Distance, depth, and 3D shape cues

- Pictorial depth cues: familiar size, relative size, brightness, occlusion, shading and shadows, aerial/ atmospheric perspective, linear perspective, height within image, texture gradient, contour
- Other static, monocular cues: accommodation, blur, [astigmatic blur, chromatic aberration]
- Motion cues: motion parallax, kinetic depth effect, dynamic occlusion
- Binocular cues: convergence, stereopsis/binocular disparity: crossed vs. uncrossed disparity, random-dot stereogram and the correspondence problem, fusion and rivalry, neural coding
- Cue combination

Basic distinctions

- Types of depth cues
  - Monocular vs. binocular
  - Pictorial vs. movement
  - Physiological
- Depth cue information
  - What is the information?
  - How could one compute depth from it?
  - Do we compute depth from it?
  - What is learned: ordinal, relative, absolute depth, depth ambiguities

Definitions

- Spatial vision (2D) vs. Space perception (3D)
- Distance: Egocentric distance, distance from the observer to the object
- Depth: Relative distance, e.g., distance one object is in front of another or in front of a background
- Surface Orientation: Slant (how much) and tilt (which way)
- Shape: Intrinsic to an object, independent of viewpoint

Distance, depth, and 3D shape cues

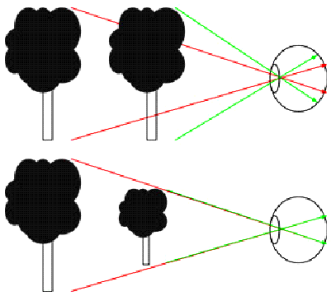
- Pictorial depth cues: familiar size, relative size, [brightness], occlusion, shading and shadows, aerial/ atmospheric perspective, linear perspective, height within image, texture gradient, contour
- Other static, monocular cues: accommodation, blur, [astigmatic blur, chromatic aberration]
- Motion cues: motion parallax, kinetic depth effect, dynamic occlusion
- Binocular cues: convergence, stereopsis/binocular disparity
- Cue combination

Epstein (1965) familiar size experiment

How far away is the coin?

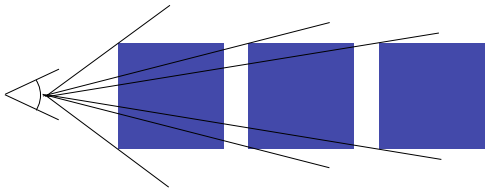
Monocular depth cues

Retinal projection depends on size and distance

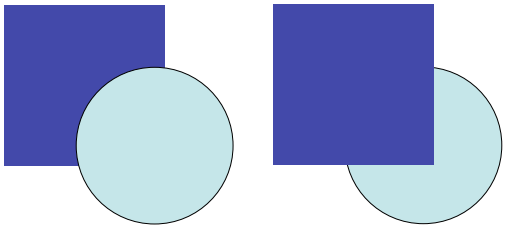


Relative size as a cue to depth

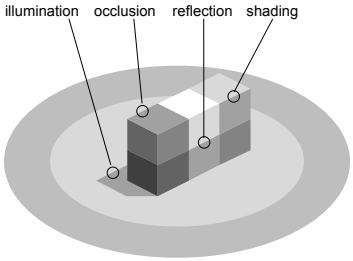
Relative size as a cue to depth



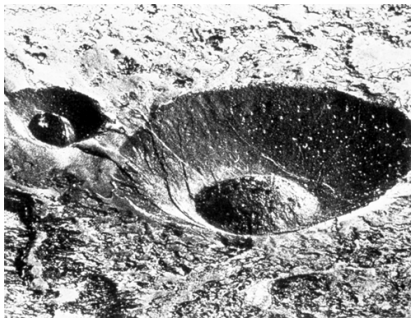
Occlusion as a cue to depth



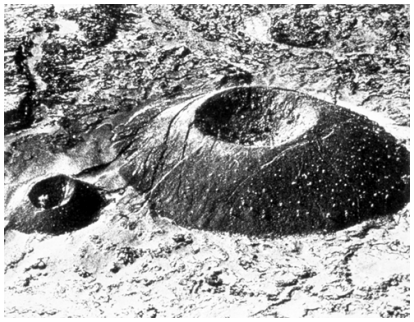
Shading, reflection, and illumination



Shading – assumption of light-from-above

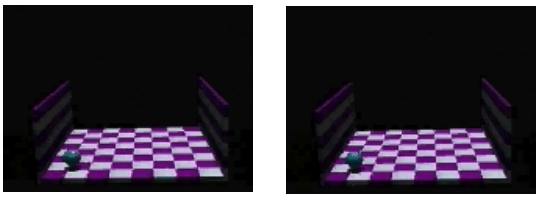


Shading (flip the photo upside-down)

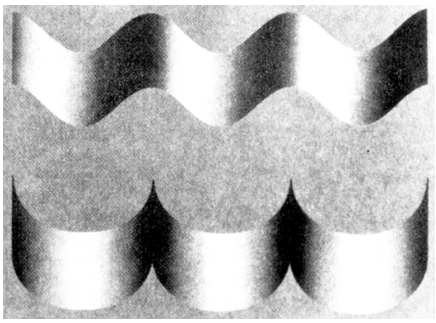


Cast Shadows

Dynamic Cast Shadows



Shading and contour

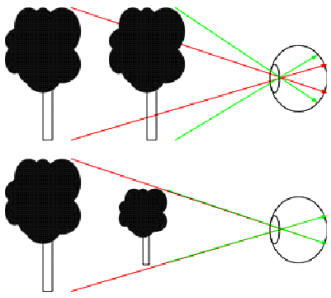


Aerial/Atmospheric Perspective

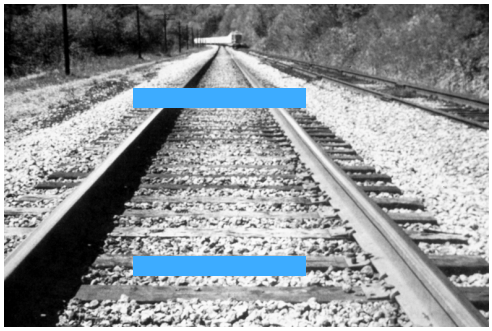
Geometry of Linear Perspective

Retinal projection depends on size and distance:

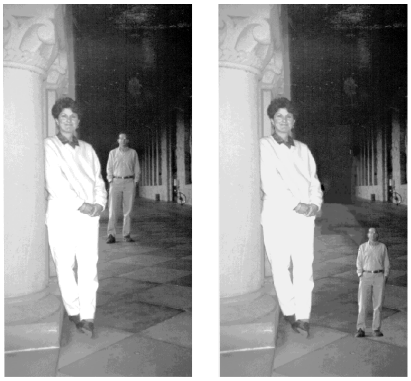
Size in the world (e.g., in meters) is proportional to size in the retinal image (in degrees) times the distance to the object



Linear perspective

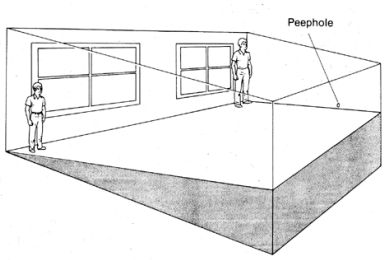


Size constancy

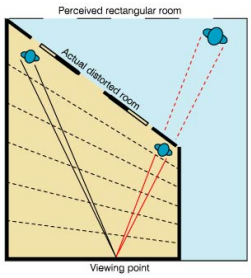


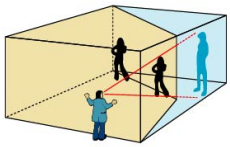
Ames room

Ames room



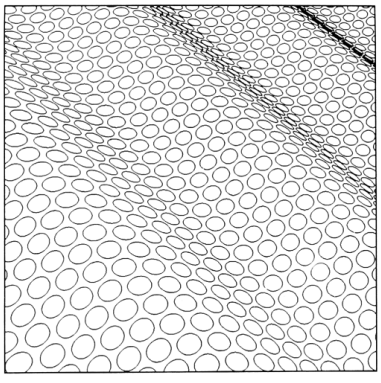
The Ames Room





Texture

1. Density
2. Foreshortening
3. Size



Height Within the Image

Distance, depth, and 3D shape cues

- Pictorial depth cues: familiar size, relative size, brightness, occlusion, shading and shadows, aerial/ atmospheric perspective, linear perspective, height within image, texture gradient, contour
- Other static, monocular cues: accommodation, blur, [astigmatic blur, chromatic aberration]
- Motion cues: motion parallax, kinetic depth effect, dynamic occlusion
- Binocular cues: convergence, stereopsis/binocular disparity
- Cue combination

Monocular Physiological Cues

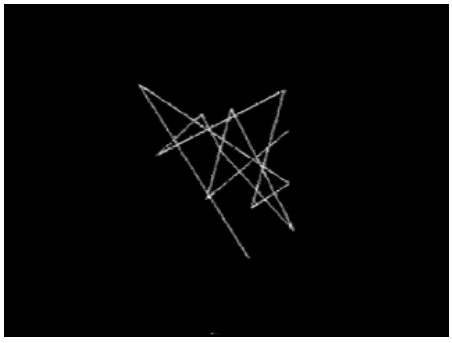
- Accommodation – estimate depth based on state of accommodation (lens shape) required to bring object into focus
- Blur – objects that are further or closer than the accommodative distance are increasingly blur
- Astigmatic blur
- Chromatic aberration

Distance, depth, and 3D shape cues

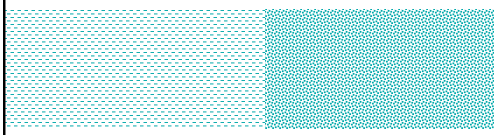
- Pictorial depth cues: familiar size, relative size, brightness, occlusion, shading and shadows, aerial/ atmospheric perspective, linear perspective, height within image, texture gradient, contour
- Other static, monocular cues: accommodation, blur, [astigmatic blur, chromatic aberration]
- Motion cues: motion parallax, kinetic depth effect, dynamic occlusion
- Binocular cues: convergence, stereopsis/binocular disparity
- Cue combination

Motion Parallax

The Kinetic Depth Effect



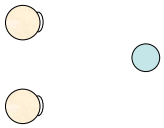
Dynamic (Kinetic) Occlusion



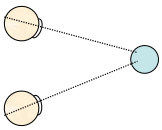
Distance, depth, and 3D shape cues

- Pictorial depth cues: familiar size, relative size, brightness, occlusion, shading and shadows, aerial/ atmospheric perspective, linear perspective, height within image, texture gradient, contour
- Other static, monocular cues: accommodation, blur, [astigmatic blur, chromatic aberration]
- Motion cues: motion parallax, kinetic depth effect, dynamic occlusion
- Binocular cues: convergence, stereopsis/binocular disparity
- Cue combination

Vergence Angle As One Binocular Source

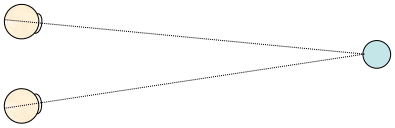


Vergence Angle As One Binocular Source



Vergence Angle As One Binocular Source

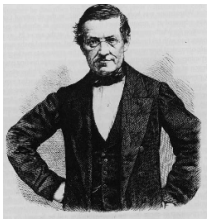
Vergence Angle As One Binocular Source

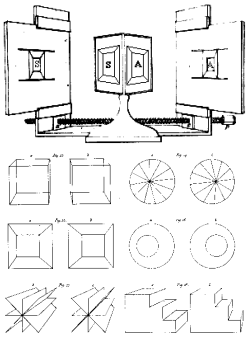


Retinal Disparity as a Source of 3D Information

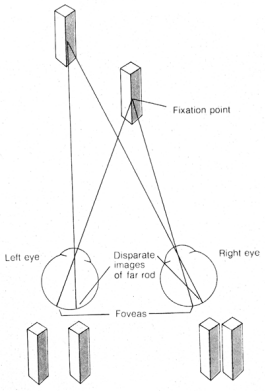
Stereograms (anaglyphs)

Sir Charles Wheatstone's Famous Invention

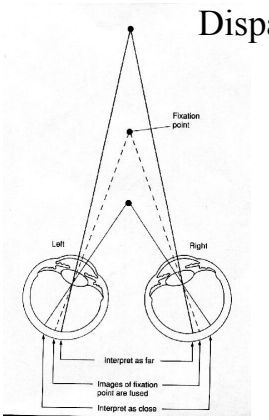




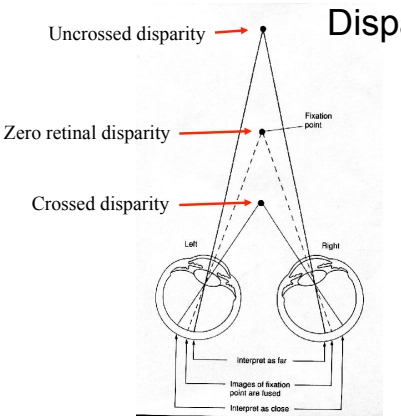
Binocular disparity



Disparity

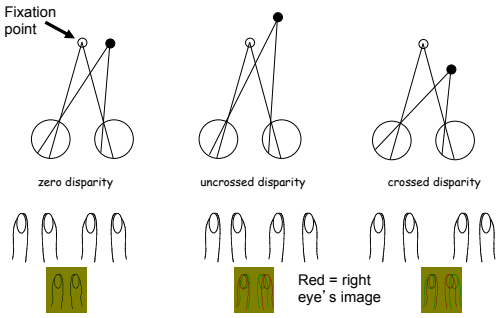


Disparity

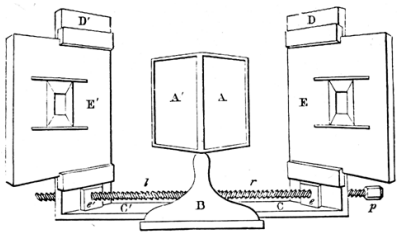


Stereopsis (literally, "seeing solid") - 3D vision resulting from slight differences in left and right eye images, arising because the two eyes view the world from slightly different perspectives

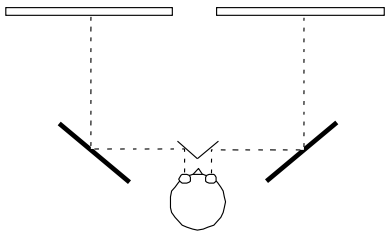
Disparity - slight differences in positions of "features" in the left and right eyes' views



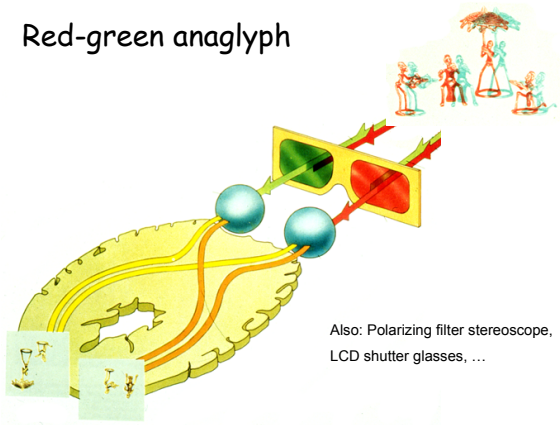
Wheatstone stereoscope (c. 1838)



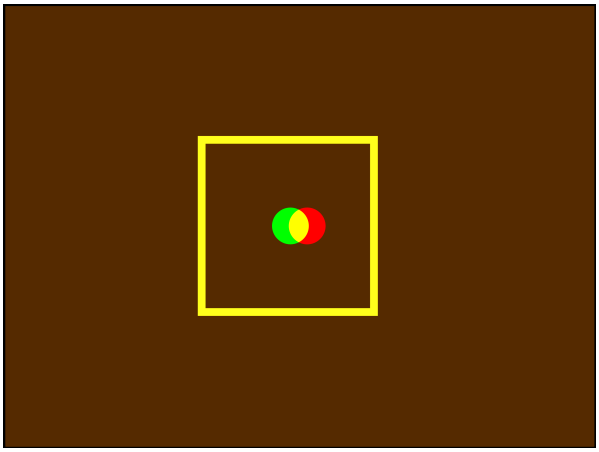
Dual mirror stereoscope



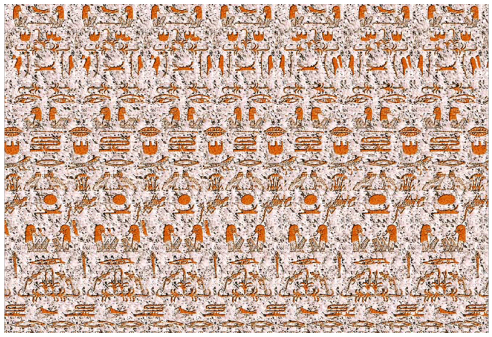
Red-green anaglyph

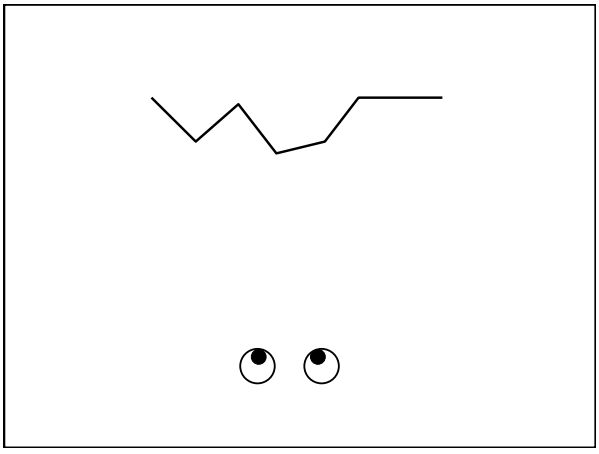


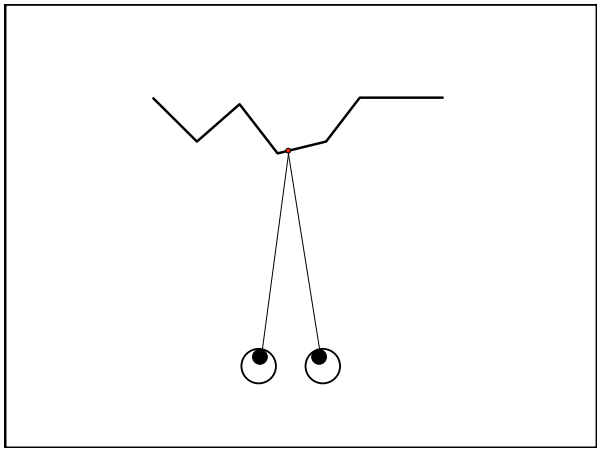
Also: Polarizing filter stereoscope, LCD shutter glasses, …

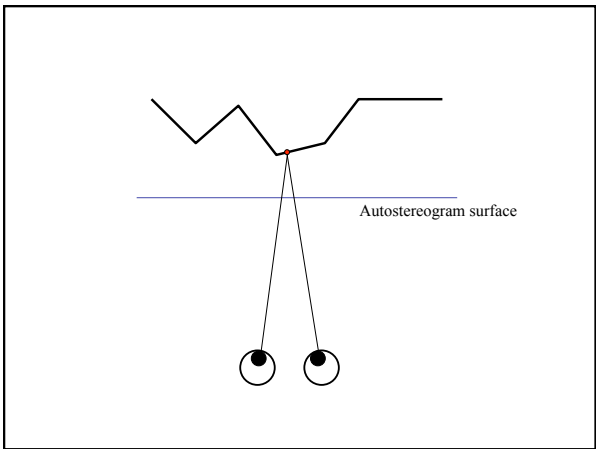


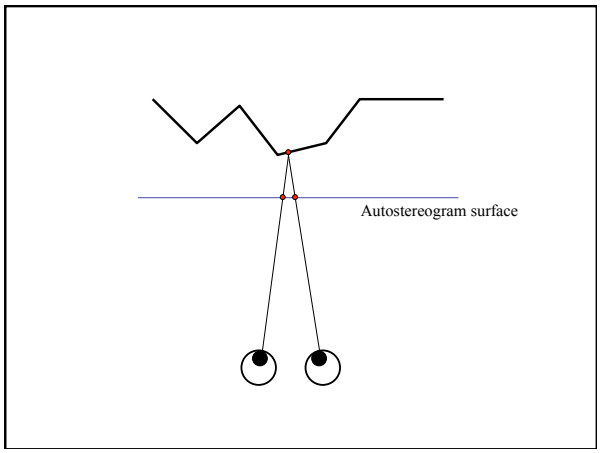
Stereograms ("Magic Eye")

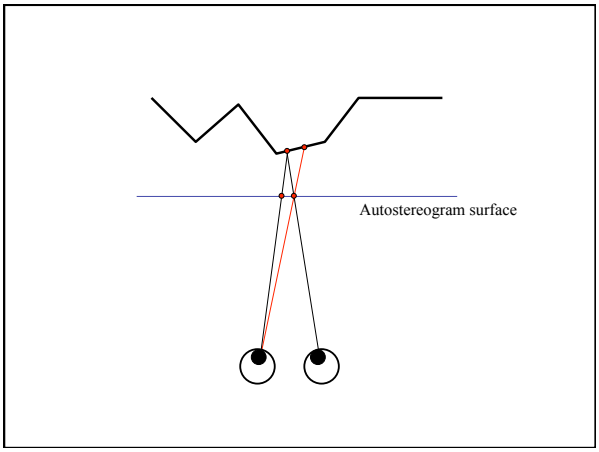


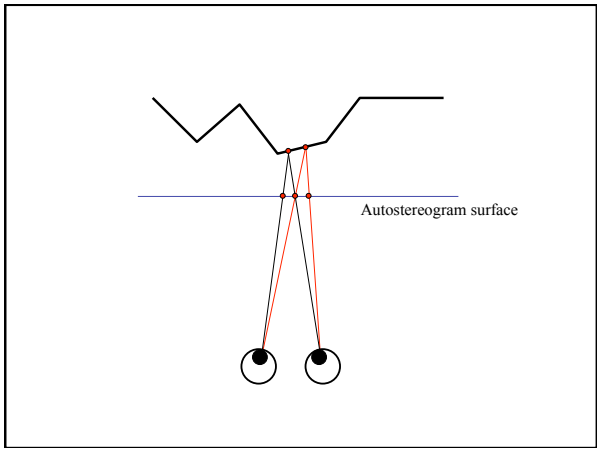


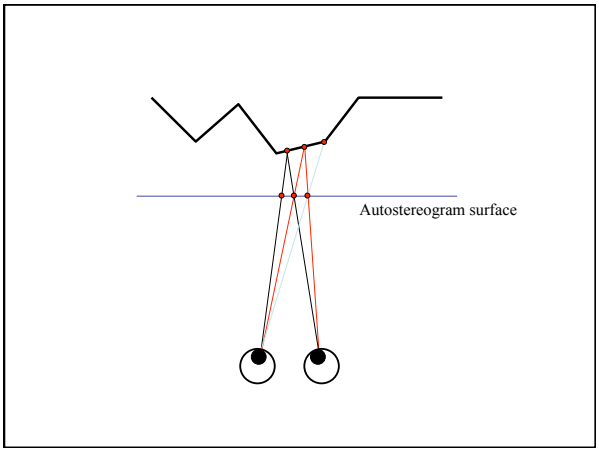


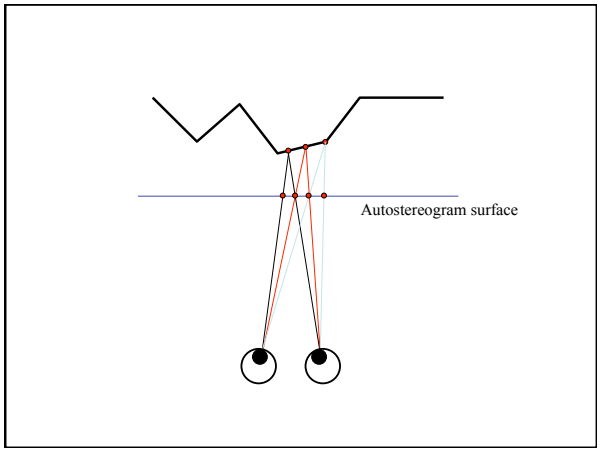

Autostereogram surface

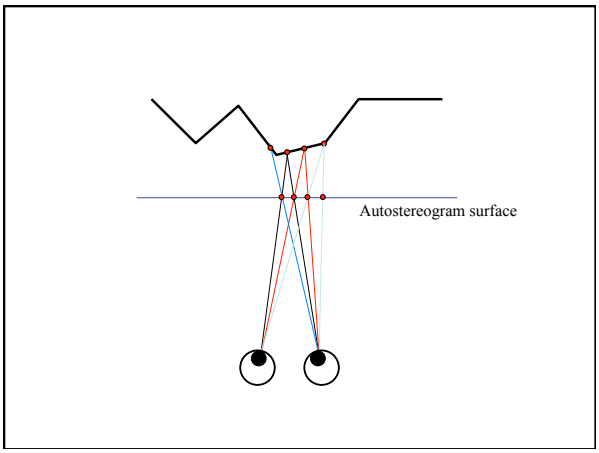

Autostereogram surface

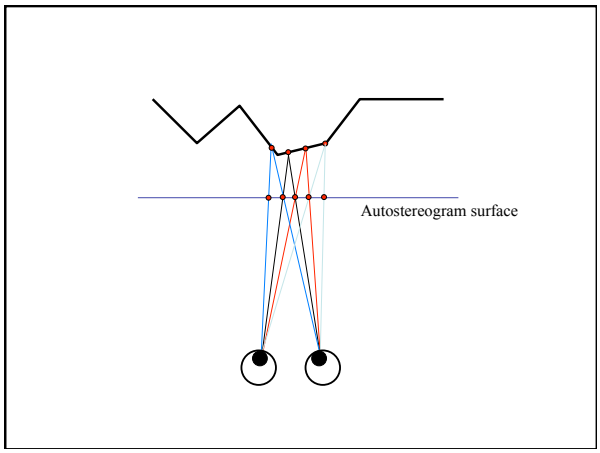

Autostereogram surface

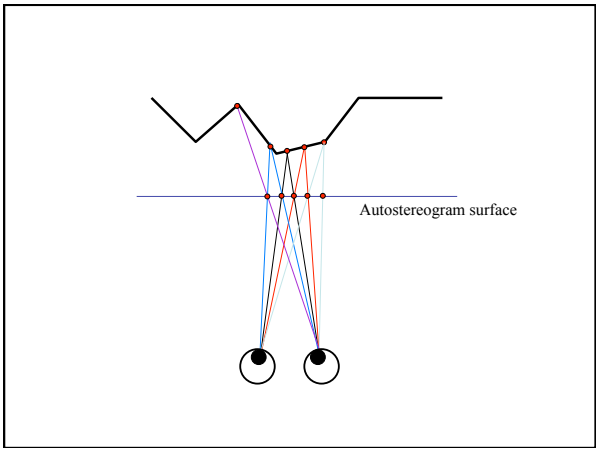

Autostereogram surface

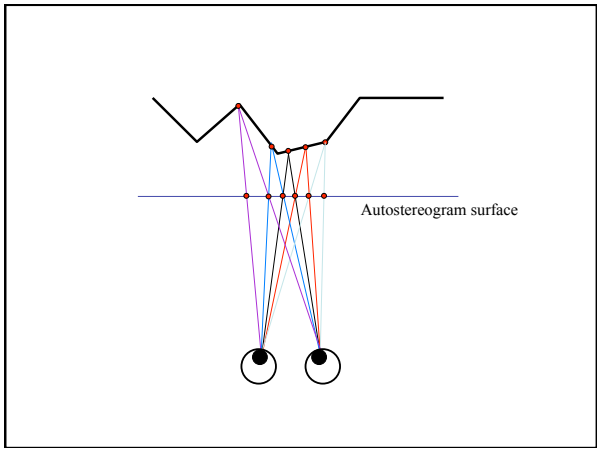

Autostereogram surface


Autostereogram surface

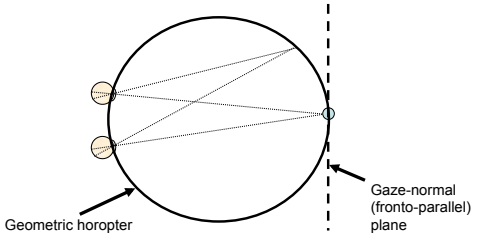




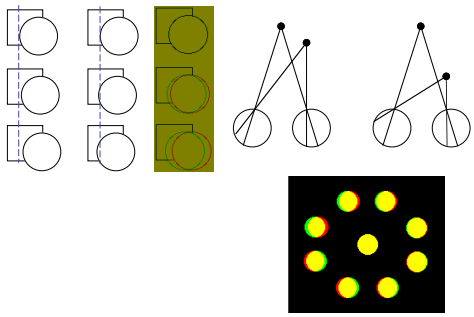




The horopter: the locus of points in the world with zero disparity relative to fixation

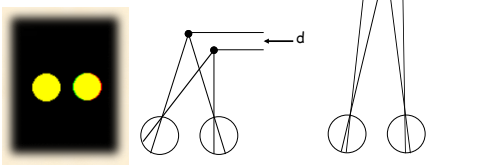


Magnitude of Disparity Signifies Depth Difference



Disparity Magnitude Also Varies with Viewing Distance

Stereopsis works only within 10 - 20 ft of the observer; once the visual axes are parallel, objects beyond the point of fixation provide no disparity. Also: disparities don't imply depth; they first must be scaled for the viewing distance.



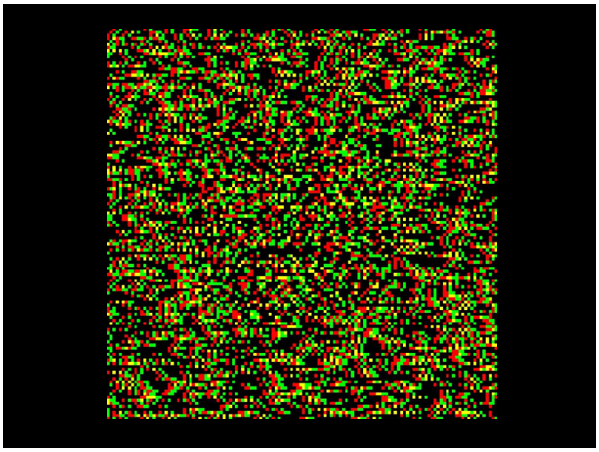
Stereoacuity: The smallest resolvable disparity

Under ideal conditions ≈ 5 arc seconds !!!

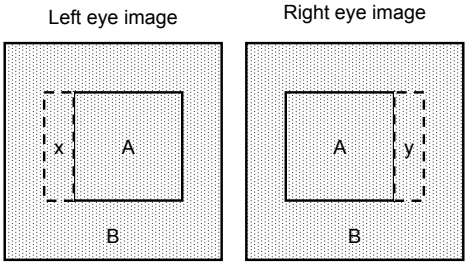
You should be able to compute what the difference in distance between two objects would need to be in order to give rise to a disparity value this small. Remember:

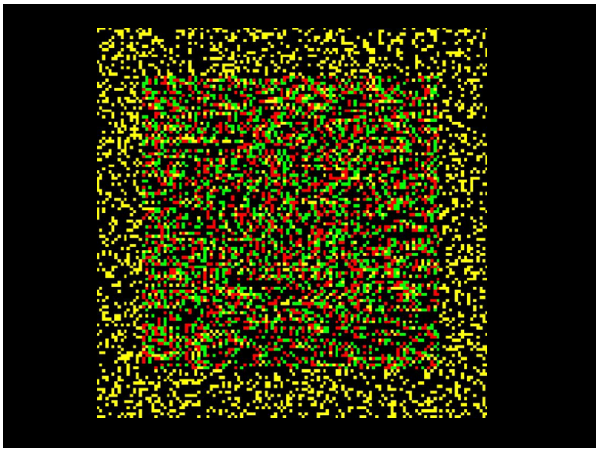
1 deg = 60 arc min

1 arc min = 60 sec



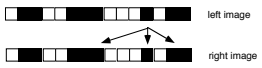
How to make a random-dot stereogram





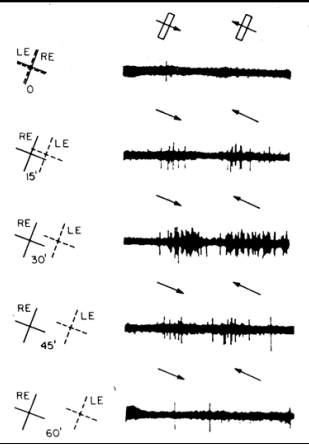
How Does the Brain "Solve" This "Correspondence" Problem?

What dot in one eye's view goes with which dot in the other eye's view?

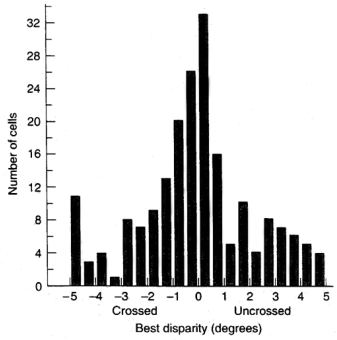


Derive the solution that maximizes the overall number of matches - i.e., that is most *globally* consistent.

Disparity selectivity in V1



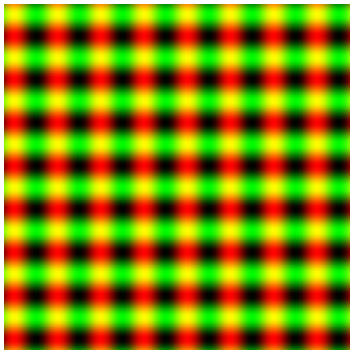
Distribution of disparity preferences



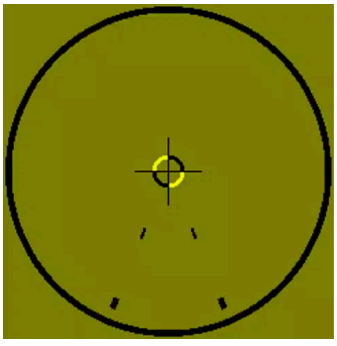
Things that can happen with 2 eyes

- Fusion
- Suppression
- Diplopia
- Rivalry

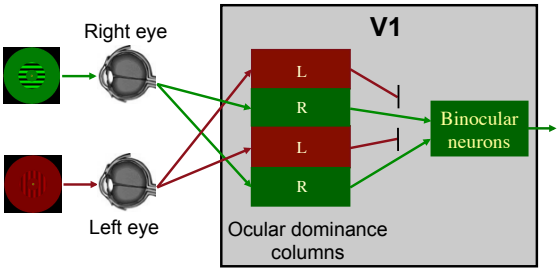
Binocular rivalry



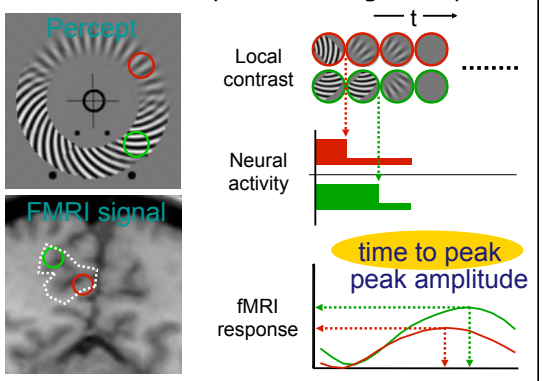
Binocular rivalry



Binocular rivalry



Predicted fMRI responses during rivalry



Wave of activity in V1 follows with percept during binocular rivalry

Depth Cue Combination

- There are these dozens of depth cues we have reviewed
- Yet, you typically have only a single percept of depth (slant, shape, distance, …) for each image feature. How are the cues combined?

Depth Cue Combination

- The result of many recent studies: Humans are typically "optimal" at depth cue combination
- That is, they combine all the information from the various cues.
- Further, cues are given higher weight if they are more reliable.
- This "reliability" can change from scene to scene, or even from place to place within a single scene.