomy of humans to other animals we can better understand how our eyes work and maybe learn new ways to cure human eye diseases.

Animal eyes look different and sometimes perform differently from human eyes depending on where they live and what they do. A good example is an eagle's eyes. While humans can change only our lenses to bring things into focus, an eagle can change both its lens and cornea. That advantage increases an eagle's focusing power and explains how an eagle can see so well while flying high in the air.

Just like humans, animals' eyes are tools that help their brains understand the world. Real "seeing" happens in the brain and because we don't have an animal's brain, we may never fully understand how animals see. However, we can look at the structures of animal eyes to help us better understand our own.



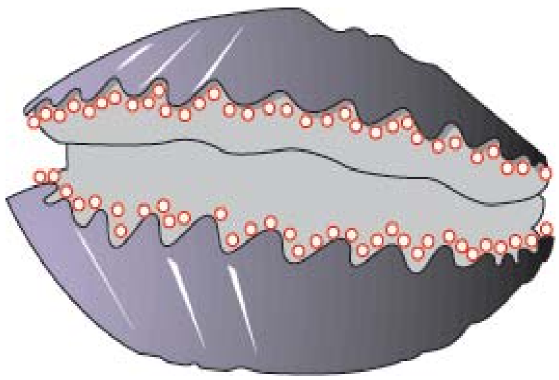
# *Different kinds of eyes*

In the animal kingdom there are many kinds of eyes. The earthworm, for example, has hundreds of tiny light-sensitive cells called eye spots. These eye spots are around its head and tail, allowing the worm to sense light and dark. An earthworm likes it best when it's in a dark, cool place and its eye spots help to find its way. Other animals with eye spots include leeches, caterpillars and jellyfish.

The housefly sees in a different way. Flies have compound eyes that are made up of hundreds of separate units called *ommatidia* (o-ma-TI-di-a). Light enters these units and is picked up by light-sensitive cells. Information from these cells is sent to the fly's brain via the optic nerve, just like in humans. Once it was thought that flies saw hundreds of separate pictures, one from each ommatidia, but it's now believed that their brains mix all the information into one picture of the world. Other animals with compound eyes include bees, butterflies, ants, beetles, shrimp, crabs and lobsters. The more units a compound eye has, the more an animal can see. An ant has several hundred ommatidia in each eye. A housefly as 2,000. And a dragonfly has the most of all- 30,000 units in each eye.

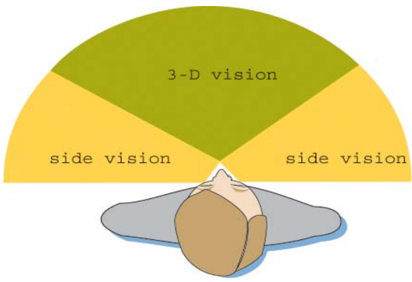
Some animals have eye structures that are unique. The scallop, for example, is an animal that lives in the ocean inside a shell. Around the edge of the shell the scallop has 50-100 eyes, each with a tiny structure that looks like a mirror. Light enters the scallop's eye, hits the mirror at the back and is finally reflected onto the light sensitive cells in the middle of the eye.

Dr. Michael Land discovered the structure of the scallop's eye. Recalling that moment he said, "It was one of those slightly magic events that don't come very often. When you look into the scallop's eye, you see an upside down picture of yourself, rather bright, coming back at you, and this image is sort of in the eye…I cut section's of the eye and looked for optical structures of various kinds and it became clear, quite quickly, that there was only one way that this image could be formed and that was by the concave reflector at the back of the eye.  I had a lucky break, a good start, and it was a real "aha!" moment and I said, "Hang on, this is an eye that isn't like anything else on earth," and that is still pretty much true."

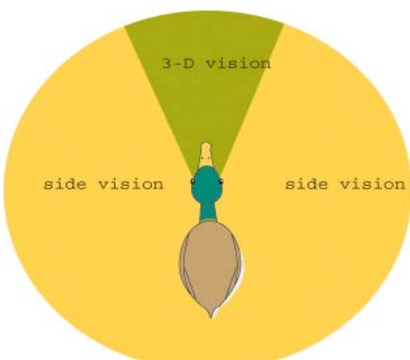


# Different places on different faces

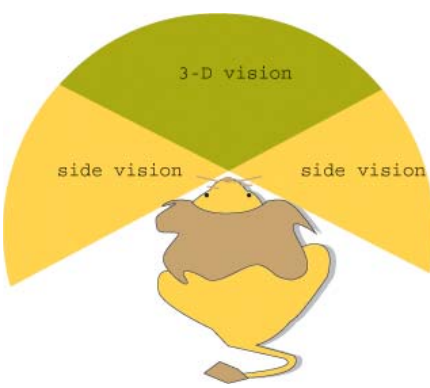
Different animals have eyes in different places. The position of an animal's eyes determines what it can see. How much an animal can see without turning its head is called its field of view. Depending on where the eyes are positioned, an animal can have a large or small field of view.




For example, if you were to stand on the pitchers mound at a baseball stadium your field of view would include home plate and part of the baselines between 1st base and 3rd base. However, you would have to turn your head to actually see the outfielders and throw a ball to make an out. If you were an American woodcock your eyes would be set higher and closer to the back of your head. An American woodcock on the pitchers mound could see home plate, all the bases, the entire outfield and even the seats – without moving its head! Having a large field of view like the American woodcock helps animals look out for predators. Zebras, ducks, rabbits and chameleons have more side vision than we do, allowing them to see what might be coming from above, the side or even behind them.




You would think that these animals would have an enormous advantage being able to see all that, but there are advantages to where human eyes are on our faces. Having both our eyes in front of our heads helps us to see in 3-D. Since our eyes are about 2 inches apart, each eye sees a slightly different view. Our brains combine these views giving us binocular or 3-D vision. Binocular vision helps us see depth so that we can walk down stairs, shake someone's hand, or catch a baseball. Other animals with binocular vision include monkeys, lions and cheetahs.



# Multiple Eyes

Most animals that you're familiar with have two eyes. But many animals have more. Some have several different kinds of eyes and others have lots of eyes that are all the same.

For example, spiders can have 8 eyes, lizards can have three and sea stars have one eye on each arm, which can mean having 40 eyes in some species! Why these animals have so many eyes is still a mystery in many cases.

Even more mysterious are animals with different kinds of eyes. Grasshoppers have two compound eyes on the sides of its head, one eye in the middle of its forehead and two more behind its antennae. The grasshopper's brain is getting information from all of these eyes and yet we don't know what it sees exactly. Similarly, the horseshoe crab has two compound eyes on the sides of its shell, five small eyes on the top, two eyes in the middle of its body and an eye spot under its tail. Now that's a lot of eyes!

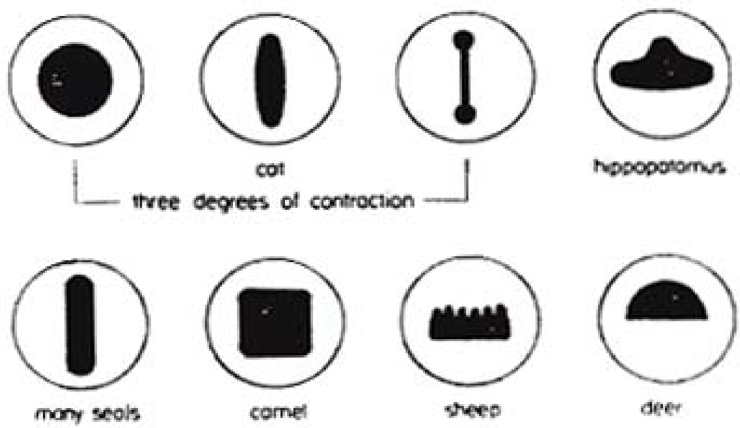
# *Seeing in the Dark*

Animals that see well in the dark usually have big eyes with large pupils. The bigger the eyes, the more light they can collect. Owls are known for their good night vision. Although an owl's head is smaller than yours, its eyes are bigger and shaped different, too. A small Asian monkey called a tarsier has the biggest eyes of any mammal compared to its head size.

Certain eye structures help an animal see at night. A raccoon has big eyes with large pupils that help them gather as much light as it can in the dark. Their retinas have many more photoreceptors called cones and rods that can convert light waves into information for its brain. In addition, raccoons have a reflector in the backs of their eyes that double the amount of light their eyes can use. This reflector is called a *tapetum*. When you see a raccoon at night it looks like their eyes glow, but what you're really seeing is the tapetum reflecting light. Other animals with tapetums include cats, cows, sharks, crocodiles, deer, zebra, lions and moths.

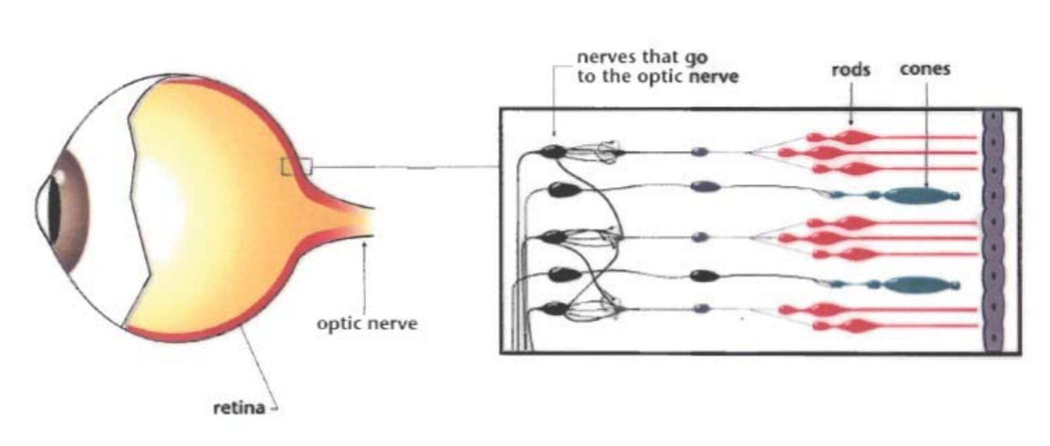
In photographs it sometimes looks like human eyes have a tapetum, we call it "red eye", but humans do not have reflectors. Instead, what is being photographed is the light from the camera's flash bouncing off the back of our eyes or retinas. Human retinas are red, hence the "red eye." At night your pupil's get bigger to let in more light. Special cells in your retina called rods turn on to gather that light. You have about 95 million rods scattered across your retina. Rods are good at gathering light, but they don't see color or detail. That's why it's hard to match your socks in the dark.

Animals that see well in the dark don't necessarily see well in the daytime. Their big eyes and large pupils can draw too much sunlight. A gecko, for example, has excellent night vision but is often awake during the day. To compensate, the gecko's pupil closes to four tiny holes. These holes let in just enough light so the gecko can see without hurting its eyes. Fish that live in the deep dark sea are used to almost no light at all. Dr. Tammy Frank studies the eyes of deep sea animals. She sends a net down 2,000 feet, catching shrimp, squid and fish in a special light-proof container on the end of the net. Then she brings the animals to her lab to study their eyes under dim red light. She has to keep them in the dark because the bright light we're used to would make these animals go blind.

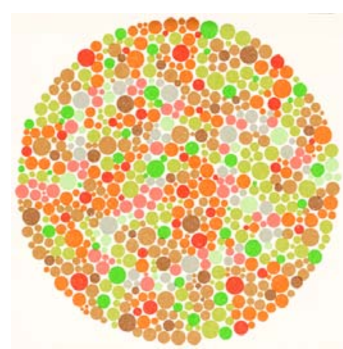


# Color Vision

In order to see color, humans and animals must have at least two different kinds of color-sensitive cells. These cells, called cones, send messages about color to our brains. If the brain can understand the messages then it will see color. Cones work in bright light and help you see color during the day. Cones also help you pick out details like the leaves on a tree or the fine print in a newspaper. When it's dark your cones turn off. That's why it's hard to see color at night. You have about six million cones on your retina. There are three different kinds, each sensitive to a different color: red, green and blue. Your brain mixes the messages from these cones to see all the colors of the rainbow.




Some people can not see some or all colors, this condition is called color blindness. Color blindness occurs when some of the cones in the eye's retina are not working properly or may be missing. This sometimes happens due to an injury or disease, but most color blindness is inherited and is present from birth. The most common form of color blindness is red/green. A person who has red/green color blindness either cannot see red and green at all or can see only a limited number of shades. Very rarely a person will have yellow/blue color blindness and even more rarely a person can be absolutely color blind, where they perceive the world only in shades of gray. For humans, the most popular test for color blindness was developed in 1916 by Dr. Shinobu Ishihara.



In 1969 a scientist named Anita Rosengren studied color vision in dogs and found that they do see in color. However dogs can't see as many colors as you do. Its eyes have only two different kinds of cones and your eyes have three. Dogs can tell the difference between blue and yellow, but can't tell red from green. The same is true for cats, squirrels and many other animals.

While some animals can not see as many colors as we do, some can see more. While you only have three different kinds of cones, butterflies have four and pigeons have five. Scientists study why animals see more colors than we do. For example, in 1910 Karl Von Frisch discovered that the bee can see ultraviolet (UV) light. UV is a color that is invisible to our eyes. Bees use this UV vision to see special patterns on flower petals. These patterns help a bee to see where the nectar is.

The mantis shrimp has amazing color vision. A mantis shrimp has at least 12 different kinds of color-sensitive cells. The mantis shrimp probably sees more colors than any other animal. A vision scientist named Dr. Thomas Cronin remarked, "People like me study animal vision because we are inherently interested in the problems and we see a puzzle out there that we'd like to solve. Why do animals see ultraviolet light for example? We don't see it, what's the advantage? The thing that caught me most by surprise in my career was discovering that mantis shrimps have so many different kinds of color receptors. It was completely unexpected. "