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Lecture 08: Introduction to Stereo

Reading: T&V Section 7.1

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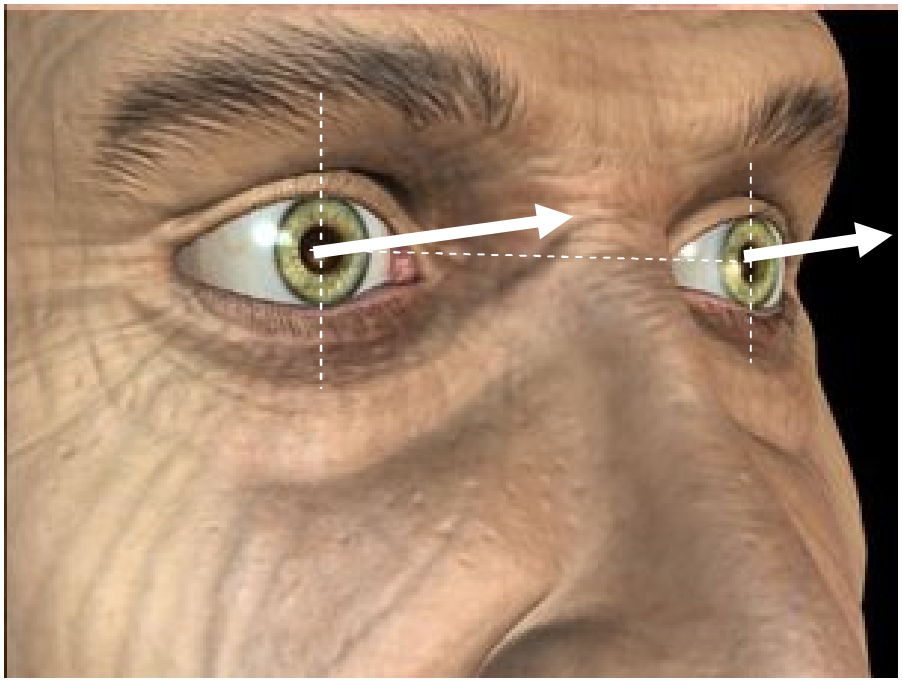
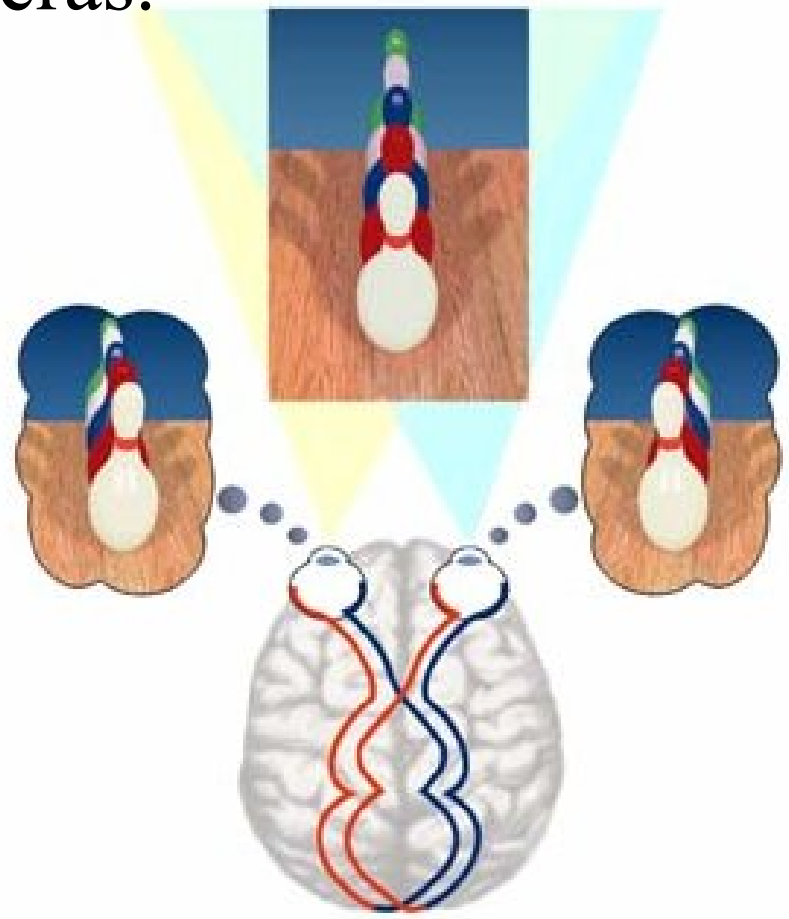
Stereo Vision

Inferring depth from images taken at the same time by two or more cameras.





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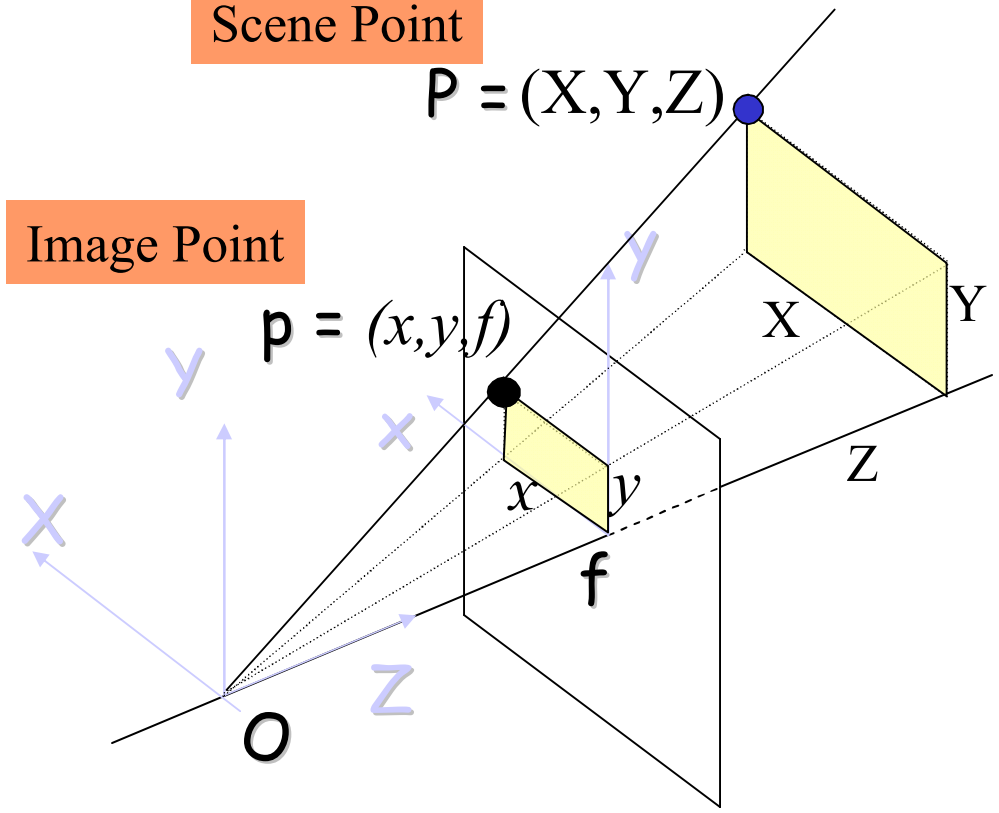
Basic Perspective Projection

Scene Point

Image Point



Perspective Projection Eqns

$$x = f\frac{X}{Z}$$

$$y = f\frac{Y}{Z}$$

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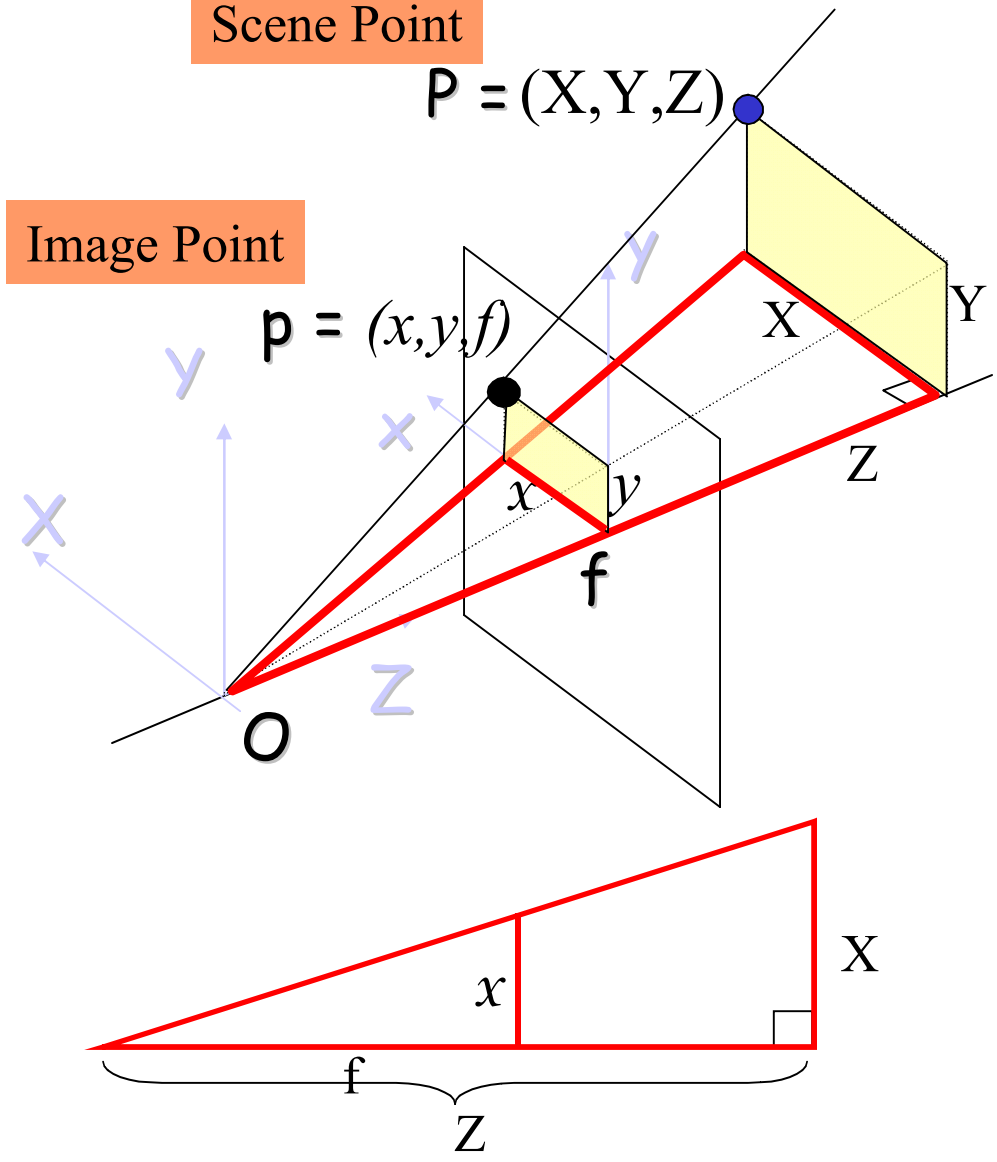
Basic Perspective Projection

Scene Point

Image Point



Perspective Projection Eqns

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Basic Perspective Projection

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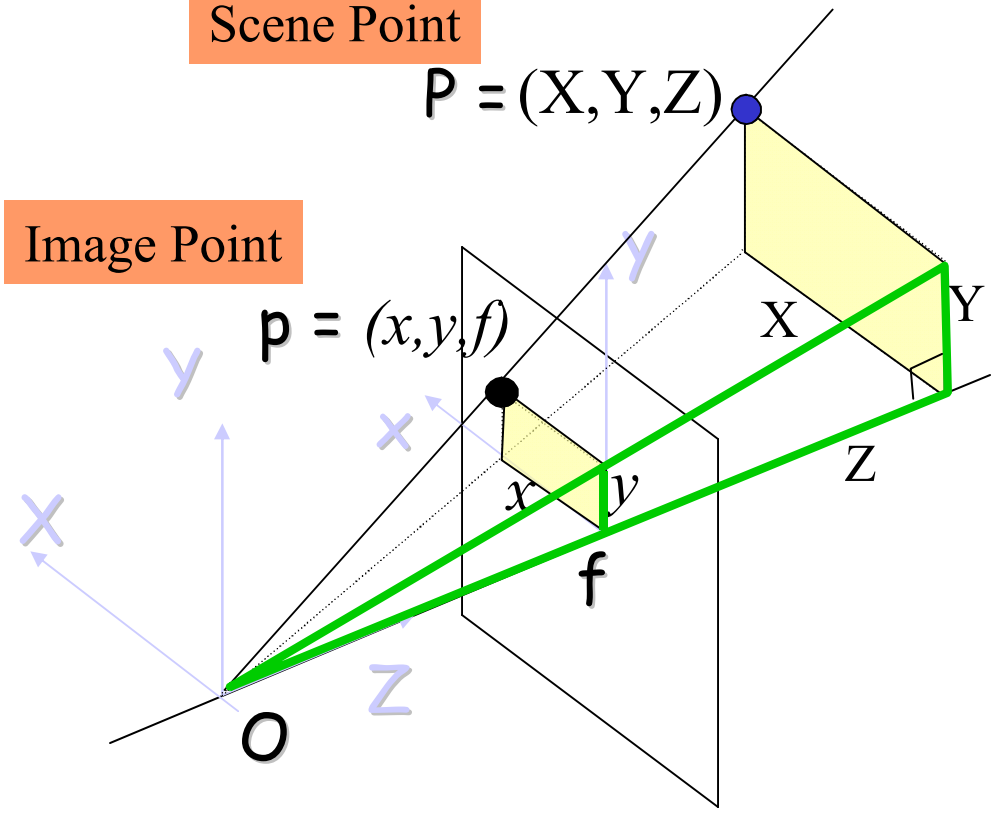
Image Point



Perspective Projection Eqns

$$x = f\frac{X}{Z}$$

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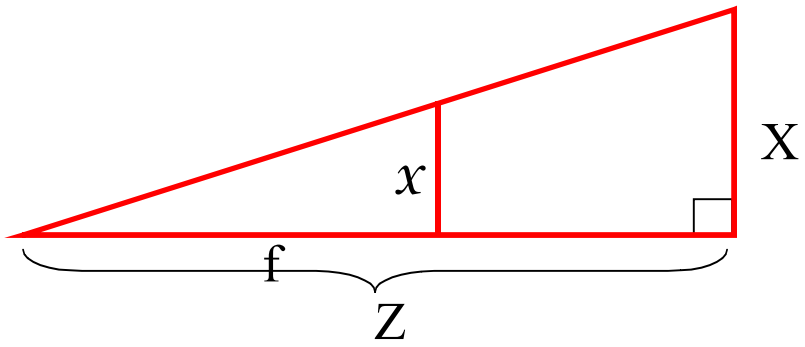

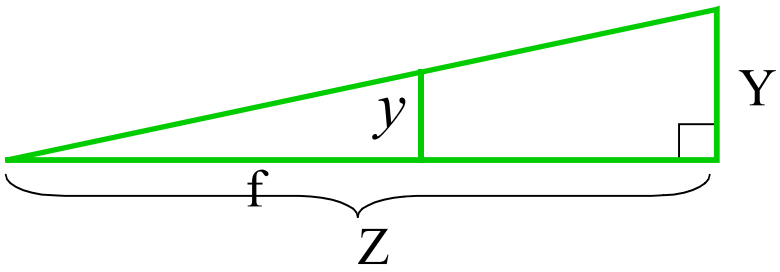

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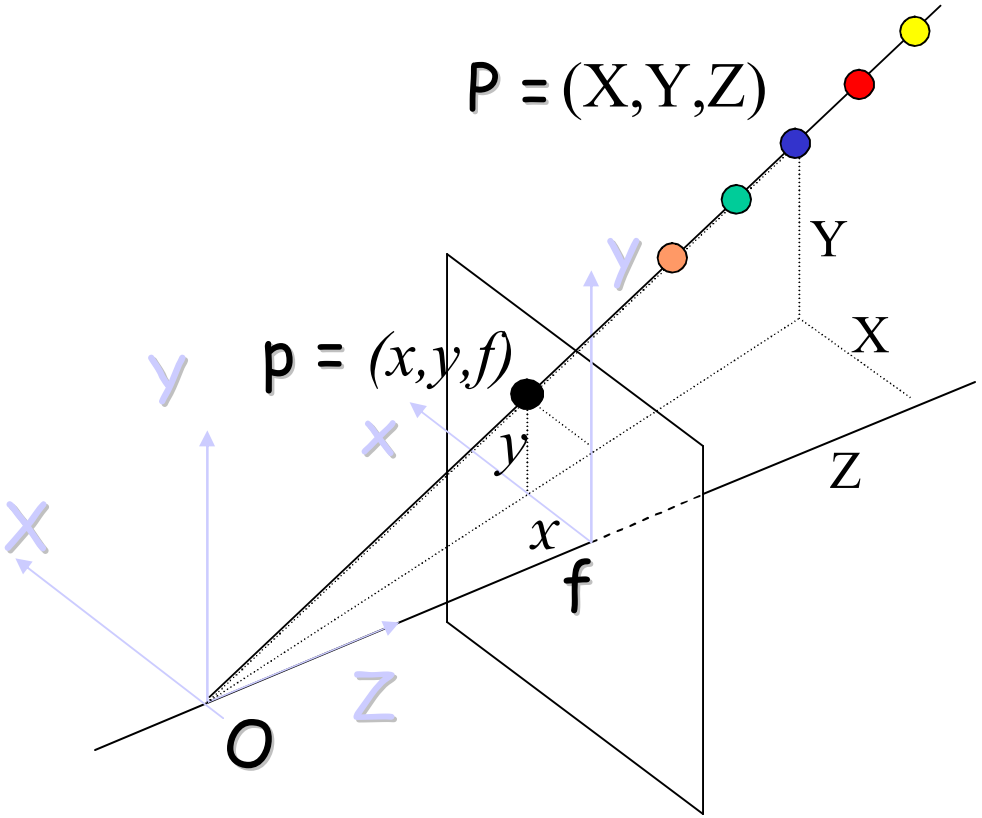
Why Stereo Vision?



$$x = f\frac{X}{Z} = f\frac{kX}{kZ}$$

$$y = f\frac{Y}{Z} = f\frac{kY}{kZ}$$

Fundamental Ambiguity:

Any point on the ray OP has image p

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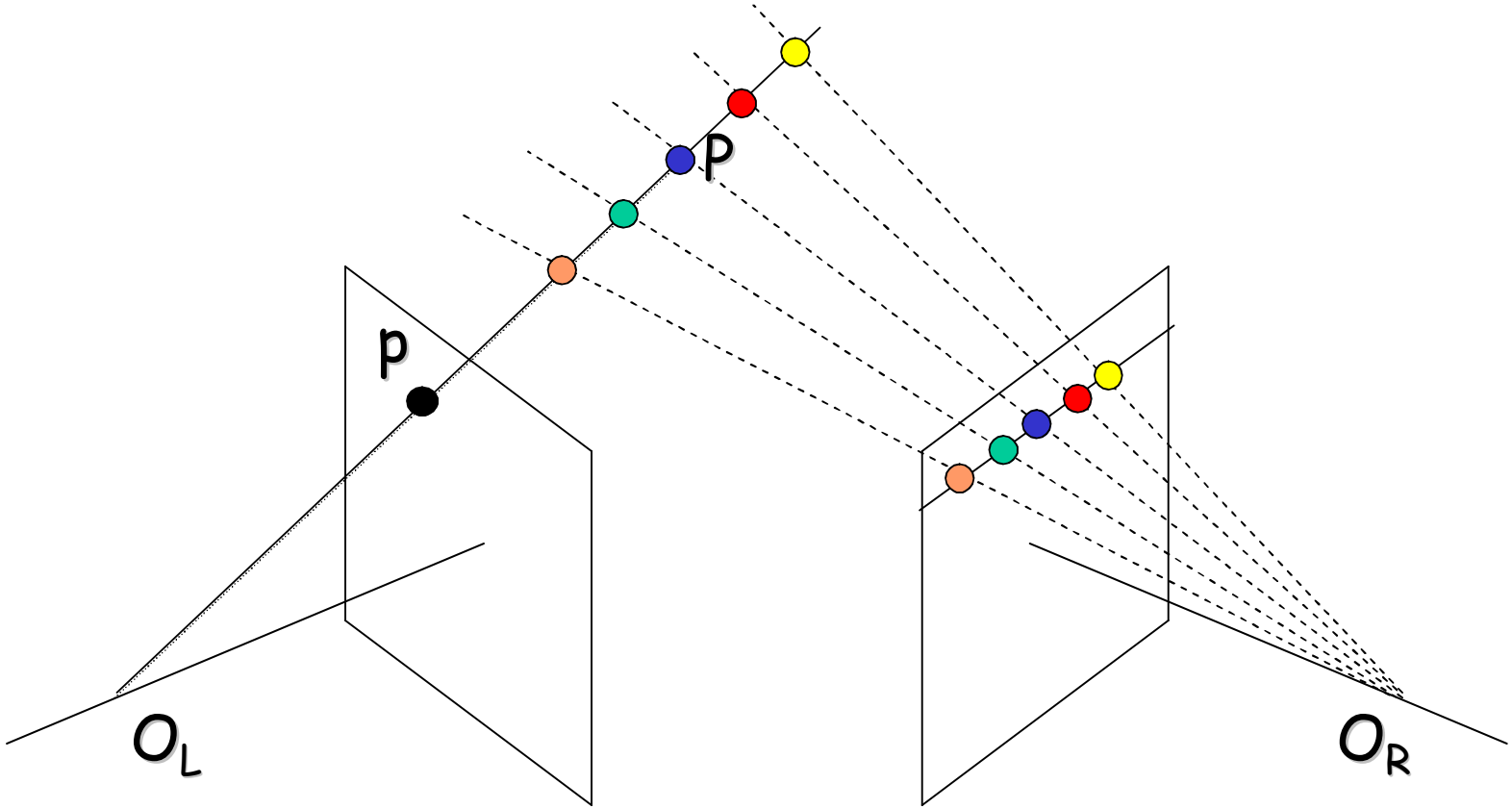
Why Stereo Vision?



A second camera can resolve the ambiguity, enabling measurement of depth via triangulation.

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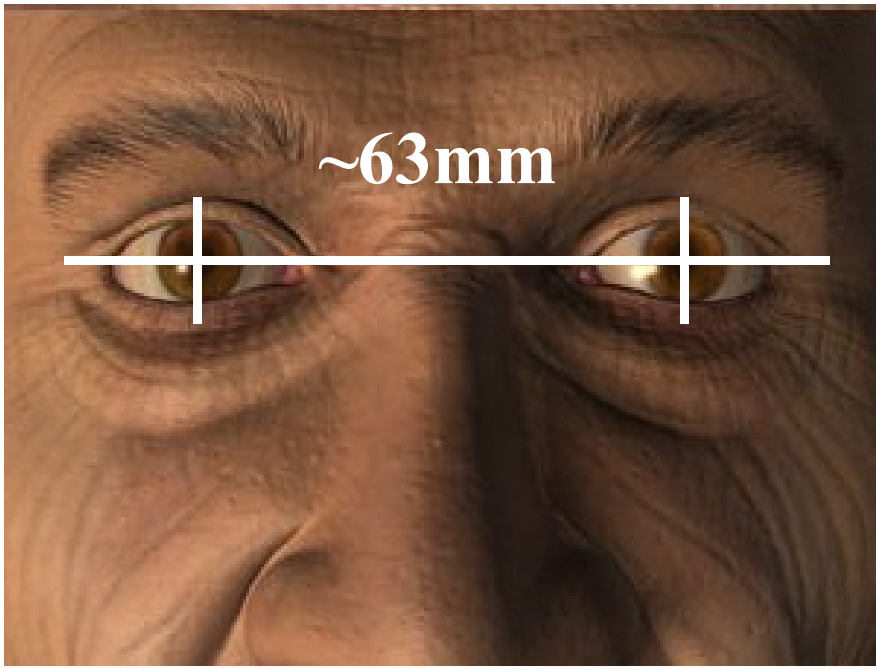
Why Stereo Vision?



Your two eyes form a stereo system

The right and left eyes see the world from slightly shifted vantage points.

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Key Concepts for Today

- Parallax
- Anaglyphs
- Random Dot Stereograms
- Mathematics of Simple Stereo

Do-it-Yourself Parallax Demo

Show:

- Points at different depths displace differently
- Nearby points displace more than far ones

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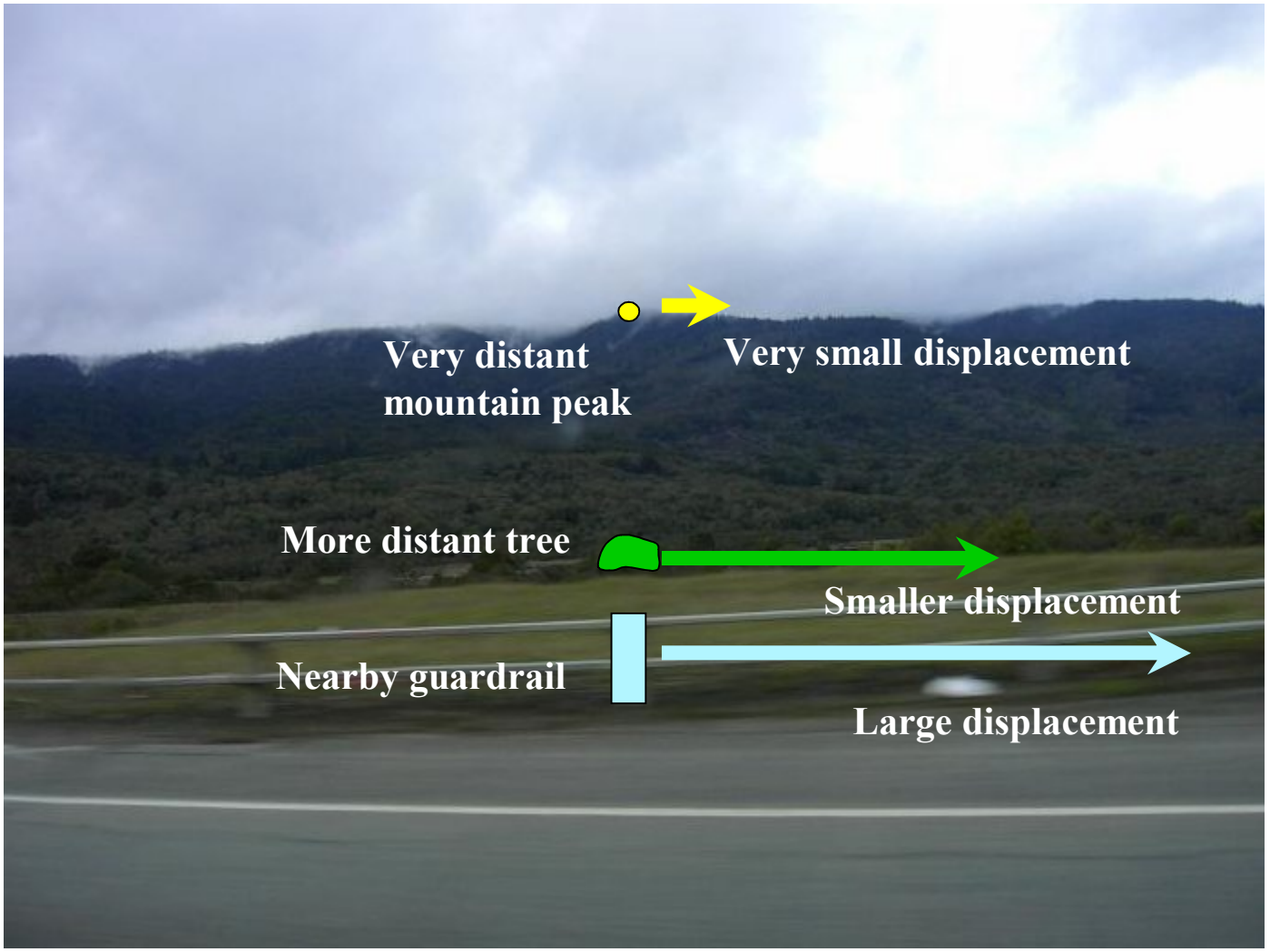
A Hitchhiker's Guide to Parallax

Parallax = apparent motion of scene features located at different distances



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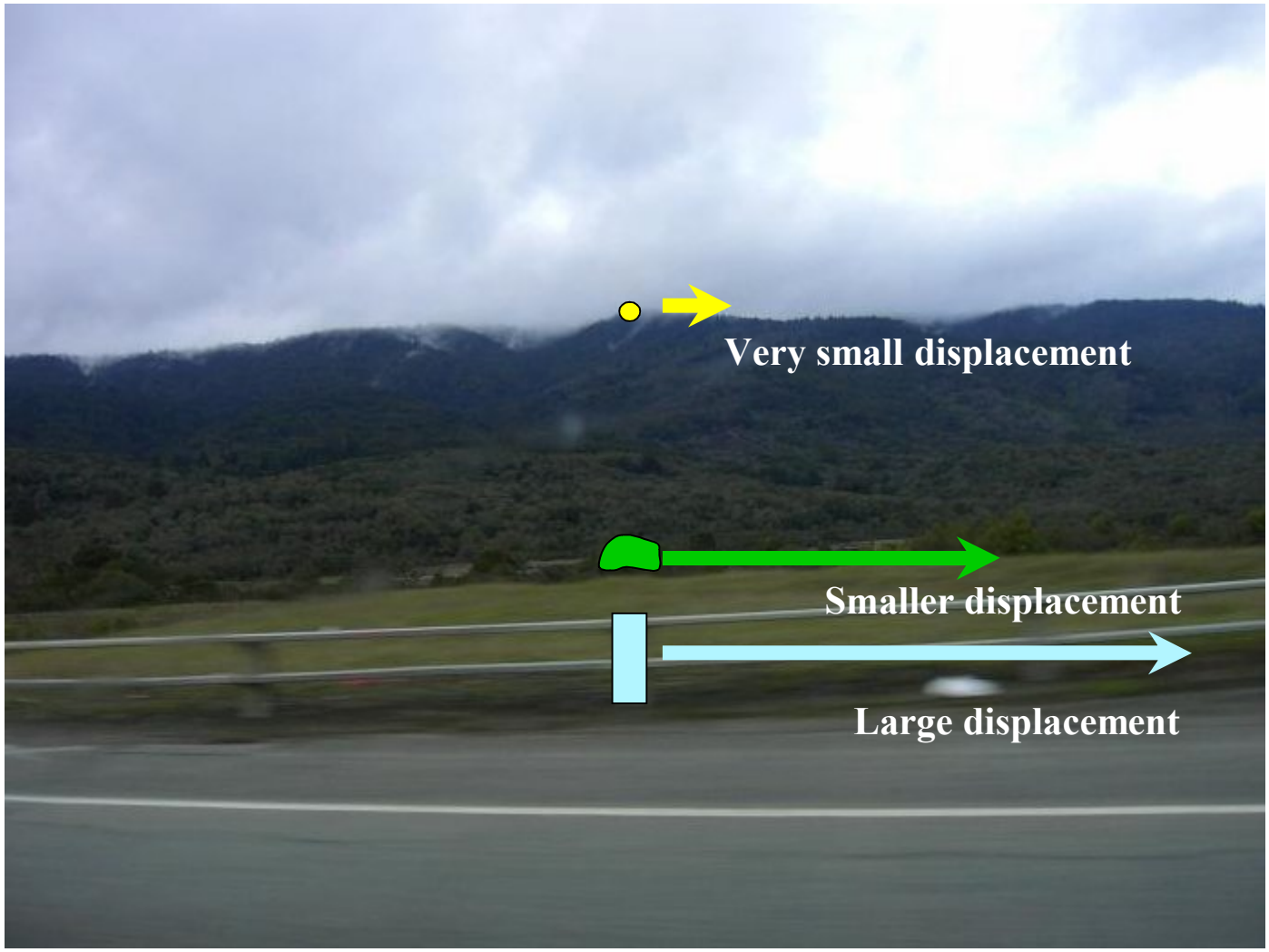
General Idea of Stereo

Infer distance to scene points by measuring parallax.



INFER

Far

Midrange

Close

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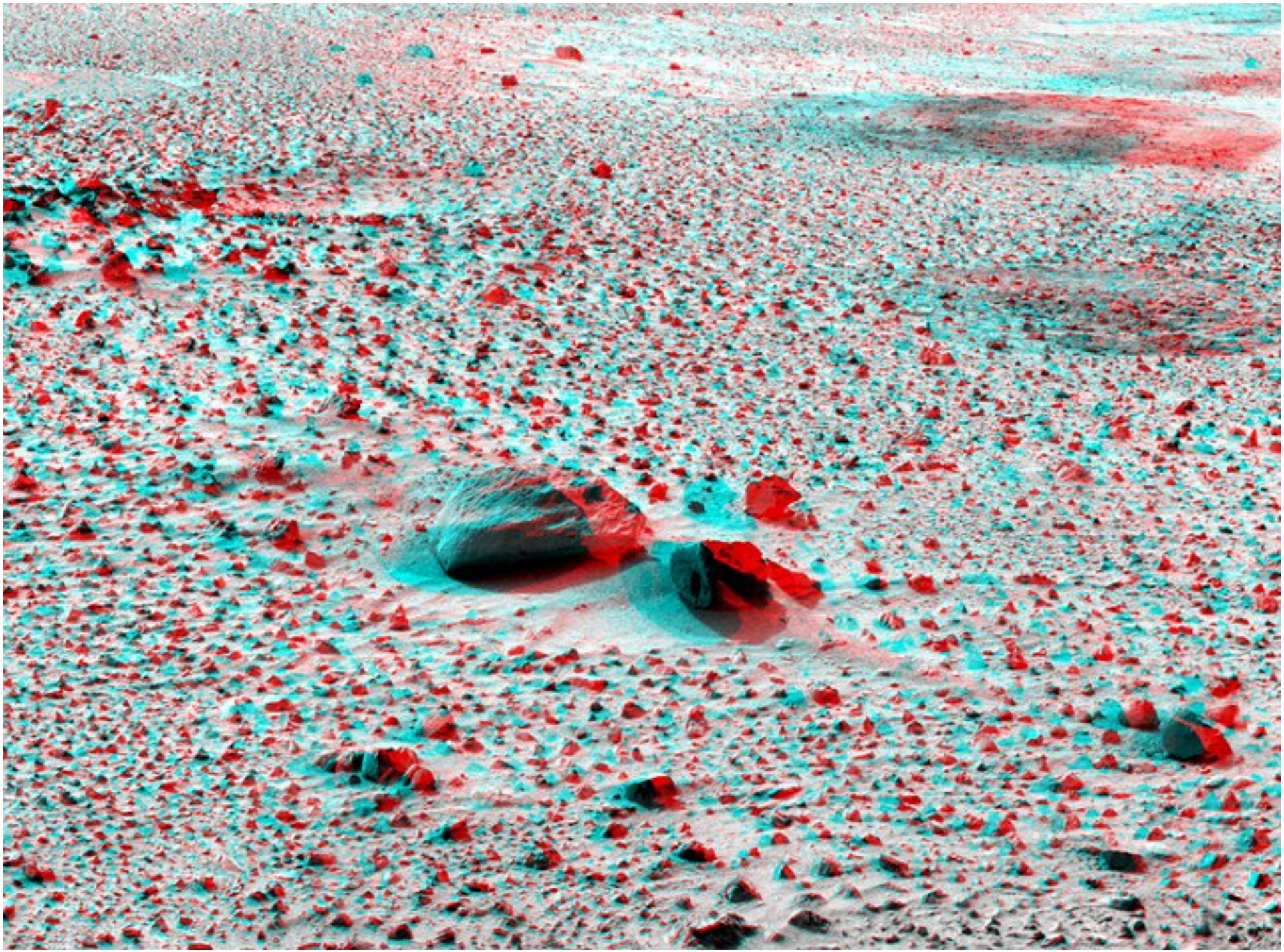
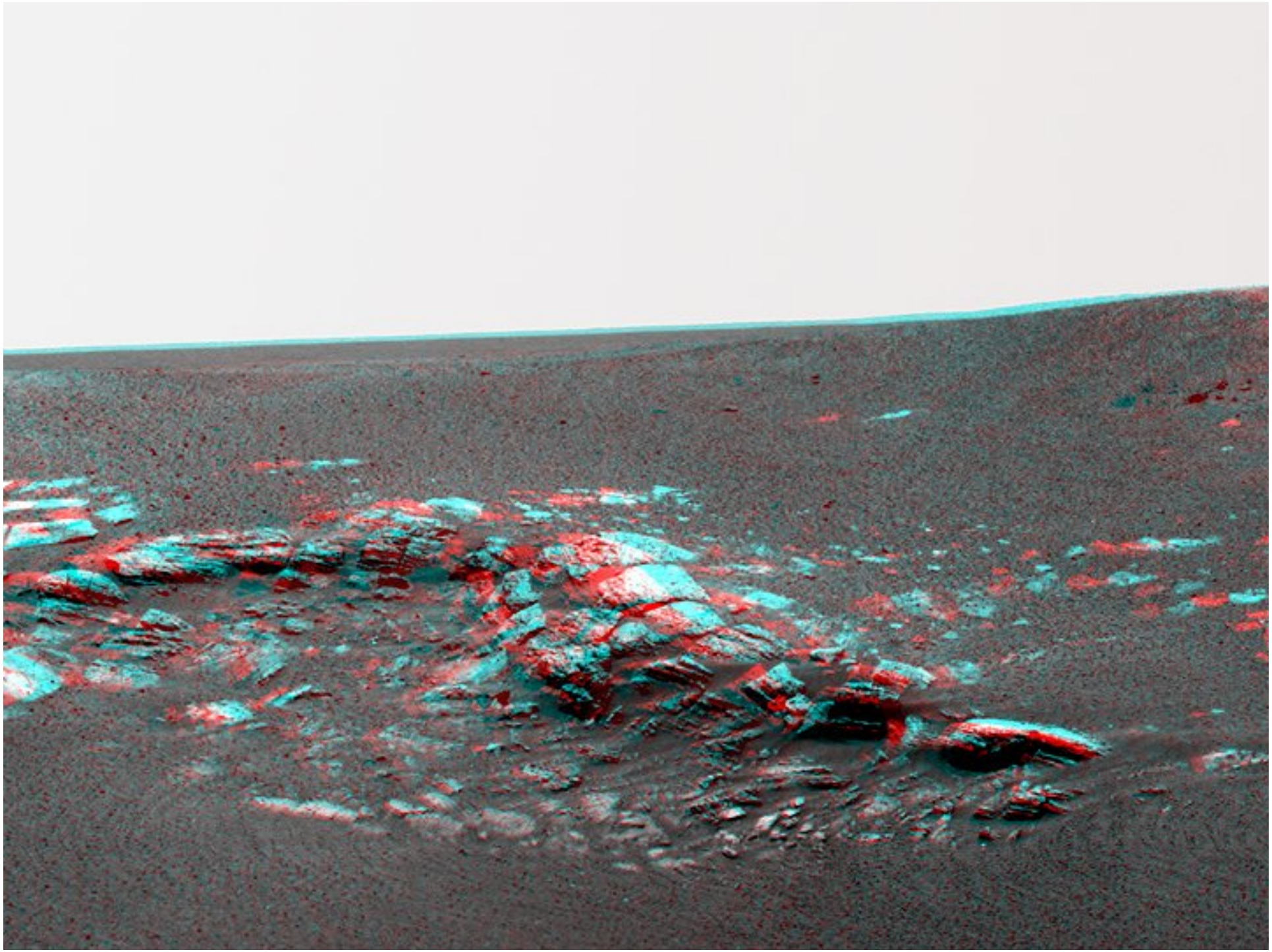
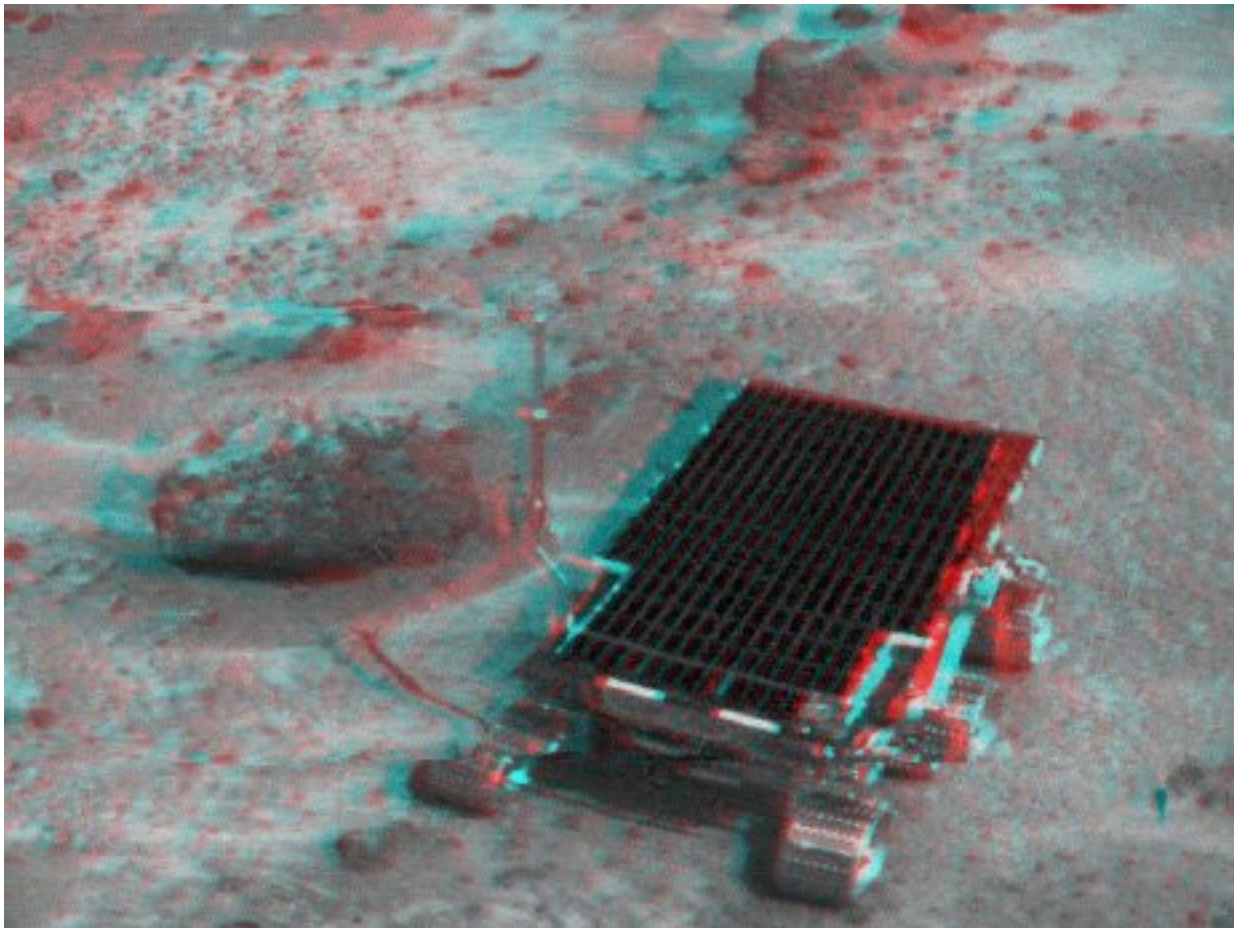
Anaglyphs

Anaglyphs are a way of encoding parallax in a single picture. Two slightly different perspectives of the same subject are superimposed on each other in contrasting colors, producing a three-dimensional effect when viewed through two correspondingly colored filters

Put red filter over left eye







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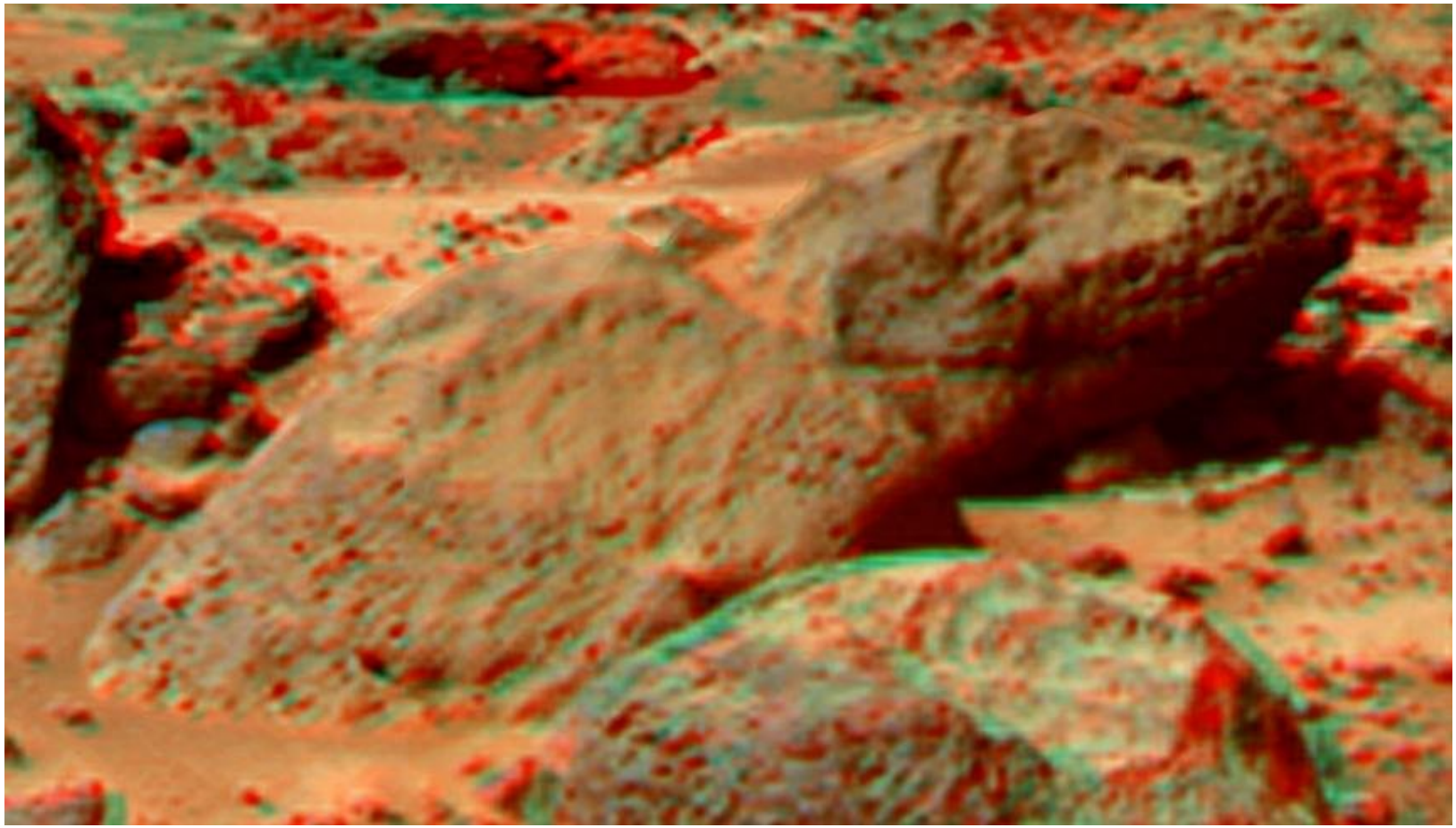

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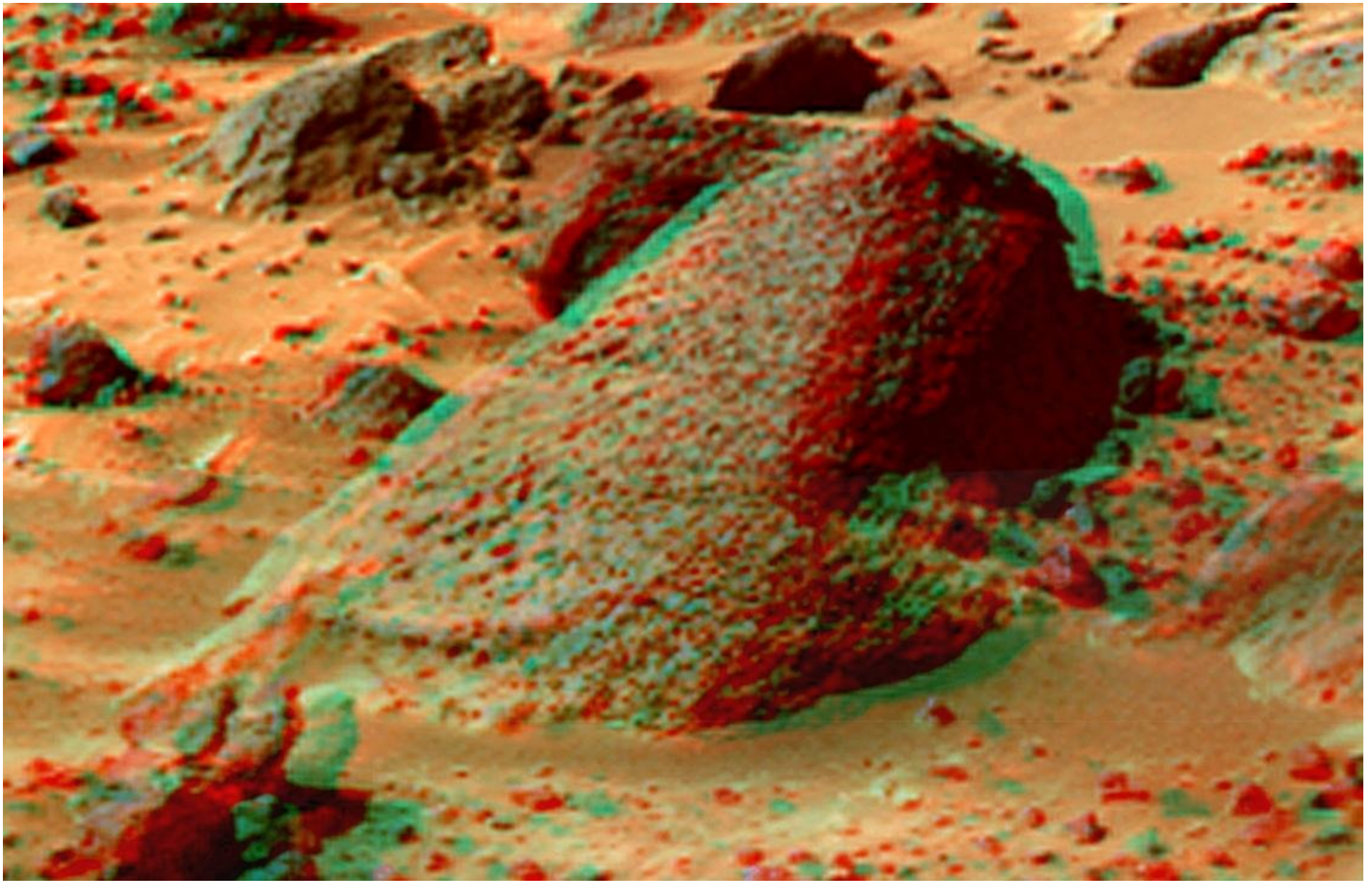

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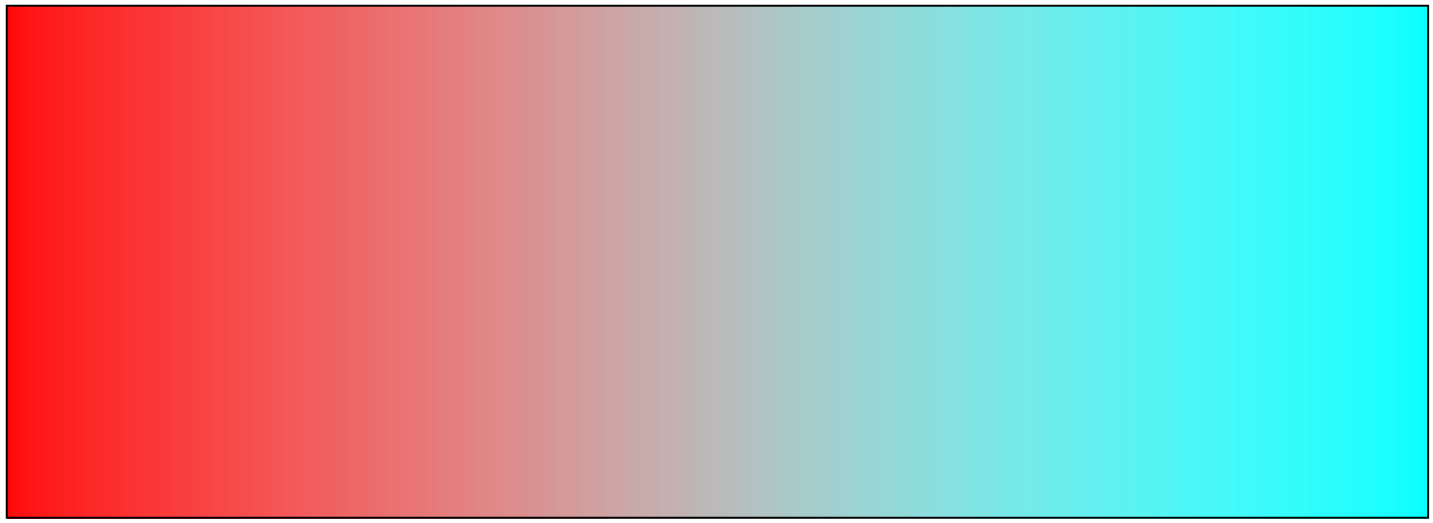
How Anaglyphs Work



Close right eye, then close left. What do you observe?

Red filter selectively passes red color, and similarly for cyan filter and cyan color.

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Making an Anaglyph

Take a greyscale stereo pair.

Copy the left image to the red channel of a new image (the anaglyph image)

Copy the right image to the green and blue channels of the anaglyph image (note: green+blue = cyan)

Now when you view with red-cyan glasses, the left eye sees only the left image, and the right eye sees only the right image. The brain fuses to form 3D.

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Stereo Pyschophysics

How does stereo depth perception work?

In particular, at what "level" in the visual system does it occur at?

An early debate: do we infer depth from higher-level information like perspective and contours, or does it occur at a much lower level?

"The basis of this three-dimensional perception was hotly debated between Wheatstone and fellow physicist Sir David Brewster. (Though it may seem odd for physicists to concern themselves with the physiology of optics, this was felt to be a natural extension of the study of the physics of optics.) Brewster opined that perspective was the source of the apprehension of an object's shape. Wheatstone insisted that the images in the each eye had identifiable landmarks that were combined to assign depth to the landmarks."

-- Ralph M. Siegel Choices: The Science of Bela Julesz

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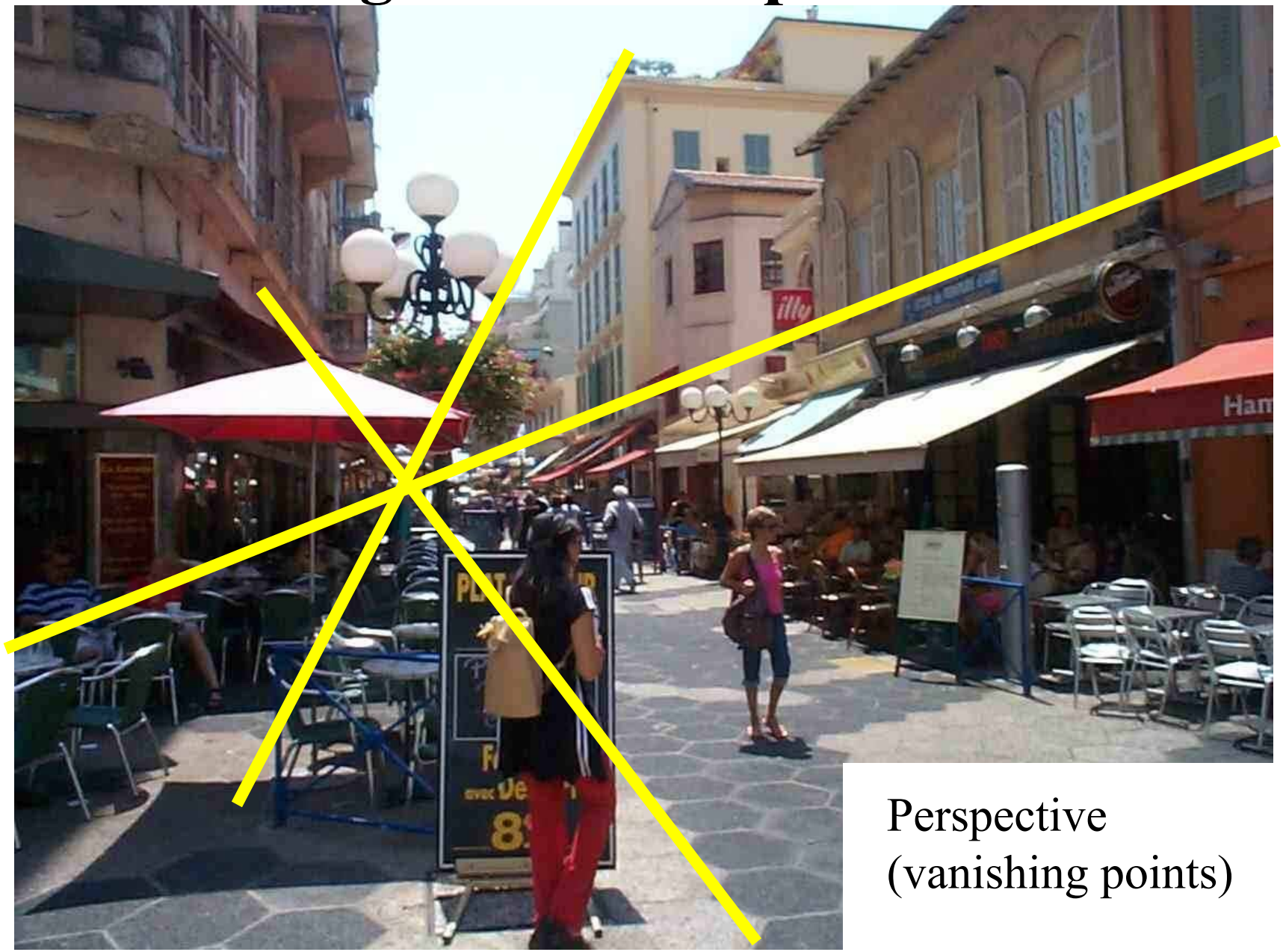
Higher-level Depth Cues



Perspective
(vanishing points)

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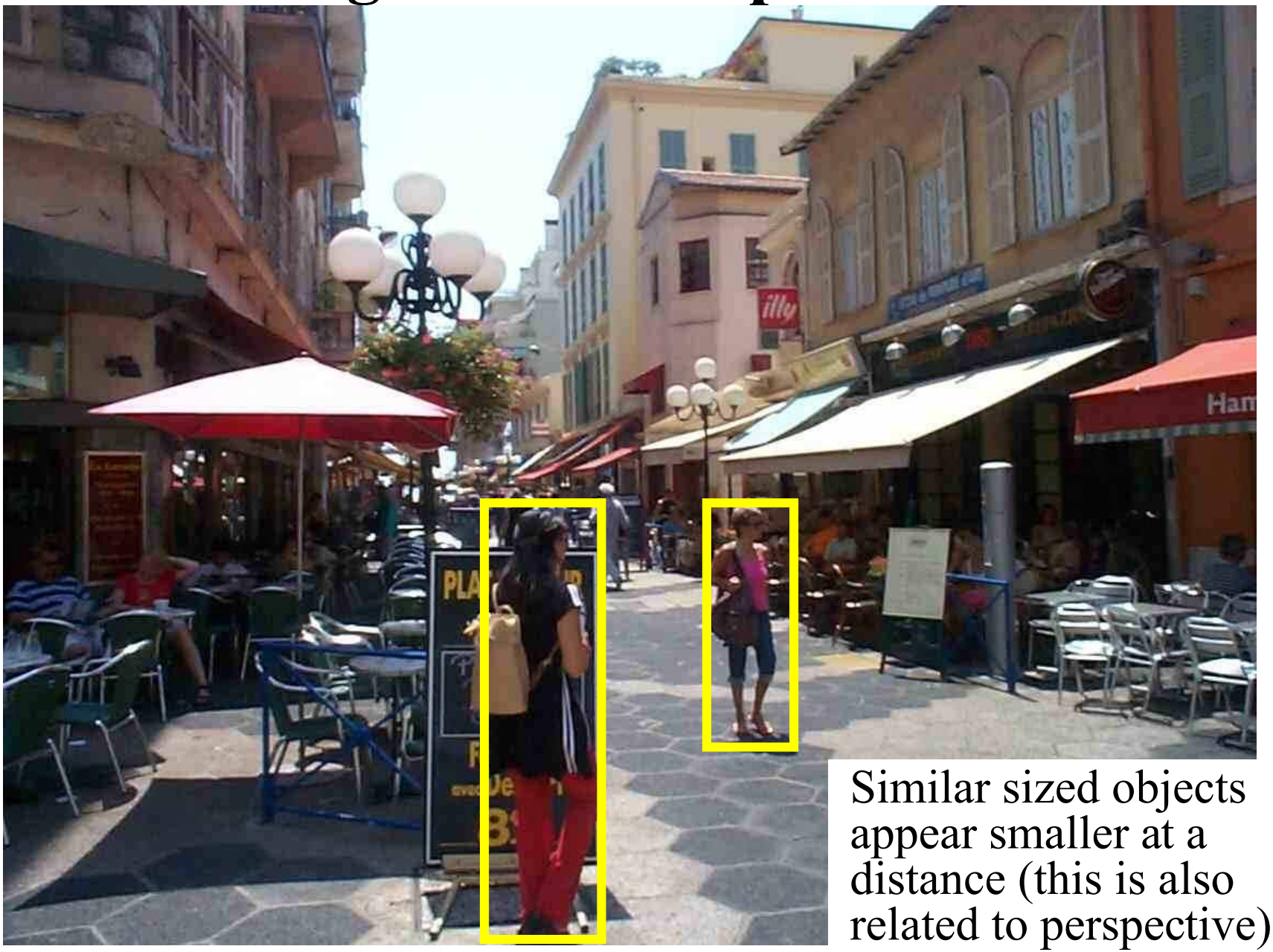
Higher-level Depth Cues



Similar sized objects appear smaller at a distance (this is also related to perspective)

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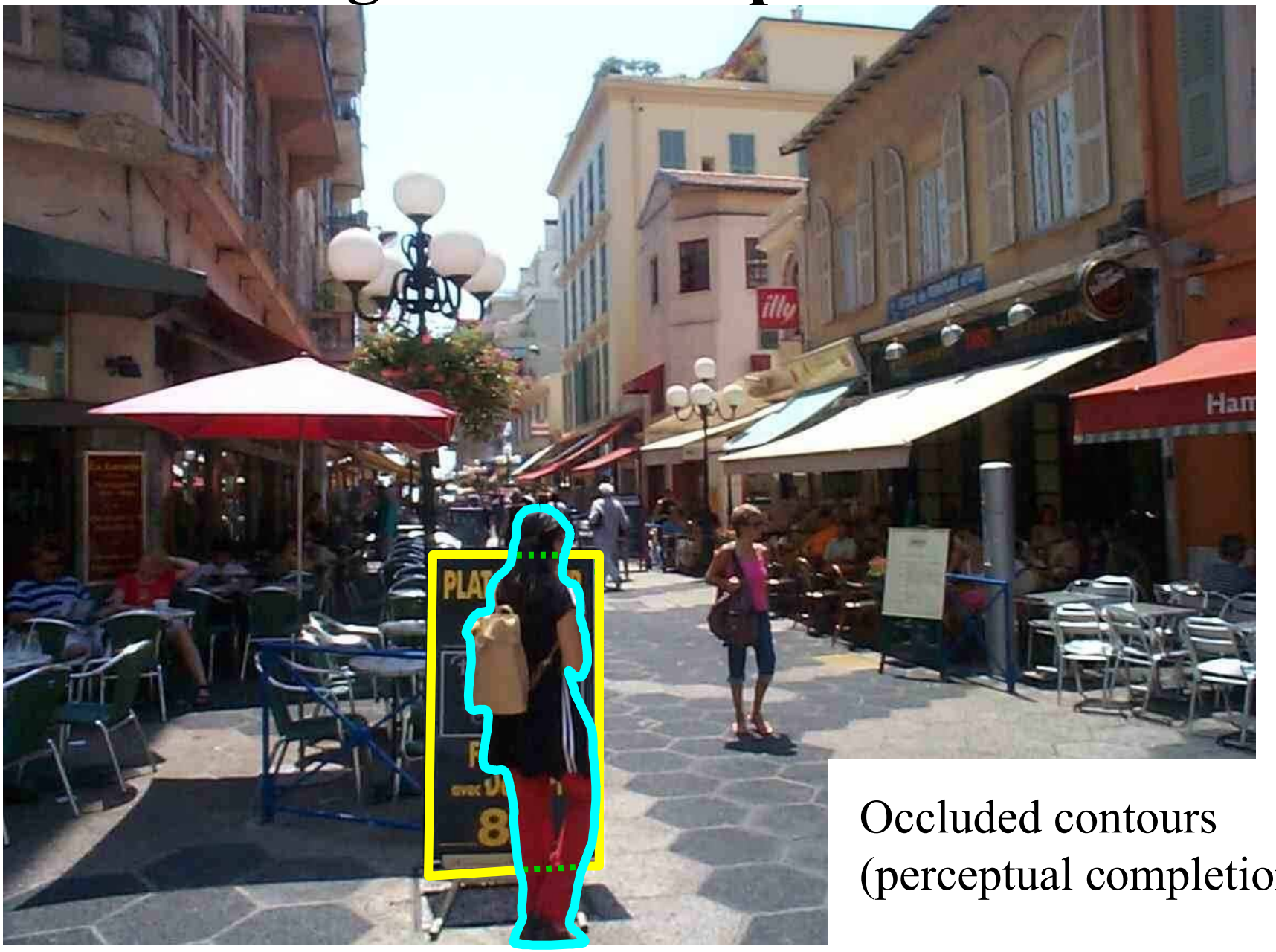
Higher-level Depth Cues



Occluded contours
(perceptual completion)

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Stereo Pyschophysics

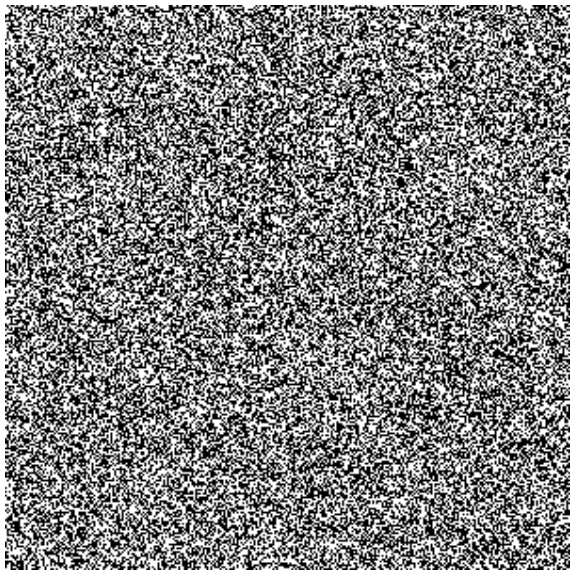
Obviously perspective and contours are important, (particularly for monocular depth perception), but are they necessary for binocular stereo depth perception?

Bela Julesz answered this question in 1960 with his experiments with random dot stereograms.

"In 1960, Bela's experiment with what eventually became known as Julesz random dot stereograms unambiguously demonstrated that stereoscopic depth could be computed in the absence of any identifiable objects, in the absence of any perspective, in the absence of any cues available to either eye alone." **-- Ralph M. Siegel** Choices: The Science of Bela Julesz

Julesz Random-Dot Experiment

Generate a random dot pattern using a computer



e.g. im = roicolor(rand(300,300), 0.5, 1);

By definition, this is just “noise”, so there are obviously no monocular depth cues here.

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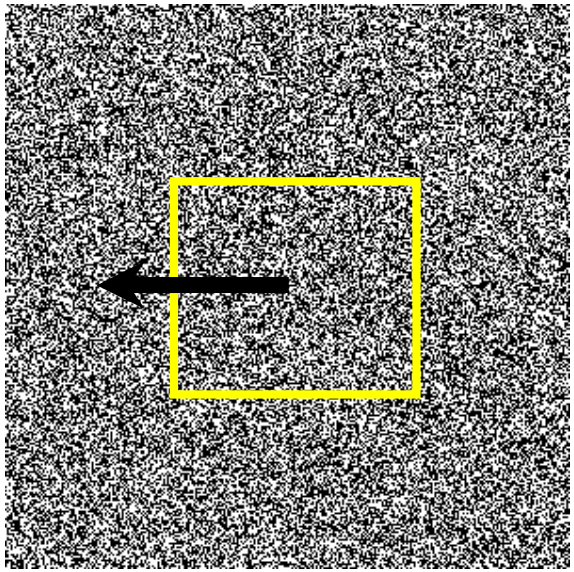
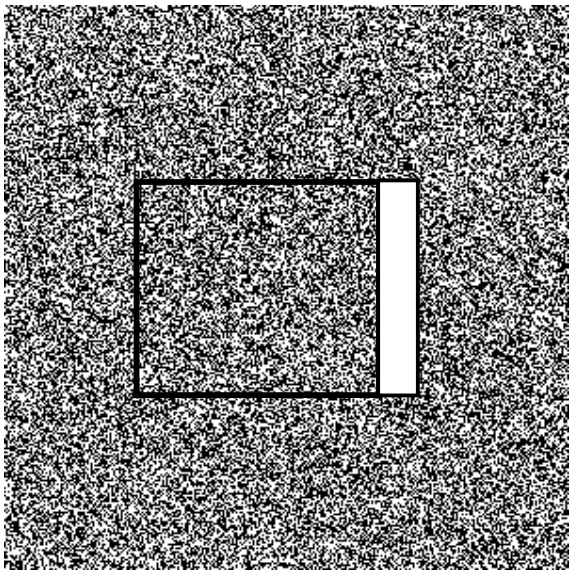
Julesz Random-Dot Experiment





Clip out a square region and shift it to the left

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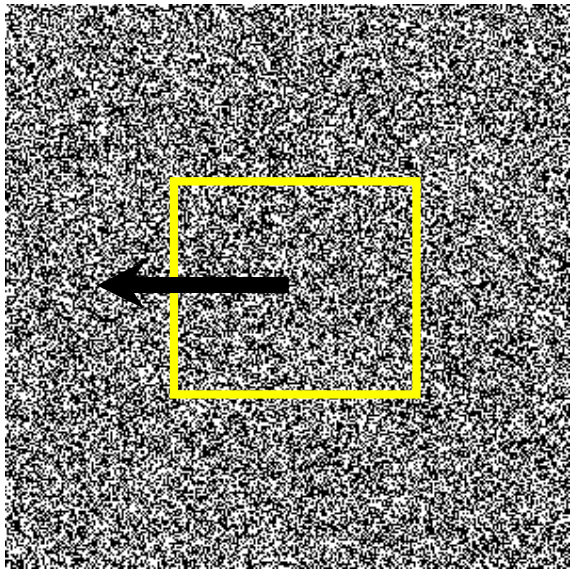
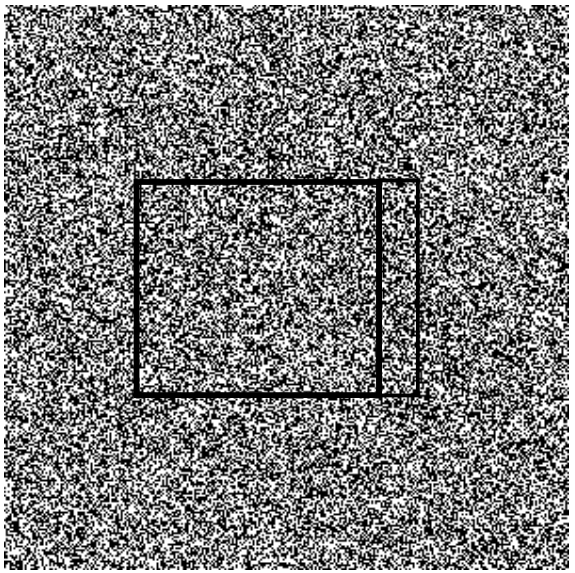
Julesz Random-Dot Experiment





Clip out a square region and shift it to the left

Fill in the “hole” left behind with more random dots.

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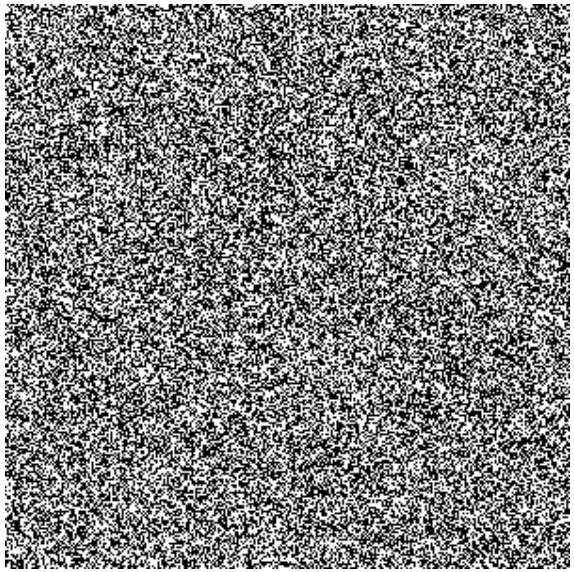
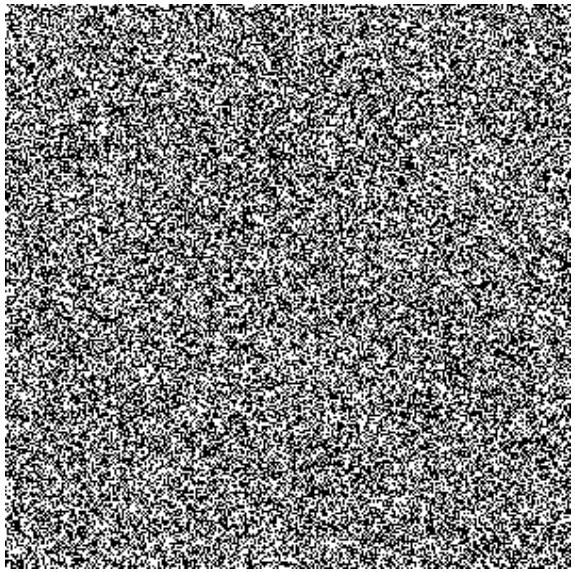
Julesz Random-Dot Experiment



Original dot image



Dot image with shifted square

Now view as a stereo pair.
Julesz used a special viewer, but we will display as an anaglyph (get your glasses!)

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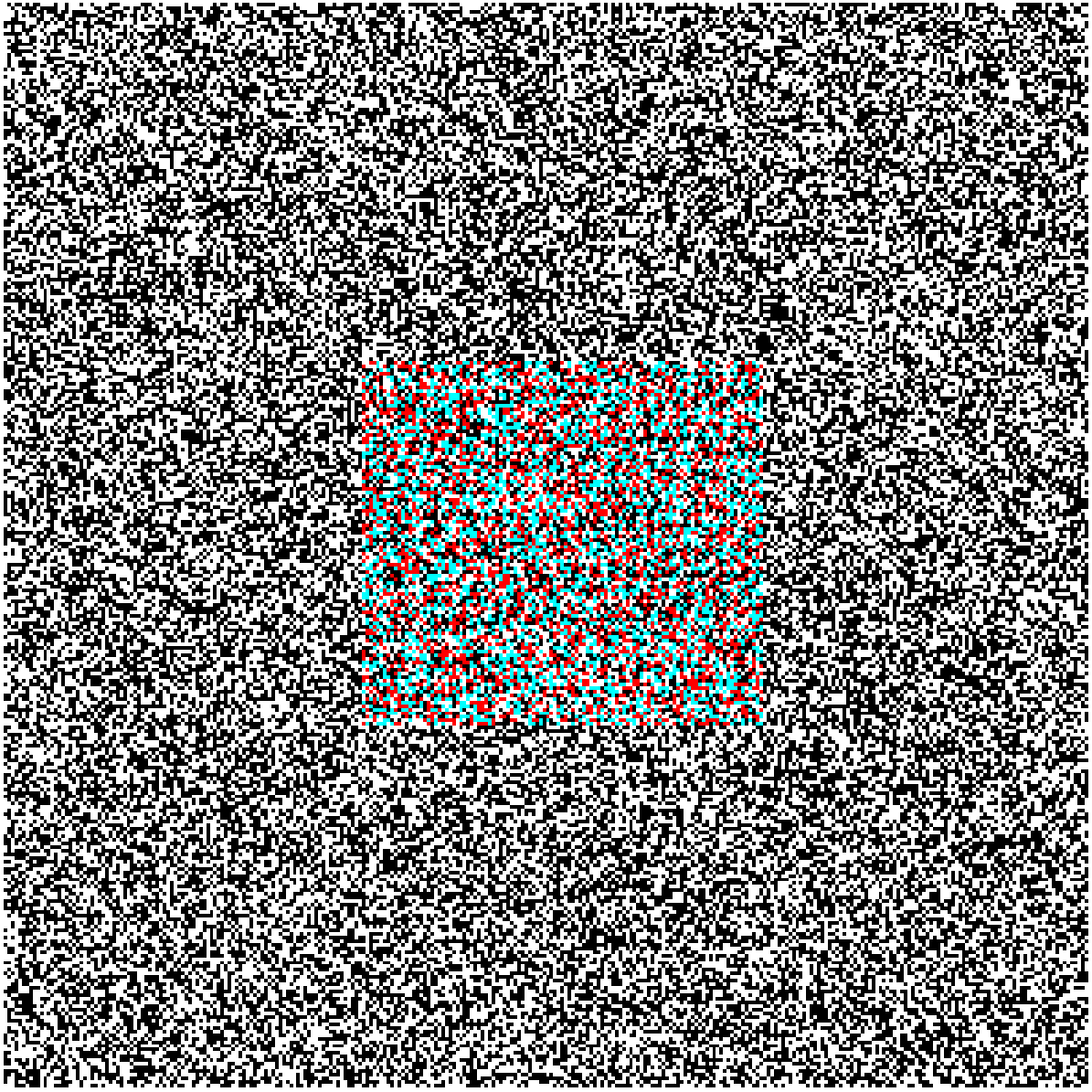

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Make Your Own

%make an image with random dots
```
im = roicolor(rand(300,300),.5,1);
```
%second image starts as a copy of that
```
im2 = im;
```
%shift a square of pixels to the right
```
im2(100:200,110:210) = im(100:200,100:200);
```
%fill in the "hole" with more random dots
```
im2(100:200,100:110) = roicolor(rand(101,11),.5,1);
```

%encode image2 in red channel of a color image
```
ana = 255*im2;
```
%encode image1 in blue and green channels
```
ana(:,:,2) = 255*im;
ana(:,:,3) = 255*im;
```
%take a look (remember to wear your red/cyan glasses!)
```
image(uint8(ana))
```

Try this: what happens when you shift the square to the left instead of to the right?

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Stereograms

Another method of encoding parallax in a single image. Subtle shifts of repeated texture encode disparity of depths in a scene (a technique made famous under the “Magic Eye” brand name).

Unlike anaglyphs, you don’t need special glasses to see these, just some practice focusing your eyes behind the page.

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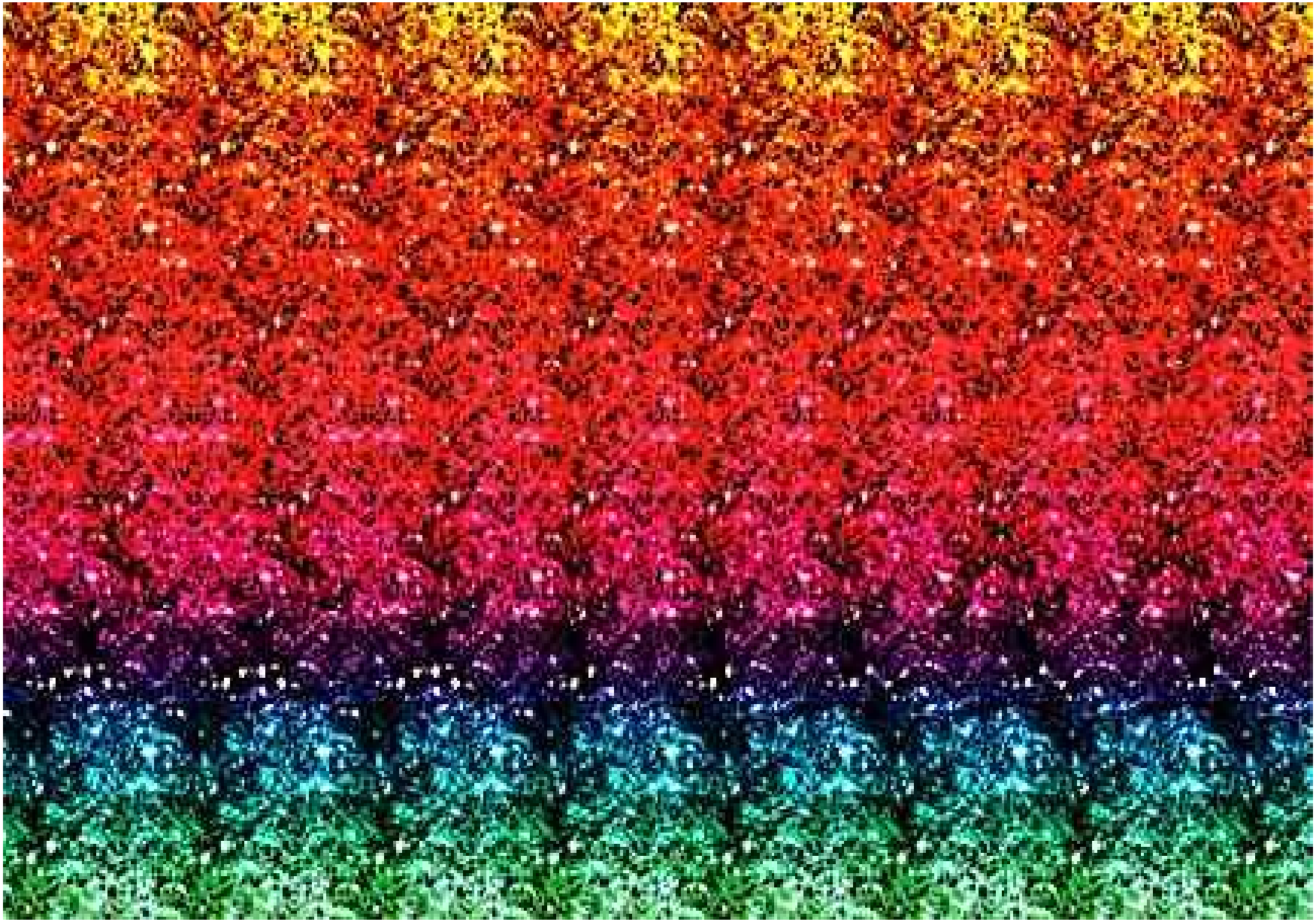
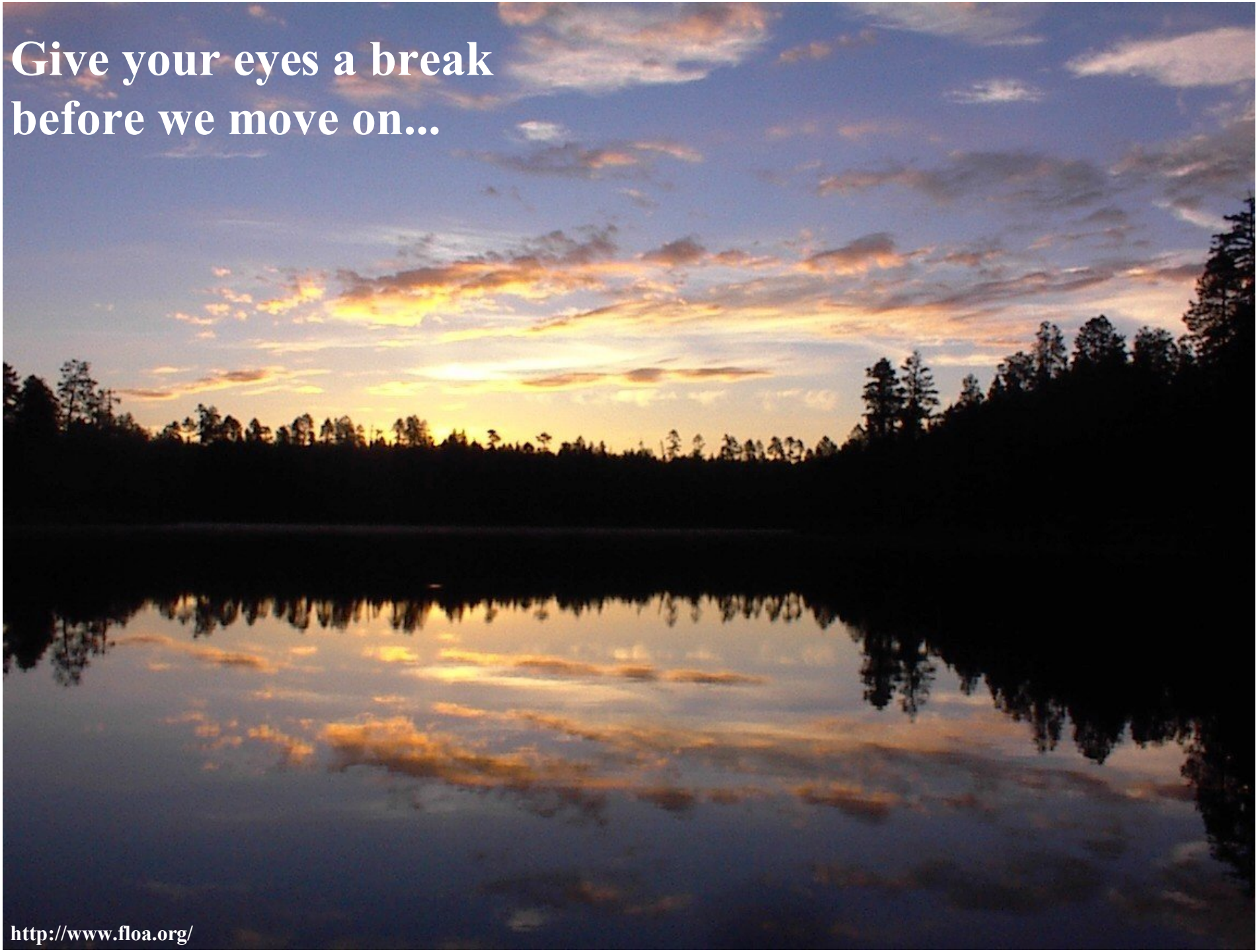
Stereograms




Give your eyes a break
before we move on...
http://www.floa.org/

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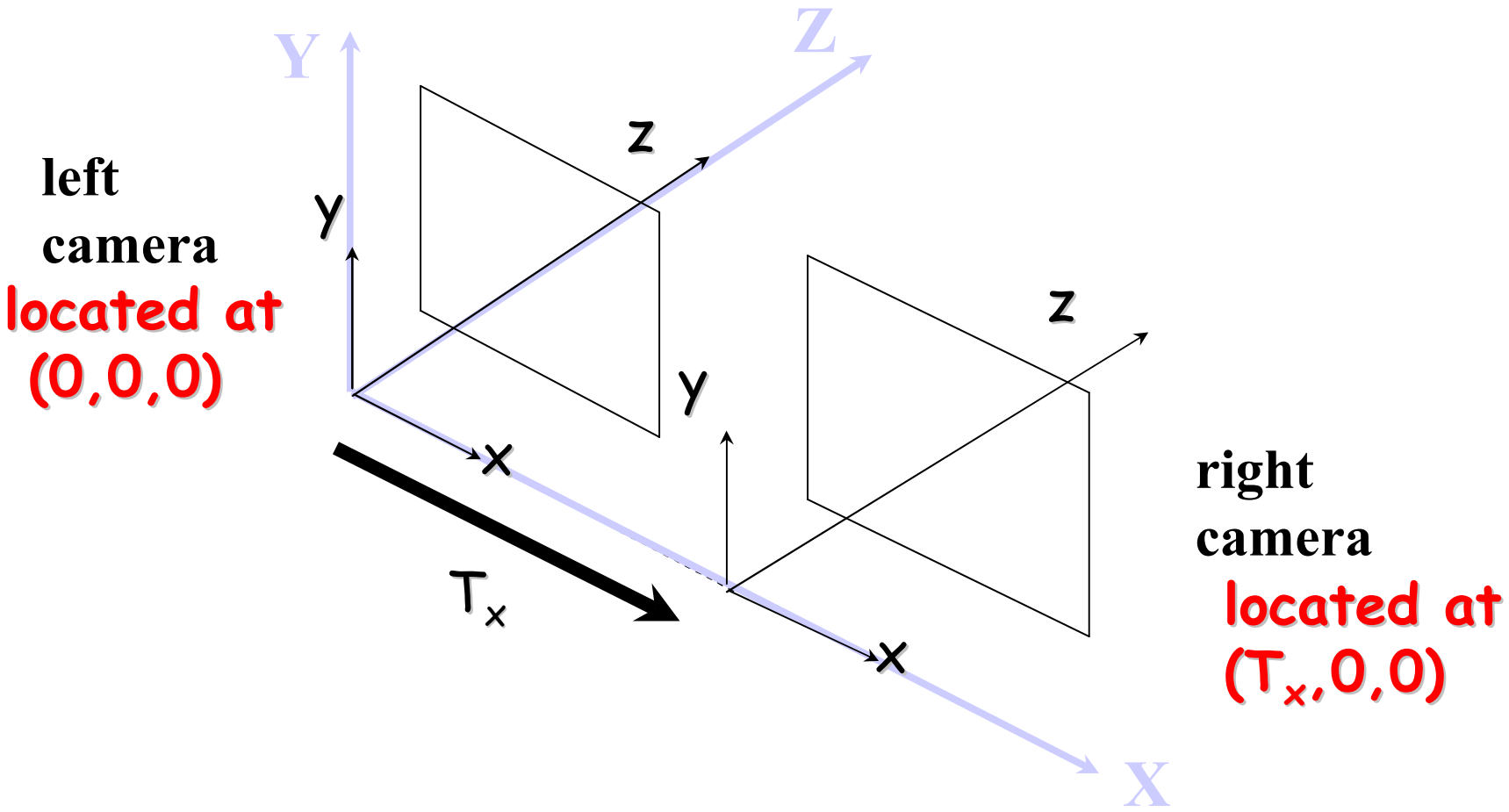
A Simple Stereo System



Right camera is simply shifted by Tx units along the X axis. Otherwise, the cameras are identical (same orientation / focal lengths)

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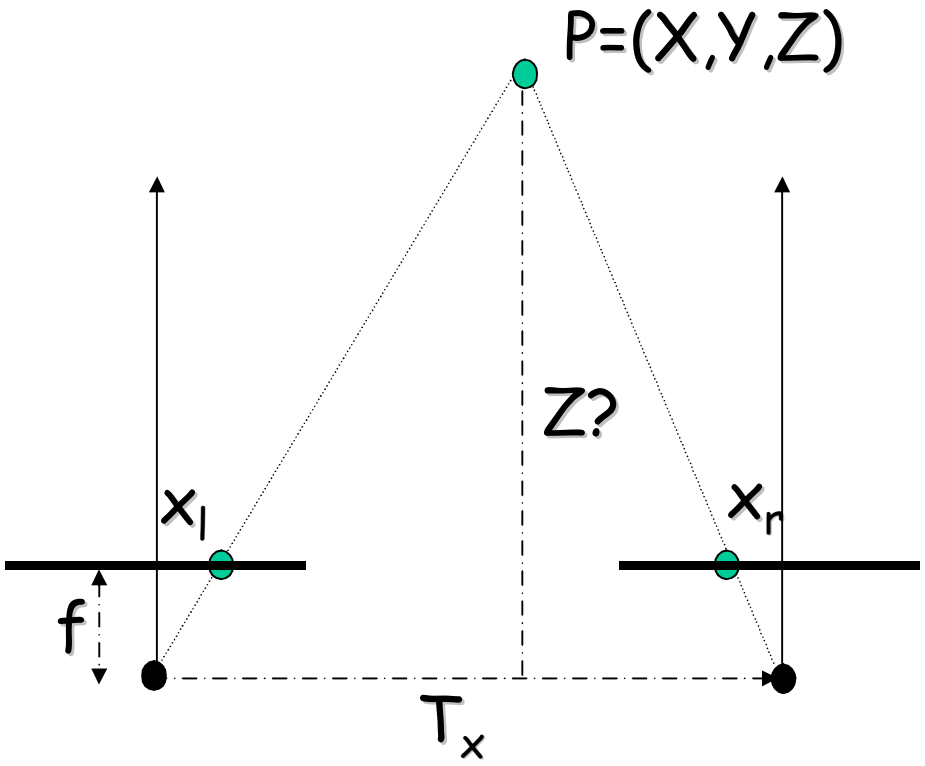
A Simple Stereo System
Top Down View (XZ plane)



Translated by a distance T_x along X axis
(T_x is also called the stereo "baseline")

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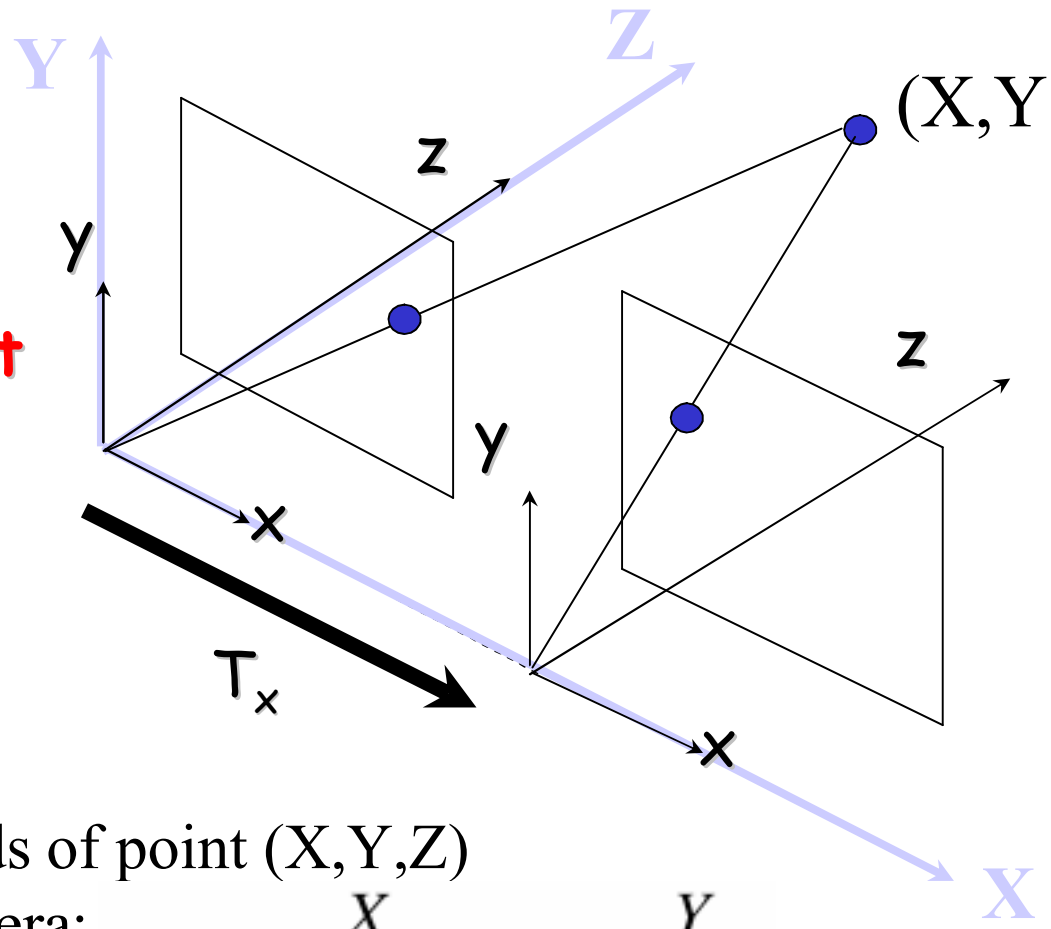
A Simple Stereo System



left camera located at (0,0,0)

right camera located at (T_x,0,0)

Image coords of point (X,Y,Z) in Left Camera:

$$x_l = f\frac{X}{Z} \qquad y_l = f\frac{Y}{Z}$$

What are image coords of that same point in the Right Camera?

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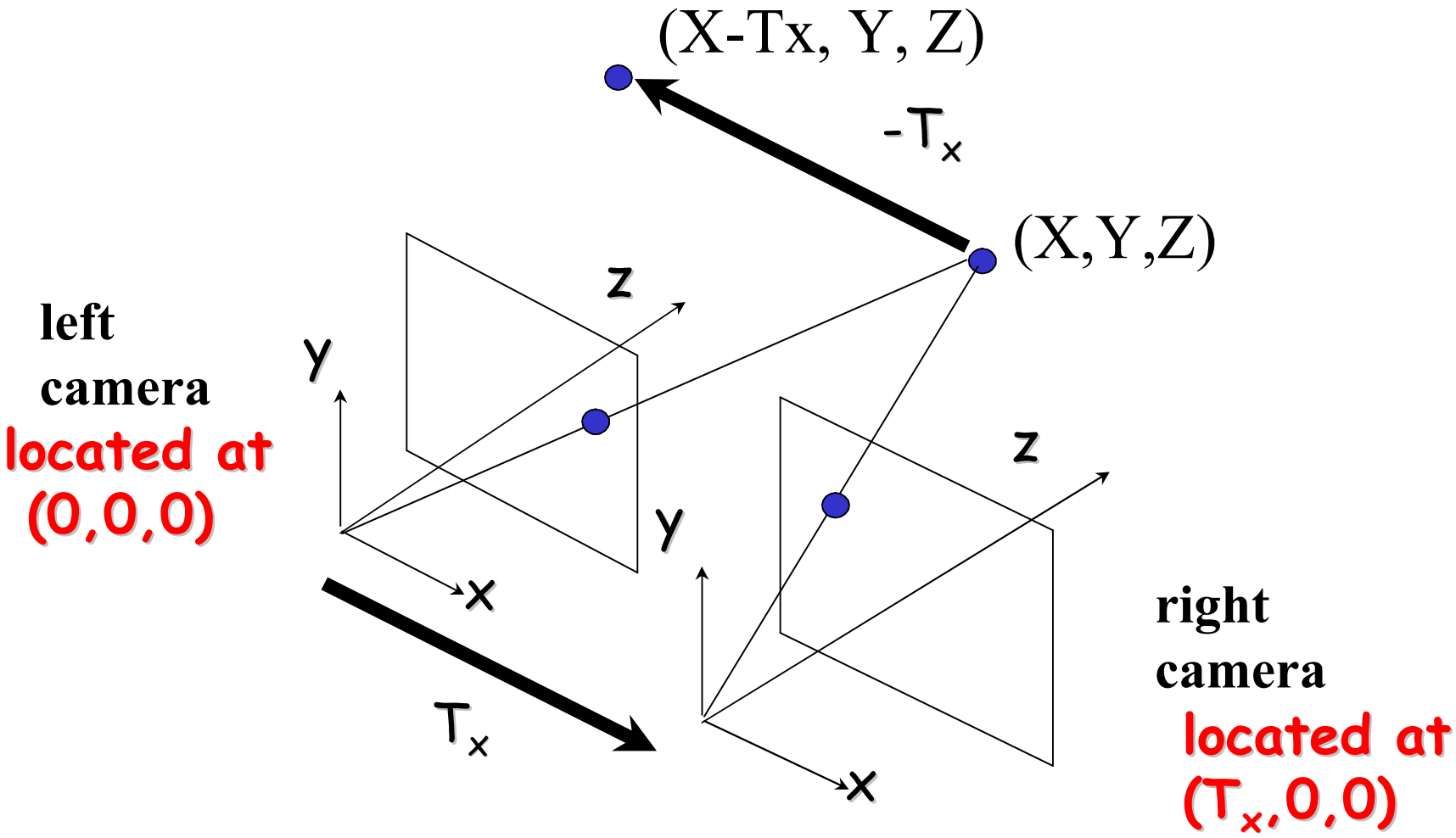
A Simple Stereo System



Insight: translating camera to the right by Tx is equivalent to leaving the camera stationary and translating the world to the left by Tx.

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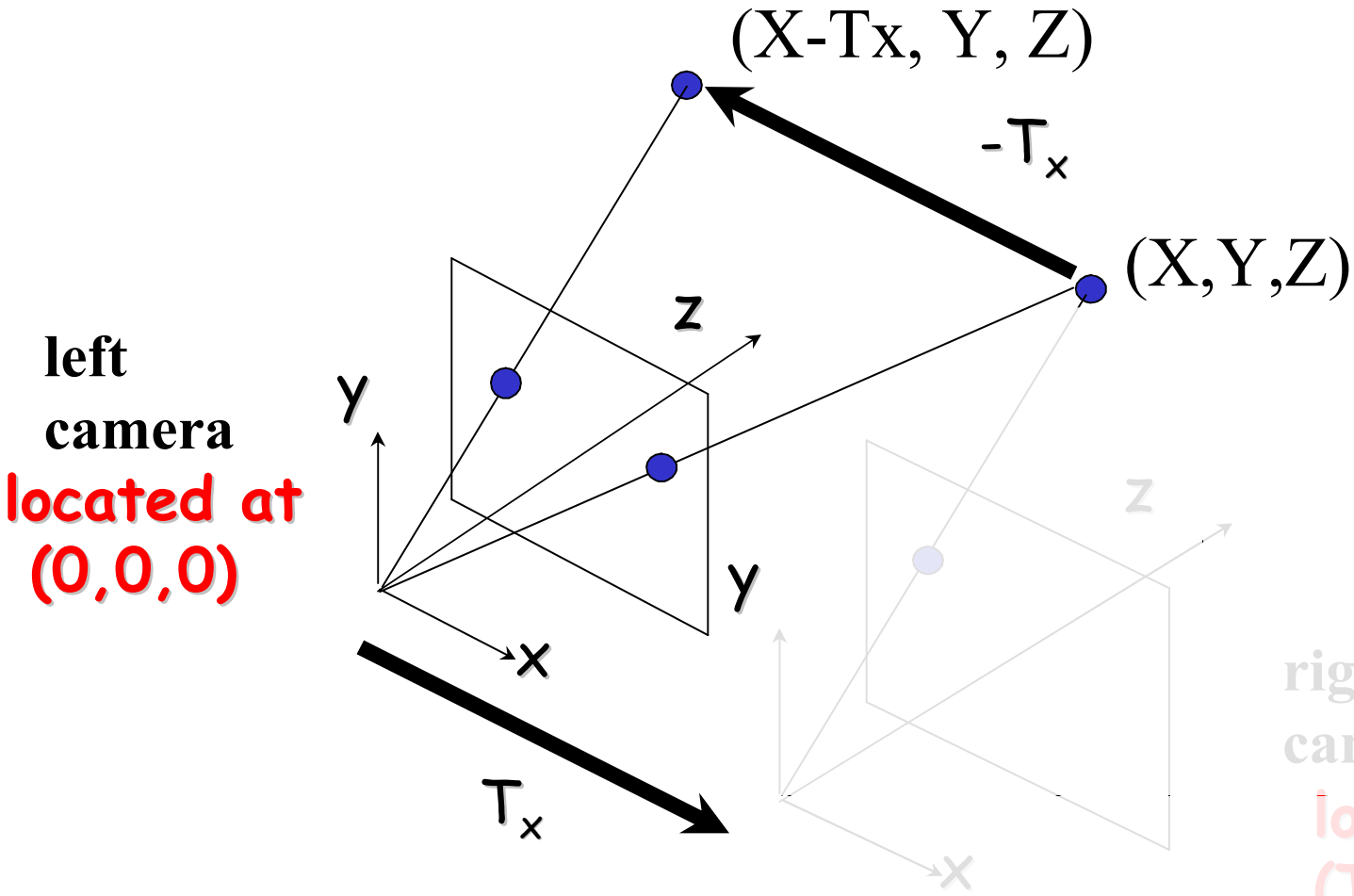
A Simple Stereo System



$$x_r = f\frac{X - T_x}{Z} \qquad y_r = f\frac{Y}{Z}$$

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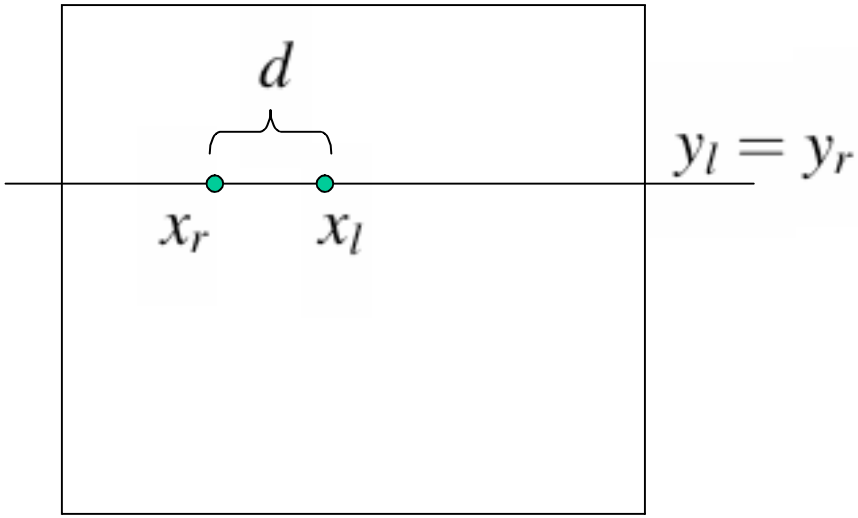
Stereo Disparity

Left camera

$$x_l = f\frac{X}{Z} \qquad y_l = f\frac{Y}{Z}$$

Right camera

$$x_r = f\frac{X - T_x}{Z} \qquad y_r = f\frac{Y}{Z}$$



Stereo Disparity

$$d = x_l - x_r = f\frac{X}{Z} - \left(f\frac{X}{Z} - f\frac{T_x}{Z}\right)$$

$$d = \frac{f\,T_x}{Z}$$

depth **baseline**

$$Z = \frac{f\,T_x}{d}$$

disparity

Important equation!

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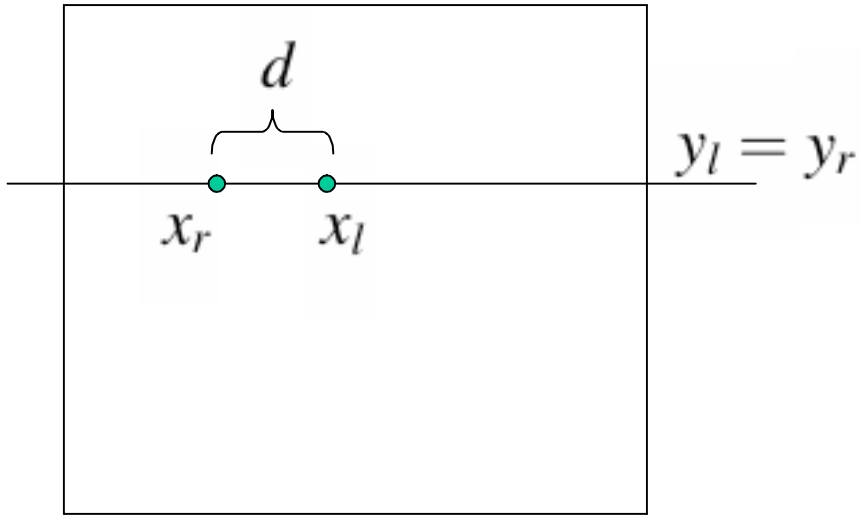
Stereo Disparity

Left camera

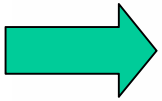
$$x_l = f\frac{X}{Z} \qquad y_l = f\frac{Y}{Z}$$

Right camera

$$x_r = f\frac{X - T_x}{Z} \qquad y_r = f\frac{Y}{Z}$$



Note: Depth and stereo disparity are inversely proportional



depth

$$Z = \frac{f\,T_x}{d}$$

disparity

Important equation!

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Stereo Disparity / Parallax

Tie in with Intro: for our purposes

Disparity = Parallax

⇒Disparity/Parallax inversely proportional to depth

⇒ this is why near objects appear to move more than far away ones when the camera translates sideways