

SEEING NEAR AND FAR – DISTANCE PERCEPTION

As we look around us, we see objects arrayed in 3-dimensional (3D) space, with some objects closer to us than others. This perception of space is created in our brains from 2-dimensional (2D) images that are formed at the backs of our eyes, on our retinas, when we look around us. The brain process that transforms 2D images into a sense of space is called depth perception. How does the brain create the perception of 3D space from 2D images?

The brain uses a combination of cues in 2D images to determine which objects are closer and which are more distant. Some of these cues can be found in a single 2D image. These are called monocular (one-eye) cues. Other cues require the images from both eyes. These are called binocular (two-eye) cues.

This exploration station examines some of these cues to see how they elicit a sense of distance. It is the combination of these cues from a single image that produces a strong sense of space. Such combinations are used by artists who use them to create 2D visual artworks that elicit from our brains a sense of 3D space.

Many of the visual cues our brains use to perceive distance are based on experience, much of it gained in early childhood. Infants and children are constantly exploring, examining and learning how various sensory perceptions correlate with each other. The brain uses information from all of our senses, vision, hearing, and somatosensation (touch and body position) to produce our perception of 3-dimensional space.

DISTANCE PERCEPTION

Some of the cues used by our visual system (eyes and brain) to perceive distance and space are listed and illustrated here. First, the monocular cues.

MONOCULAR (ONE-EYE) CUES

1. ***Occlusion or overlap***. Objects block the view of other objects that are behind them.



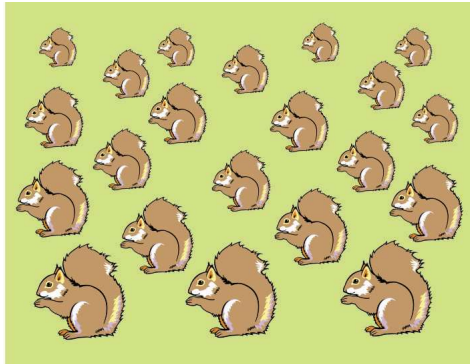
In this image, the triangle appears to be in front of the circle, which is in front of the square. They look this way because we can see the entire triangle, but the triangle prevents us from seeing the entire circle. The triangle appears to occlude or overlap the circle. Similarly, the circle prevents us from seeing the entire square. The circle occludes or overlaps the square.

Our brains really want to see it this way. Our brains are so committed to this interpretation, that it allows us to talk about the circle and the square, even though we can't see an entire circle or square. What we are looking at are actually only portions of a circle and square.

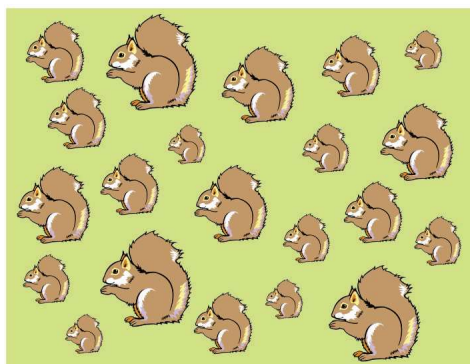


Yet, in the first image, we have no difficulty in seeing a square behind a circle and a circle behind a triangle, because this is how our brains interpret the image.

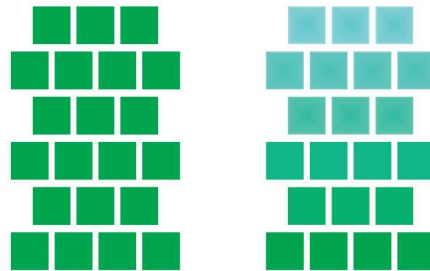
2. **Perspective.** Objects appear smaller when they are farther from us.



In the image of the squirrels above, the squirrels near the top of the image appear farther away than the squirrels at the bottom. They appear this way because the squirrels at the top are smaller than those at the bottom. There are some more subtle aspects of the picture that enhance the distance perception. One is that all of the elements in the image are squirrels, so we readily assume they are all the same size and that the ones that are smaller look that way because they are farther away. Another aspect is that the change in size is regular – the squirrels get gradually smaller as they get nearer the top of the image. The image below shows that a random arrangement of the squirrels will weaken, or even eliminate, the perception that the small squirrels are farther away.



3. **Aerial perspective.** Objects in the far distance are blurred and appear somewhat blue because the air between the objects and the viewer scatters the light between them. Our brains interpret blurry, bluish objects to be farther away than clear ones.



AERIAL PERSPECTIVE

In the array of square on the left, all of the squares are the same color. They appear flat, like tiles on a wall.

In the array of squares on the right, the color fades, gradually becoming bluer in the squares toward the top. The edges of the squares near the top are also somewhat more blurry than those at the bottom. These effects can make the squares near the top appear to be farther away than those at the bottom.

Our brains make this association of blurry blue with distance because this is what we are accustomed to seeing in the world around us, as illustrated in the photo below.



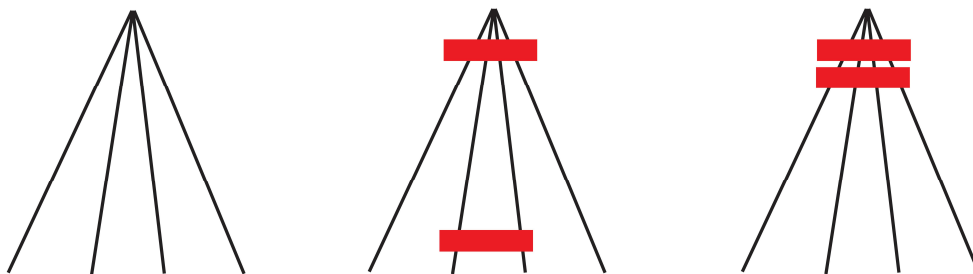
4. **Linear perspective.** Parallel lines appear to approach each other as they recede into the distance.

In the picture of the hotel hallway, we know that the walls are the same distance apart all along the hallway. However, they appear to get closer together farther down the hall.



We can draw lines that follow the joints between the floor tiles and where the walls meet the floors. [The kit contains a print of the hallway photo along with a transparency containing the lines that can be superimposed on the photo.]

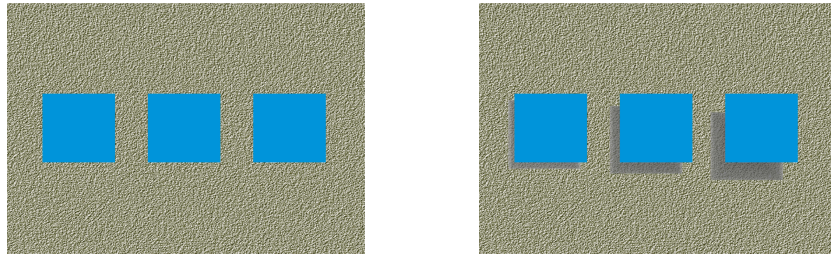
Our brains are inclined to see this arrangement of lines even by itself as representing parallel lines that are receding into the distance. We can see this by putting two identical bars over the lines, one near the bottom and the other near the top of the set of lines. When we do this, the bar at the top will appear longer than the one at the bottom, even when we know they are the same. The brain interprets the bar near the top as being farther away, and therefore larger than the one at the bottom. By placing the bars near each other, we can see they are the same.



[The kit contains print of the lines on cardstock, along with some post-it strips to affix to the print to demonstrate the length illusion. Don't attach the strips to the transparency – the adhesive can pull off the black lines.]

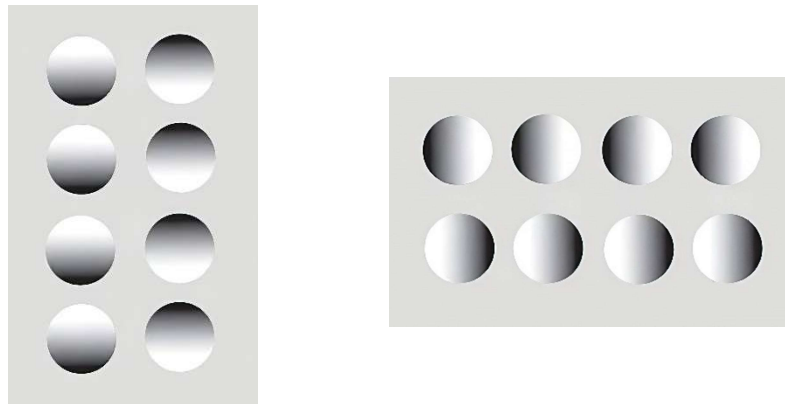
5. **Shading:** An object casts a shadow that reveals the direction of the light and the distance between the object and the surface on which the shadow is formed.

In the image on the left, the blue squares appear to be lying on the pebbled surface, or maybe there are holes in that surface revealing the sky beyond.



In the image on the right, shadows have been added. The shadows make it appear that light is coming from the upper right, and that the squares are in front of the pebbled surface, with the square on the left closer and the square on the right farther away from the surface.

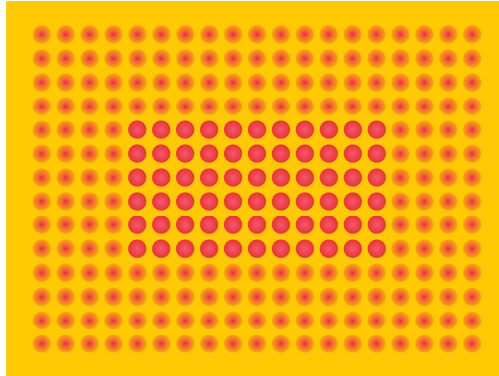
When the direction of light is not clear, our brains automatically assume that light is coming from above. This is the case because we are accustomed to light coming from the sun, which is above us during the day. In the image on the left below, the dots on the left appear to be bulges and those on the right appear to be dents, because we assume light is coming from above. It is actually difficult to perceive the reverse, dents on the left and bulges on the right.



However, when the image of dots is rotated 90 degrees and placed horizontally, as on the right above, the top row can easily be seen as either dents or bulges, with the bottom row as the opposite. This is relatively easy for us to do, because we can imagine light coming from either left or right.

6. **Defocus blur.** When the eyes are focused on an object, other objects that are closer or more distant are blurred because they are out of focus.

Try this first. Hold up one finger about a foot from your face. Now look directly at your finger and focus on it. Keeping your finger in focus and not looking away from it, pay attention to what is behind or beyond your finger. You will see that everything farther away is out of focus and blurry.



Now look at the center of the array of red circles. The circles in the middle will appear to be closer than those around the edges. The circles in the center have sharp edges, while those around the outside have blurry edges. This simulates the distance relationship between what is in focus and what is out-of-focus when you look at an object.

7. **Motion parallax.** When a viewer moves, objects nearby appear to move more and faster than those farther away.

Try this first. Hold up one of your thumbs at arm's length from your face. Line up your thumb with some object in the distance. Close one eye (this is a monocular cue) and look at your thumb. While looking at your thumb, turn your head side to side as though saying "no." Notice how far your thumb appears to move left to right relative to the object in the distance. While keeping one thumb at arm's length, hold up the other thumb near the elbow of the first arm so it blocks your view of the first thumb. Your second thumb is closer to you than the first. Now again, while looking at your thumb, turn your head side to side. You will see that the closer thumb will appear to move side to side against the object in the background. It will also move more and faster than the farther thumb appears to move. When a viewer moves, closer objects appear to move more than distant objects.

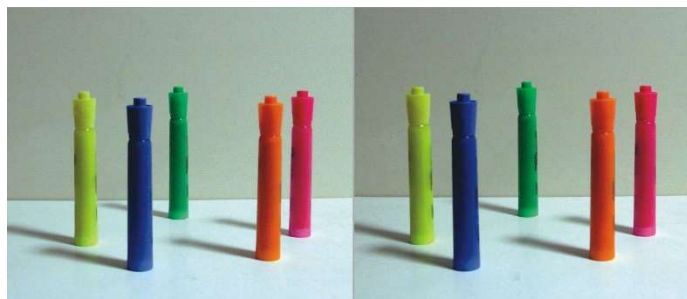


Motion parallax is commonly observed when a viewer is travelling in a vehicle and looking out a side window. Objects close to the road appear to move past much faster than those in the distance. The two images above were taken seconds apart. The foreground has changed completely, while the trees appear to have moved only a bit. This indicates that the trees are farther away than the shrubs in the foreground. Furthermore the pair of trees seems to have moved more than the solitary tree on the right, indicating that the solitary tree is farther away. [A video of this effect can be displayed.]

BINOCULAR (TWO-EYE) CUES

1. **Binocular vision.** Your two eyes are in slightly different locations in your head. Because of this, the images that form on the retinas of the two eyes are slightly different. The brain uses the differences to produce what is probably the most vivid perception of 3D space.

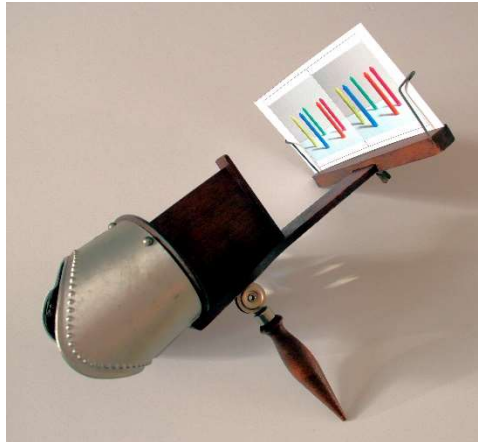
You can observe for yourself that each eye sees a slightly different view. Try this: Hold up one of your thumbs at arm's length from your face. Close one eye. Line up your thumb with some object in the distance, so your thumb hides the object. Without moving your thumb or head, close your open eye and open the other. Your thumb will no longer hide the object but appear to one side. Your two eyes have different views of your thumb and the object. One eye saw the thumb in front of the object while the other sees your thumb to one side. Your brain uses the differences between the two views from your two eyes to locate objects in space.



Above are two photographs of a group of markers. In each photograph there are monocular cues that indicate the relative positions of the markers in space. The central (green) marker is smaller than the others, indicating that it is farther away. The second marker from the left (blue) is larger, indicating that it is closer. The second marker from the right (orange) occludes the shadow of the marker on the right (red), indicating that it is in front of the shadow.

These two photographs are slightly different. In the one on the left, the orange and red markers are closer together than they are in the photograph on the right. This is the case because the two photographs were taken from two slightly different locations. These locations were as far apart as are human eyes (about 2.5 inches). The left photograph is what the left eye of a viewer would see, and the right photograph is what would be seen by the right eye when the viewer is looking at the markers.

When these two photographs are viewed in a stereoscope, the left photo will be seen by the left eye and the right photo by the right eye. The brain will then be able to use the differences in the images to generate a very strong sense of the space occupied by the markers.



[There is an assortment of stereoscope cards available for trials. Some are antique images, some contemporary Madison views, some computer-generated chemical images. Stereoscopes and stereoscopic photography was very popular during the latter half of the 19th Century. They were the virtual reality of their time.]

There is a framed image of a garden. This image contains two photos of the garden. The two photos were taken from locations separated by the same distance as human eyes. The two photos were combined into a lenticular display that shows one photo to the left eye and the other photo to the right eye.



When you look at the framed image your brain uses the differences between the two photos to generate a strong perception of space. The branches at the top left appear closer to you than those on the right, and the path appears to recede into

the distance. You can see how this sense of space depends on both eyes by covering one eye as you look at the picture. Immediately, the vivid sense of space disappears.

[The lenticular image has an array of thin vertical strips of lenses that allow one photo to be seen when viewed from the left and the other photo when viewed from the right. This image was created by Michael Brown.]

2. ***Eye Convergence***. When you look at an object close to you, your eyes angle inwards towards each other. The effort exerted by the muscles that position your eyes gives a clue to the brain about how far away the object is.

Try this. Hold up one of your fingers at arm's length from your face. Focus your view on your finger. While focused on your finger, gradually bring it toward your face. As your finger gets close, you will be able to feel the muscles around your eyes working to keep your finger in focus. The closer your finger comes to your face, the more effort you will feel the muscles exert. If you try the same motion with one eye closed, your eyes do not turn toward each other, and you will not feel the same muscle effort.

3. ***The Pulfrich Phenomenon***. The Pulfrich phenomenon is a binocular effect that occurs under specific and uncommon conditions. It requires a scene involving motion, that is, a scene with one or more moving objects. It also requires that the intensity of light entering one eye be different from the intensity entering the other eye.

The eye that receives the more intense light responds more quickly than the other eye and transmits its response to the brain more quickly than the eye that receives the weaker light. So the brain receives the signal from the bright eye sooner than that from the dimmer eye. The brain interprets this time difference to mean that the moving object is farther along its path as seen from the brighter eye. In other words, the bright eye sees the object ahead of where the dim eye sees it. The brain fuses the images from the two eyes into a single scene, and in doing this it interprets the discrepancy in the positions of the object to mean that

the object is actually in a different position than it actually is. The brain interprets the object to be either closer or farther away than it is.

Another way to understand the effect is to compare it to the way the two images in a stereoscope generate a 3D view. The two images in a stereoscope are slightly different, each taken from a slightly different position. A similar situation occurs in the Pulfrich phenomenon. In the Pulfrich phenomenon the images received by the brain from the two eyes are also different. They differ because they are from slightly different times. The brain interprets this difference the same way it interprets the images in a stereoscope – by generating a sense of 3D space.

The video contains three scenes of carnival rides with seats moving in circles around a central axis. The video is to be viewed while holding a dark lens from a pair of sunglasses over one eye. This will reduce the intensity of the light received by that eye. In two of the scenes the ride rotates so that the foreground seats move right to left and in the other the foreground seats move left to right. When the foreground seats move right to left and the lens is held over the left eye, the foreground seats will appear closer than those in the background that are moving left to right. This generates a 3D view. When the foreground seats are moving left to right and the lens is held over the right eye, the foreground seats will appear closer than those in the background moving right to left.

The Pulfrich phenomenon was exploited by Coca Cola in a television advertisement during the Super Bowl game in 1989. To create the 3D effect, viewers used special glasses, distributed by the advertiser, in which the lens over the right eye was tinted gray and the one over the left eye was clear. [A video of this advertisement is available.]