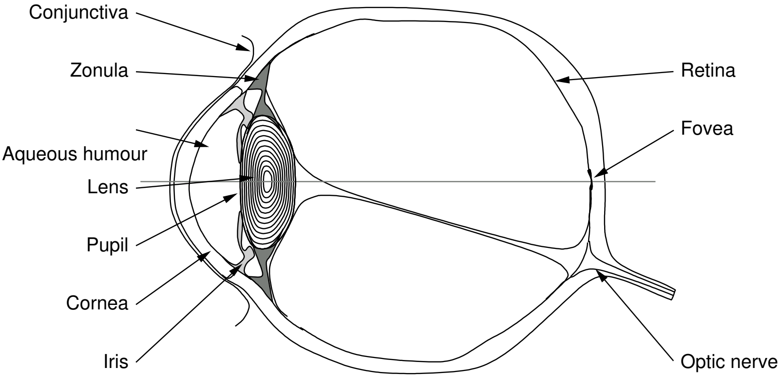
Human Vision

The Visual System

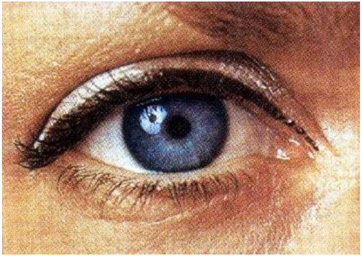
- The visual system consists of two parts.
  - The *eyes* act as image receptors.
  - The *brain* acts as an image processing and interpretation unit.
- Understanding how we see requires that we understand both components.

The Human Eye

(The Right Eye Viewed From Above)



Constricted and Dilated Pupils



Constricted

Dilated

Retinal Structure

- Receptor cells are at the back of the retina.
- Light passes “through the wiring”.
- Horizontal cells do some initial signal processing.

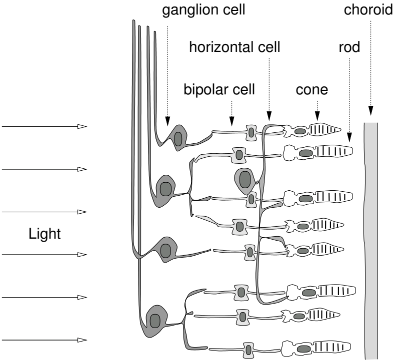
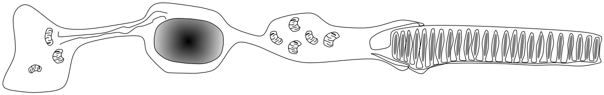


Photo Receptor Cells

- The eye contains two different classes of light sensitive cells (or photo receptors).
- *Rod cells* provide sensitive low-light vision.
- *Cone cells* provide normal vision.

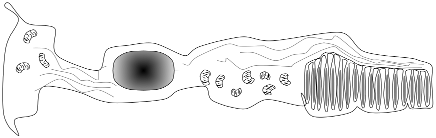
Rod Cells

- Rod cells provide low-light vision.
- There is only one type of rod cell.
- Rod cells provide no colour discrimination.



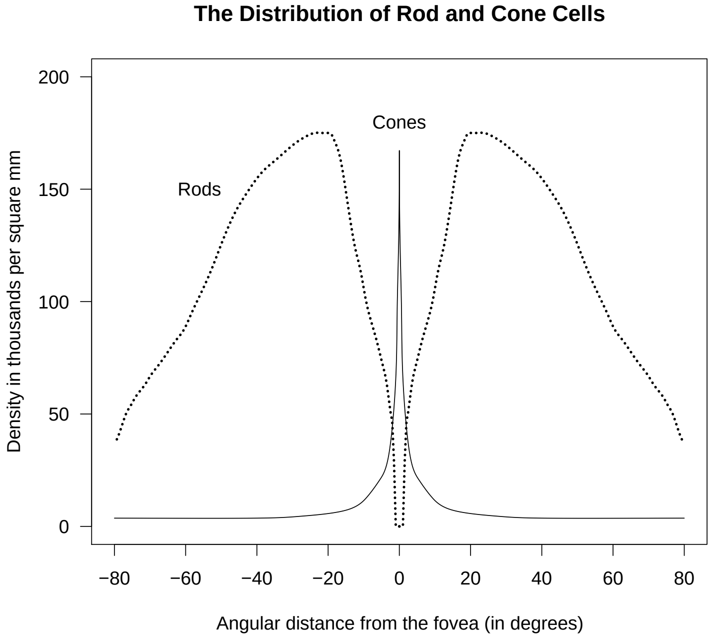
Cone Cells

- Cone cells operate at medium and high light levels.
- There are three different kinds of cone cells, each sensitive to different light wavelengths.
- The sensitivity to different wavelengths is what provides us with colour vision.



Rod And Cone Distribution

- The distribution of rod and cone cells is not uniform across the retina.
- The cones are concentrated at the centre rear of the retina and the rods are more evenly distributed away from that area.

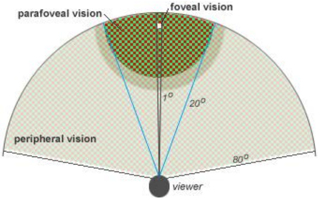

The Distribution of Rod and Cone Cells
Cones
Rods
Density in thousands per square mm
200
150
100
50
0
−80
−60
−40
−20
0
20
40
60
80
Angular distance from the fovea (in degrees)

The Macula And Fovea

- The centre-rear of the retina has a small yellow spot known as the *macula*.
- At the centre of the macula is a region called the *fovea* which has a large concentration of cone cells, and no rod cells at all.
- In normal light, the fovea is the part of the eye which yields the highest resolution.
- The fovea occupies about $1.5°$ of our visual field (slightly larger than the moon).
- The highest resolution of all is given by the *fovea centralis* which gives occupies about one tenth of this.

High Resolution Vision

The picture on the right shows the resolution with we would expect to see the face of the child if we were to stare fixedly at the child's right eye.



Neural Connections and the Blind Spot

- A network of nerves gathers signals from the photo-sensitive cells of the retina and conducts them to the *optic nerve*, which is attached to the sclera at the rear of the eye.
- The optic nerve conveys the information from the retina to the visual processing centres of the *brain*.
- There are no photo receptors where the optic nerve reaches the retina.
- This creates a “blind spot” in the visual field of each eye.

Finding Your Blind Spot

- Draw a cross and a dot about 8cm apart as shown below.
- Close your right eye.
- Look directly at the cross
- Move the page backward and forward until you see the dot disappear.

Retinal Circuitry

- In the retina, horizontal cells connect photo receptors together.
- These connections mean that some simple image processing can take place in the eye.
- Some of the most important operations are based on *lateral inhibition*.

Lateral Inhibition

- A network exhibits lateral inhibition if a positive outcome in one element of the network, induces a negative outcome in its neighbours.
- Lateral inhibition can be used to produce a simple form of edge enhancement.
- It can also be used to help provide hue and tone discrimination.
- The phenomenon of *Mach Banding* shows the effect of lateral inhibition in the vision system.

A “Lateral Inhibition” Filter

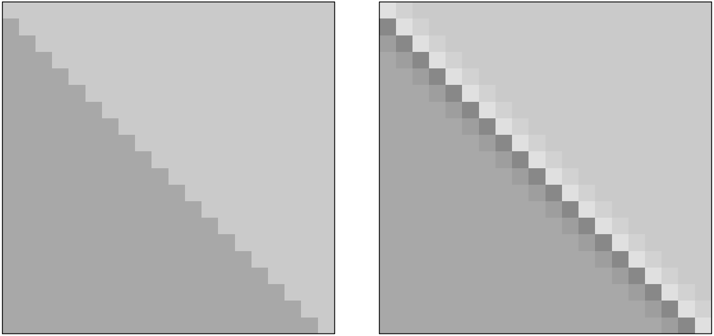
- Consider the image filter takes an image and creates a new one by replacing each pixel by 3 times the value of that pixel minus the twice the average of its eight neighbours.

$$\frac{1}{4}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 12 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

- The effect of the filter is to exaggerate (or enhance) any edges present in an image.

- This is directly analogous to the lateral inhibition found in the neural circuitry of the eye and brain.

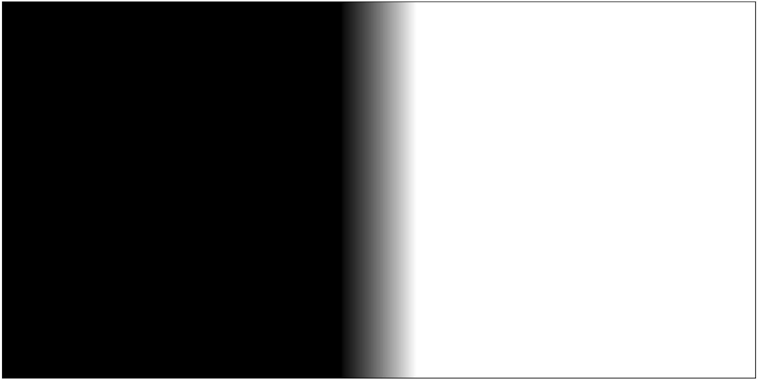
The Effect of the “Lateral Inhibition” Filter



The image on the right shows the effect of a “lateral inhibition” filter applied to the image on the left.

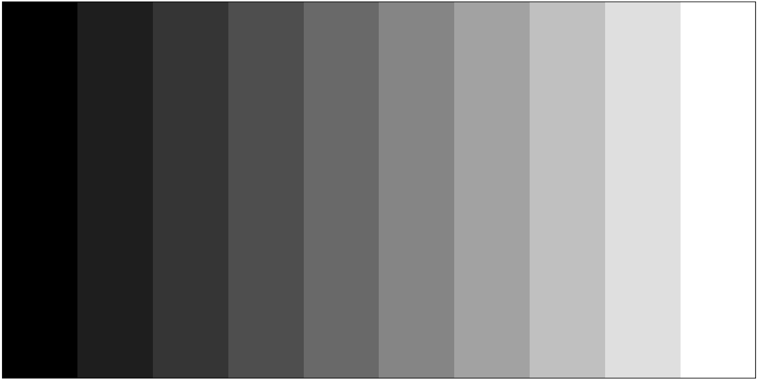
Mach Bands

Notice the apparent dark band to the left and apparent light band to the right of the grey ramp. This can be explained by the effect of lateral inhibition.



The Chevreul Illusion

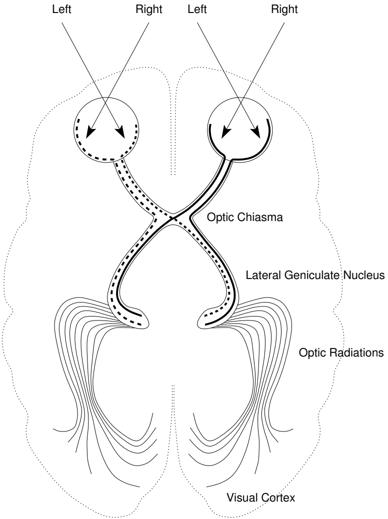
The bands in this image are each a fixed shade of grey, but appear to be lighter on their right side than on their left one.



Neural Processing

- After the visual signal leaves the eye, further processing takes place in stages down the *visual pathway*.
- Many of the steps in the processing of the visual signal are incompletely understood, but some progress has been made in understanding the process.

The Eye-Brain System



Transmission To The Cortex

- The visual signal from the retina is transmitted down the optic nerve.
- There are roughly 1,000,000 nerve fibres in the optic nerve and some 125,000,000 receptors in the retina. The signal is thus not transmitted in a one-fibre per receptor fashion.
- The greatest convergence occurs for the rod cells — the signals from 1000 or more rods may be carried by the same nerve fibre.
- There is evidence that each receptor in the central fovea is connected to two nerve cells.

The Optic Chiasm

- The optic nerves from the two eyes converge and cross at structure call the *optic chiasm*.
- Signals from each eye are mixed at this point. Such combination is clearly necessary for filling in the blind-spot and for comparison leading to the extraction of depth information.

The Lateral Geniculate Nucleus

- The signals a transmitted back through the brain to the *lateral geniculate nucleus*. The LGN acts as a kind of relay station which dispatches the signal to the visual cortex.

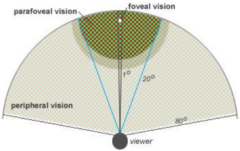
- The true function of the LGN is more complex than just acting as a relay, because it also receives a good deal of input from the cortex in addition to the optic nerve.

The Visual Cortex

- The visual cortex contains a number of neural structures which extract basic information from the visual signal.
- There are groups of neurons which are dedicated to detecting lines with particular orientation.
- Other groups take this information and use it to detect shapes.
- The signal is processed at higher and higher levels and eventually passed forward to the higher brain centres.

High Resolution Vision

- For a full visual examination of objects, we must move our eyes so that all parts of the object's image fall for a time on the fovea.
- We do this by moving our eyes from place to place over the object in a jerky fashion.



Eye Movements

- *Fixation* : A period of time when the eye is focused on a single point.
- *Saccade* : An eye motion from one fixation point to another.
- Normal vision alternates between saccades and fixations, with each lasting just 100ths of a second.

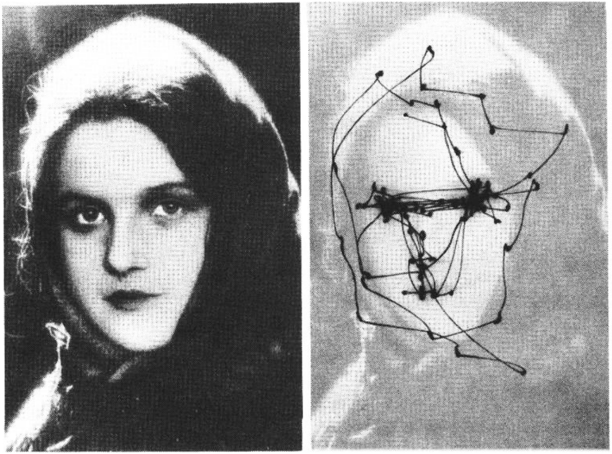
Eye Movement Studies

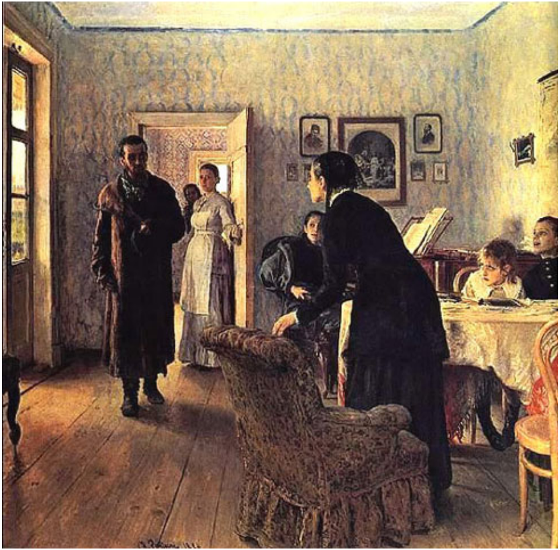
- An image is presented to a subject.
- The subject may (or may not) be given a specific task to carry out.
- A record is made of where the subjects eyes are directed as they study the image.

Studies by I. L. Yarbus

- Experimental work carried out in Russia during the 1940s and 1950s.
- A suction "cap" was fitted directly onto a subject's eyeball.
- A small mirror on the cap reflected a light beam on to photo-sensitive paper.

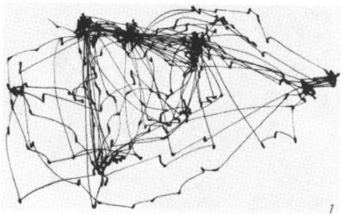
How We Look At Faces



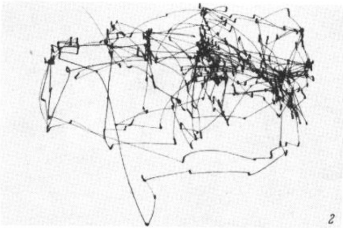


An Unexpected Visitor by I. E. Repin.

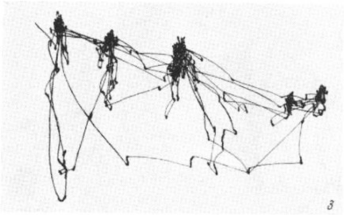
Examine the picture.



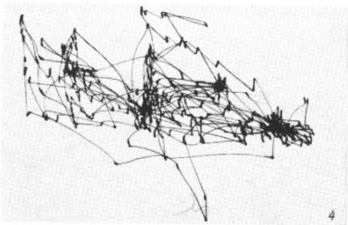
Decide how wealthy the family is.



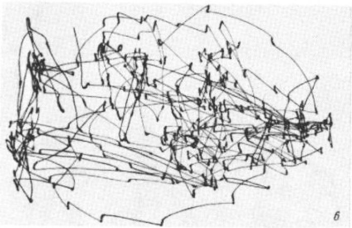
Estimate the ages of the people in the room.



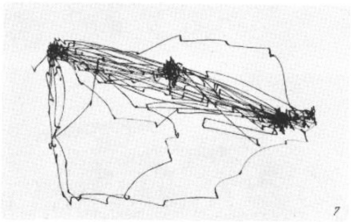
Decide what the family were doing before the visitor arrived.



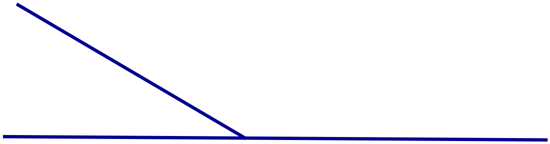
Remember the position of the objects and people in the room.



Estimate how long the visitor has been away.

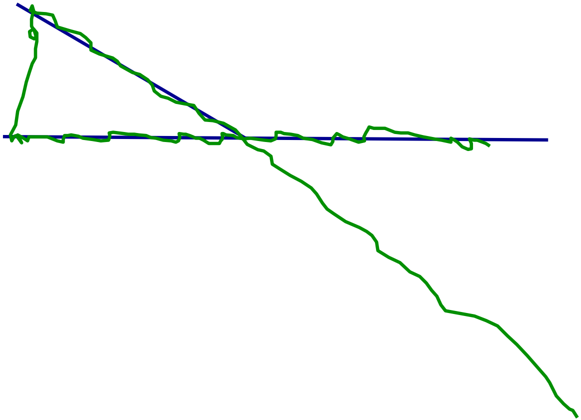


A Perceptual Experiment



Trace the figure right-to-left, then trace the sloping line and follow its direction beyond the horizontal line.

A Perceptual Experiment



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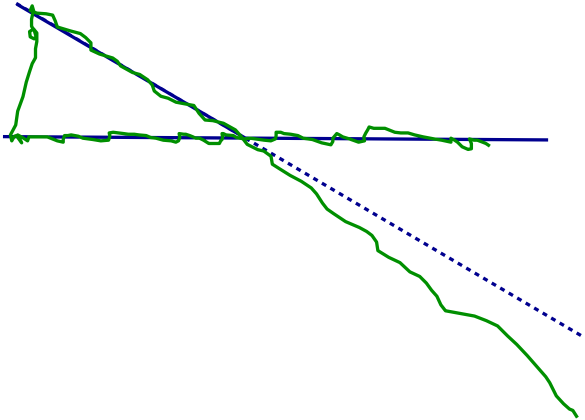
A Perceptual Experiment



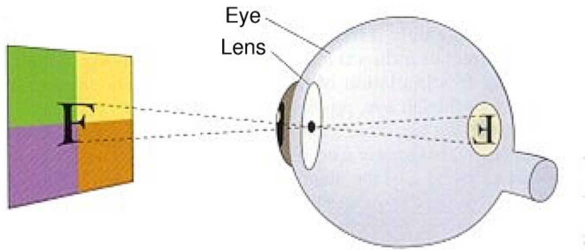
Trace the figure right-to-left, then trace the sloping line and follow its direction beyond the horizontal line.

Seeing in Three Dimensions

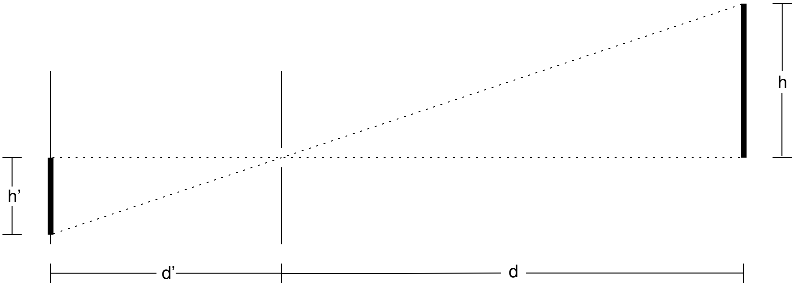
- Images projected through the pupil on to the retina are two dimensional.
- When we look at the world, we perceive it as three dimensional.
- How do we achieve this sense of depth?

The Eye as a Pinhole Camera

- Because light passes through a narrow hole (the pupil) before begin projected on the retina, the eye acts as a pinhole camera.
- Left/Right and Up/Down are inverted.



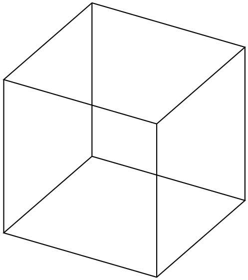
Perspective



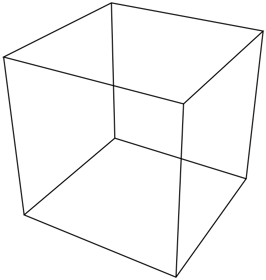
$$\frac{h'}{d'} = \frac{h}{d} \qquad h' = \frac{d'}{d}h$$

Perspective Example

Projections



Orthographic



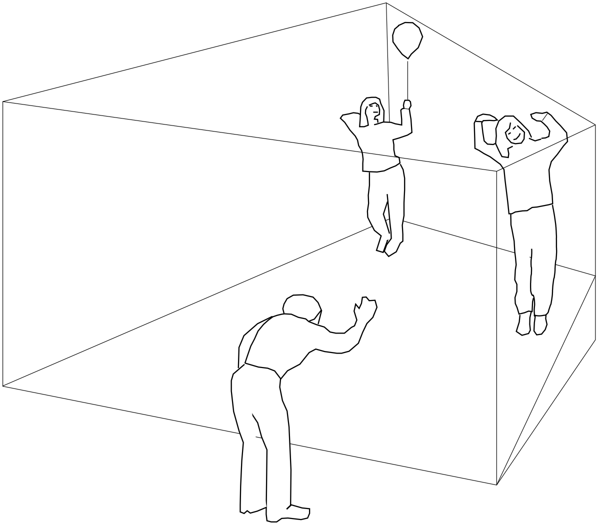
Perspective

Perspective as a Depth Cue

- Perspective gives us information about depth for objects at near to medium distances.
- When there is any hint of perspective, our visual systems try hard to extract depth information from the scene.
- We can be fooled by the appearance of perspective.

The Ames Room

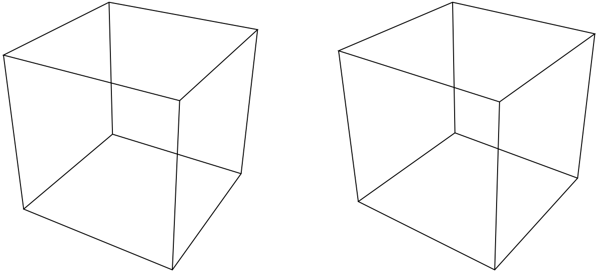
The Ames Room Explanation



Stereoscopic Vision

- Each of our eyes occupies a different position in space.
- When we look at an object, each eye sees a slightly different image.
- The brain can use the difference between the images to infer depth information.

A Cube As Seen By The Left And Right Eyes

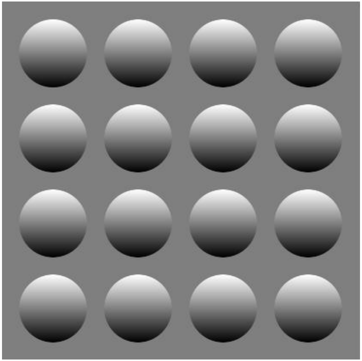


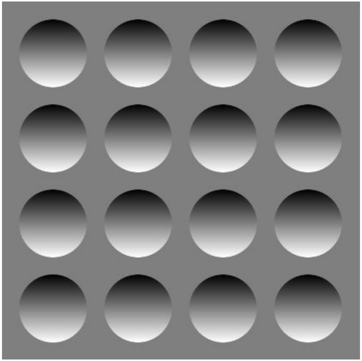
A Stereopticon and Virtual Reality Helmet

Light and Shade

- The pattern which light makes when it falls on an object can give us strong depth information.
- Light and shadow can reveal very fine detail on the surface of illuminated objects.

Lighting Effects

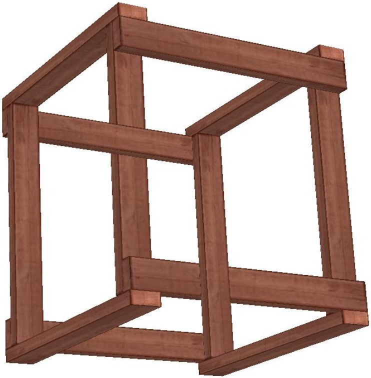




A Shaded Relief Topographic Map

Occlusion

Objects which are close, hide objects further away.



Haze and Fog