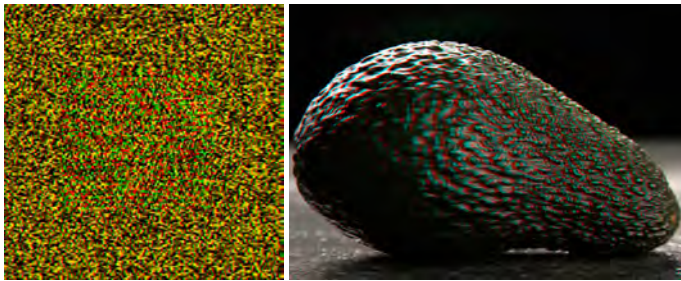


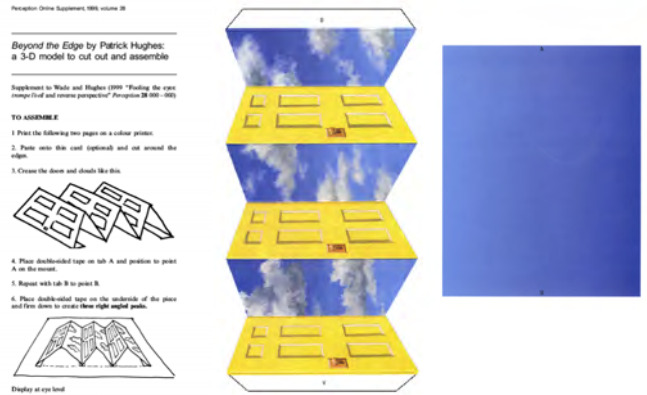
### 3D perception: Stereo vision



Glasses instructions: **Right eye green**

1

### Make your own reverse perspective...



### Pictorial depth **cues**

- Occlusion
- Size
- Perspective
  - Geometric perspective
  - Texture perspective
  - Aerial perspective
- Shading



Information provided by pictorial depth cues is not always correct!



Work by exploiting regularities of our environment, and provide **cues** about 3D shape of objects and their relative and absolute depth.

(note that *motion parallax* is not on this list!)

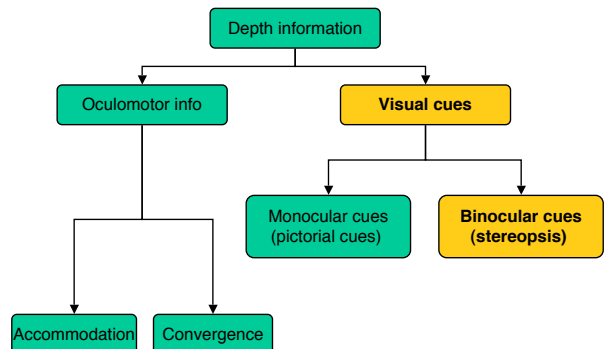
3

4

Information provided by pictorial depth cues is not always correct!



### Solving the inverse problem **exactly**: Stereo vision (stereopsis)



6

## Basis of stereoscopic vision

**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

1. **Perception of stereo depth** requires two 2D images taken from slightly different positions, and presented one to each eye
2. This creates **retinal disparity**, whose magnitude increases with depth differences
3. Brain has to match images from two eyes to compute depth, i.e. solve the **correspondence problem**

7

## Basis of stereoscopic vision

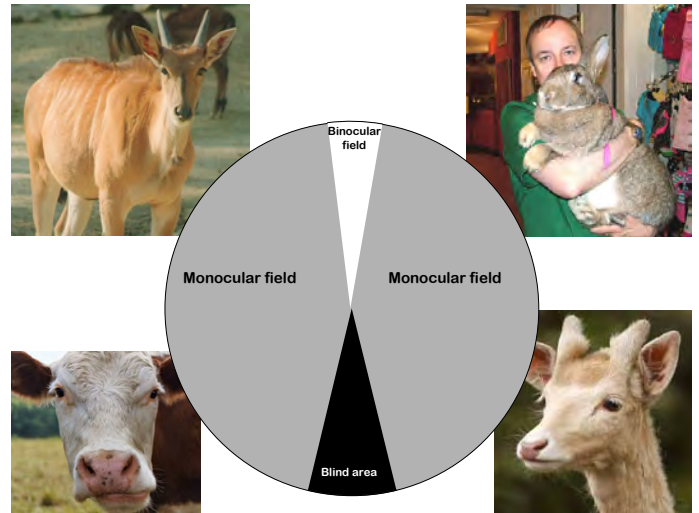
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8

Stereopsis requires two 2D images taken from slightly different positions

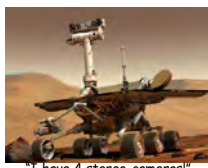
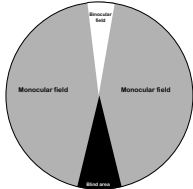


**predators** typically have both eyes on the front of their heads, and consequently have large binocular visual fields. In contrast, **prey** typically have one eye on either side of their heads, and consequently have small, if any, binocular visual fields

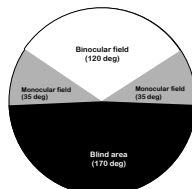


"So what, I see almost everything around me"

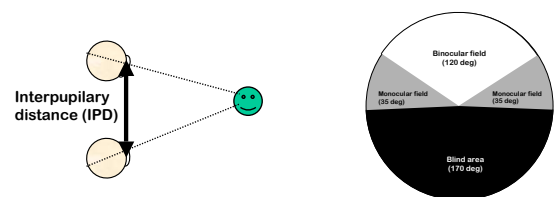
"I have better depth perception"



"I have 4 stereo-cameras!"

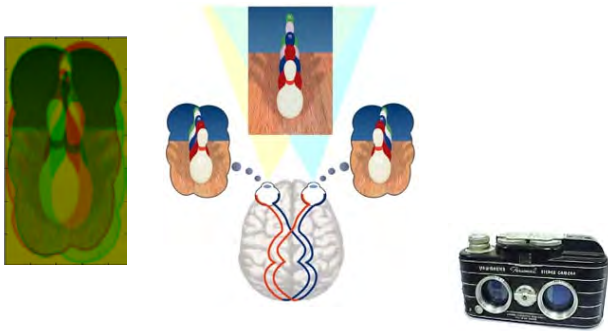


Stereopsis requires two 2D images taken from slightly different positions



12

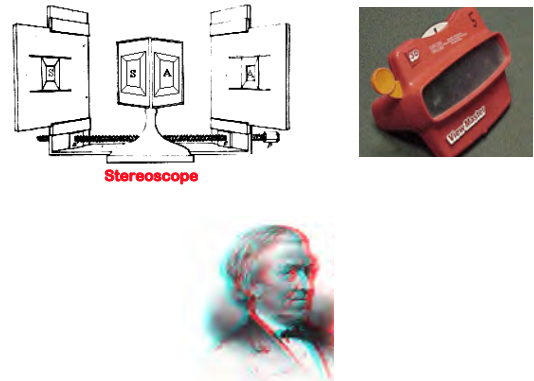
Stereopsis requires two 2D images taken from slightly different positions



Glasses instructions: Right eye green

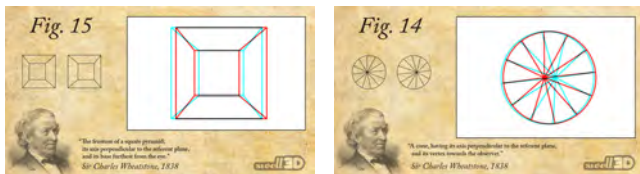
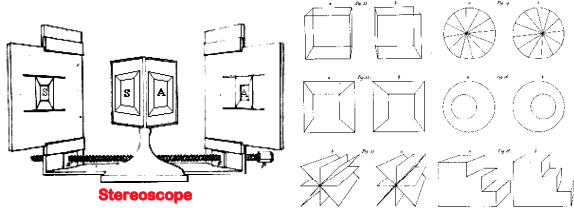
How do we know that having two images taken from slightly different positions is **sufficient** for stereopsis (i.e., 3D vision)?

### Sir Charles Wheatstone's Famous Invention



How do we know that having two images taken from slightly different positions is **sufficient** for stereopsis (i.e., 3D vision)?

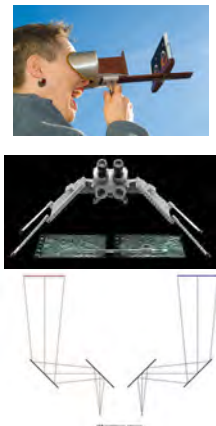
### Sir Charles Wheatstone's Famous Invention



Glasses instructions: Right eye green

Different ways of providing 2 images taken from slightly different positions

- Opening your eyes
- Stereoscope
- Anaglyph glasses
- Polarized glasses
- Active shutter glasses
- Eye crossing
- Autostereograms
- ????



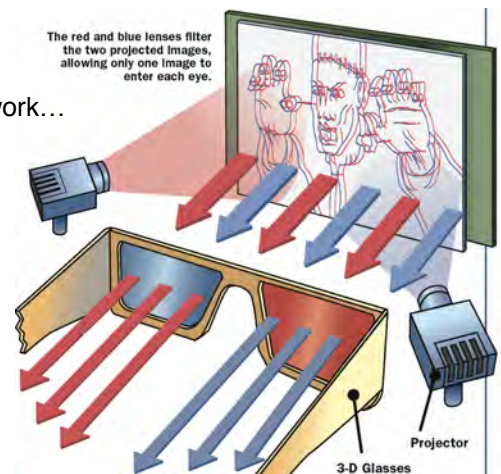
Stereopsis requires two 2D images taken from slightly different positions

### Anaglyph glasses

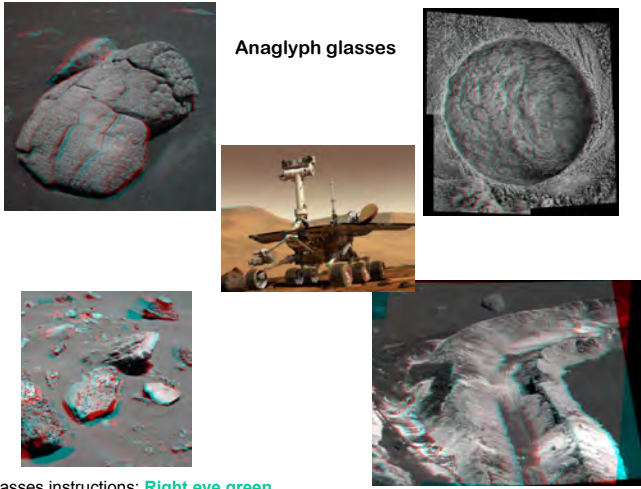


Glasses instructions: Right eye green

### Anaglyphs How they work...

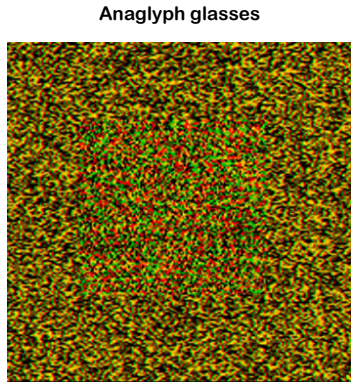


Anaglyph Stereograms - Blue/Red shown, Green/Red anaglyphs were used in class



Anaglyph glasses

Glasses instructions: Right eye green



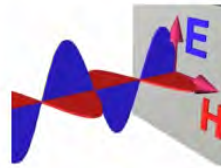
Anaglyph glasses

Glasses instructions: Right eye green



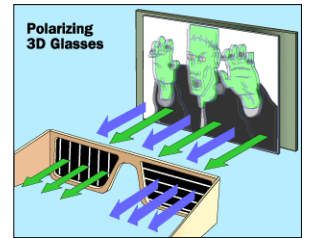
Anaglyph glasses

Glasses instructions: Right eye green



Light waves involve oscillations in electric and magnetic fields

Polarized glasses



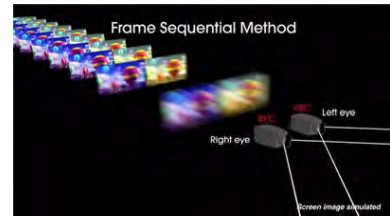
Polarized lenses only pass light whose oscillations are oriented in a particular direction

Active shutter glasses

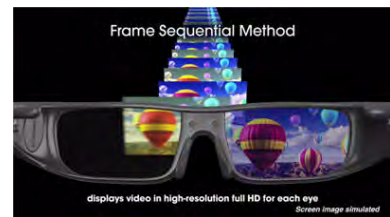


Active shutter glasses

Filming



Displaying

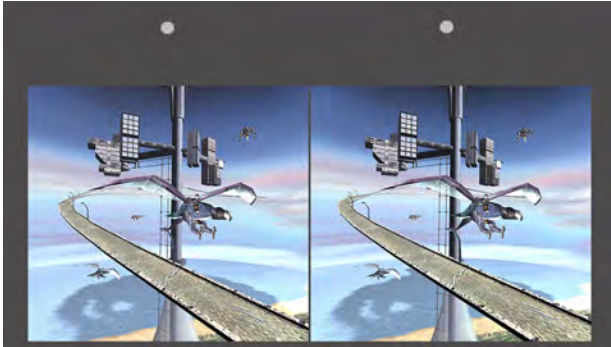


displays video in high-resolution full HD for each eye

It is possible to experience stereopsis by crossing (or diverging) your eyes to make the images visually fuse.

The following two examples are designed for convergent viewing. To see the stereo effect you must cross your eyes (i.e., converge to a point in front of the image) so that you see three equally wide panels.

(most will find this to be quite difficult or impossible)



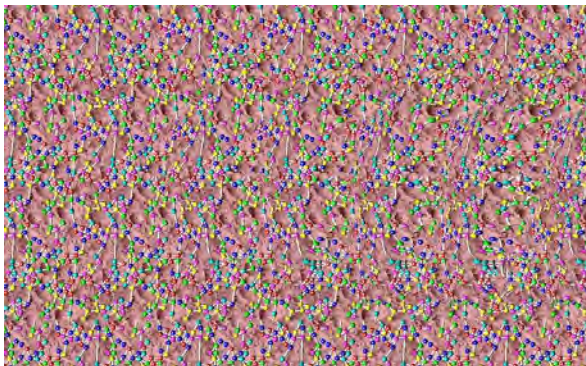
Stereopsis requires two 2D images taken from slightly different positions  
**An exception (that proves the rule)**



autostereogram (Magic Eye)

The following autostereogram (Magic Eye) is designed for divergent viewing. In order to see it correctly you must point your eyes to a point that is behind the image. If you do this correctly you will see two star shaped donuts floating in front of the background. It helps to have a visible object behind the monitor to help you focus your attention.

(If instead you see a surface with spikes sticking out then you have fused it by converging your eyes rather than divergence)



Different ways of providing 2 images taken from slightly different positions



- Opening your eyes
- Stereoscope
- Anaglyph glasses
- Polarized glasses
- Active shutter glasses
- Eye crossing
- Autostereograms
- ????



### Basis of stereoscopic vision

**Stereopsis** (literally, "seeing solid"):

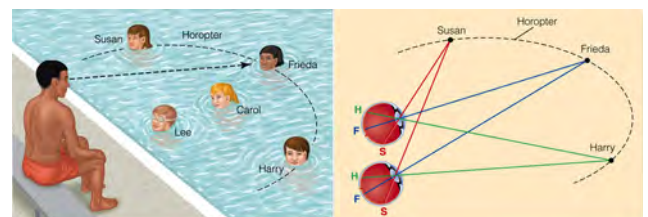
3D vision resulting from slight differences in left and right eye images, arising because the two eyes view the world from slightly different perspectives

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2. This creates **retinal disparity**, whose magnitude increases with depth differences
3. Brain has to match images from two eyes to compute depth, i.e. solve the **correspondence problem**

**Retinal disparity**: a slight separation between retinal images of objects in left and right eyes.

Retinal disparity depends on the object's distance relative to the fixation point, and as such, it provides the **geometric basis** for stereopsis

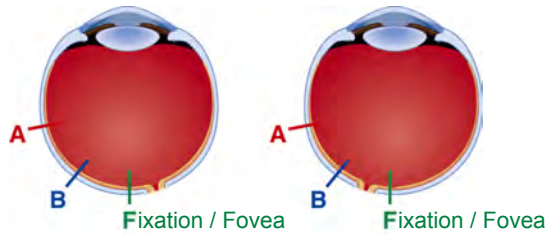
### The Horopter



A line connecting points (i.e., objects) that produce **corresponding retinal points** in the two eyes is called the **horopter**.

These objects are all at the same distance as the eye fixation point.

**Corresponding retinal points  
= NO Disparity**



Points at the same position on each eye correspond to one another – i.e. they have the same **retinal coordinates**.

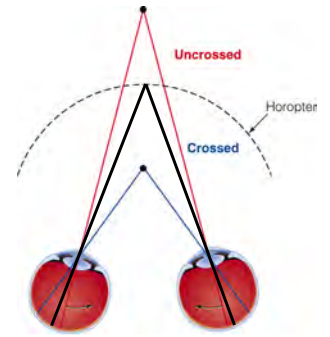
**Non-corresponding retinal points  
= Retinal Disparity**

Objects that are not on the horopter will be projected to **non-corresponding** points on the two retinas.

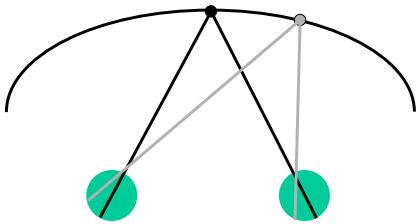
The direction of the disparity indicates whether an object is:

**in front of the horopter  
(crossed disparity)**

**or behind the horopter  
(uncrossed disparity).**



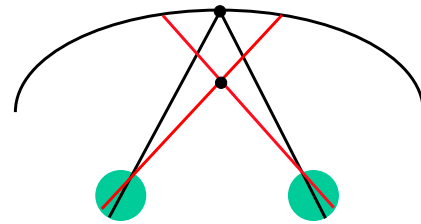
**Retinal Disparity**



**Zero Disparity** – right eye's image and the left eye's image are at the same location. Point is located on the horopter (ie., fixation plane). 33

**Retinal Disparity**

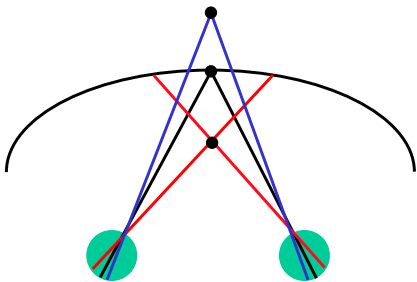
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**Retinal Disparity**

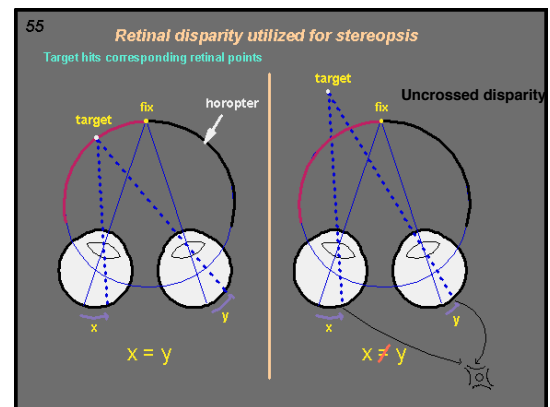
**Crossed Disparity** – Point is in front of the fixation plane.  
**Uncrossed Disparity** – Point is behind the fixation plane.



**Zero Disparity** – right eye's image and the left eye's image are at the same location. Point is located on the horopter (ie., fixation plane). 35

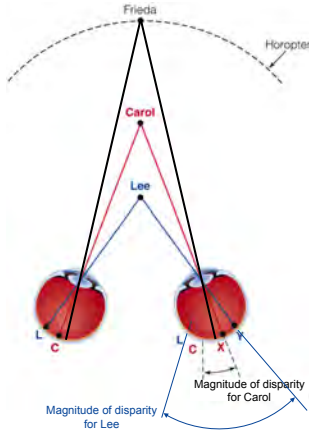
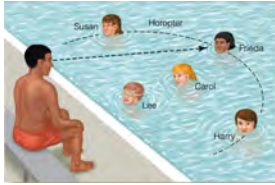
**Retinal Disparity**

Disparity - slight differences in positions of "features" in left and right eye views  
**(Disparity is a geometric fact!)**



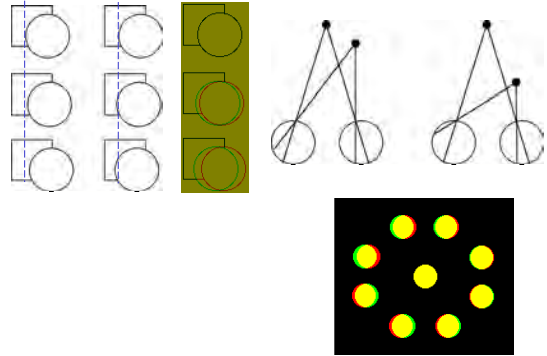
# Retinal Disparity = information about depth

The magnitude of disparity for any given point is defined as the difference in retinal coordinates between the optical projections of that point in the left and right eye.

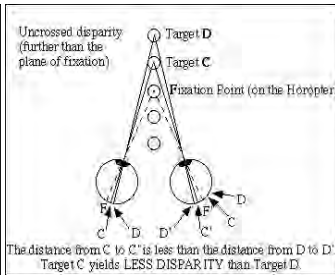
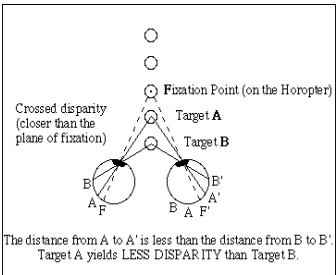


# Retinal Disparity = information about depth

Glasses instructions: **Right eye red**



# Retinal Disparity = information about depth

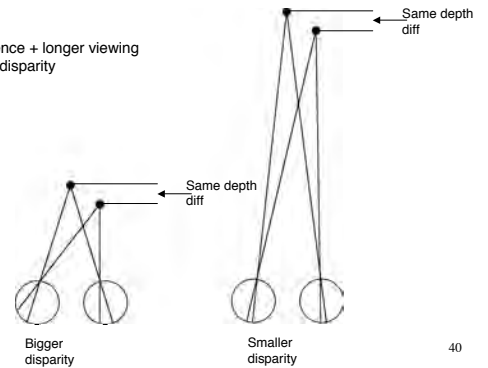


# Retinal Disparity is RELATIVE

Disparity information provides information about **relative depth**

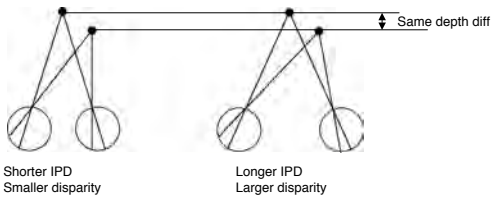
**stereopsis works only within 10 - 20 ft of the observer**

Same depth difference + longer viewing distance = smaller disparity



# Retinal Disparity is RELATIVE

Disparity depends on IPD



"ipd" = interpupillary distance (averages 6.5 cm in humans)

# Stereoacuity

The smallest resolvable disparity

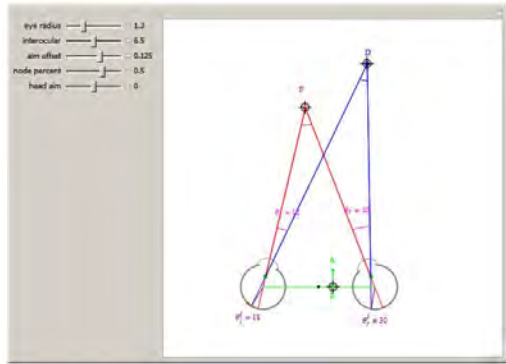


Under ideal conditions = 5 arc seconds !!!

how much/little is 5 arc sec?  
 -view your index finger at arms length  
 - 5 arc sec = about 1/500 finger width

Glasses instructions: **Right eye red**

# Retinal Disparity DEMO



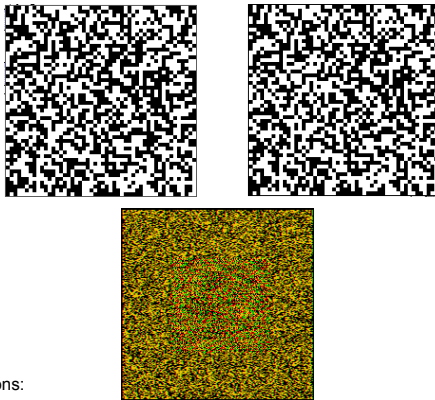
<http://demonstrations.wolfram.com/EyeParametersVisualDepthPerception6/>

# Basis of stereopsis

1. Perception of stereo depth requires two 2D images taken from slightly different positions, and presented one to each eye
2. This creates **retinal disparity**, whose magnitude increases with depth differences
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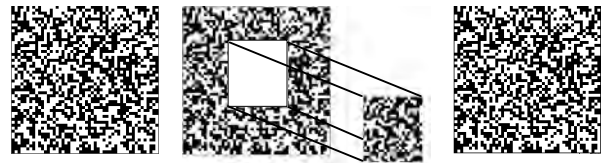


## Let's make it hard! Random-dot Stereograms (Julesz, 1971)



Glasses instructions:  
Right eye red

## How They're Made

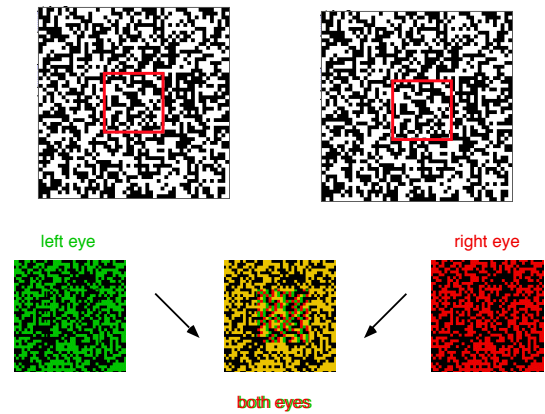


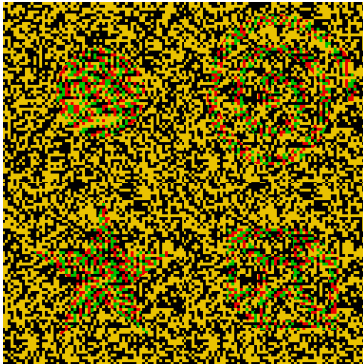
Let's make one...



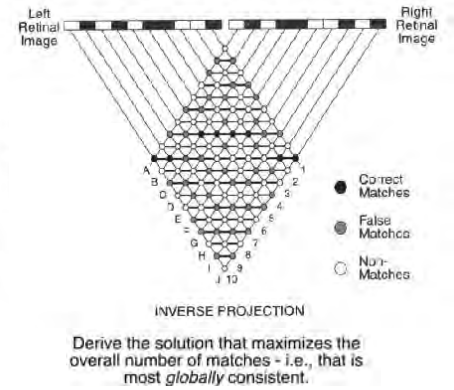
Glasses instructions: Right eye red

Let's make one...

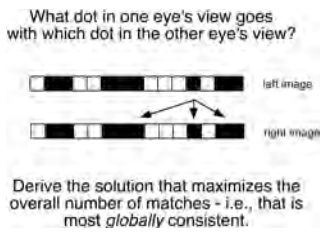




### How Does the Brain “Solve” This Problem?



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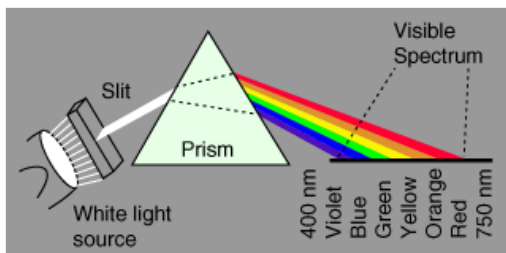


### Basis of stereopsis

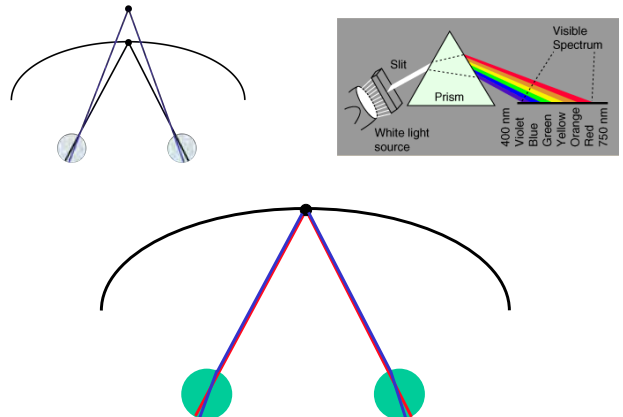
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### Chromostereopsis



### Chromostereopsis

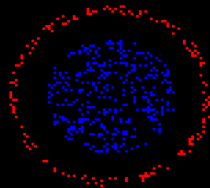


Short wave lengths refract more than long wavelengths.

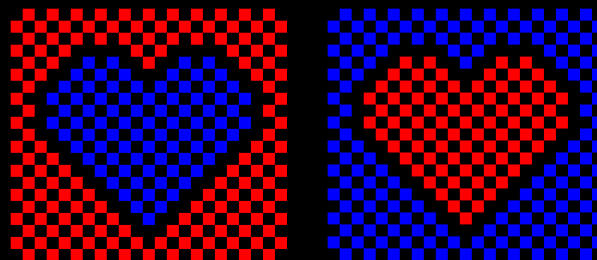
Thus, when light is refracted through the lens of the eye, blue and red light will be focused at slightly different positions on the retina (blue light toward the nose and red light toward the temple).

This creates a **disparity** between each eye's view that is perceptually interpreted as a difference in depth. <sup>53</sup>

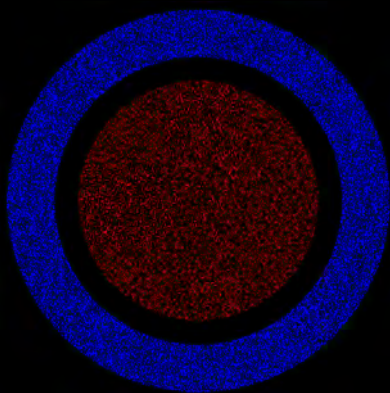
### Chromostereopsis



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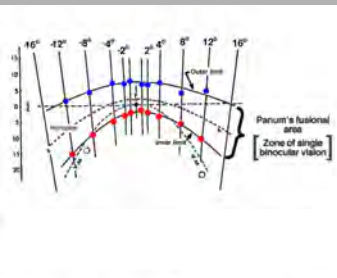
### Chromostereopsis



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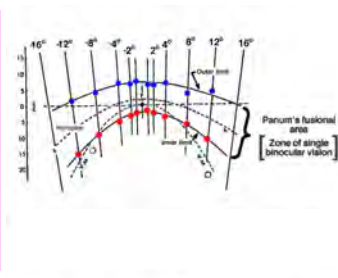
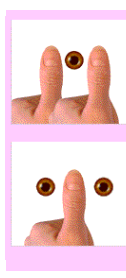


### What Happens When Binocular Matches Cannot Be Found?



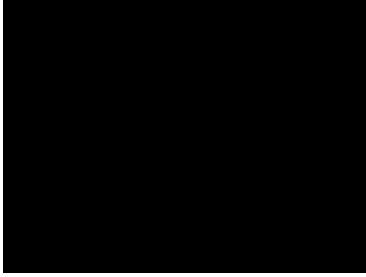
diplopia - double vision  
Can occur if the disparity is too large

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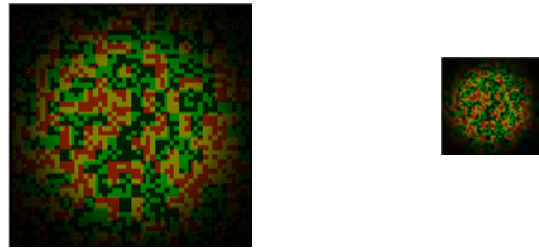
What Happens When Binocular Matches Cannot Be Found?



diplopia - double vision  
Often a consequence of traumatic brain injury

61

What Happens When Binocular Matches Cannot Be Found?



If images in two eyes are radically different, a combined stereo cannot be found  
This is a phenomenon called **binocular rivalry**

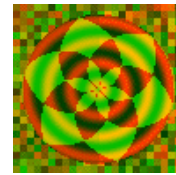
62

Binocular rivalry



63

Binocular rivalry



64

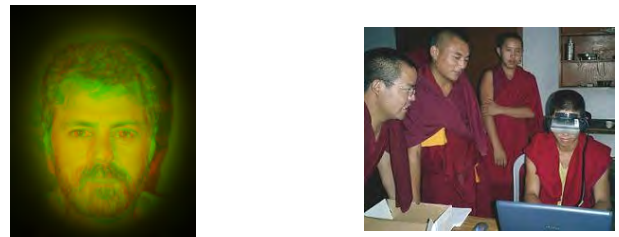
Binocular rivalry



65

Does One Eye Dominate?

Binocular rivalry



66

Can you control it?