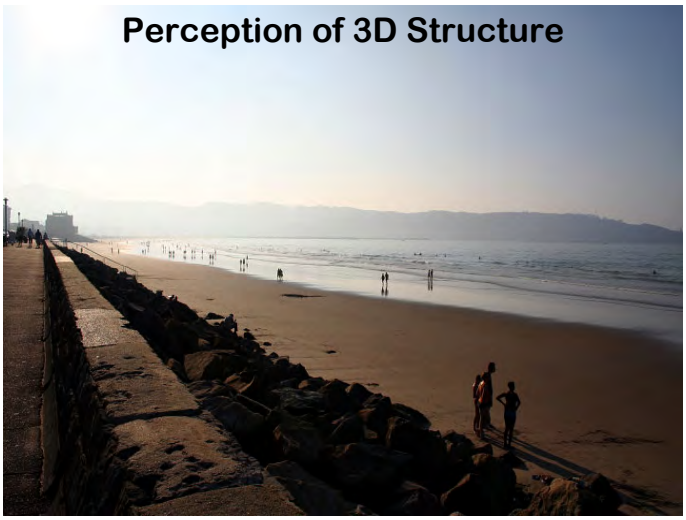
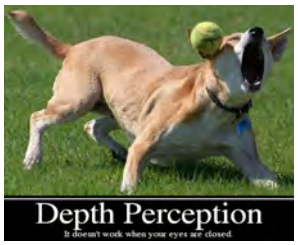
Perception of 3D Structure



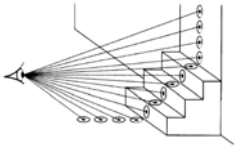
Depth perception is crucially important for everyday activities

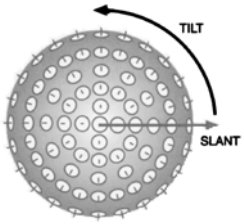
- Getting out of bed in the morning
- Reaching for nearby objects (such as the alarm clock)
- Pouring coffee into your cup
- Tossing an object (e.g., keys) to someone
- Driving or biking to school
- Crossing the street
- Navigating a cluttered environment (e.g., a crowded dining room)
- Engaging in sports (e.g.., tennis, basketball)
- Eating dinner (coordinating your knife and fork, reaching for a glass)
- Lighting a candle
- Threading a needle
- Tossing your clothes into the laundry hamper
- Jumping into bed for the night



What is Depth perception?

- How far is it from you to an object in the environment?
  - ***Absolute distance***
- How far away is an object relative to other objects in the visual field?
  - ***Relative distance***
- Not limited to just **depth**
  - **3D Surface layout:** recovering orientation at a distance
  - Slant, Tilt & Curvature = **object shape**





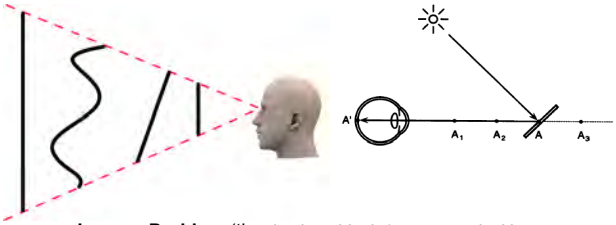
Depth perception - BIG question

How does the visual system "reconstruct" a 3D world from the <u>FLAT</u>, 2D retinal image?

Depth perception - BIG problem

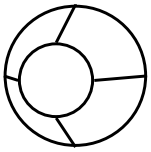
The optical projections of objects are inherently ambiguous.

For example, all of the black lines shown below would produce **<u>exactly</u>** the same image on the observer's retina. One of the great mysteries of perception is how the visual system is able to resolve this ambiguity to accurately perceive the 3D structure of the environment.



Inverse Problem (the depth ambiguity) = same retinal image can correspond to an infinite number of real world objects

Our depth perception: far from flawless



DEMO

Our depth perception: far from flawless

Continuous contours in an image are interpreted as continuous contours in the 3D environment. From an accidental view, this interpretation may be illusory.

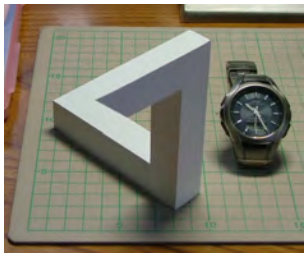
Rock Sculpture in Blackhawk, CO

Accidental view Generic view

Nonaccidental Properties: are properties of an image such as co-linearity, co-termination or parallelism that seldom occur by accident within optical projections.

Our depth perception: far from flawless

An Impossible Figure – This is a photograph of a real object, but its apparent shape is geometrically impossible. This illusion is created by having an accidental co-termination of the object's edges.



DEMO: an animated version of the impossible figure

Our depth perception: far from flawless

Unity by Mathieu Hamaekers (Belgian mathematician**)**

In this version of the impossible triangle there is an accidental view of curved edges so that they are perceptually interpreted as straight.

Our depth perception: far from flawless

An accidental view of curved edges that produces the perception of an Impossible Cube.

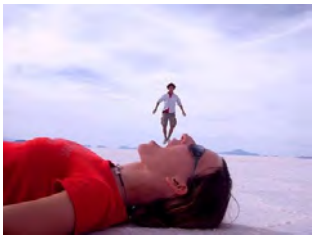
Mathieu Hamaekers

DEMO

Our depth perception: far from flawless

These images all exploit accidental smooth continuations.

These images contain accidental co-terminations.

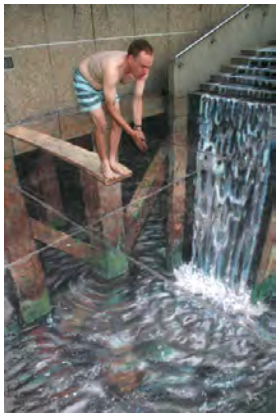


Accidental properties in art

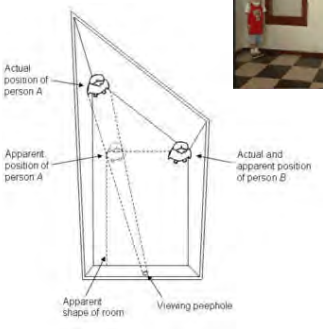
An **anamorphosis** is a distorted projection or perspective;
Which, when viewed from one, specified location, appears regular and in proportion.

Julian Beever, English chalk artist

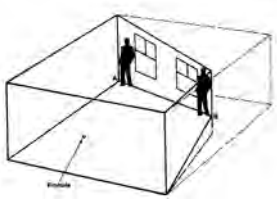
"Ana - morphosis" are Greek words meaning "formed again."

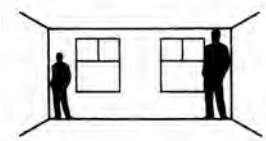


Ames room: Adelbert Ames, Jr. 1964



Ames room: Adelbert Ames, Jr. 1964





The trapezoidal shape of the room causes an **accidental parallel alignment** of the back wall when viewed through **a small hole**.

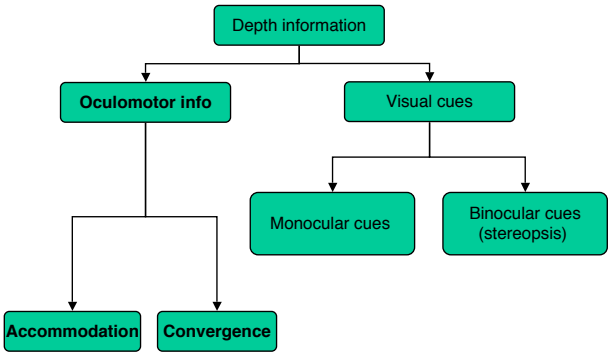
Depth perception - what we learned so far…

Extracting depth info from flat 2D retinal images is problematic (b/c of the **inverse problem**)

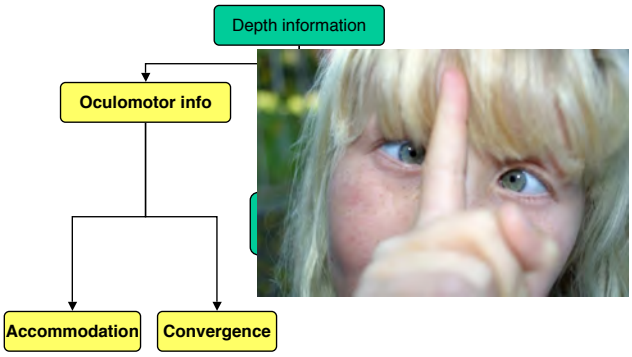
This difficulty is illustrated by many cases where our depth perception fails

However, these “fails” also illustrate some of the strategies that our brains use to deal with the inverse problem.

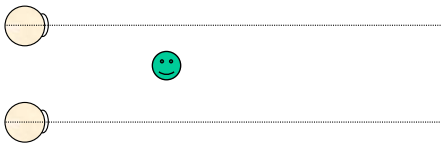
Solving the problem:
Sources of Information about 3D Structure



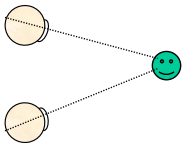
Solving the problem:
Sources of Information about 3D Structure



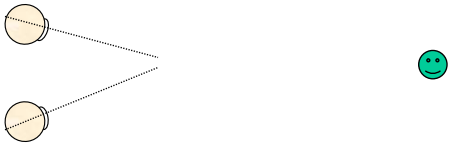
Vergence Angle (a Binocular depth cue)



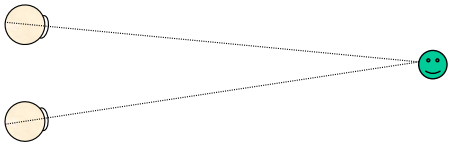
Vergence Angle (a Binocular depth cue)



Vergence Angle (a Binocular depth cue)

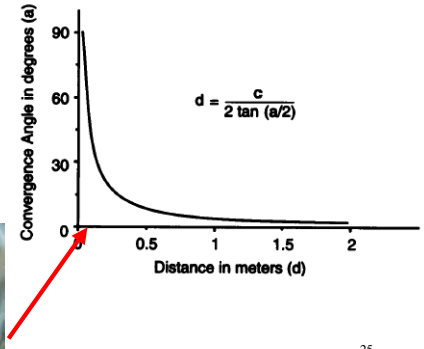


Vergence Angle (a Binocular depth cue)



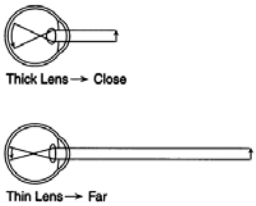
Vergence Angle (a Binocular depth cue)

Useful for only for close distances



Accommodation (a monocular depth cue)

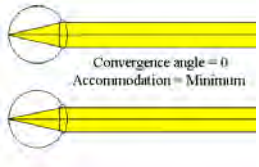
- **Accommodation** is derived by image blur so that the output of high spatial frequency channels is maximized
- Visual system should have access to the information about the tension of the muscles
- Useful for close distances
- The best depth cue in the African chameleon

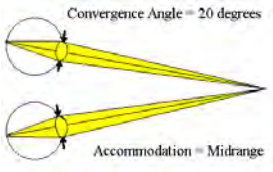


Convergence and accommodation are not independent

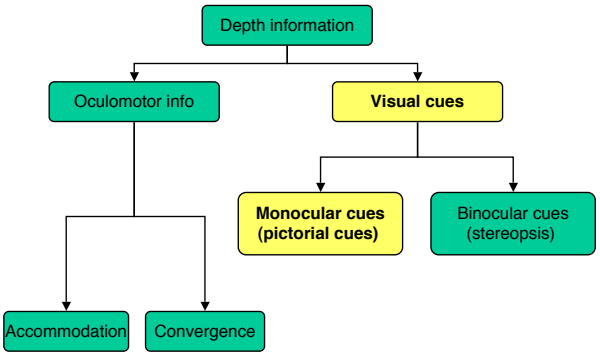
Accommodation & convergence

In principle, the distance of an object could be determined by the state of accommodation or convergence, but human observers are not very sensitive to this information





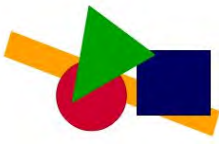
Sources of Information about 3D Structure



Monocular sources of depth information ("Monocular depth cues")

- **Occlusion:** a condition when a nearer object visually occludes at least a portion of a more distant object(s)
- Size
- Perspective
  - Geometric perspective
  - Texture perspective
  - Aerial perspective
- Shading
- Motion parallax

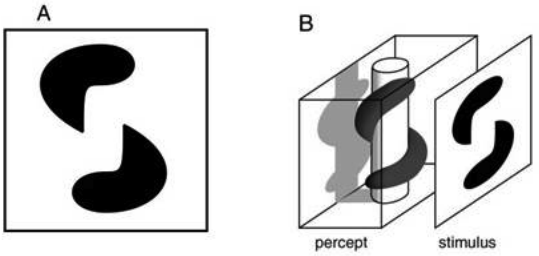
Occlusion



Illusory contours: occlusion w/o boundaries

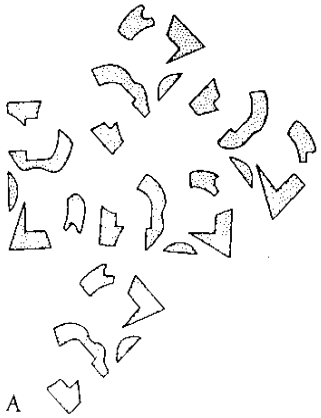
Amodal completion

Occlusion

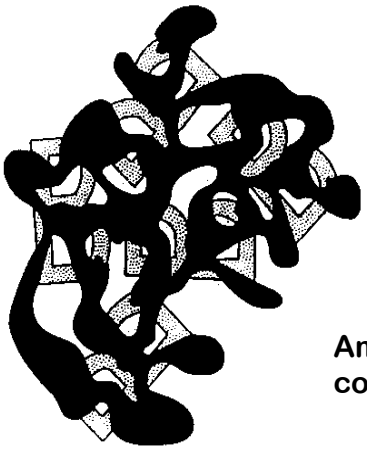


Amodal completion

Occlusion

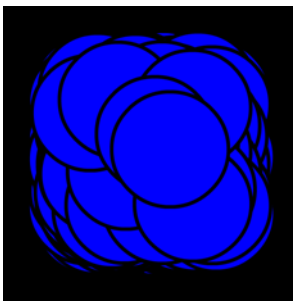


Occlusion



Amodal completion

Occlusion



Dynamic occlusion

Monocular sources of depth information ("Monocular depth cues")

- Occlusion
- **Size** (retnal image of an object depends on its size and distance. If you know the size, you can estimate the distance)
- Perspective
  - Geometric perspective
  - Texture perspective
  - Aerial perspective
- Shading
- Motion parallax

The effects of viewing distance

A bird's eye view of an observer who is watching an object moving forwards and backwards in depth

This is how the object appears to the observer.

DEMO

$$\text{Image Size} \approx \frac{\text{Object Size}}{\text{Viewing Distance}}$$

Size

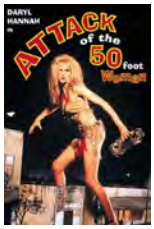
But,

Size, but…

In this case, familiar size is overridden by the accidental alignment of the hand and the cow

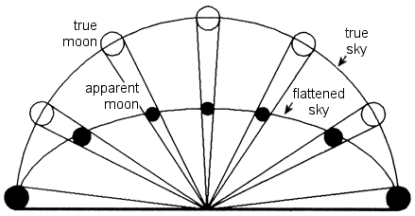
Size, but…

Overriding familiar size is the basis of many "B" science fiction movies



Size, but…

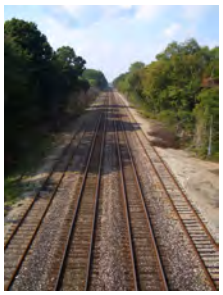
Moon illusion….

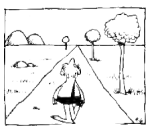


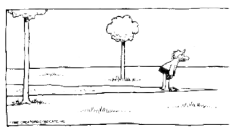
Monocular sources of depth information ("Monocular depth cues")

- Occlusion
- Size
- **Perspective**
  - **Geometric perspective** **(aka., linear perspective: convergence of lines that results in perceived depth in a 2D scene)**
  - Texture perspective
  - Aerial perspective
- Shading
- Motion parallax

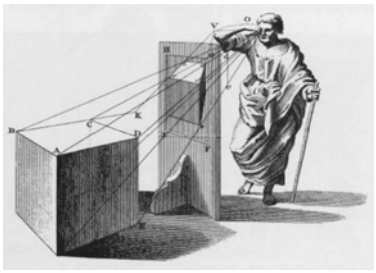
Geometric perspective





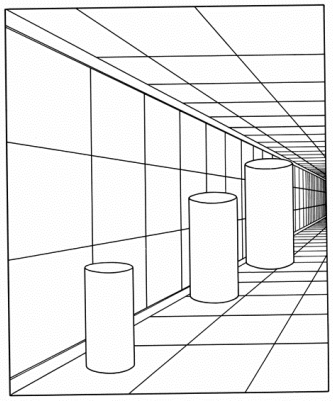


Projective Geometry



Projective geometry investigates the mathematical relationships between objects in the environment and their optical projections on the retina or on a picture.

Geometric perspective

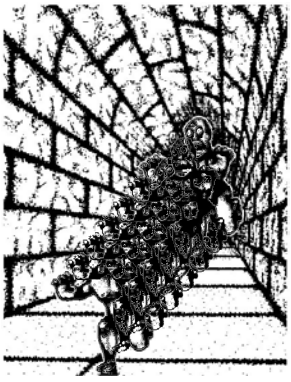


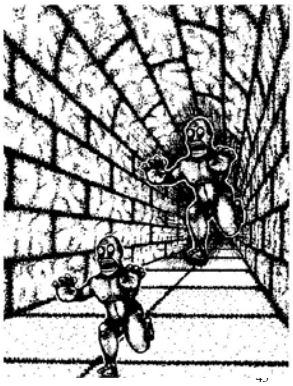
Apparent distance can have a strong effect on apparent size.

The projected sizes of all three cylinders are the same, yet their apparent sizes are quite different.

Geometric perspective

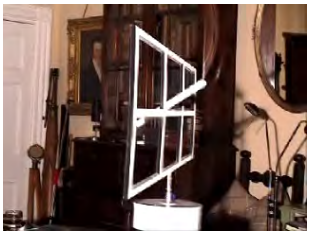
Apparent distance can have a strong effect on apparent size.





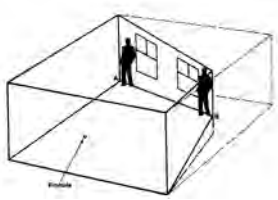
Geometric perspective

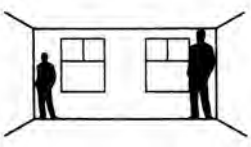
The Ames window appears to rotate through 180º and then seems to stop momentarily and reverse its direction of rotation



http://www.richardgregory.org/experiments/

Geometric perspective





Geometric perspective

Anamorphosis – distorted projection of an image on a plane or curved surface
Which, when viewed from one, specified location, appears regular and in proportion.

Geometric perspective

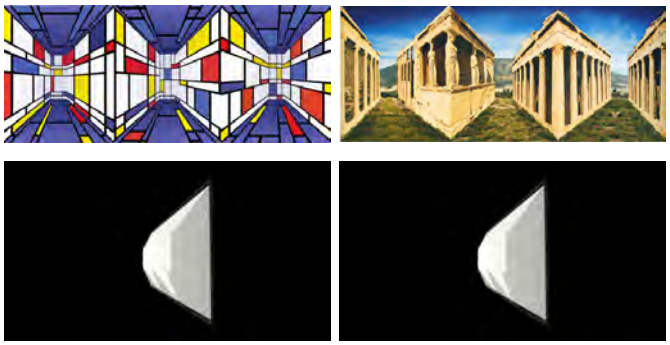
church of Sant'Ignazio di Loyola of Rome - Andrea Pozzo

Anamorphosis – distorted projection of an image on a plane or curved surface
Which, when viewed from one, specified location, appears regular and in proportion.

Geometric perspective

Anamorphosis – distorted projection of an image on a plane or curved surface
Which, when viewed from one, specified location, appears regular and in proportion.

REVERSE Geometric perspective



http://www.offthewallartprints.com/index.php

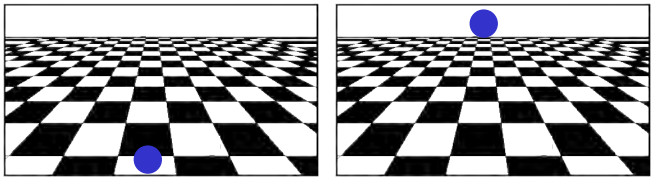
REVERSE Geometric perspective

www.patrickhughes.co.uk/

Monocular sources of depth information ("Monocular depth cues")

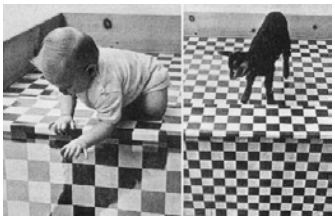
- Occlusion
- Size
- Perspective
  - Geometric perspective
  - **Texture perspective** (the density of the surface/object texture increases with distance, providing a depth cue)
  - Aerial perspective
- Shading
- Motion parallax

Texture perspective (texture gradient)

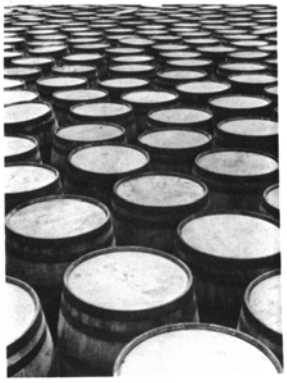


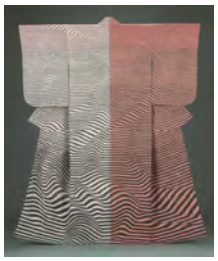
Texture perspective (texture gradient)

Visual cliff:
Not crossing the “visual cliff” is understood to indicate the ability to perceive depth

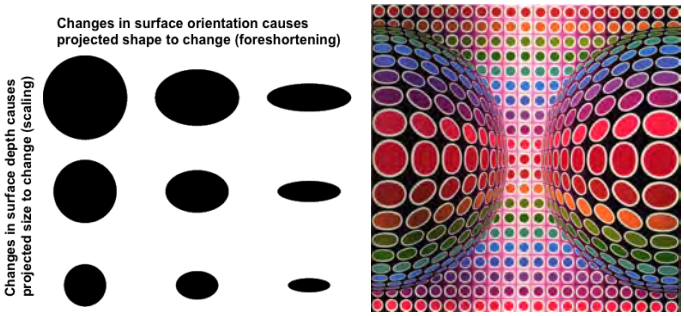


Texture perspective (texture gradient)





Texture perspective (texture gradient)

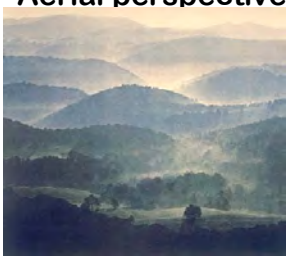


Dyss, Victor Vasarely

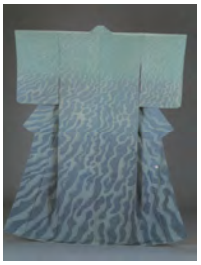
Monocular sources of depth information (“Monocular depth cues”)

- Occlusion
- Size
- Perspective
  - Geometric perspective
  - Texture perspective
  - **Aerial perspective** (objects in distance appear less clear, more blurred and low contrast because of atmosphere & pollution)
- Shading
- Motion parallax

Aerial perspective



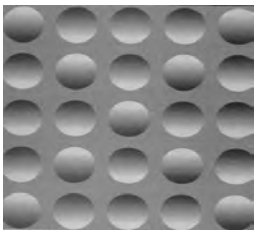
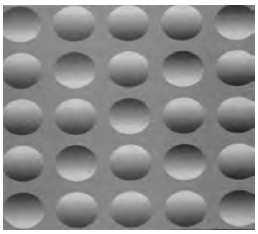
Aerial perspective



Monocular sources of depth information ("Monocular depth cues")

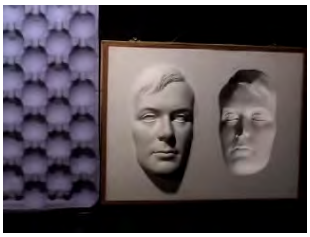
- Occlusion
- Size
- Perspective
  - Geometric perspective
  - Texture perspective
  - Aerial perspective
- **Shading** (a gradient in the reflected light on a 3D object that gives cues about object's 3D shape)
- Motion parallax

Shading (shape from shading)

- The "direction" of depth depends on the direction of the luminance gradient.
- Because we assume (as the default) that there is only one light source, and that that light source is from above, if an object is brighter on the top than on the bottom, we'll perceive that object as convex (like bumps in the picture).
- In contrast, if the object is brighter on the bottom than on the top, we'll perceive that object as concave (like the "holes").

Shading (shape from shading)

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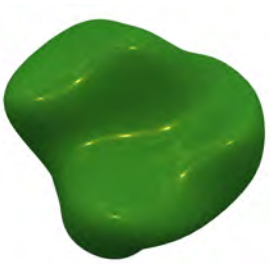
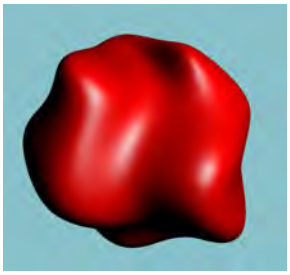
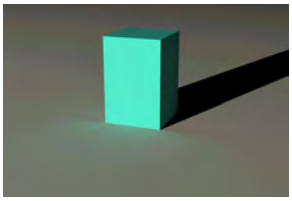
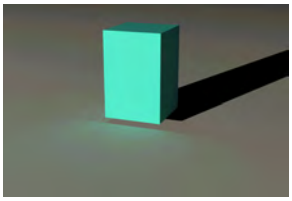
Shading (shape from shading)

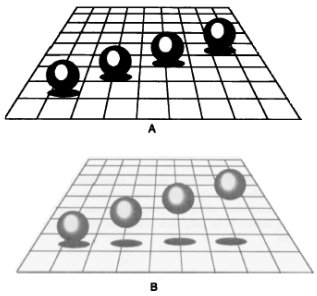
Shading provides information about 3D shape, material properties and the pattern of lighting.

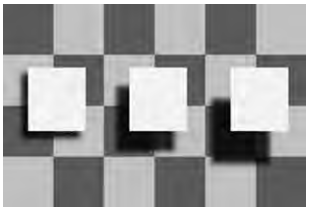
Shading

Information from shadows or indirect illumination can override the bias to perceive objects to be in contact with the ground

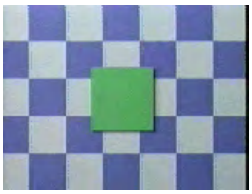



Shading





Shadow Induced Motion in Depth



In this demonstration the green square undergoes no changes whatsoever. However, the changes of its shadow creates the impression that the square is moving forward and backward in depth.

The Ball in the Box

In this demonstration the perceived motion of the ball is influenced by the motion of its shadow.

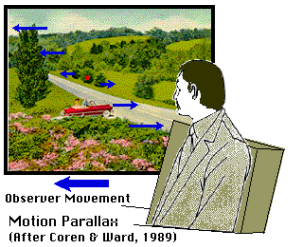
When the shadow moves with the same trajectory as the ball, the ball appears to be rolling on the ground.

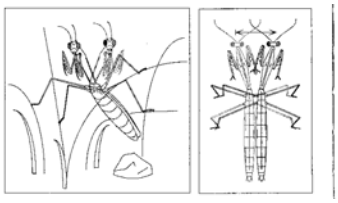
When the shadow moves with a different trajectory, the ball appears to be rising above the ground.

Monocular sources of depth information ("Monocular depth cues")

- Occlusion
- Size
- Perspective
  - Geometric perspective
  - Texture perspective
  - Aerial perspective
- Shading
- **Motion parallax** (differences in relative motion of objects located at different distances from the observer)

Motion parallax



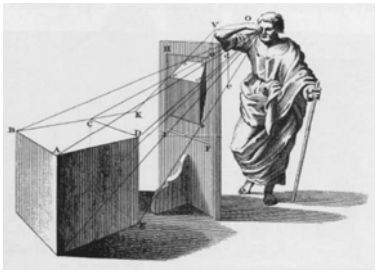


Active creation of motion parallax in praying mantis

Monocular sources of depth information ("Monocular depth cues")

- Occlusion
- Size
- **Perspective**
  - **Geometric perspective in ART**
  - Texture perspective
  - Aerial perspective
- Shading
- Motion parallax

Geometric perspective



Projective geometry investigates the mathematical relationships between objects in the environment and their optical projections on the retina or on a picture.

Geometric perspective

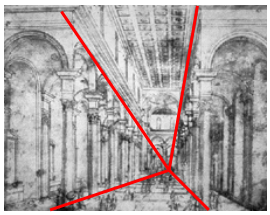


Brunelleschi's Panel


Around 1413, Filippo Brunelleschi painted a picture of the Baptistry in Florence.

To demonstrate that his painting was an exact replica that could fool the eye, he drilled a small hole in the surface and then stood directly in front of the Baptistry, looking through the peephole to see the real building. He then held up a mirror in front of his painted panel. The second mirror blocked the view of the real building, but reflected his painted version. Observers were amazed that the two images appeared nearly identical.

Brunelleschi, 1417
Drawing for Church of Santo Spirito.




In 1417, Brunelleschi was trying to obtain a commission to design the Church of Santo Spirito. He produced the drawing on the left to show his clients how the church would look after it was completed. A photograph of the actual church is shown on the right. Notice how the lines all converge to a **vanishing point** at the back of the church. This new technique, called linear perspective, was a revolutionary development in the history of art.

Masaccio, The Trinity, 1427

- Tommaso Masaccio learned the technique of linear perspective from Brunelleschi, and he was the first to apply it to painting in a rigorous manner
- This fresco is generally believed to be the first painting in which he employed the technique.
- Note how the lines from the vault converge to a single vanishing point.

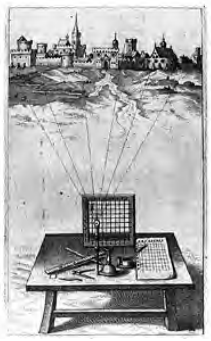
Draughtsman Drawing a Recumbent Woman, Albrecht Durer, 1525

In 1435, Leon Battista Alberti published a treatise on perspective, **Della Pitture**.

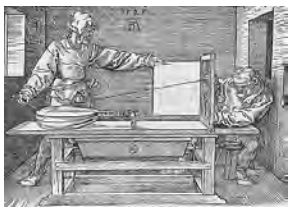
Alberti conceived of the canvas as an open window through which the subject to be painted is seen.

The term perspective comes from comes from the Latin word perspectiva, which means a view through something.

This idea of the drawing surface as a window, led to the development of special devices to aid the artist in producing more accurate perspective paintings (e.g. Alberti's window).




Examples of drawing aids used during the Renaissance that are based on the idea of Alberti's window. The artist views the scene through a window with a grid and then reproduces the projection on a drawing surface that has a corresponding grid.



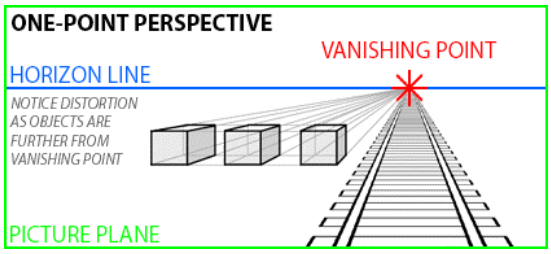
Albrecht Dürer , Man Drawing a Lute, 1525

Hieronymus Rodler (1531)

Renaissance woodcuts that depict the use of Alberti's window in order to produce more realistic drawings.

Locating the Vanishing Point, David Macaulay

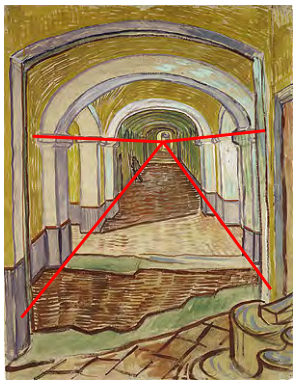
What's wrong with this picture?



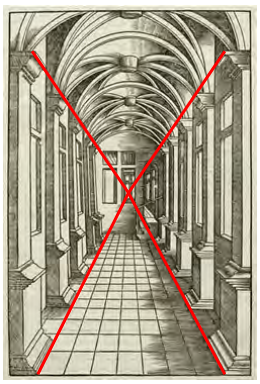
One vanishing point is typically used for roads, railroad tracks, or buildings viewed so that the front is directly facing the viewer

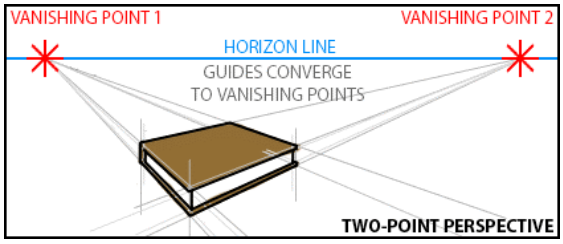
View of an Ideal City, Unknown Artist, c. 1490-1500

A Corridor in the Asylum, Vincent van Gogh, 1889

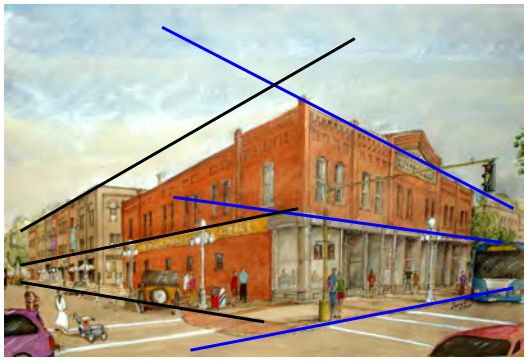


A Vault the way you'd like it, Hieronymus Rodler, 1531



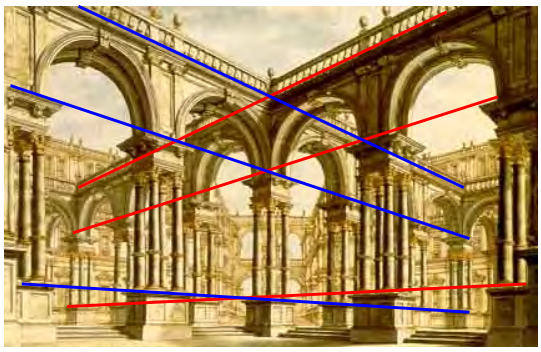


Two-point perspective is used to draw the same objects as one-point perspective but rotated, e.g., looking at the corner of a house



85

Corte con Arcate, Giuseppe Galli Bibiena , 1746

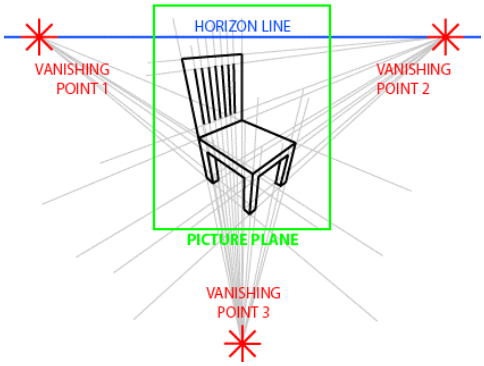


86

The Yellow House, Vincent van Gogh, 1888

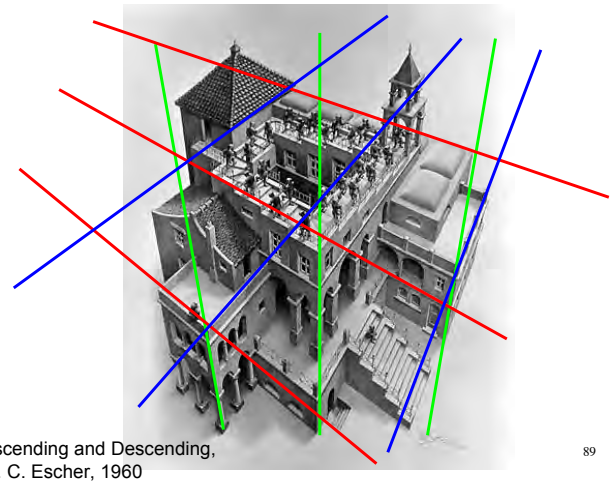
87

THREE-POINT PERSPECTIVE



Three-point perspective is usually used for buildings seen from above (or below).

88



Ascending and Descending,
M. C. Escher, 1960

89

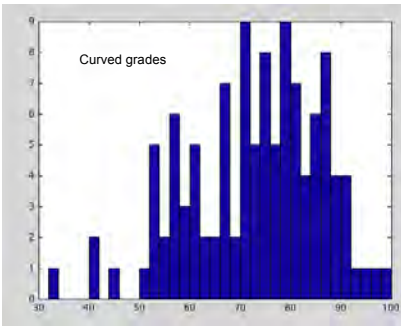
Three numbers on the back of your exam:

- smallest is the raw point score (out of 87)
- next larger # is the percentage score
- circled number is your curved score (percentage score + 4% curve)

Raw Average = 60.3/87 = 69.2%

Curved tally
Average = 73.2
Median = 74.7

"A" = 8
"B" = 29
"C" = 36
"D" = 18
"E" = 21



Questions about questions:
Ask Ruyuan about multiple choice and short answer
Ask Davis about essay questions

Note:
• Upward curve will be applied to the FINAL grades only if the final class average is less than 80%.
• If needed, final grades will be curved so that the average is brought up to 80%.

90