Multi-View Geometry (Ch7 New book. Ch 10/11 old book)

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CS-GY 6643, Spring 2016

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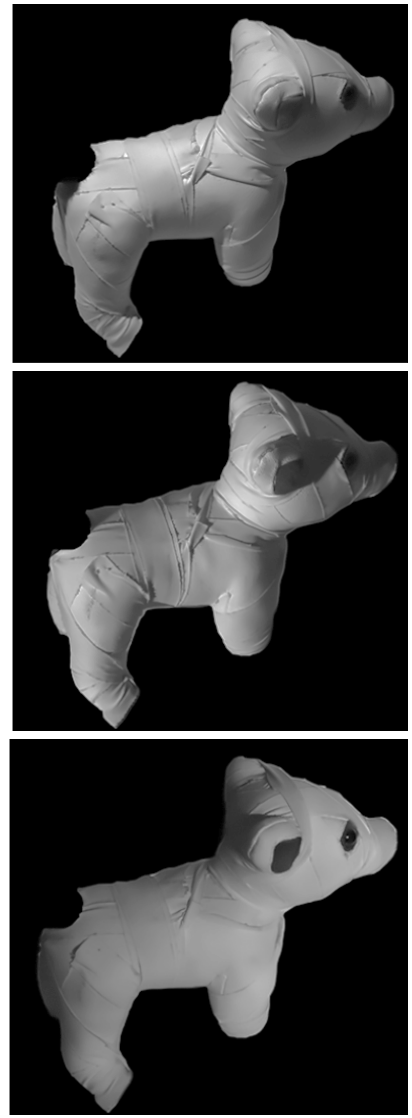
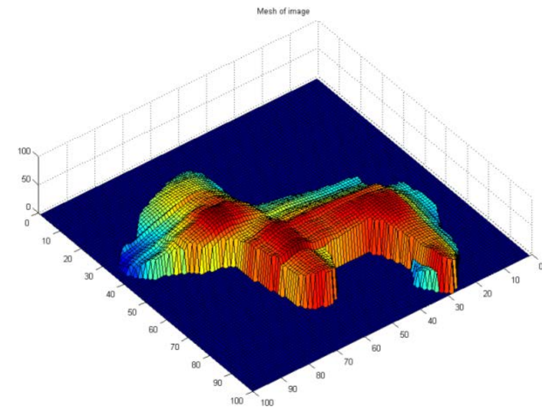
Credits: M. Shah, UCF CAP5415, lecture 23

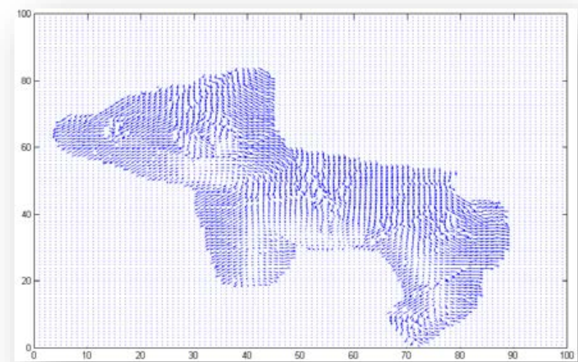
http://www.cs.ucf.edu/courses/cap6411/cap5415/, Trevor Darrell, Berkeley, C280, Marc Pollefeys

Visual cues

- Shading

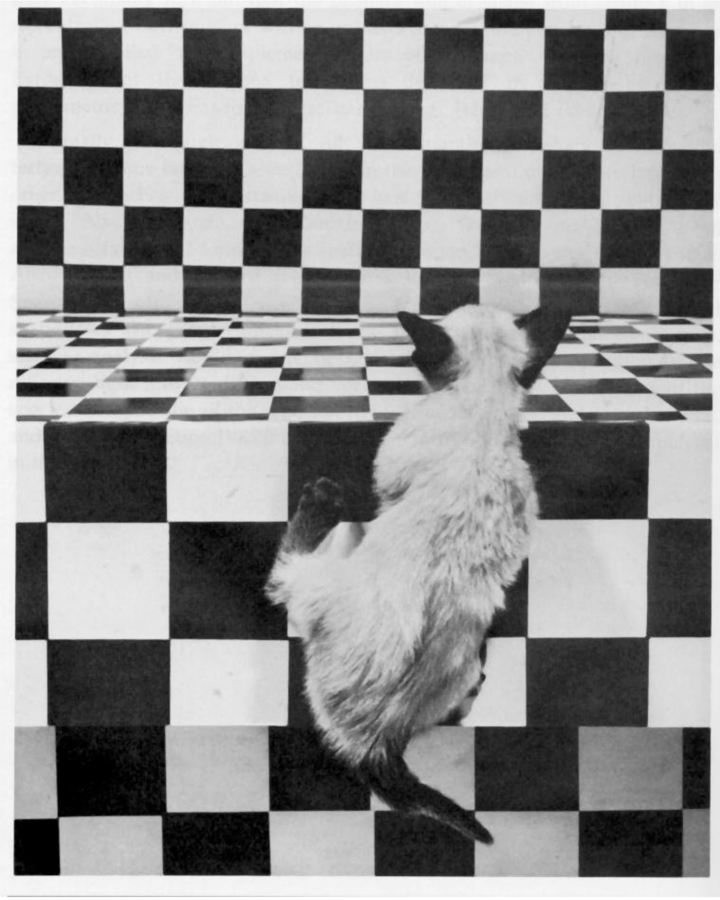






Visual cues

- Shading
- Texture



***The Visual Cliff*, by William Vandivert, 1960**

Visual cues

- Shading
- Texture
- Focus

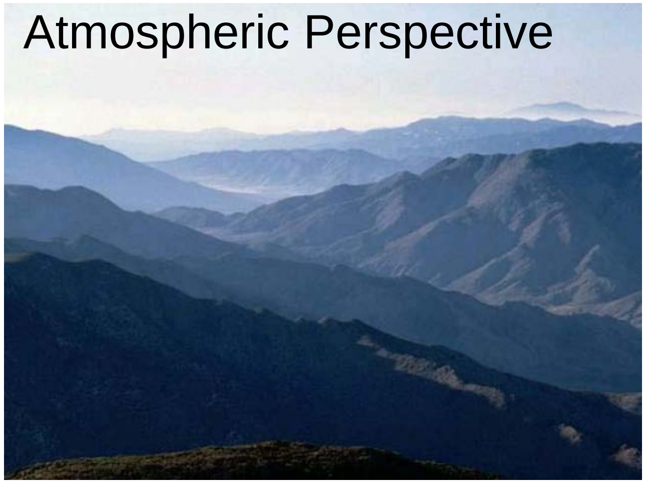
From *The Art of Photography*, Canon

Visual cues

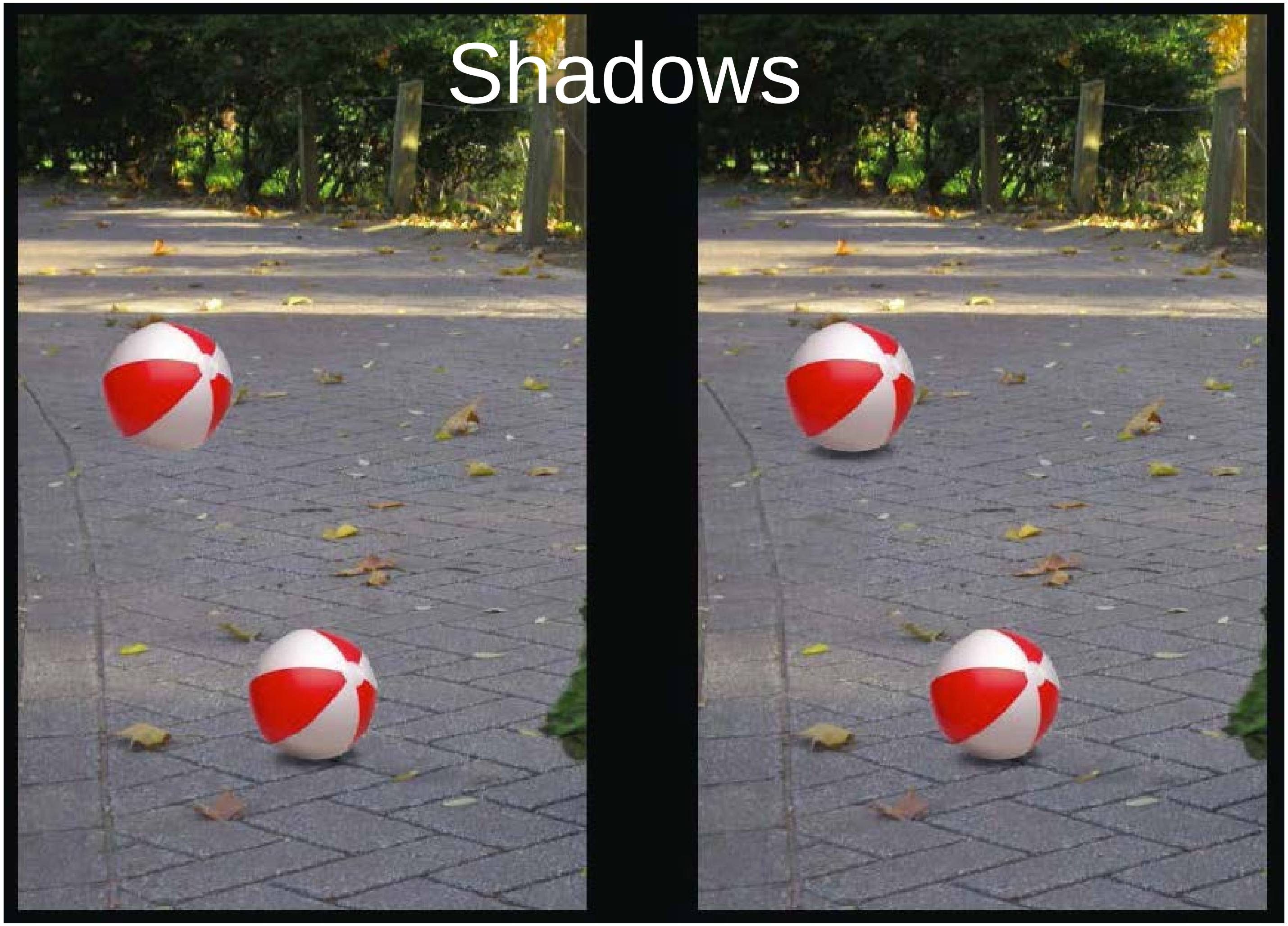
- Shading
- Texture
- Focus
- **Motion**

Visual cues

- Shading
- Texture
- Focus
- Motion
- Shape From X
  - X = (
  - shading, texture,
  - focus, motion,
  - rotation, ...)



Visual cues



Cornell CS569 S2008, Lecture 8, slide by Steve Marschner
http://www.cs.cornell.edu/courses/cs569/2008sp/about.stm

Visual cues

- Shading
- Texture
- Focus
- Motion
- Shape From X
  - (X = shading,
  - texture, focus,
  - motion, rotation, ...)
- Stereo (disparity, multi-view)

http://www.well.com/~jimg/stereo/stereo_list.html

Grauman

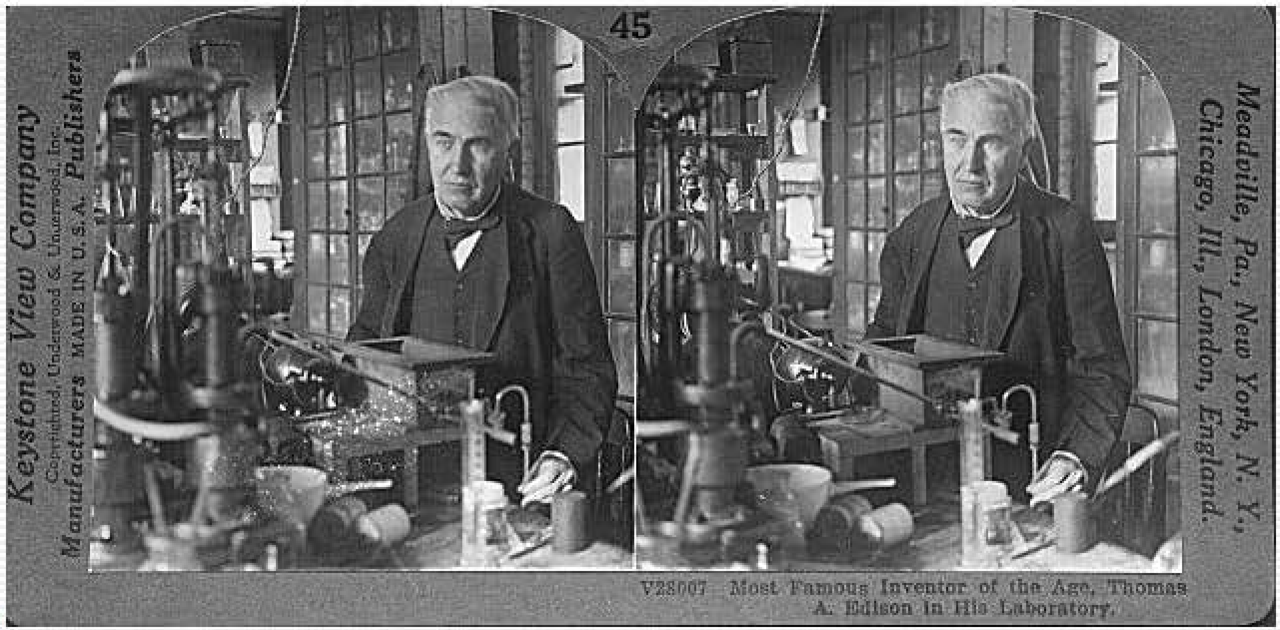
Stereo photography and stereo viewers

Take two pictures of the same subject from two slightly different viewpoints and display so that each eye sees only one of the images.

Invented by Sir Charles Wheatstone, 1838

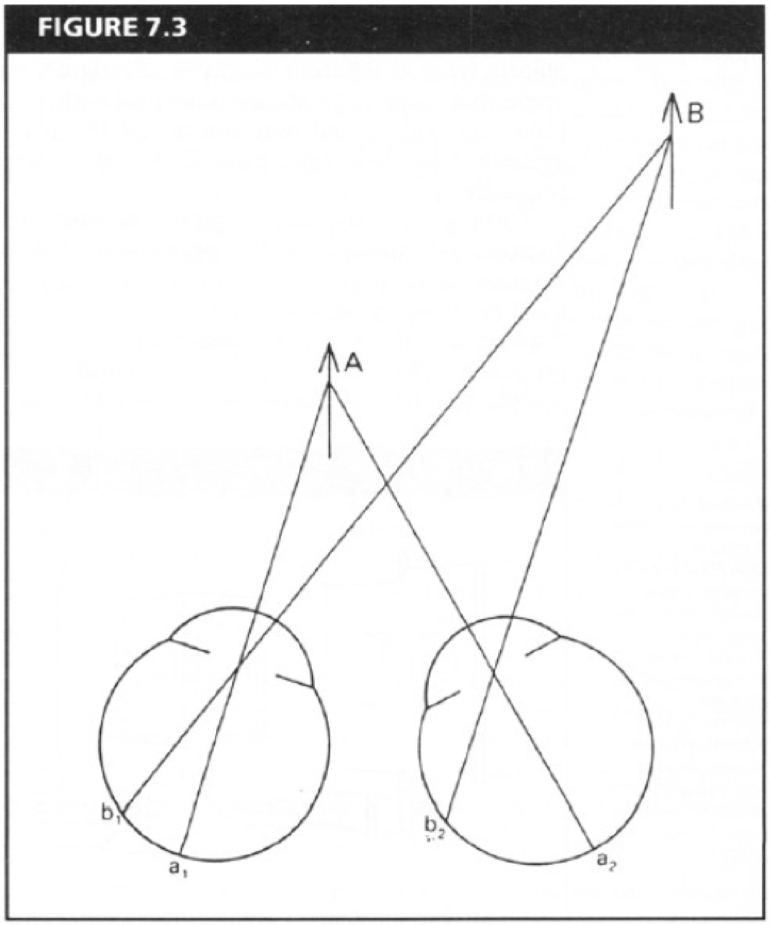
Image courtesy of fisher-price.com

© Copyright 2001 Johnson-Shaw Stereoscopic Museum



http://www.johnsonshawmuseum.org

Human stereopsis: disparity

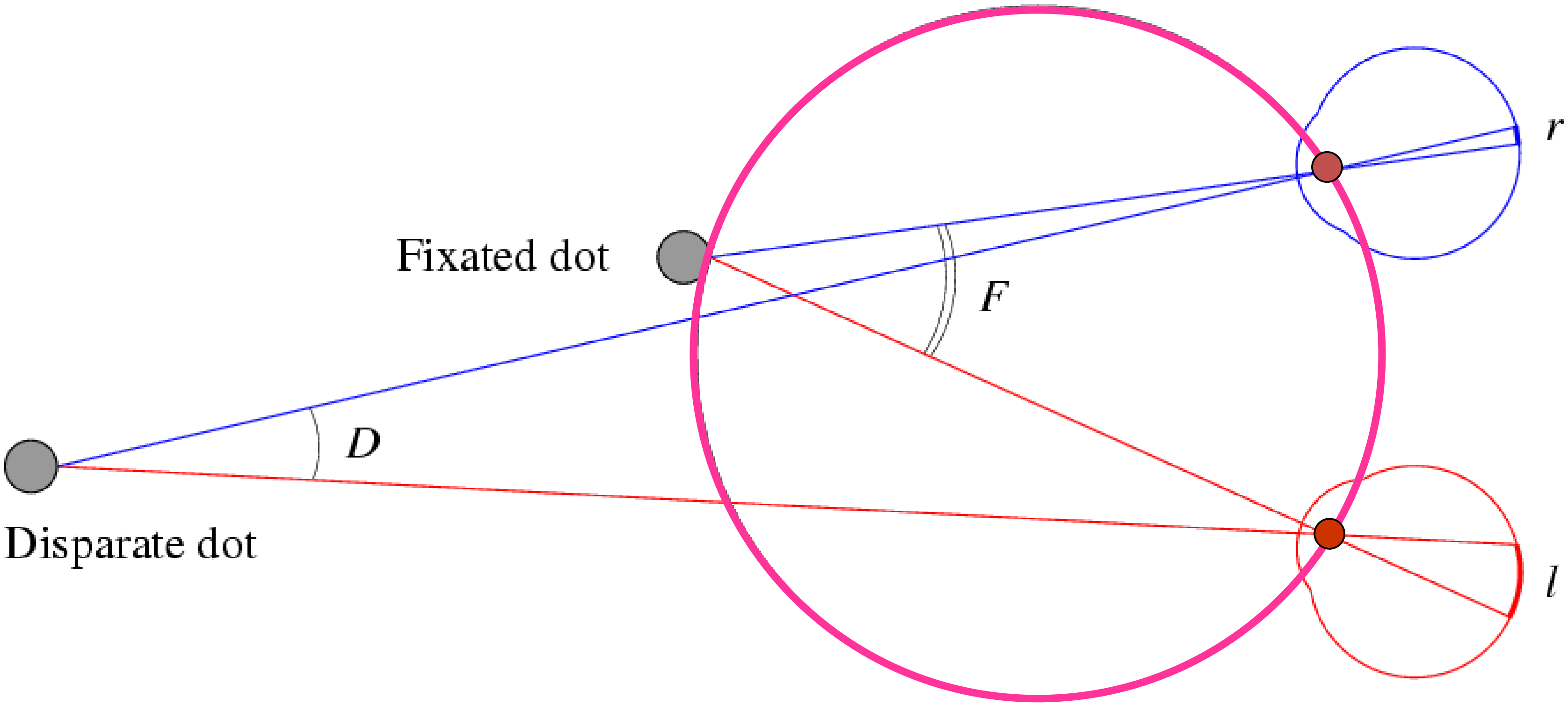


From Bruce and Green, Visual Perception, Physiology, Psychology and Ecology

Disparity occurs when eyes fixate on one object; others appear at different visual angles

Adapted from David Forsyth, UC Berkeley

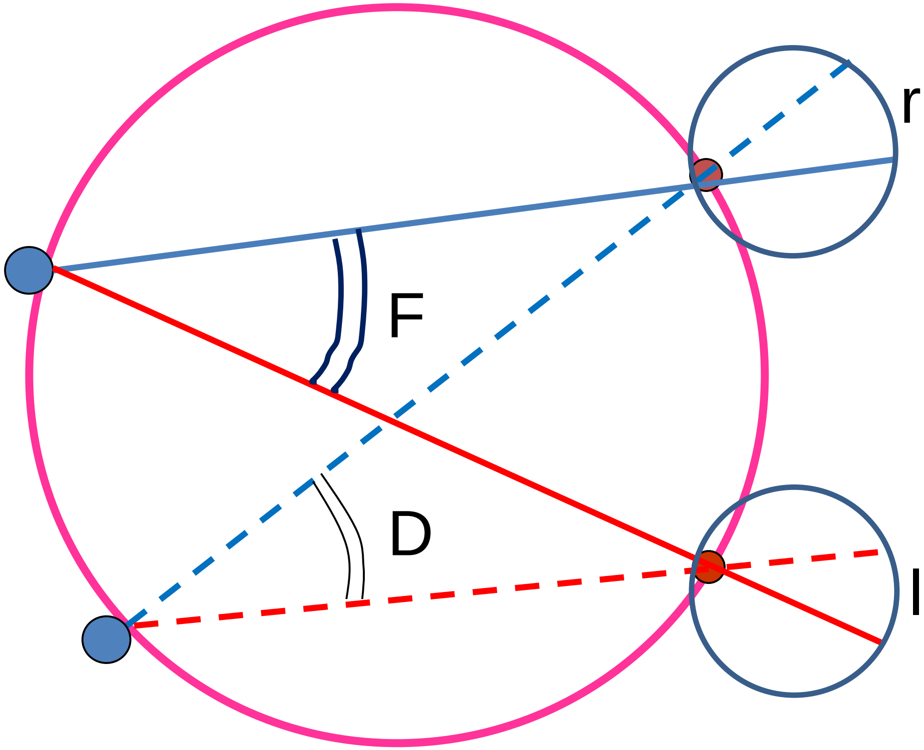
Human stereopsis: disparity



Disparity: $d = r\text{-}l = D\text{-}F.$

Adapted from M. Pollefeys

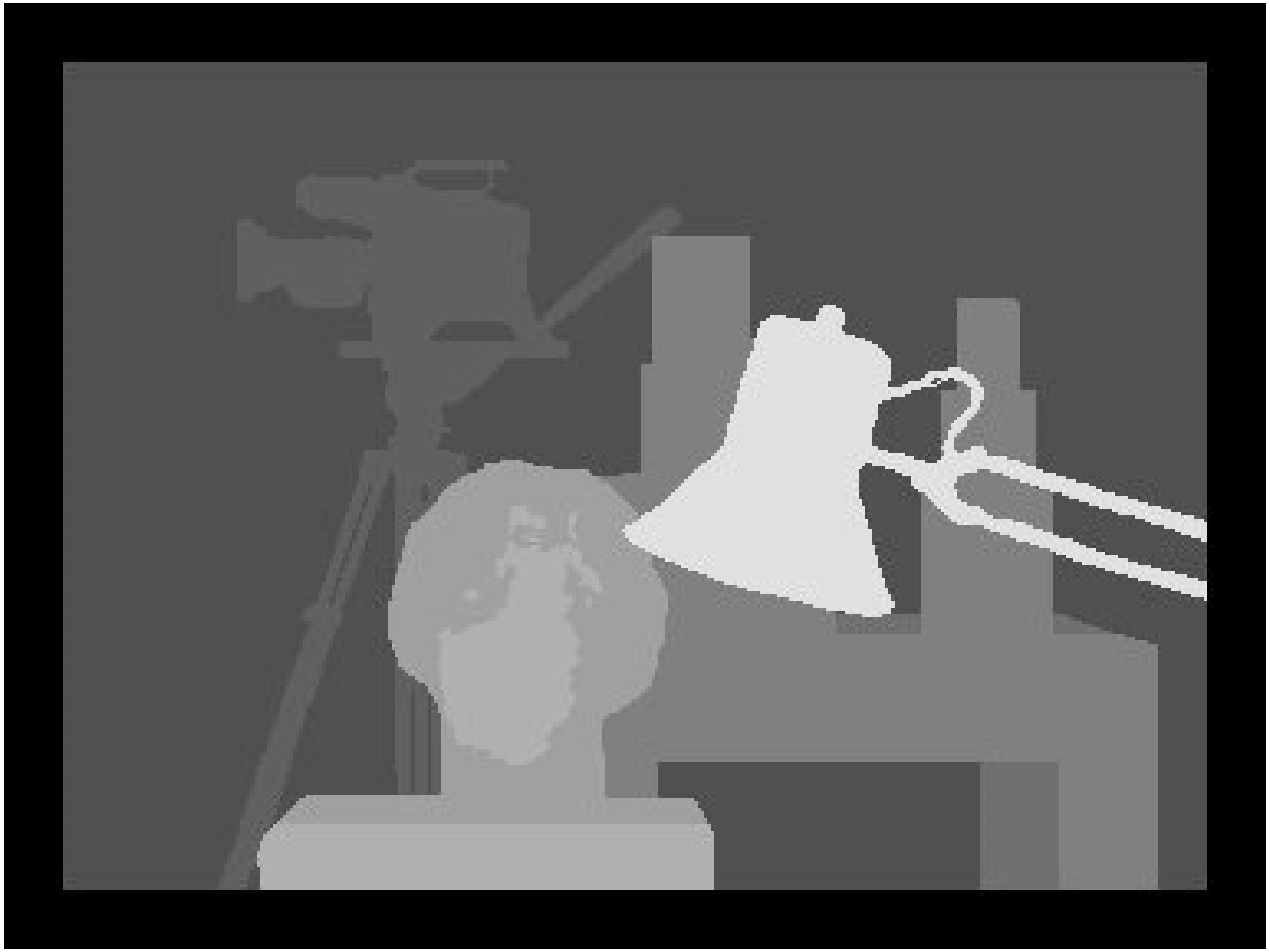
Human stereopsis: disparity



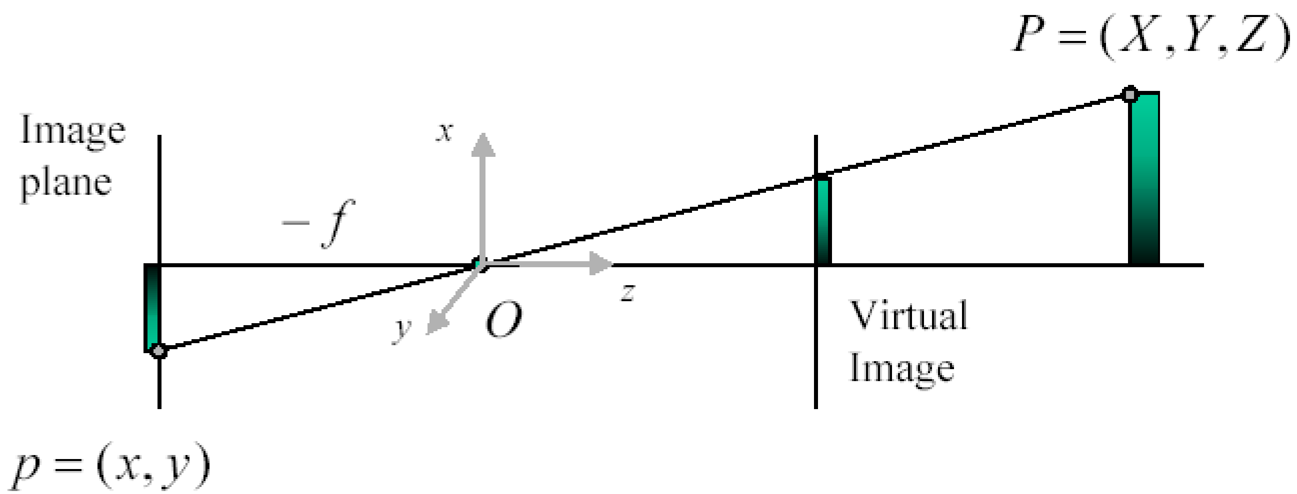
Disparity: *d = r-l = D-F = 0.*

Adapted from M. Pollefeys

Example: Stereo to Depth Map

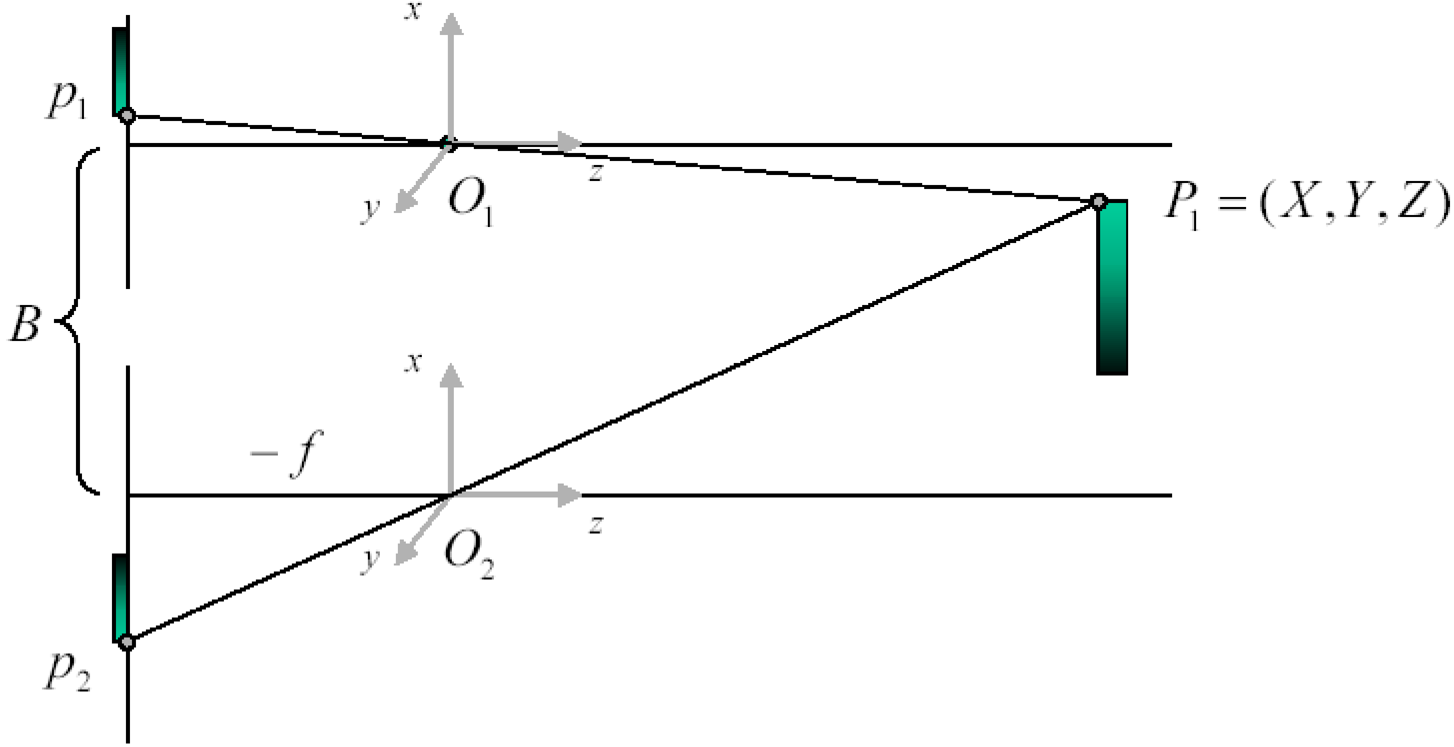


Pinhole Camera Model



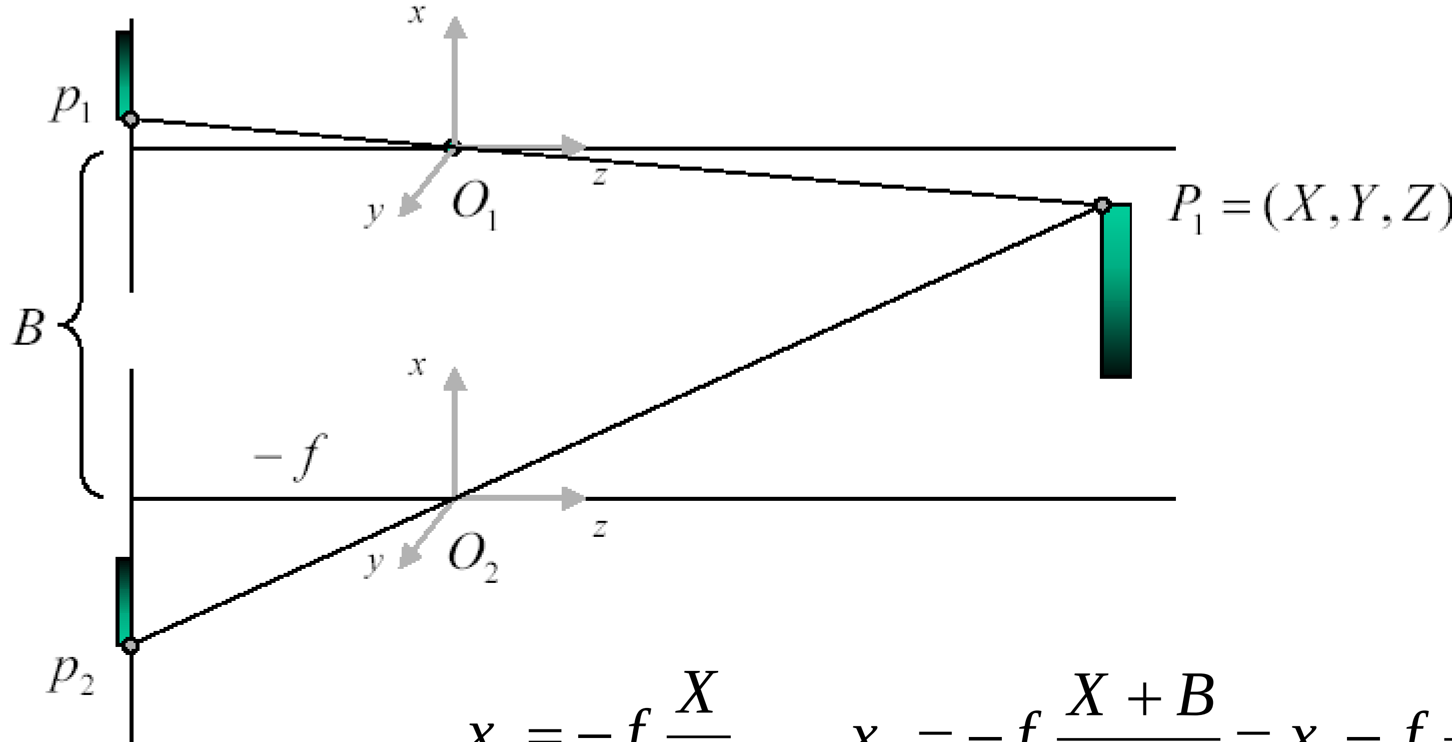
$$x = -f\,\frac{X}{Z}$$

Basic Stereo Derivations



Derive expression for Z as a function of x_1, x_2, f and B

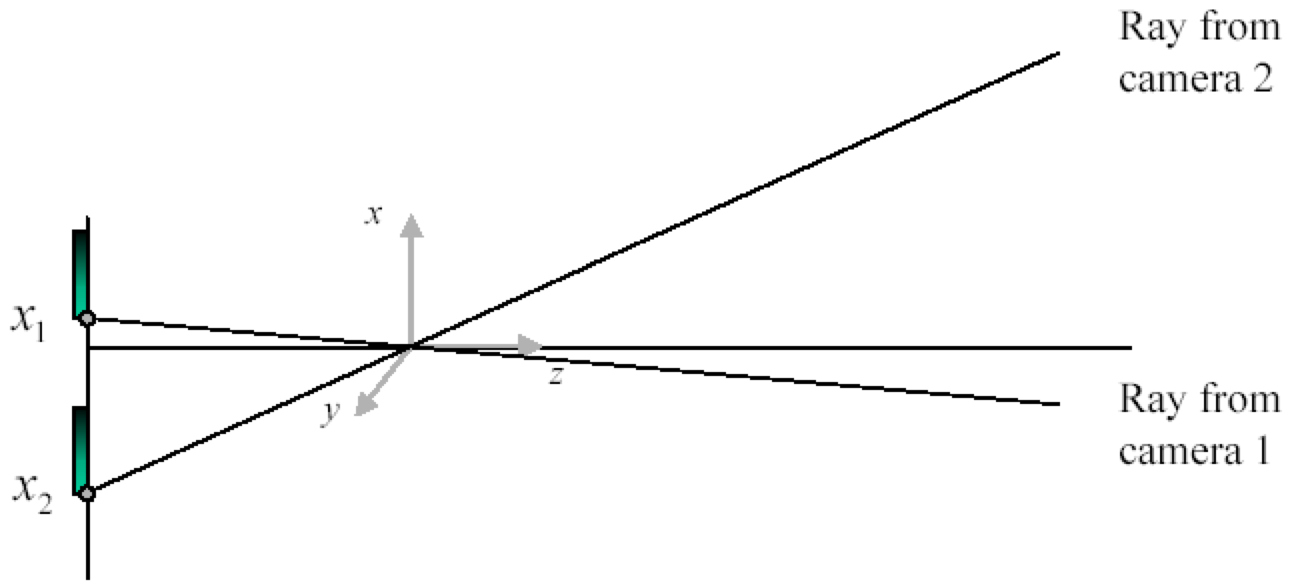
Basic Stereo Derivations



$$x_1 = -f\,\frac{X}{Z} \qquad x_2 = -f\,\frac{X+B}{Z} = x_1 - f\,\frac{B}{Z}$$

$$Z = \frac{fB}{x_1 - x_2}$$

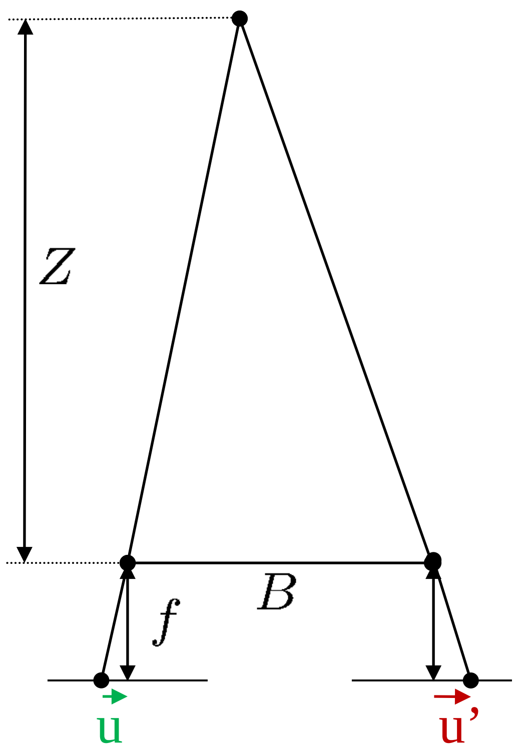
Basic Stereo Derivations

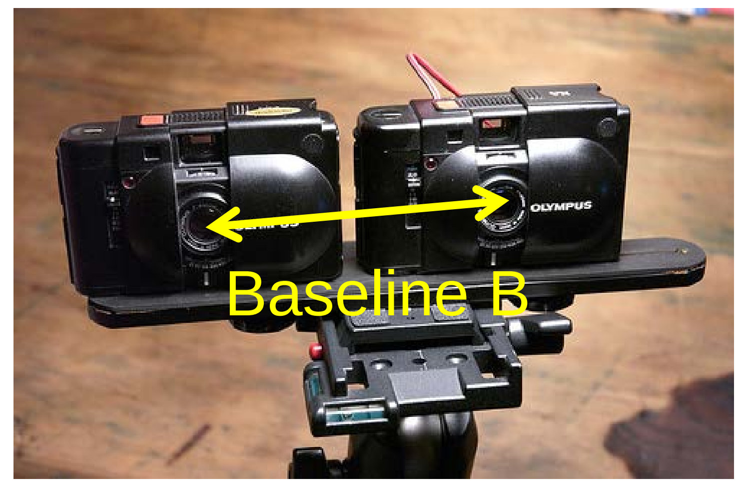


Define the disparity: $d = x_1 - x_2$

$$Z = \frac{fB}{d}$$

Standard stereo geometry

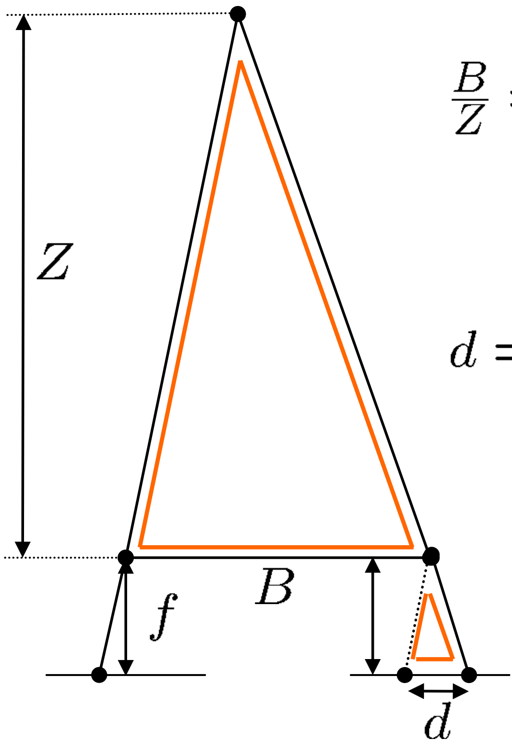




Disparity d:

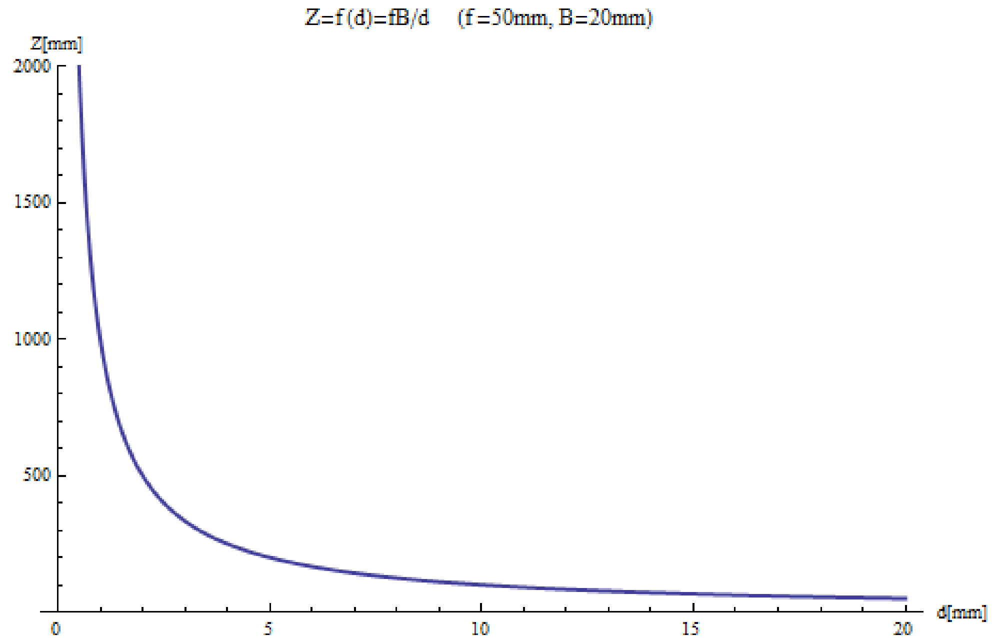
$$d = |u' - u|$$

Standard stereo geometry



$$\frac{B}{Z} = \frac{d}{f}$$

$$d = \frac{Bf}{Z}$$

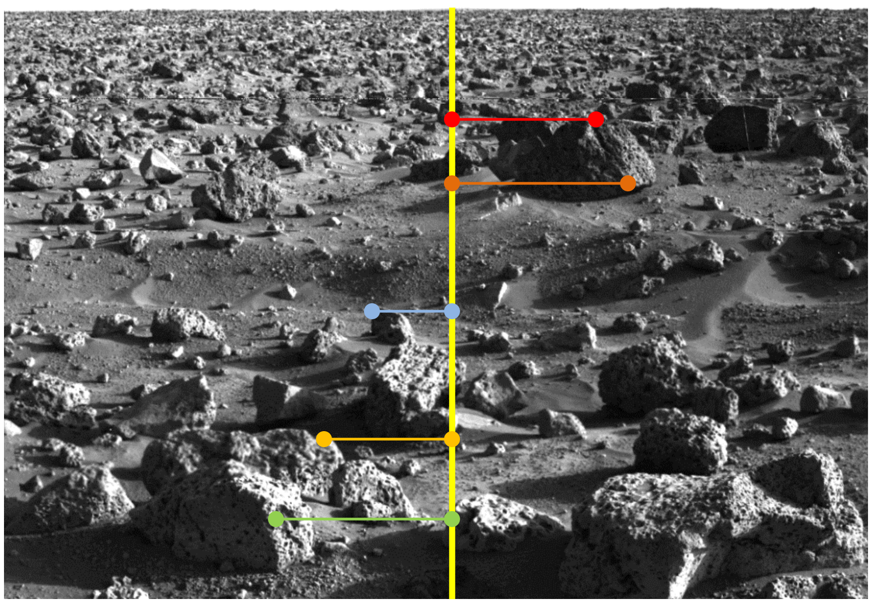
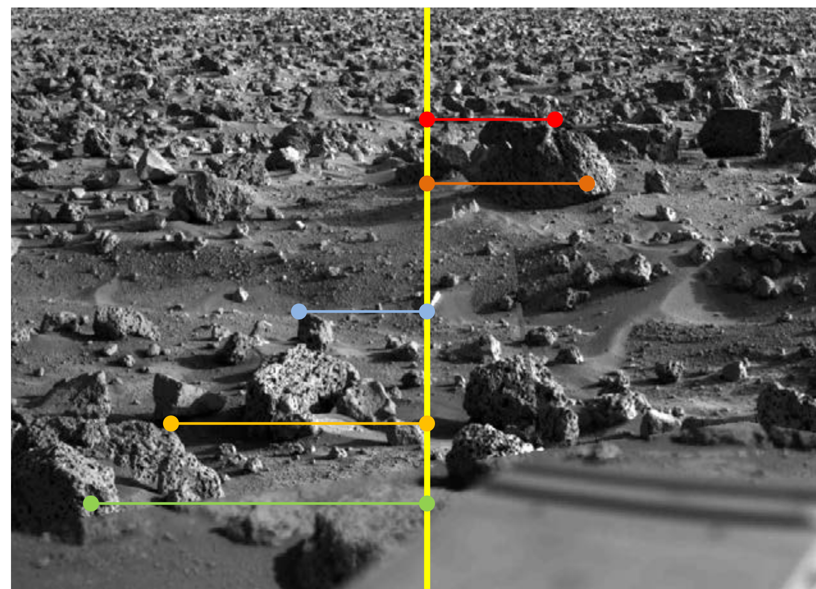


Observations on disparity:

- d shows large differences at small distances
- d gets very small on large distances

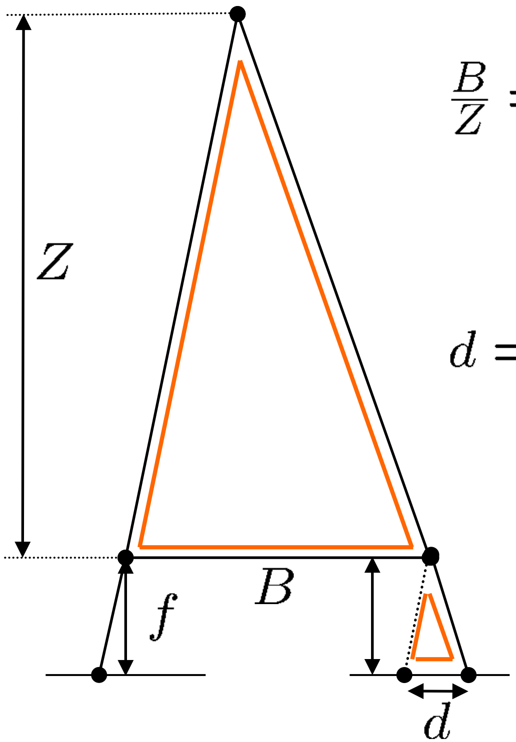
Stereo Correspondence

- Search over disparity to find correspondences
- Range of disparities to search over can change dramatically within a single image pair.

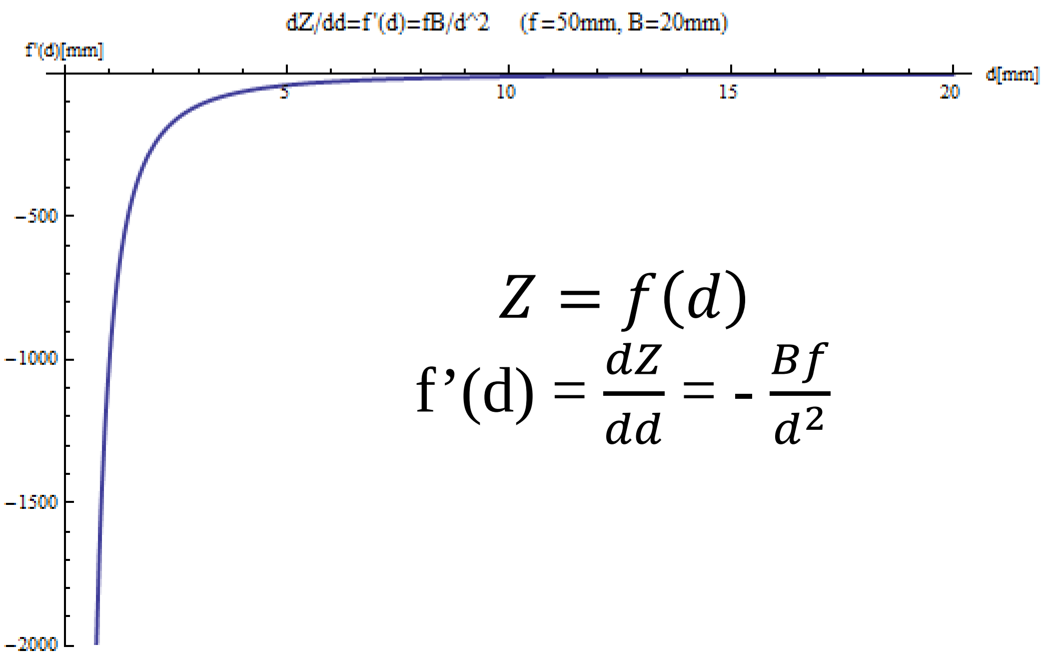
J. M. Rehg © 2003

Standard stereo geometry: Changes of ΔZ with Δd



$$\frac{B}{Z} = \frac{d}{f}$$

$$d = \frac{Bf}{Z}$$



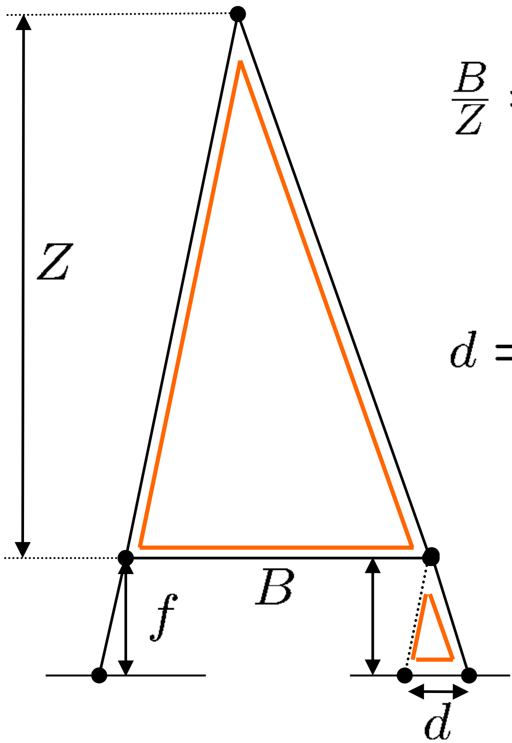
$$Z = f(d)$$

$$f'(d) = \frac{dZ}{dd} = -\frac{Bf}{d^2}$$

Observations:

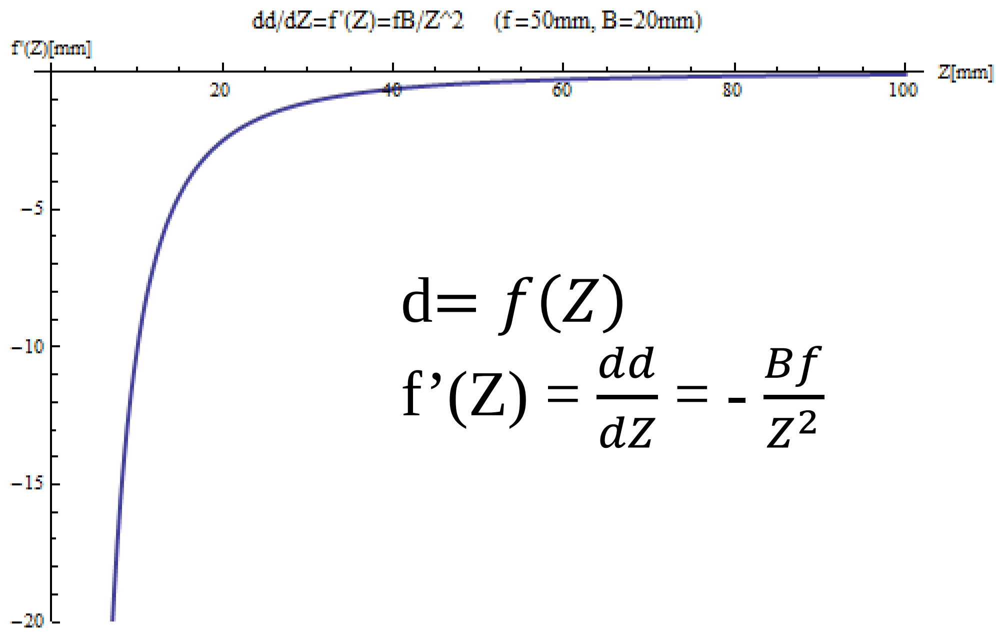
- at small d (far), Δd corresponds to large ΔZ
- at large d (close), Δd corresponds to small ΔZ
- important for analysis of precision/resolution

Standard stereo geometry: Changes of Δd with ΔZ



$$\frac{B}{Z} = \frac{d}{f}$$

$$d = \frac{Bf}{Z}$$



$$d = f(Z)$$

$$f'(Z) = \frac{dd}{dZ} = -\frac{Bf}{Z^2}$$

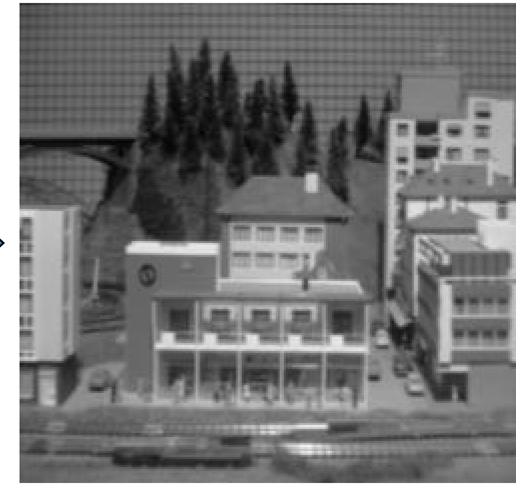
Observations:

- at small Z (close), ΔZ effects in large Δd
- at large Z (far), ΔZ effects in small Δd
- important for analysis of precision/resolution

Why is disparity important?

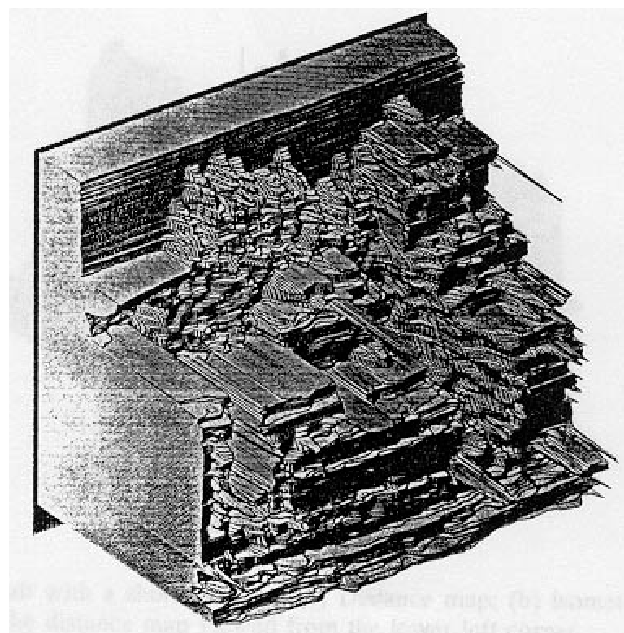
I1

I2



I10

Given dense disparity map, we can calculate a depth/distance/ range map.



Reprinted from "A Multiple-Baseline Stereo System," by M. Okutami and T. Kanade, IEEE Trans. on Pattern Analysis and Machine Intelligence, 15(4):353-363 (1993). \copyright 1993 IEEE.

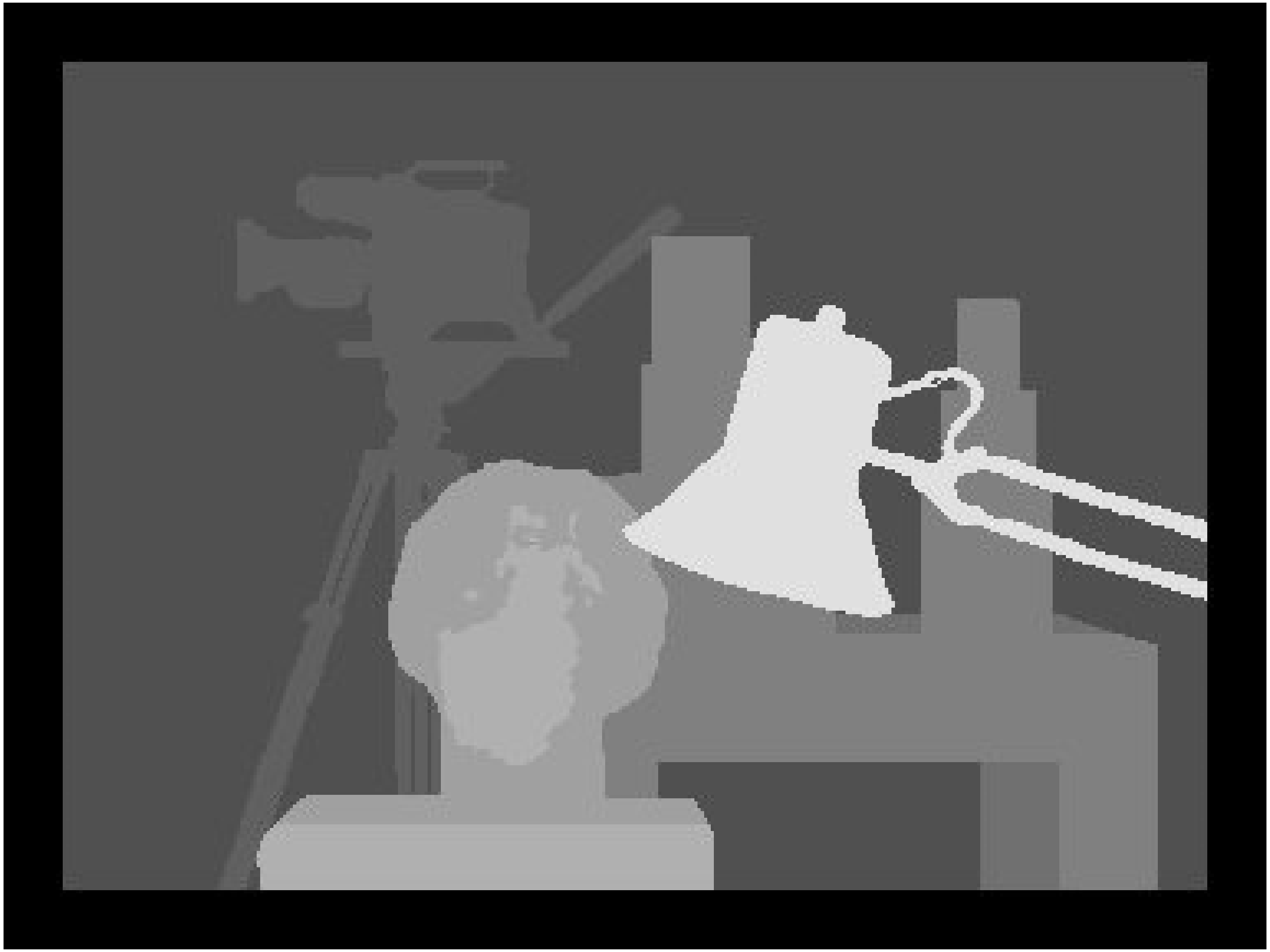
Goal: 3D from Stereo via Disparity Map

image I(x,y) | Disparity map D(x,y) | image I´(x´,y´)

$$(x',y')=(x+D(x,y),y)$$

F&P
Chapter 11

Example: Stereo to Depth Map

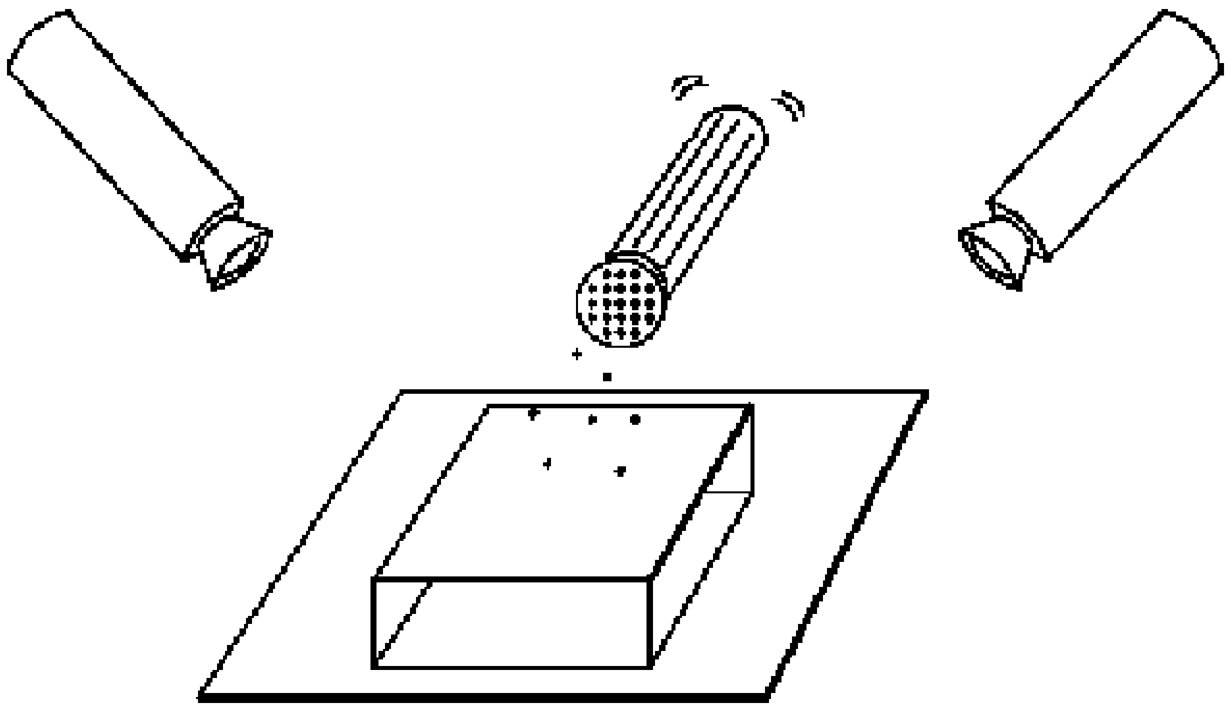


Random dot stereograms

- Julesz 1960: Do we identify local brightness patterns before fusion (monocular process) or after (binocular)?

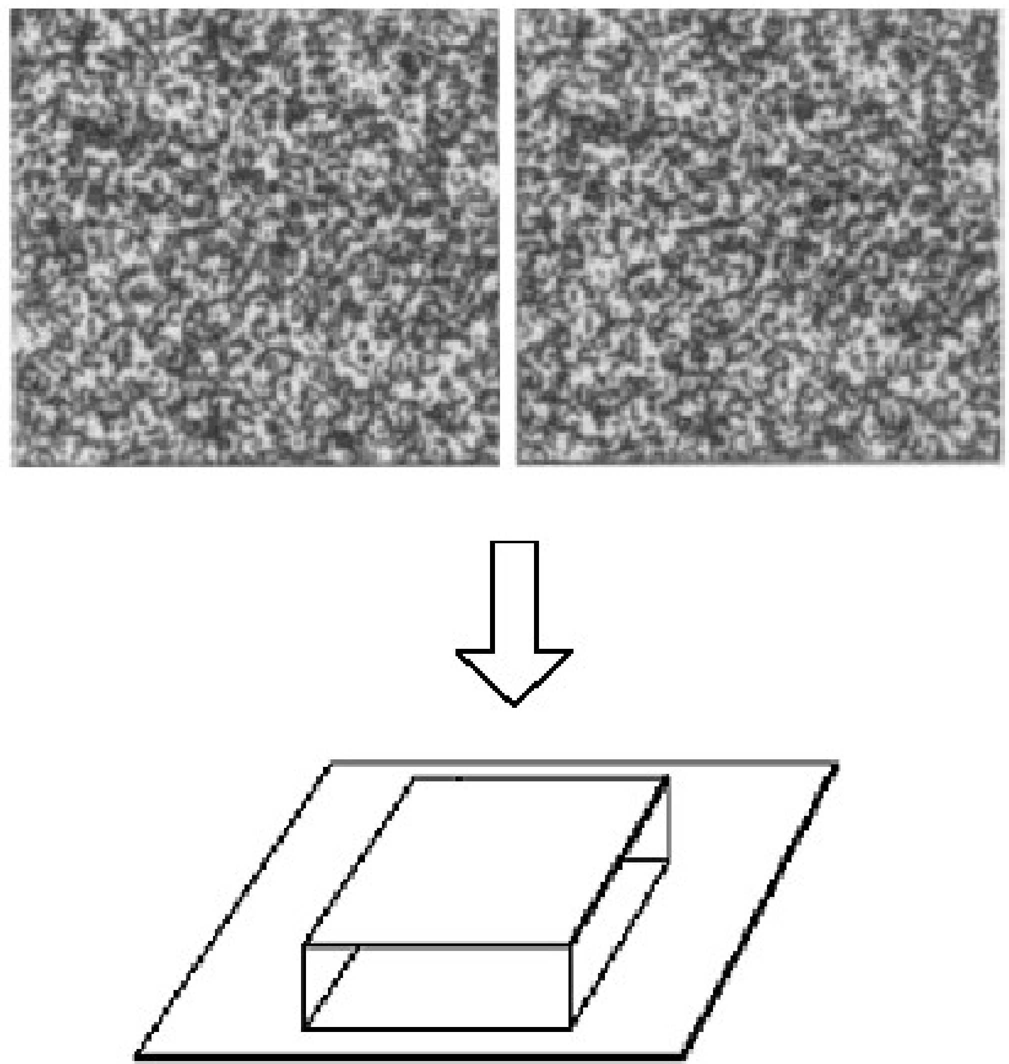
- To test: pair of synthetic images obtained by randomly spraying black dots on white objects

Random dot stereograms

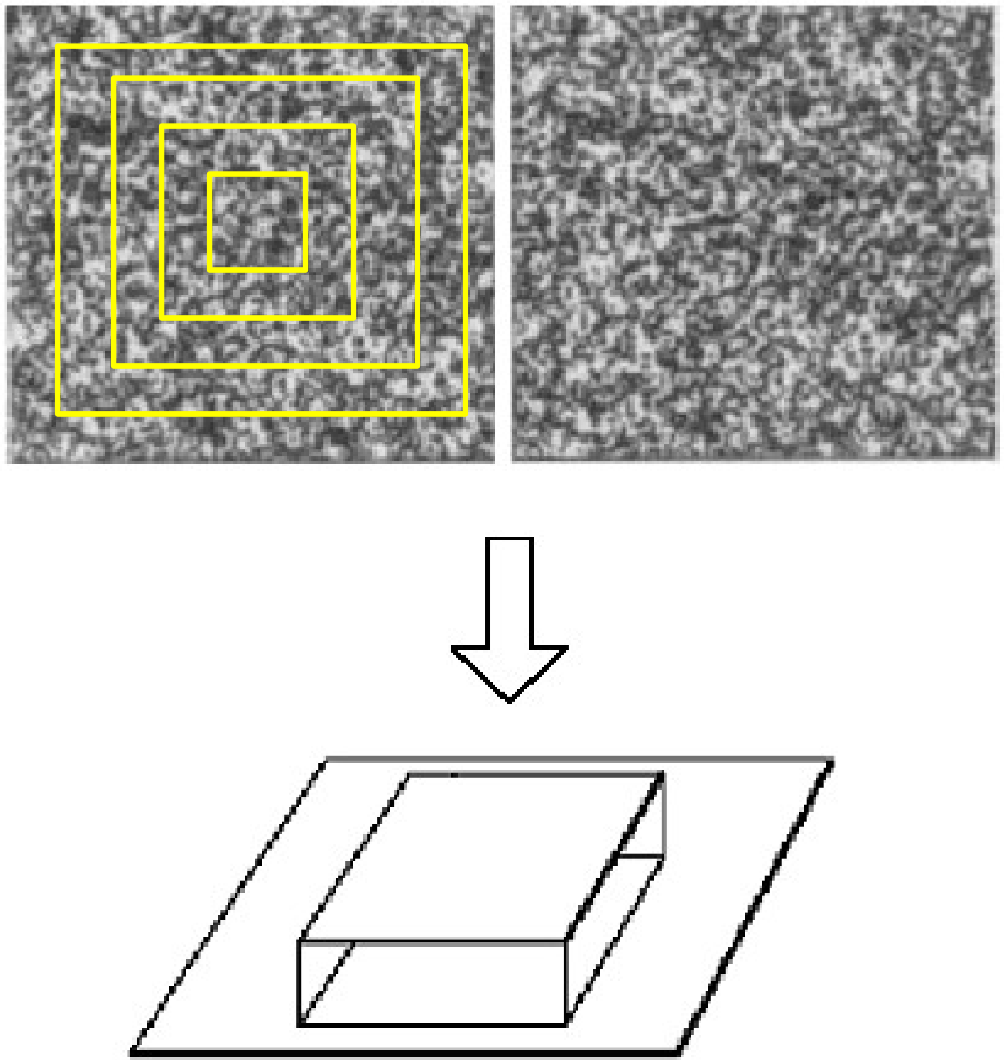


Forsyth & Ponce

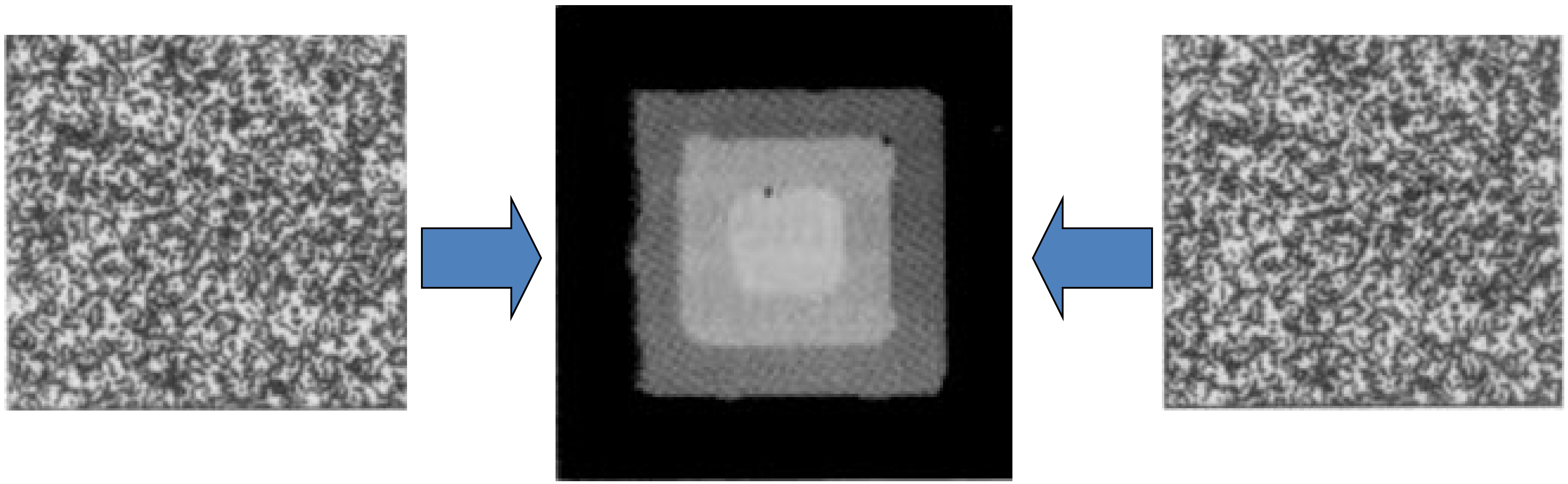
Random dot stereograms



Random dot stereograms



A Cooperative Model (Marr and Poggio, 1976



Random dot stereograms

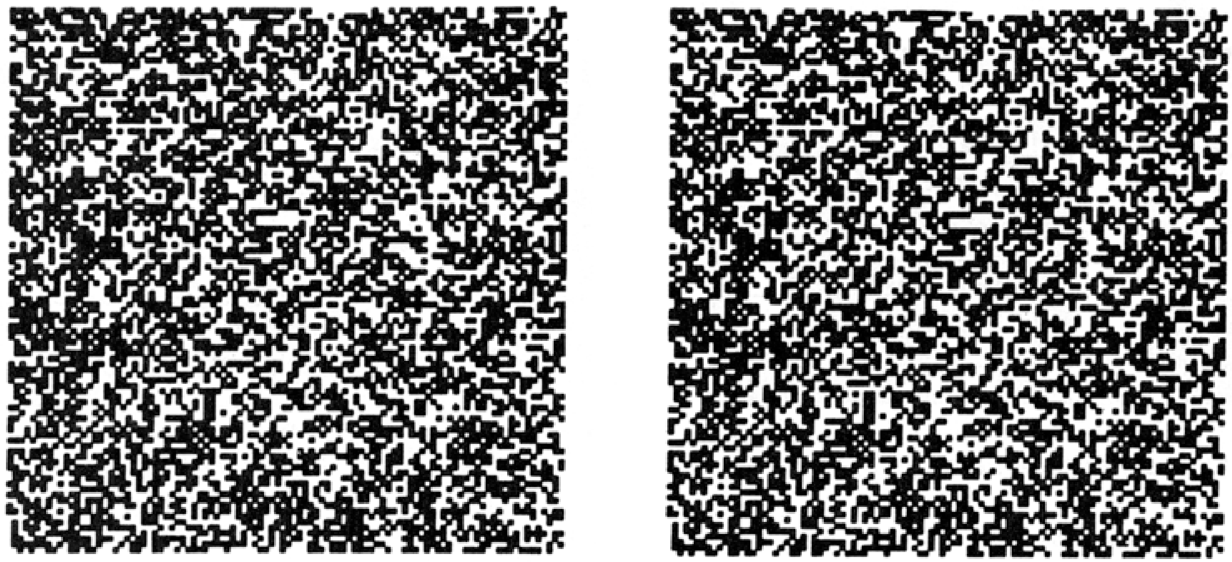


Figure 5.3.8 A random dot stereogram. These two images are derived from a single array of randomly placed squares by laterally displacing a region of them as described in the text. When they are viewed with crossed disparity (by crossing the eyes) so that the right eye's view of the left image is combined with the left eye's view of the right image, a square will be perceived to float above the page. (See pages 210–211 for instructions on fusing stereograms.)

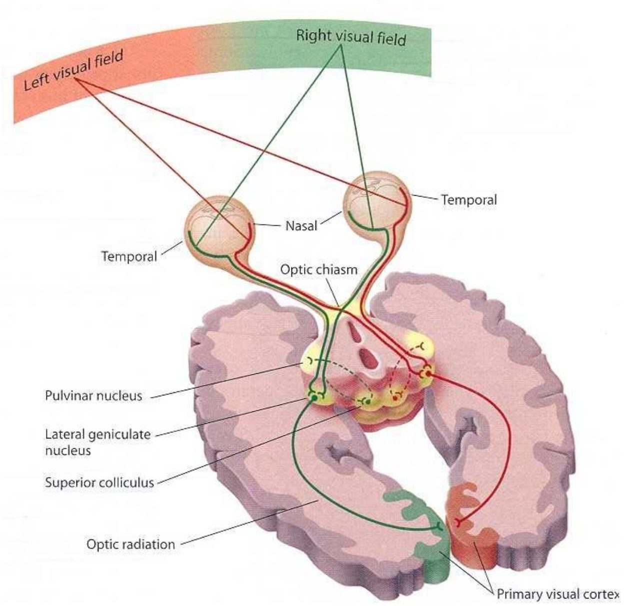
From Palmer, "Vision Science", MIT Press

Random dot stereograms

- When viewed monocularly, they appear random; when viewed stereoscopically, see 3d structure.

- Conclusion: human binocular fusion not directly associated with the physical retinas; must involve the central nervous system

- Imaginary* *“cyclopean retina”* that combines the left and right image stimuli as a single unit



Visual Pathway.jpg wiki.ucl.ac.uk

*This was because it was as though we have a cyclopean eye inside our brains that can see cyclopean stimuli hidden to each of our actual eyes.

Grauman

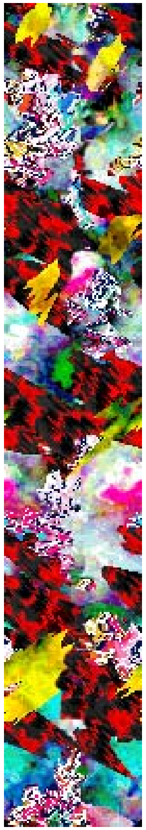
Autostereograms

Exploit disparity as depth cue using single image

(Single image random dot stereogram, Single image stereogram)

Images from magiceye.com

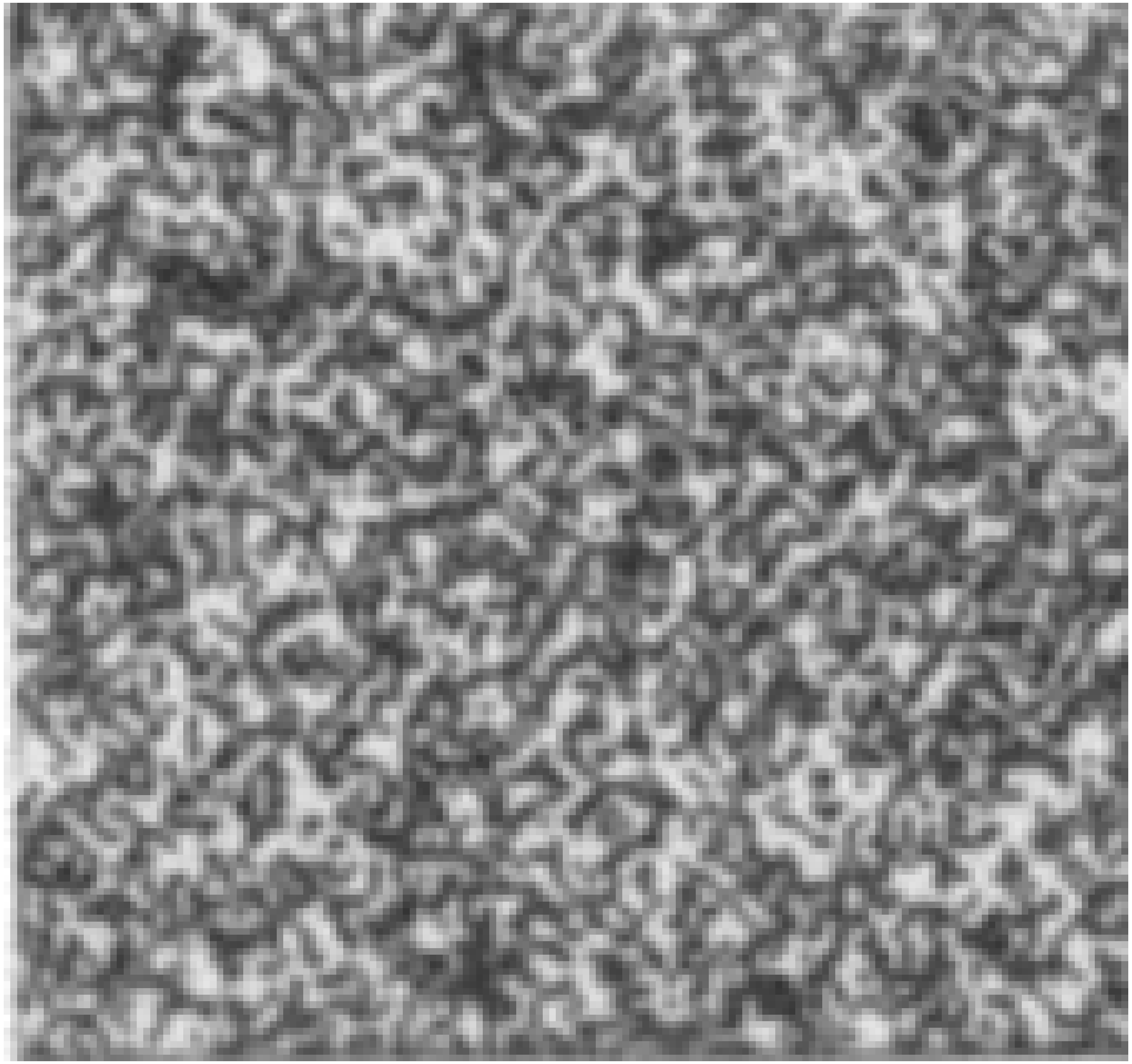
Autostereograms



Images from magiceye.com

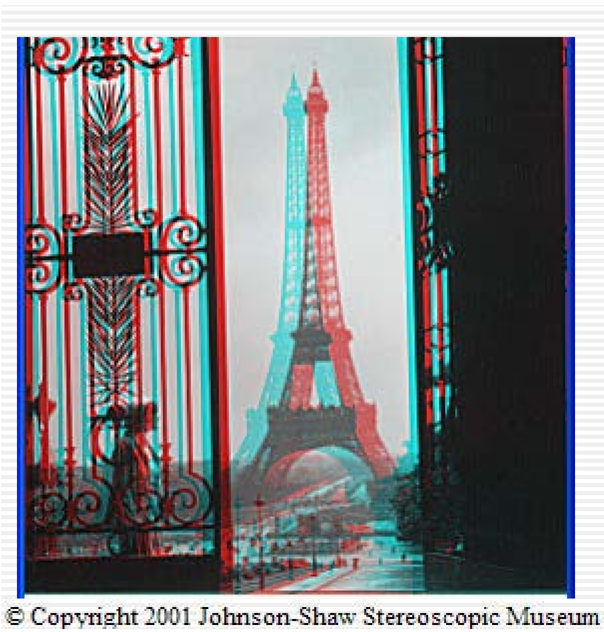
Optical flow

Where do pixels move?



Optical flow

Where do pixels move?



http://www.johnsonshawmuseum.org

Public Library, Stereoscopic Looking Room, Chicago, by Phillips, 1923