Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Stereo Photography / Imagery

* Depth / Range Imaging
* Structure / 3D Scenes
* Stereo .. Depth from 2 views

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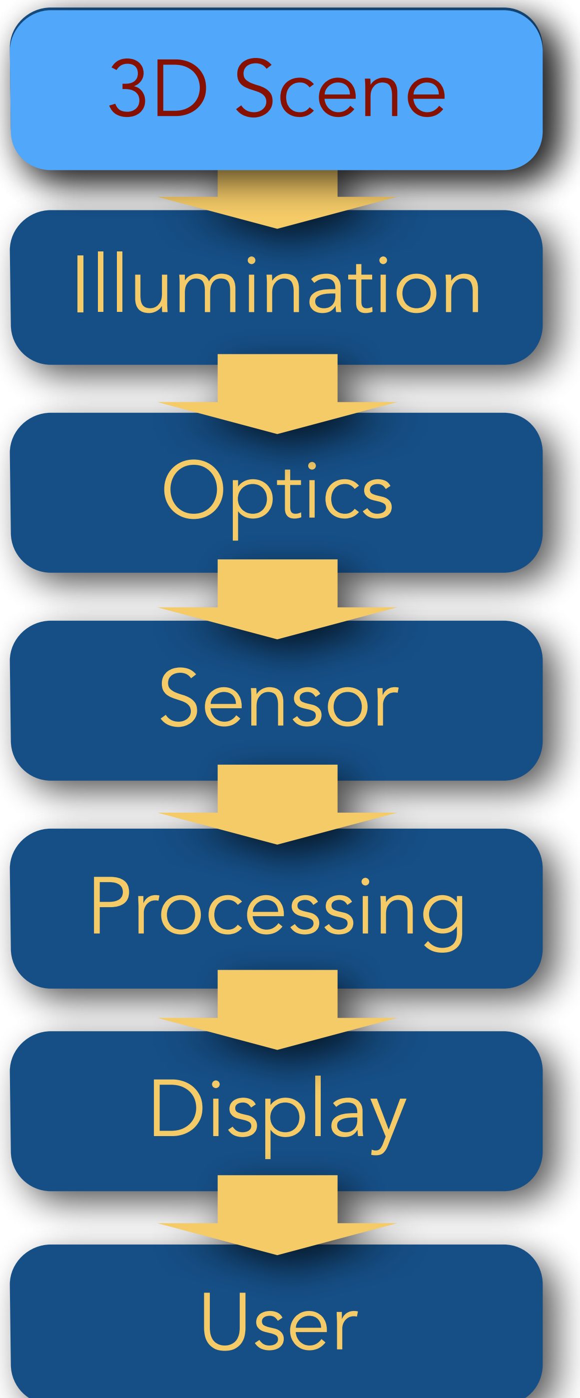
1. Geometry (Depth/Structure) in a Scene
2. Stereo
3. Parallax
4. Compute Depth from a stereo image pair

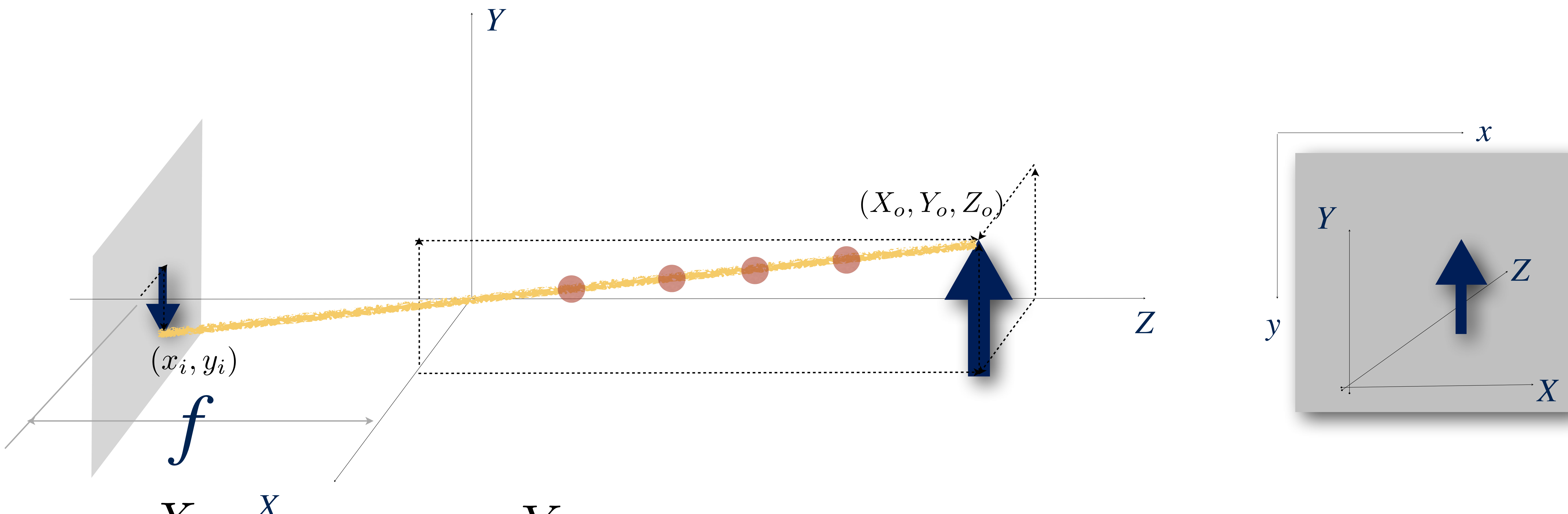
Depth (of a Scene)



* Above all, we are interested in capturing a 3D scene with Geometry
* Need Depth, Geometry, 3D

mcmillan & Gortler 1999

Compute depth / structure



$$x_i = \frac{X_o}{Z_o} f \qquad y_i = \frac{Y_o}{Z_o} f$$

$$x_i = \frac{kX_o}{kZ_o} f \qquad y_i = \frac{kY_o}{kZ_o} f$$

Fundamental Ambiguity: Any points along the same ray map to the same point in the image

Depth ambiguity

Images from S. Lazebnik and I. Essa

Depth Cues

Perspective (Vanishing Lines/points)

Depth Cues

Objects of known sizes

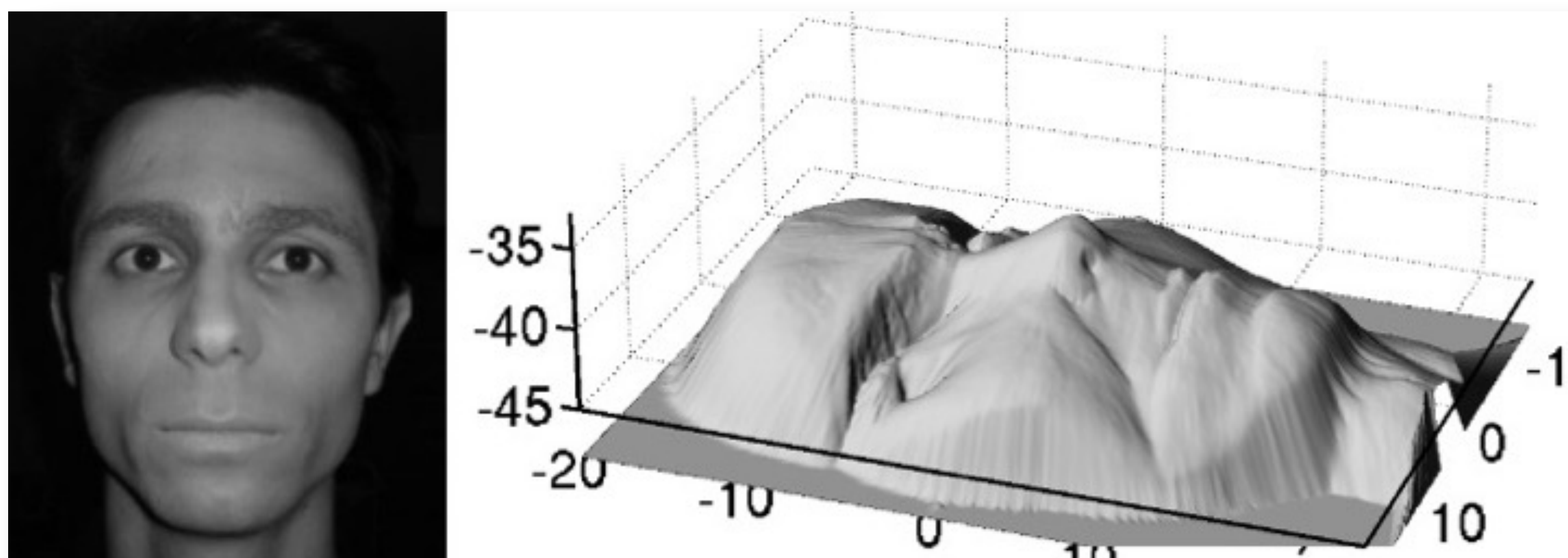
Depth Cues

Occlusions,

etc

Depth Cues

Shape from Shading

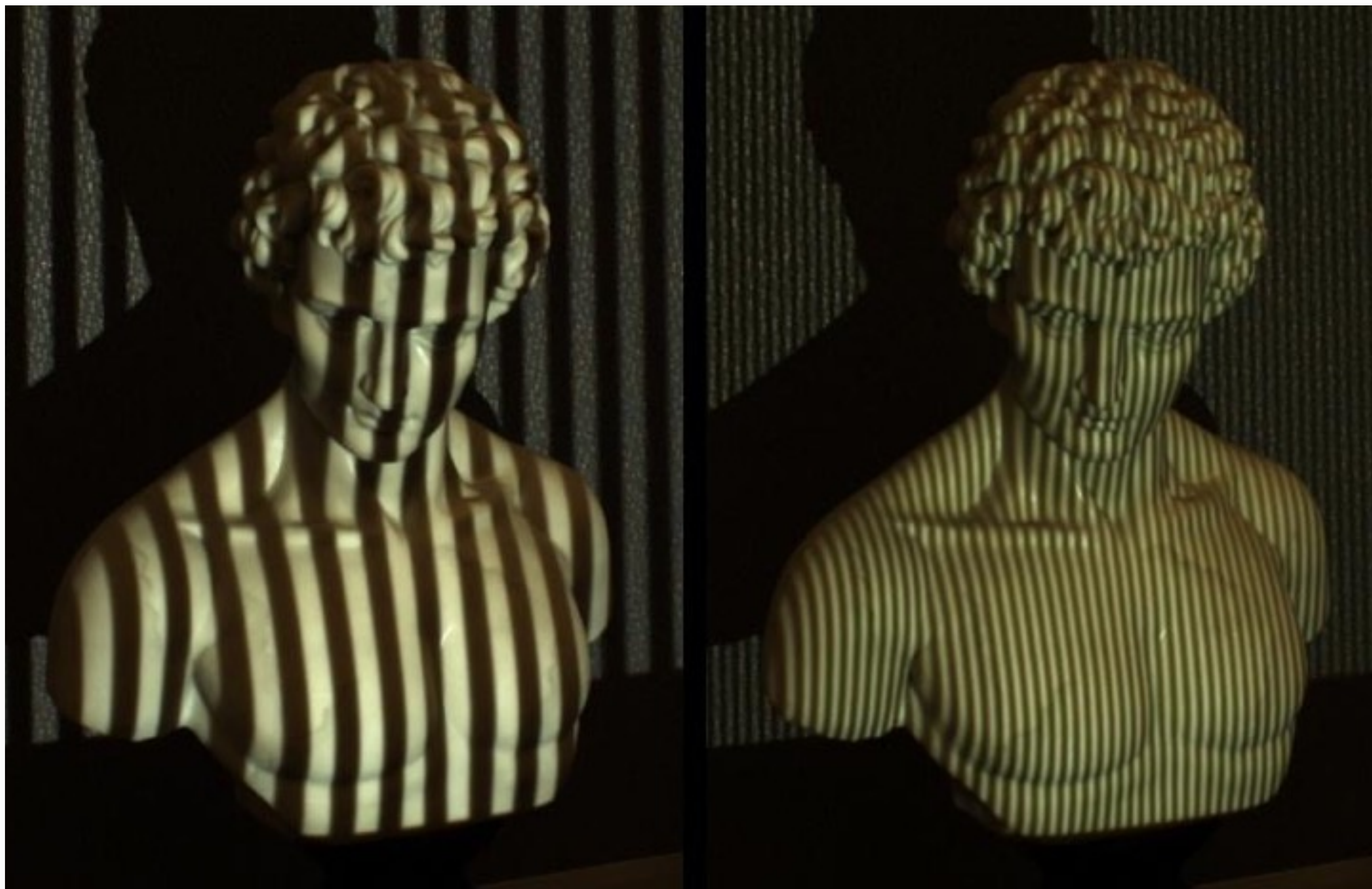


trimensional

3D Scanner for iPhone

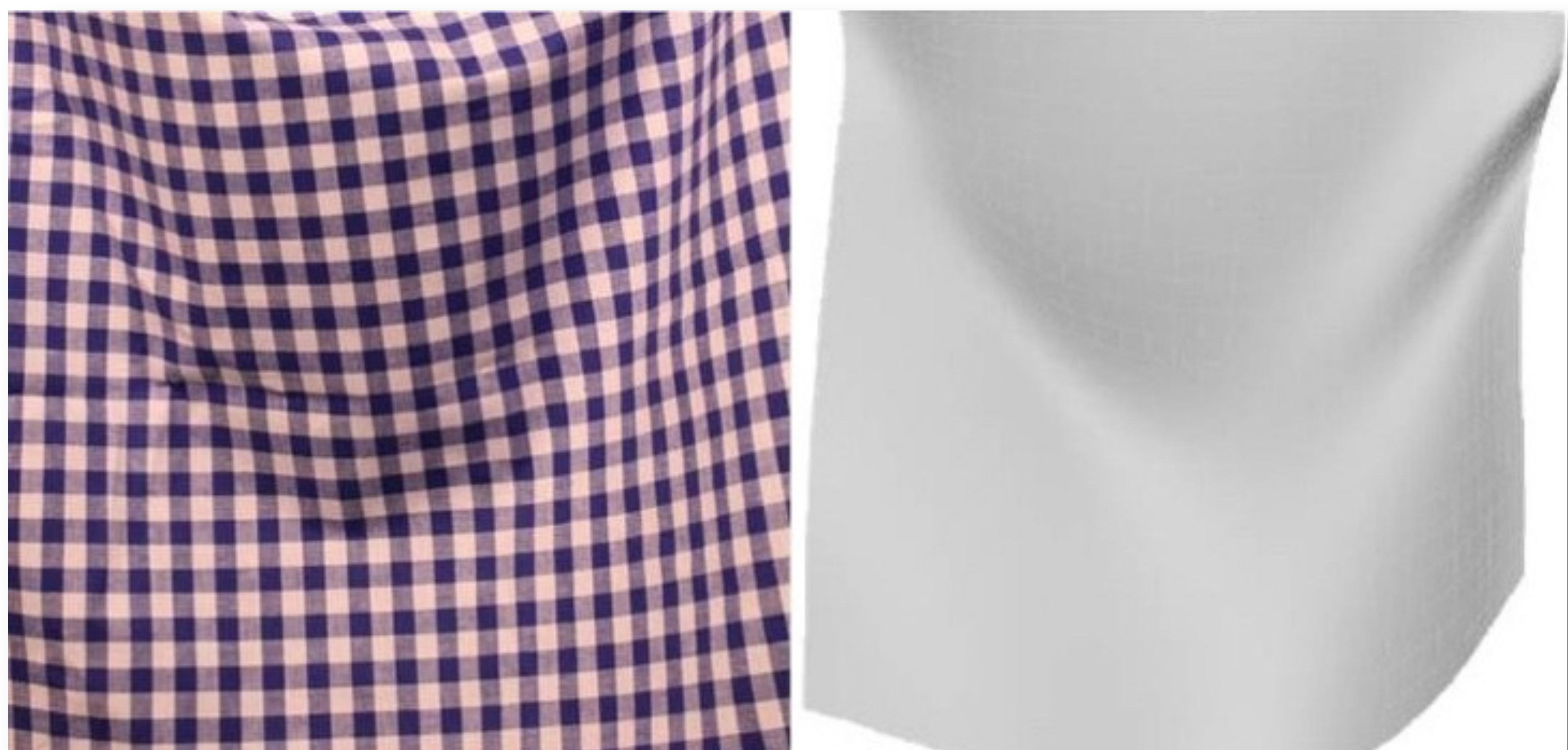
Depth Cues

Shape from Structured Light



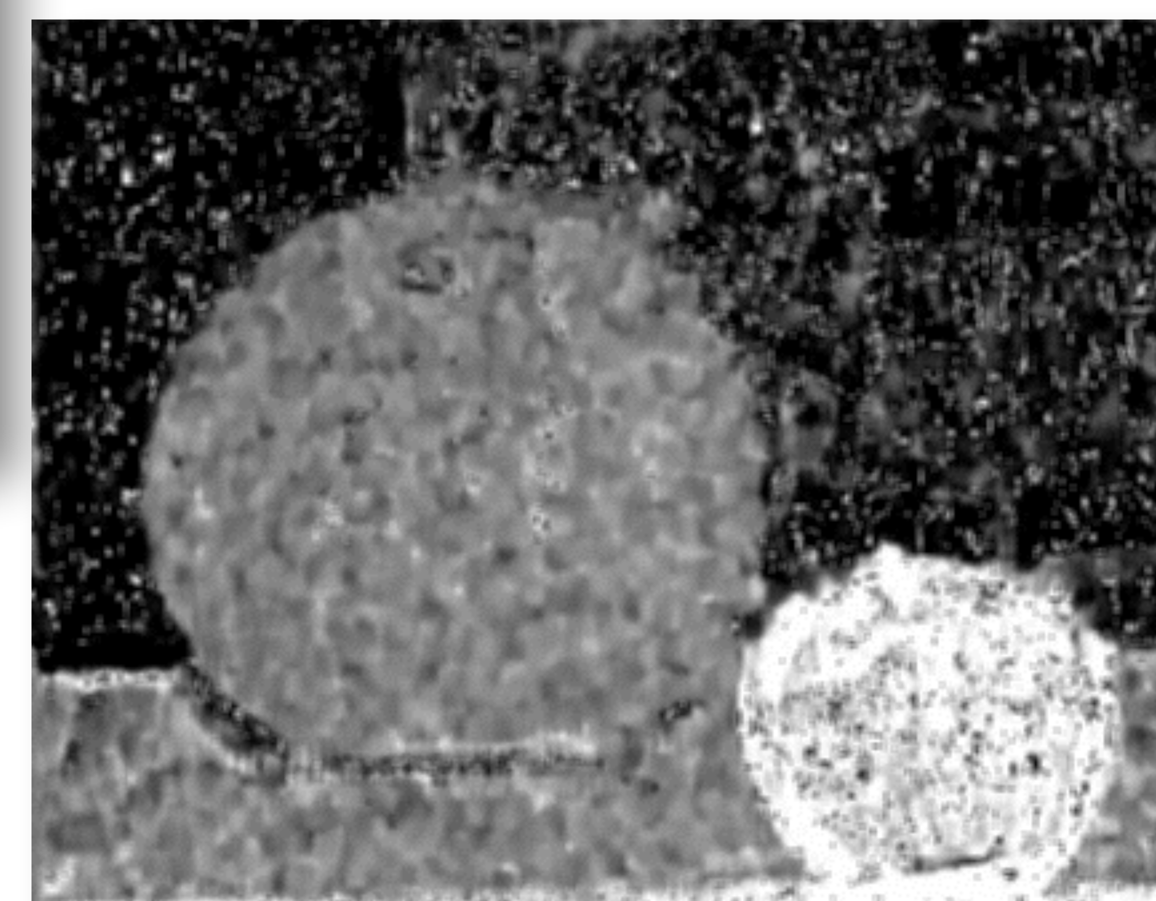
Depth Cues

Shape from Texture



Hilsmann, Schneider, Eisert (2011)

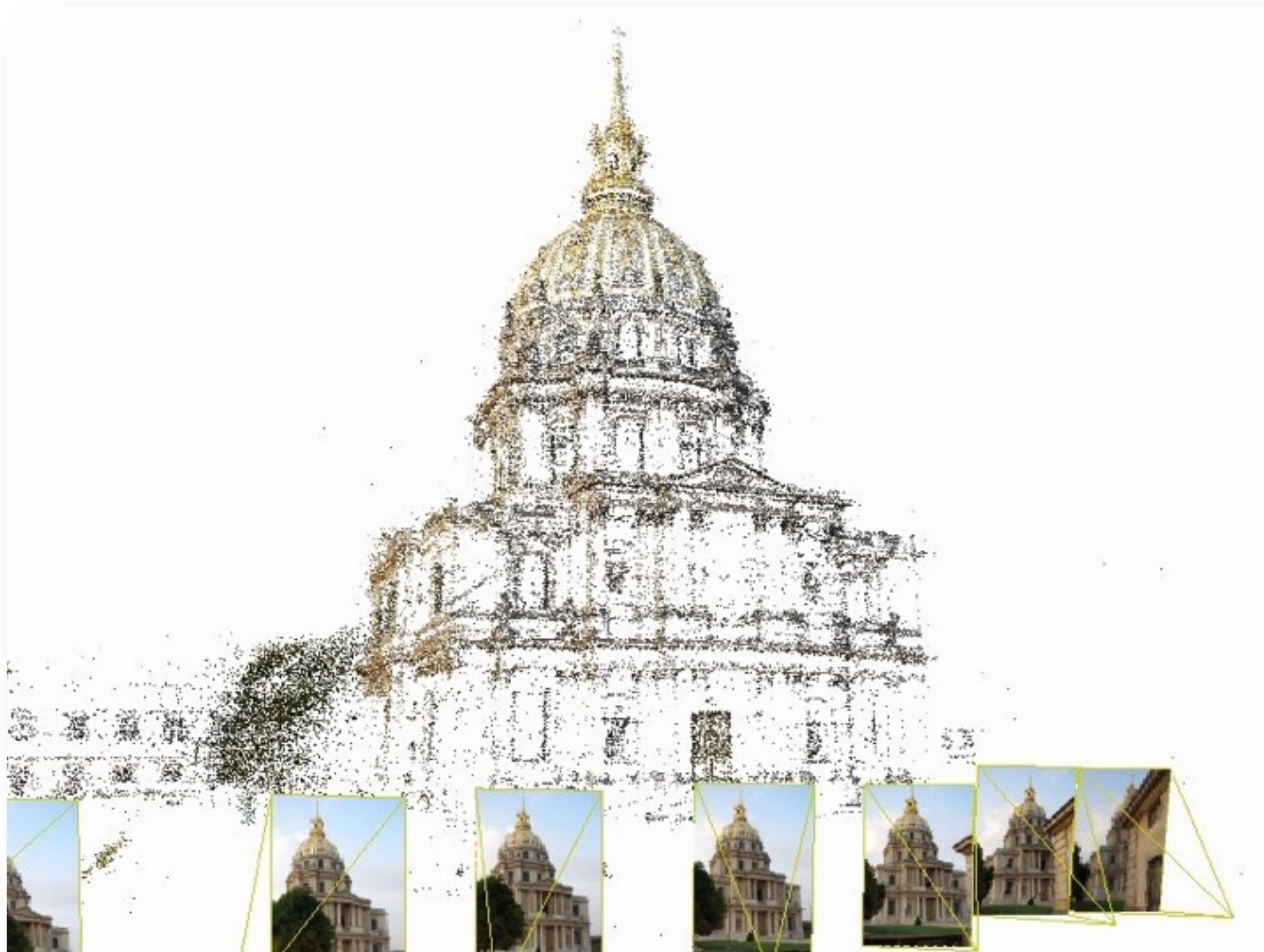
Depth Cues



Shape from De Focus

Favaro, & Soatto (1999)

Depth Cues



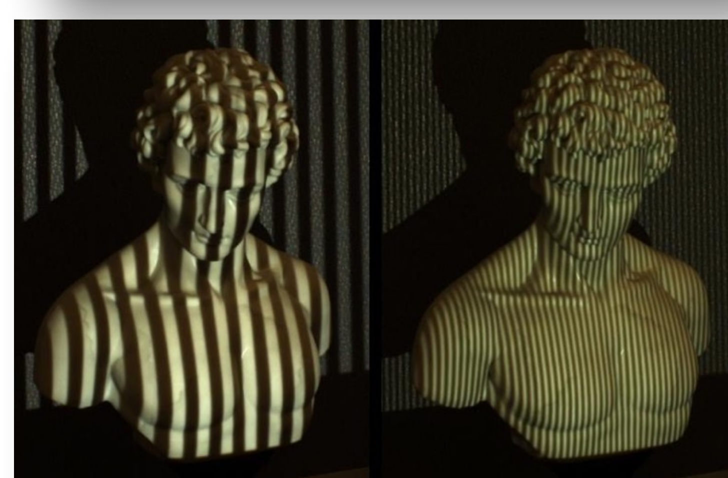
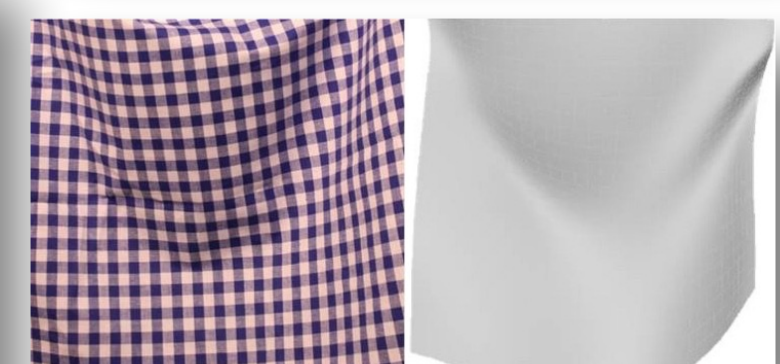
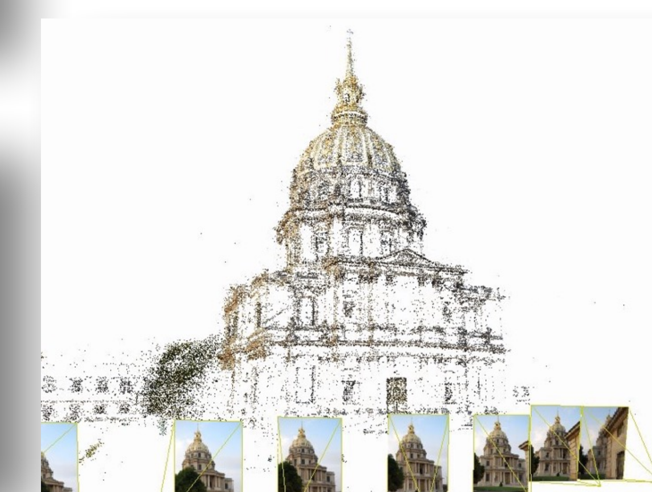
Structure from Motion

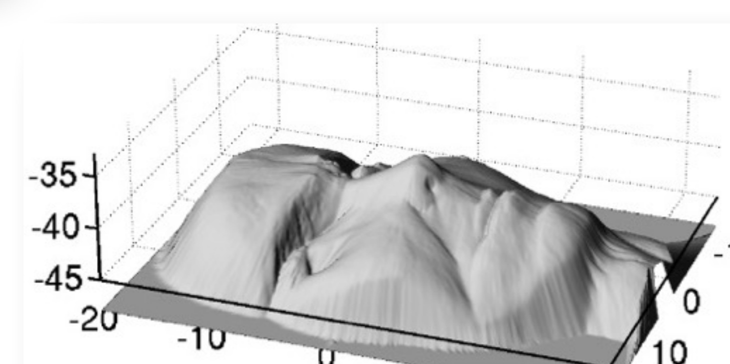
Fredriksson and Olsson (2012)

Estimating Depth / Shape From One View

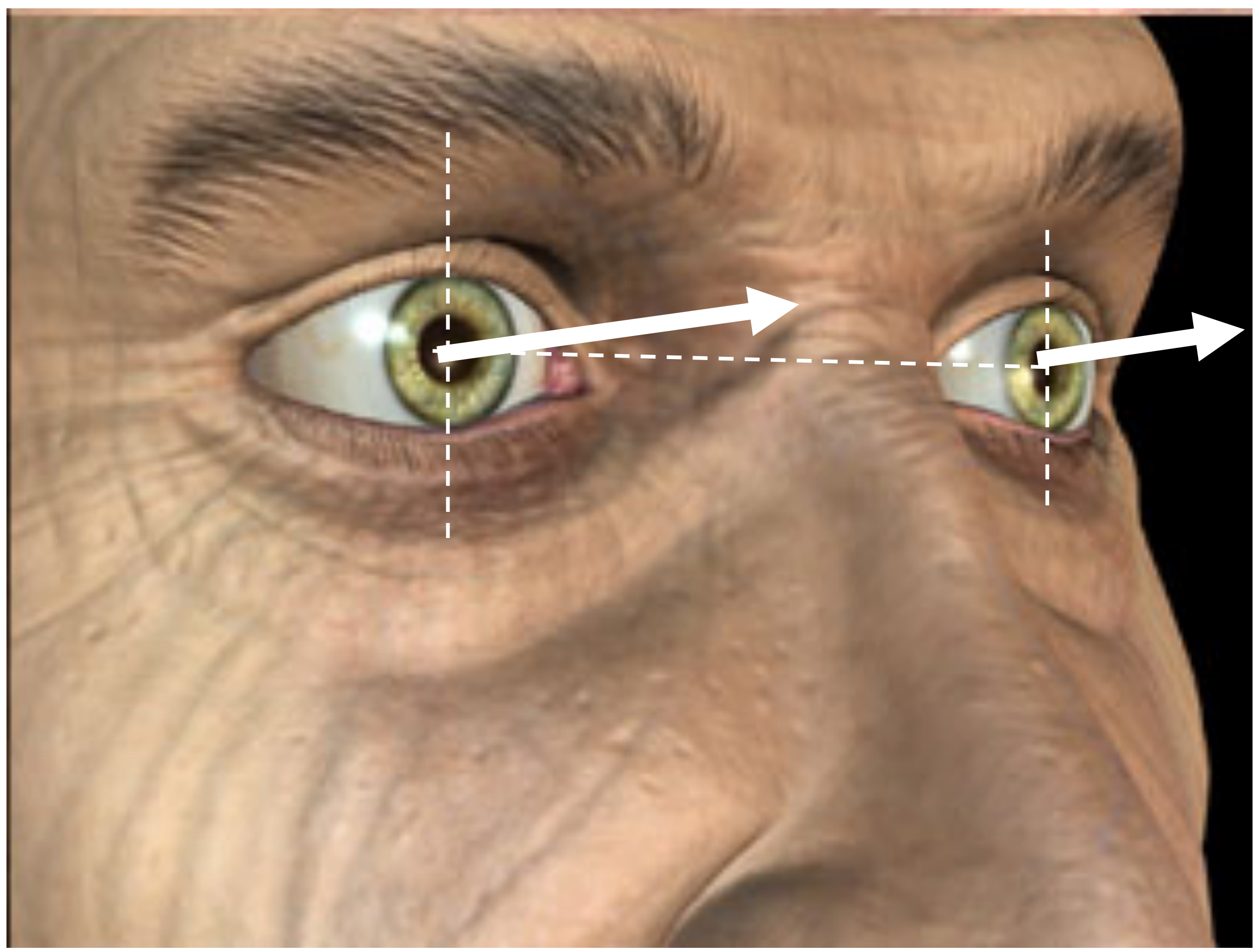
* Shape from X
  * Perspective
  * Shading
  * Motion
  * Focus
  * Occlusions
  * Objects

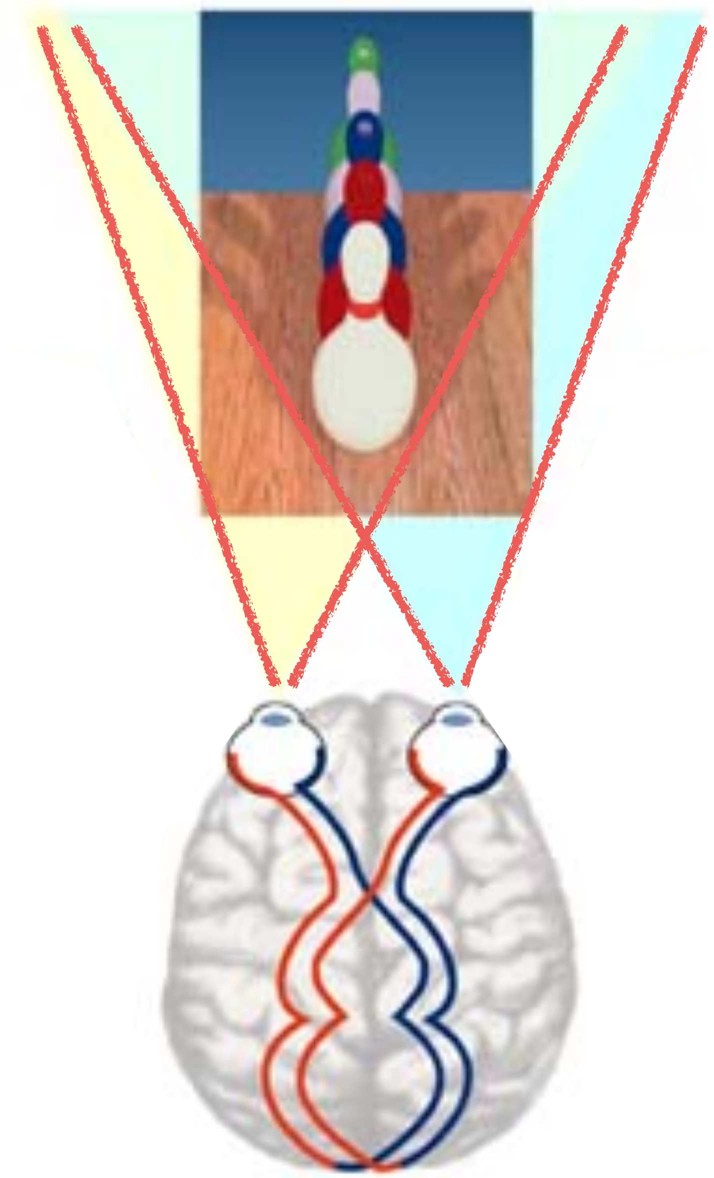




Stereo Vision

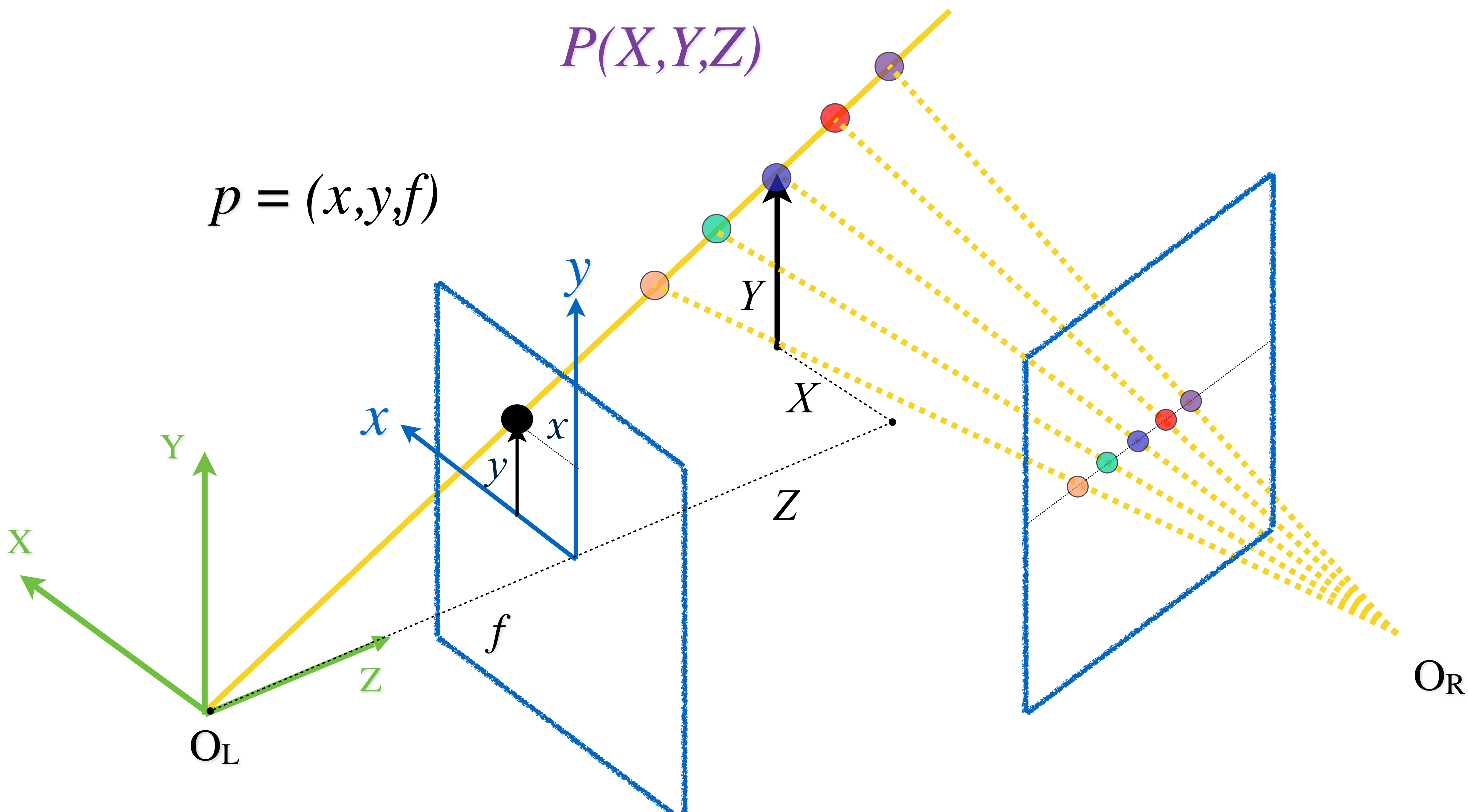




Inferring depth from images captured at the same time by two or more cameras

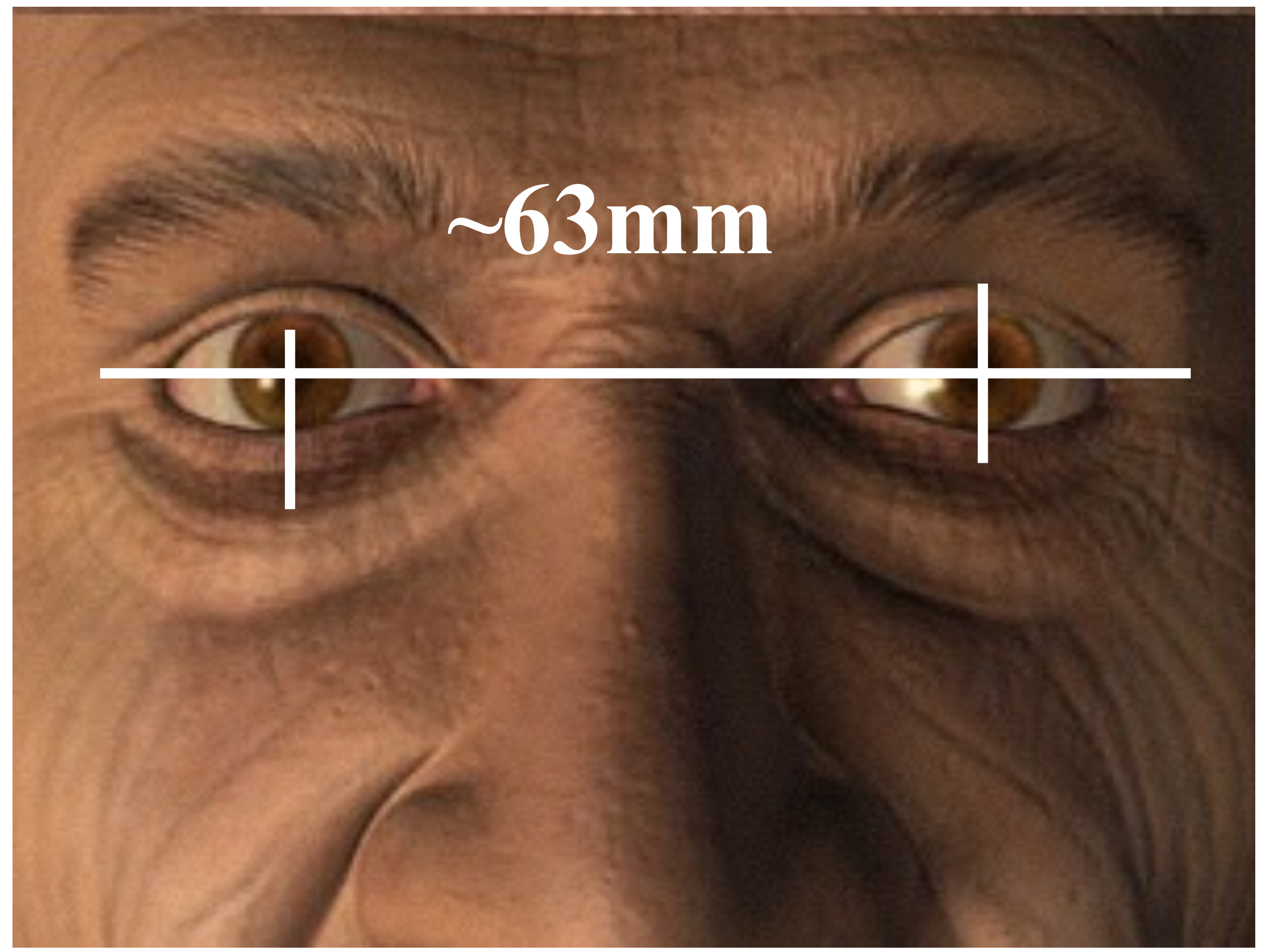
Slide courtesy: Bob Collins

Why Stereo Vision?



Slide courtesy: Bob Collins

Why Stereo Vision?



Eyes form a stereo system

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

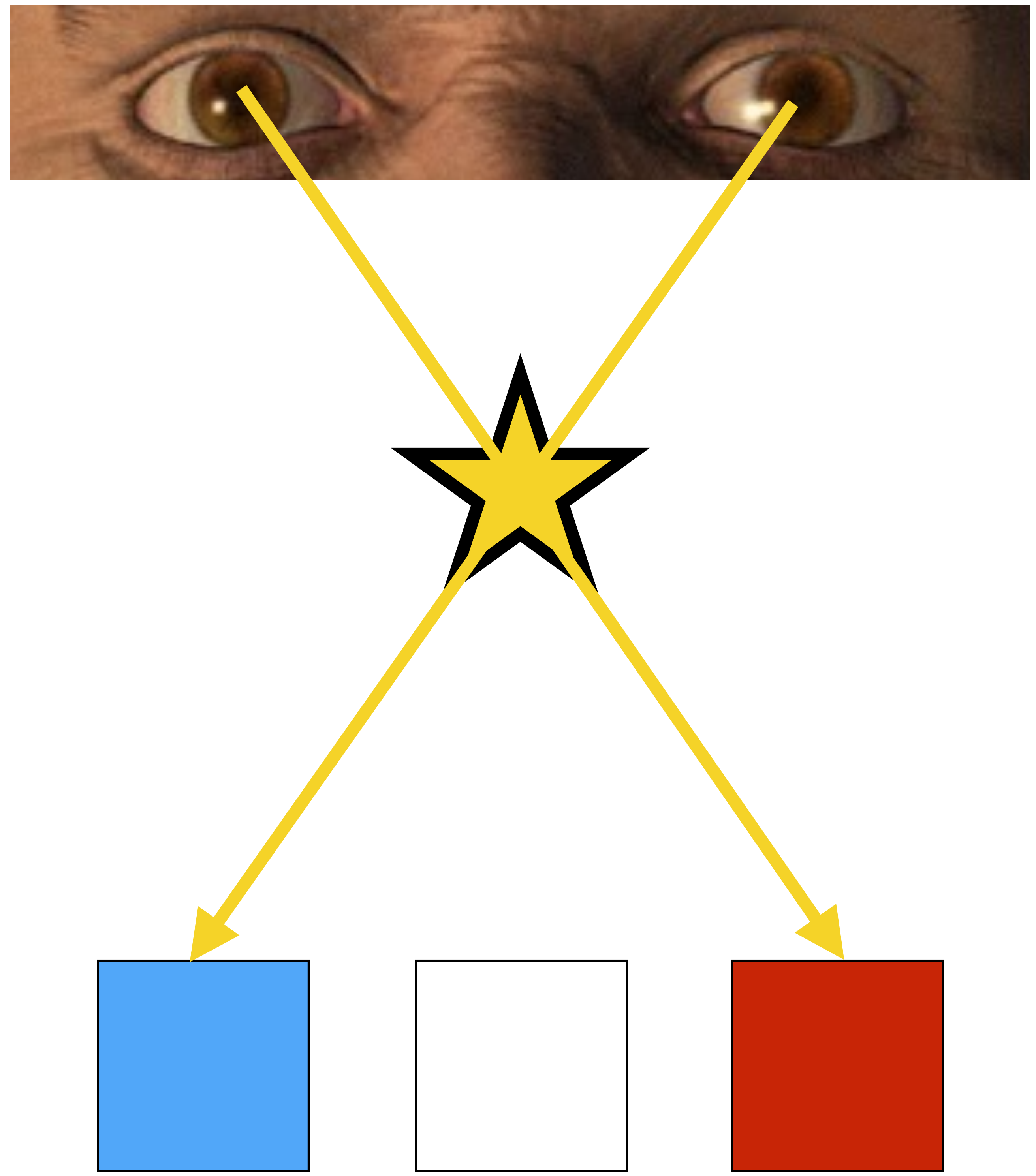
Slide courtesy: Bob Collins

Parallax

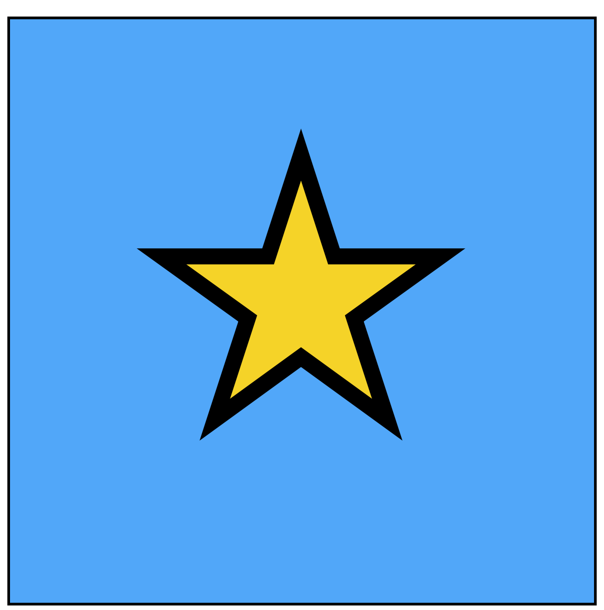
Slide courtesy: Bob Collins

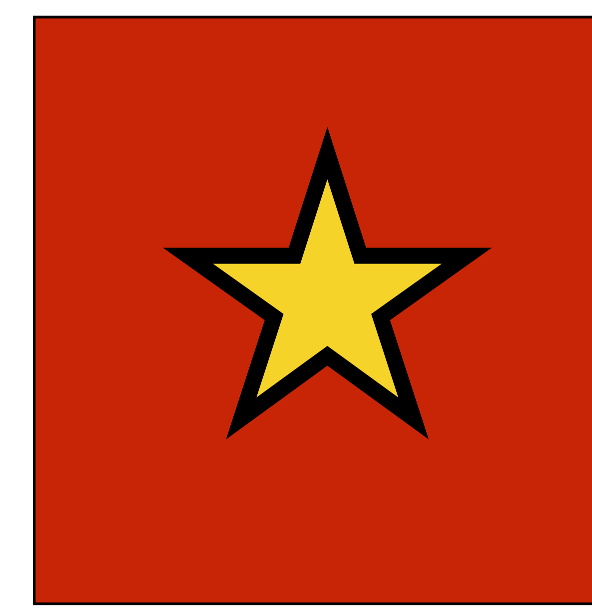
Parallax

Points at different depths displace differently



Nearby points displace more than far ones





Depth via Parallax

Parallax = apparent motion of scene features located at different distances

http://4hdwallpapers.com/wp-content/uploads/2013/03/California-Mountain.jpg

Depth via Parallax

Far

Mid

Near

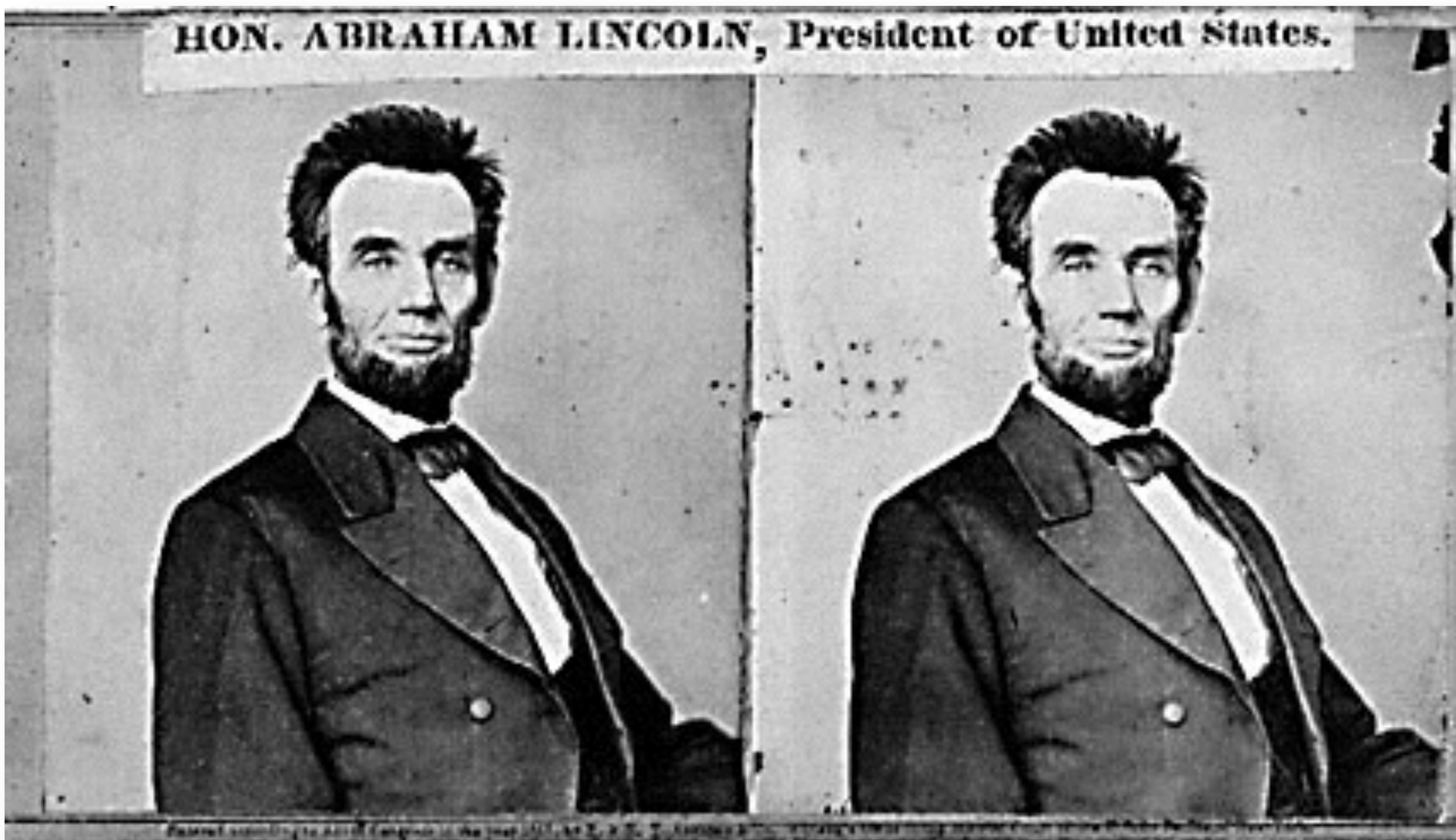
http://4hdwallpapers.com/wp-content/uploads/2013/03/California-Mountain.jpg

Stereo Photography and Stereo Viewers

Invented by Sir Charles Wheatstone 1838

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

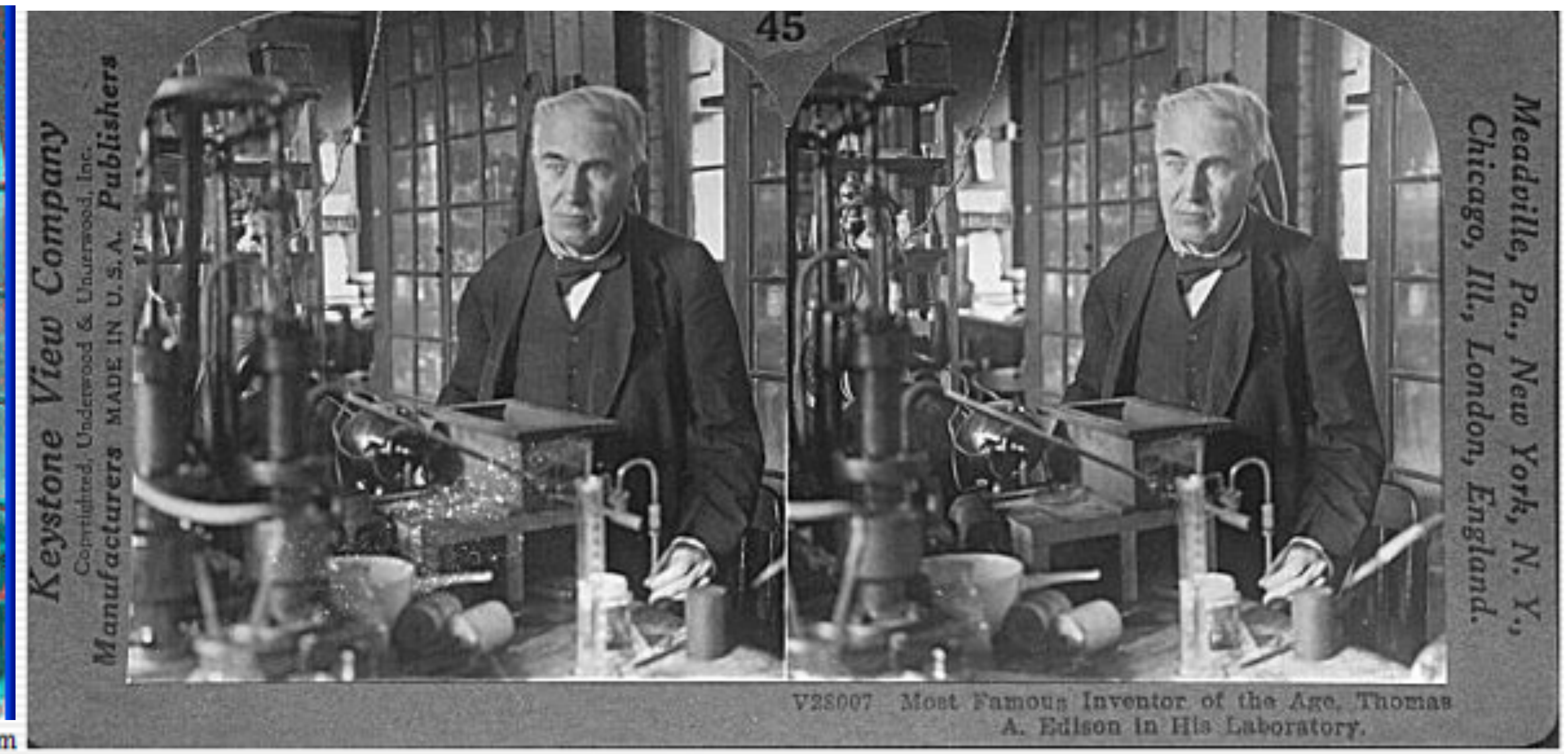
Early 3D photographs



Anaglyph

Put red filter over left eye

© Copyright 2001 Johnson-Shaw Stereoscopic Museum

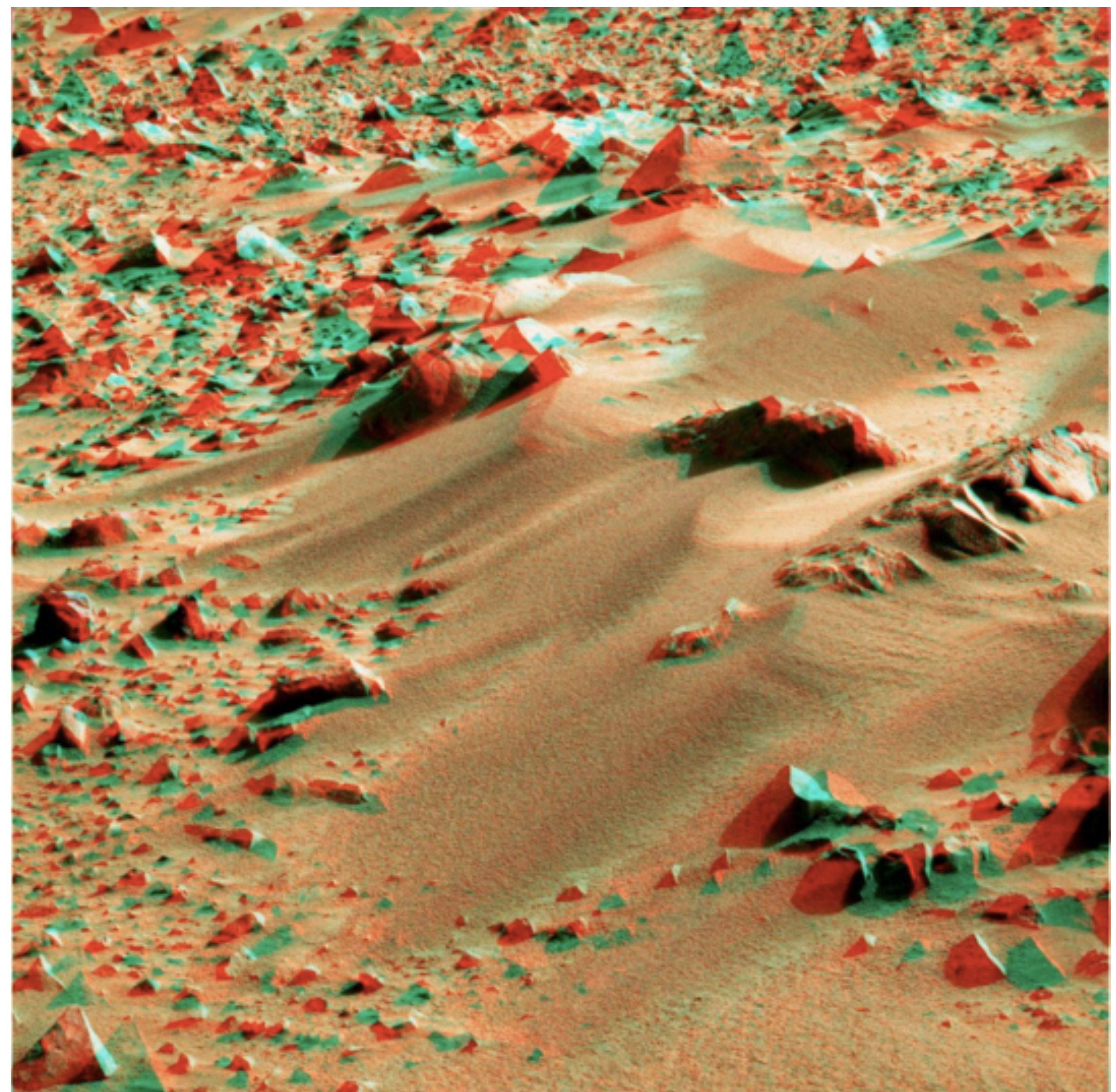


Anaglyphs encode parallax in a single picture.

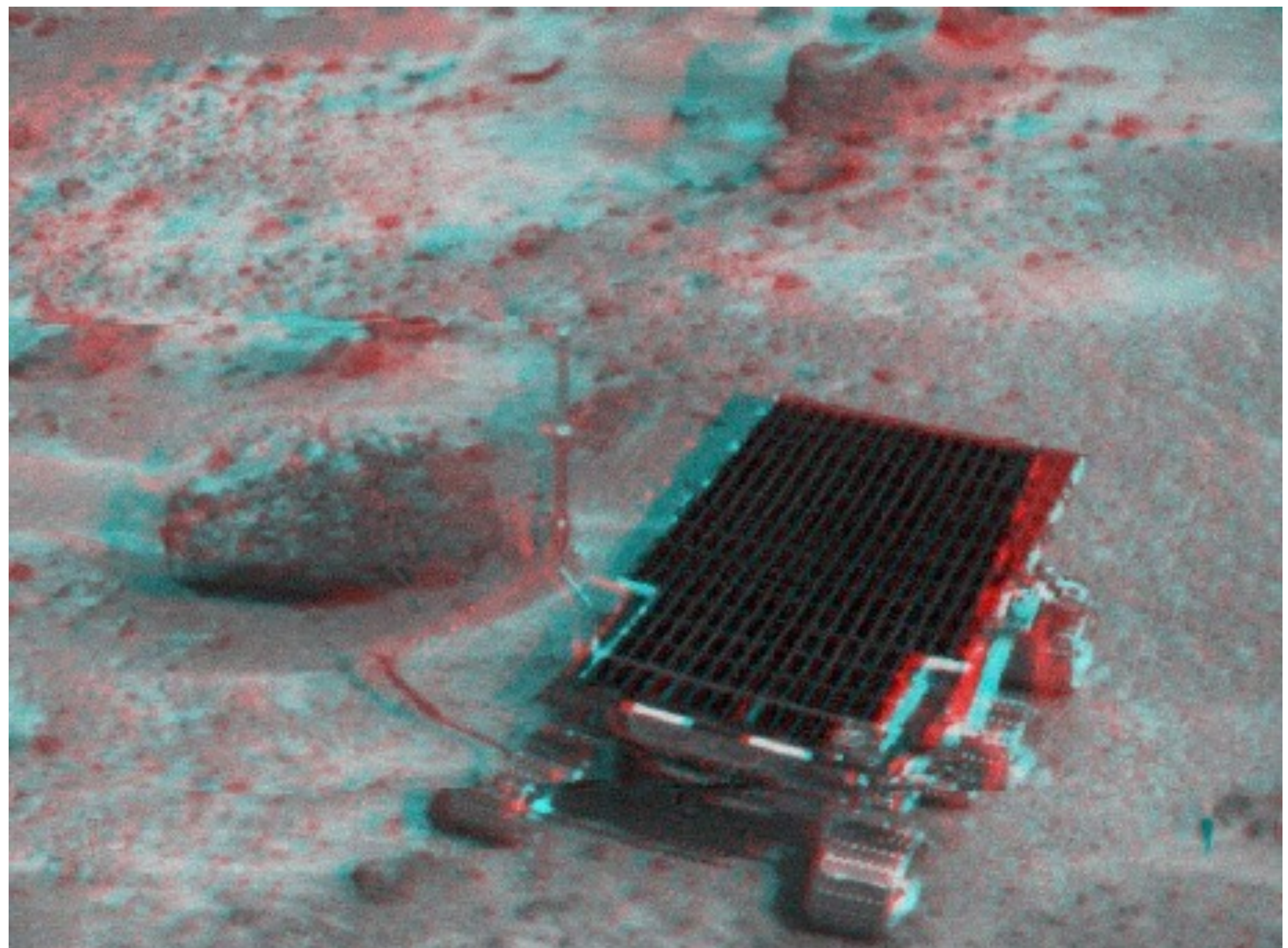
Two slightly different perspectives of the same subject are superimposed on each other in contrasting colors, producing a three-dimensional effect when viewed through two correspondingly colored filters

http://www.johnsonshawmuseum.org

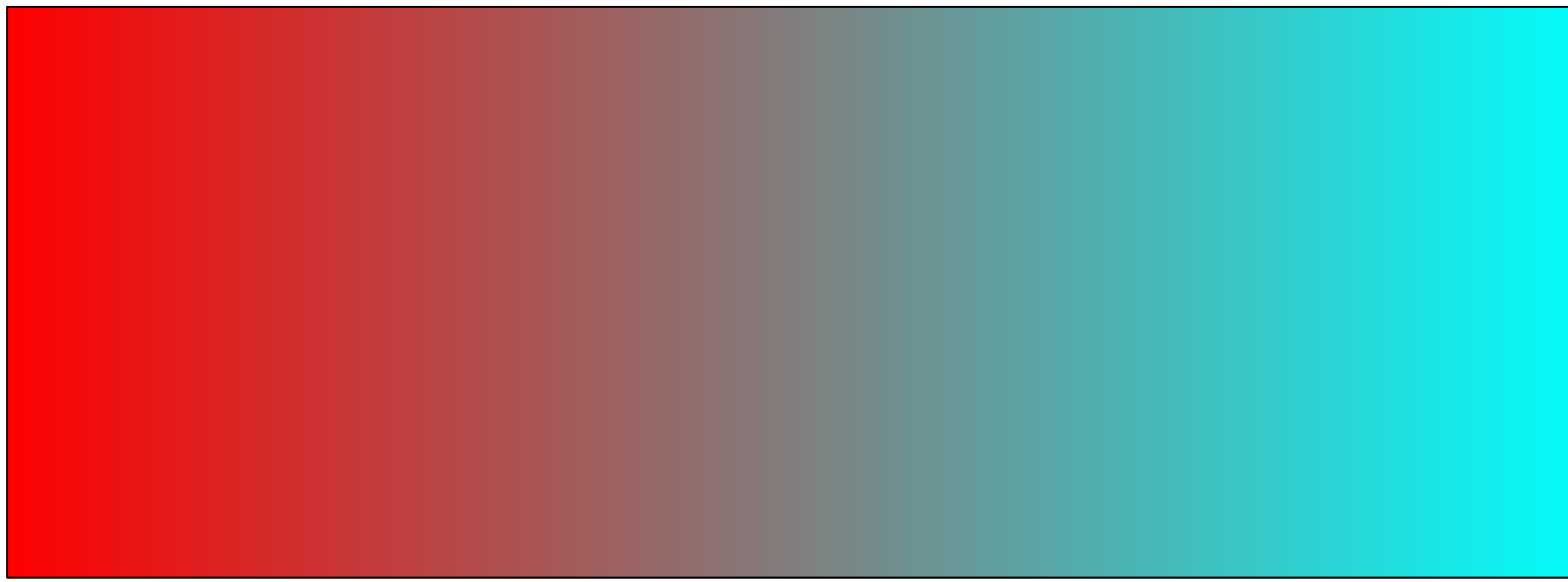
Anaglyph



Anaglyph



How Anaglyphs Work



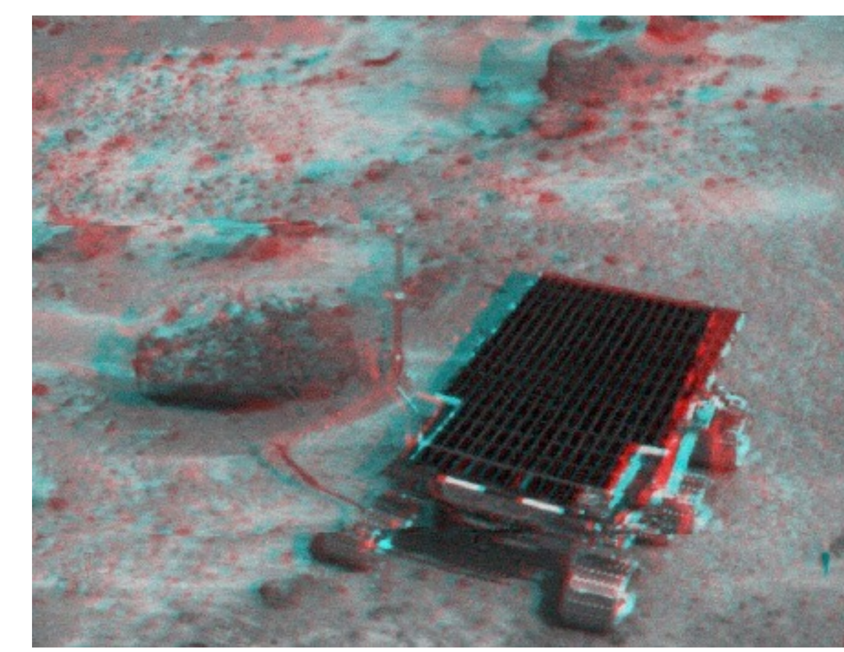
- Close right eye, then close left. What do you observe?
- Red filter selectively passes red color, and similarly for cyan filter and cyan color.

Make an Anaglyph Image

- Given: Grayscale images `img_left`, `img_right`
- Output: Red/cyan anaglyph image

Making an Anaglyph

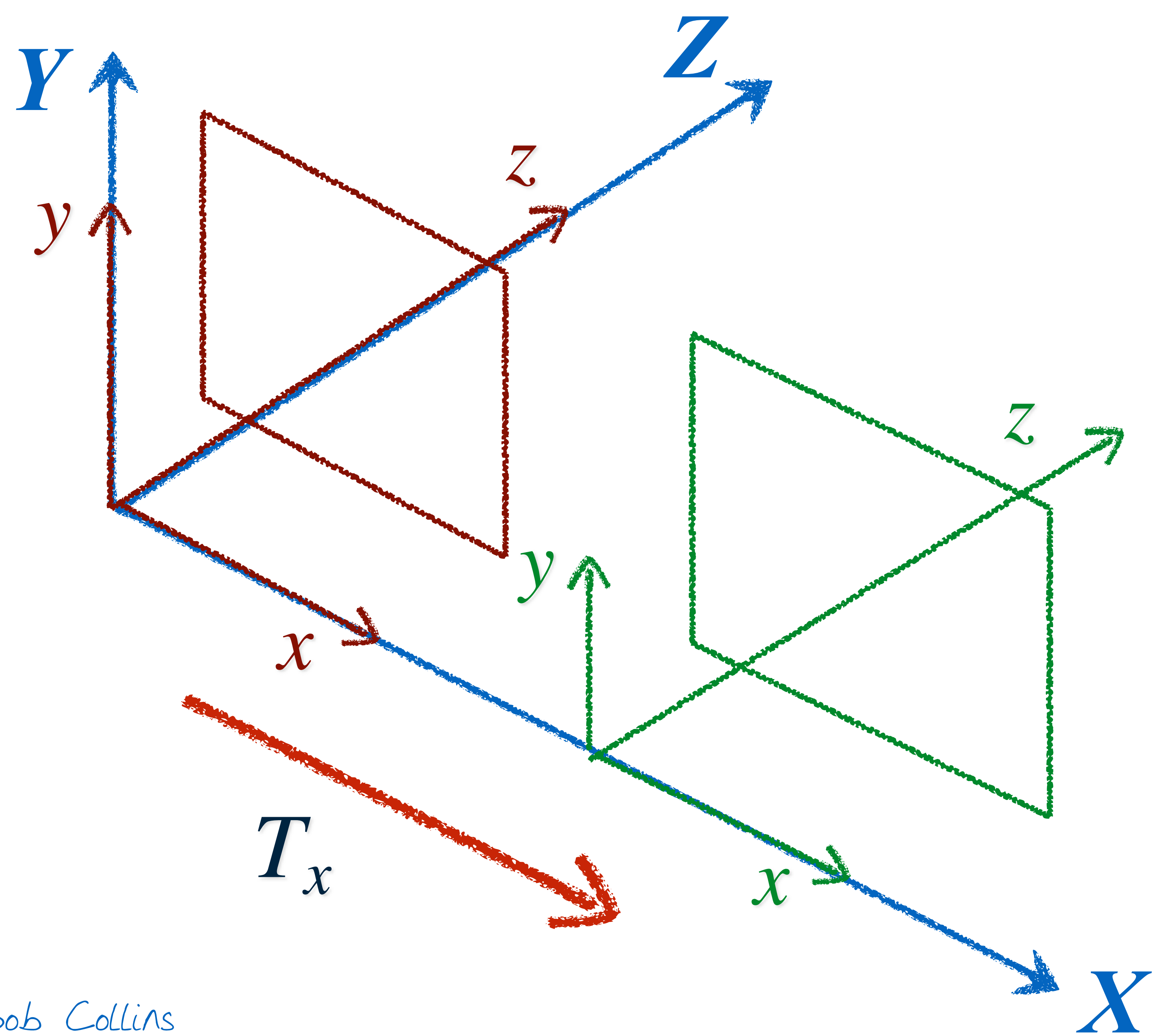
* Take a greyscale stereo pair
* Copy the left image to the red channel of a new image (the anaglyph image)
* Copy the right image to the green and blue channels of the anaglyph image (note: green+blue = cyan)
* View with red-cyan glasses,
    * left eye sees only the left image,
    * and the right eye sees only the right image
    * The brain fuses to form 3D.



A Simple Stereo System

left camera located at (0,0,0)

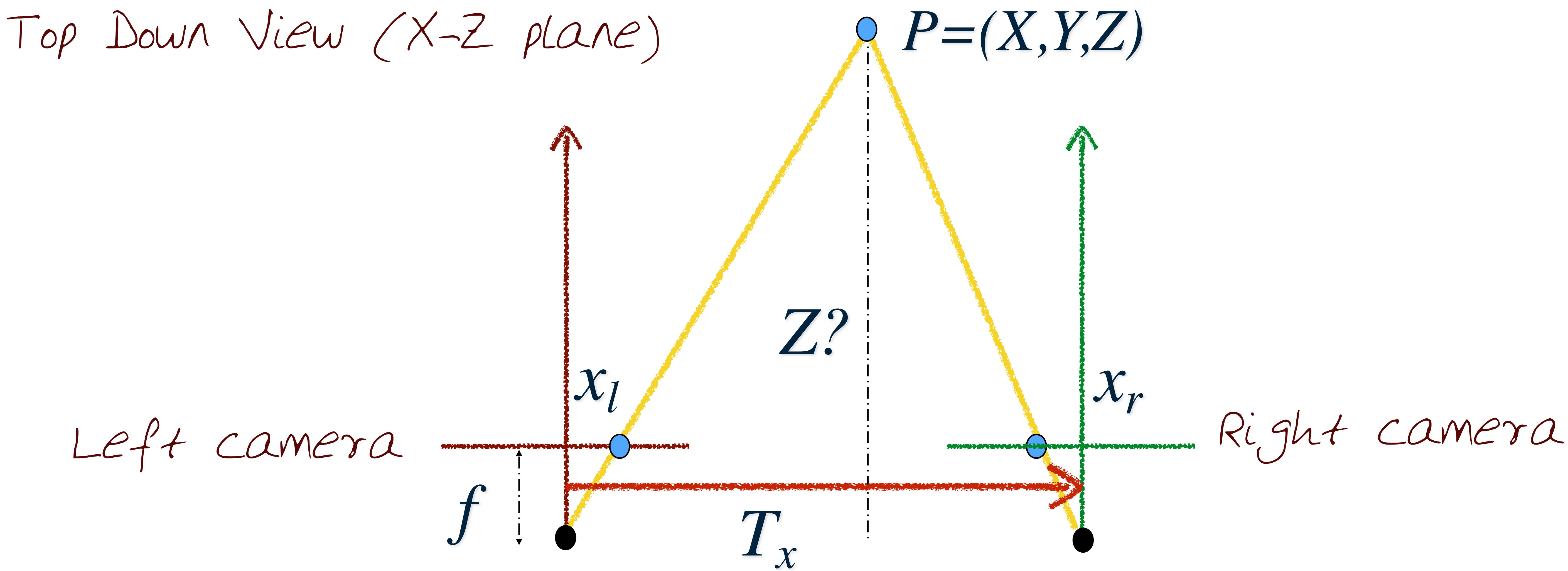
right camera located at $(T_x,0,0)$



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

Slide adapted from Bob Collins

A Simple Stereo System



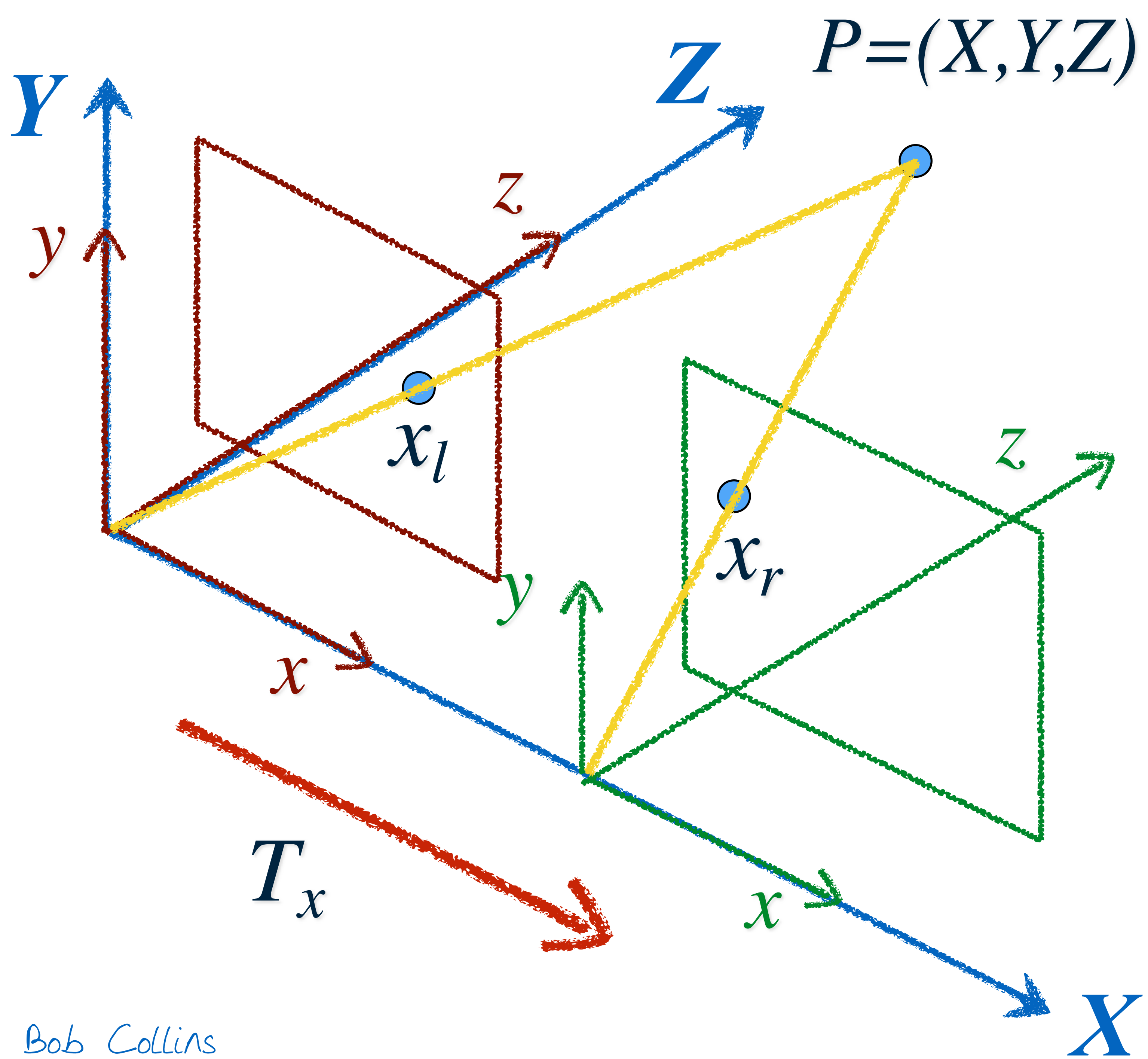
Translated by a distance T_x along X axis

(T_x is also called the stereo "baseline")

A Simple Stereo System

left camera located at (0,0,0)

right camera located at $(T_x,0,0)$



Point P in Left Camera:

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

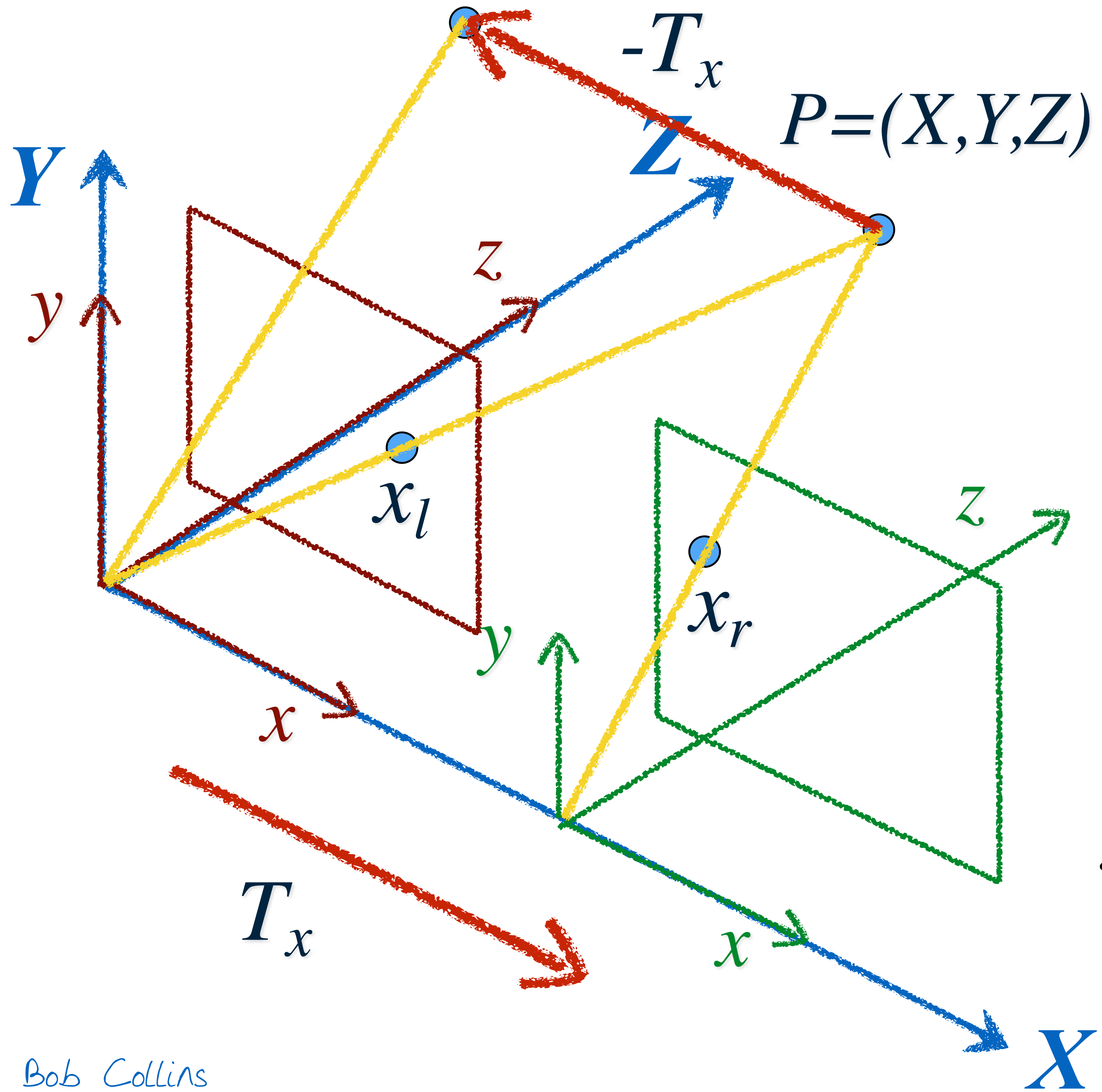
The same point in the Right Camera?

Slide adapted from Bob Collins

A Simple Stereo System

left camera located at (0,0,0)

right camera located at $(T_x,0,0)$



Point P in Left Camera:

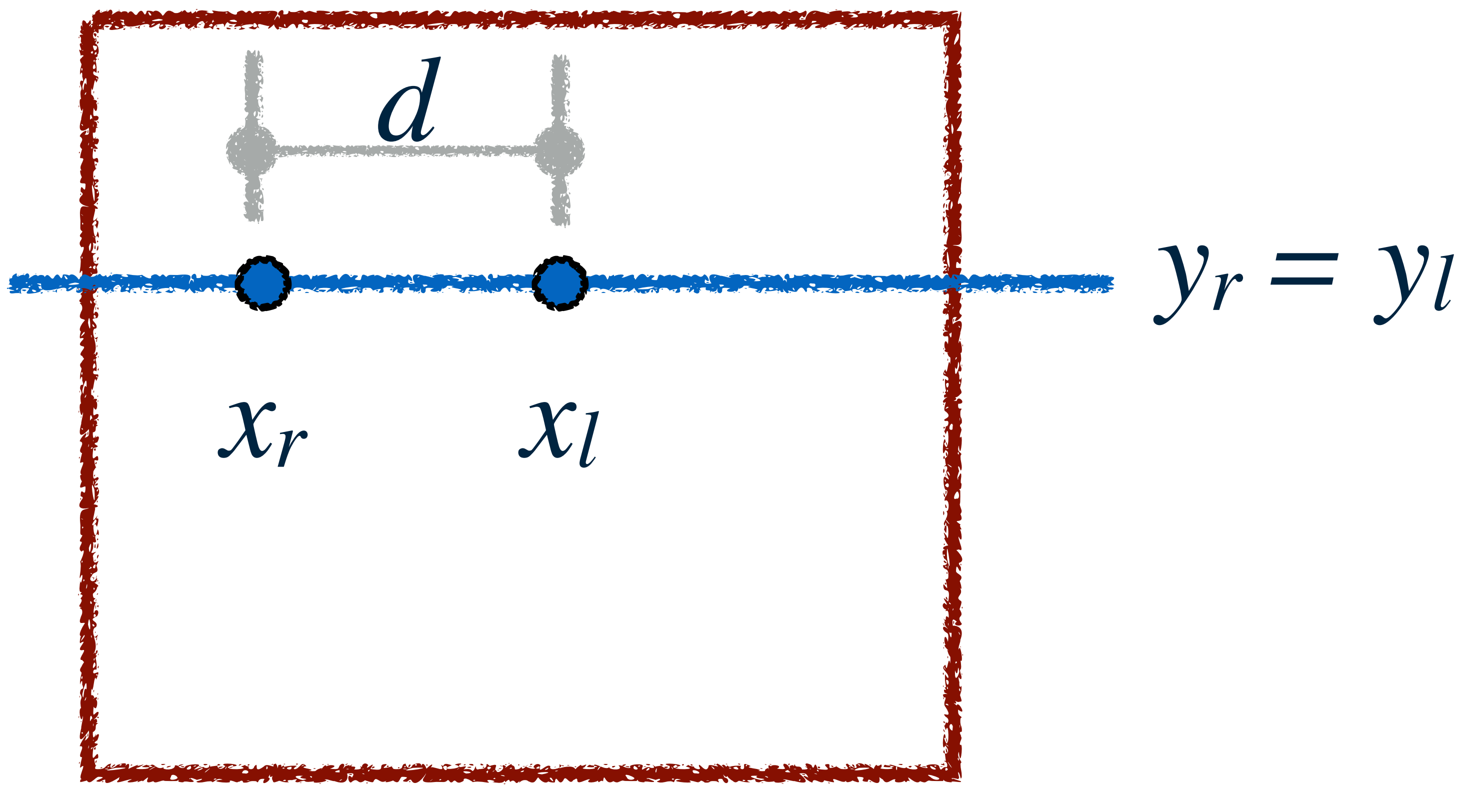
$$x_l = f\frac{X}{Z} \qquad y_l = f\frac{Y}{Z}$$

The same point in the Right Camera?

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

Slide adapted from Bob Collins

Stereo Disparity



left camera

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

right camera

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

$$d = x_l - x_r$$

$$d = f\frac{X}{Z} - f\frac{X - T_x}{Z}$$

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

baseline

depth

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

disparity

Stereo Example

Left Image

Right Image

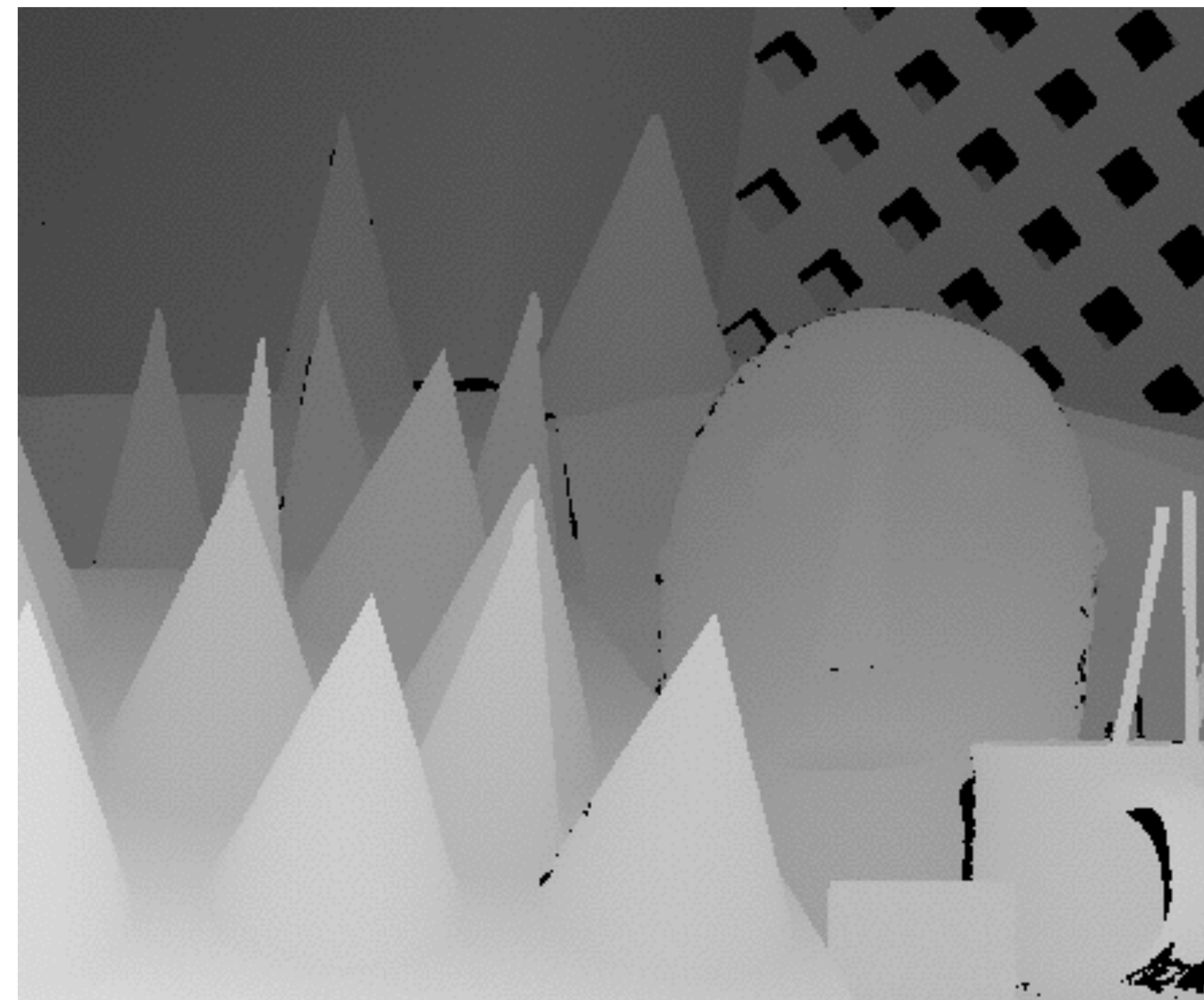
From middlebury stereo evaluation page http://www.middlebury.edu/stereo/

Stereo Example

Left image

Right image

Disparity values (0-64)

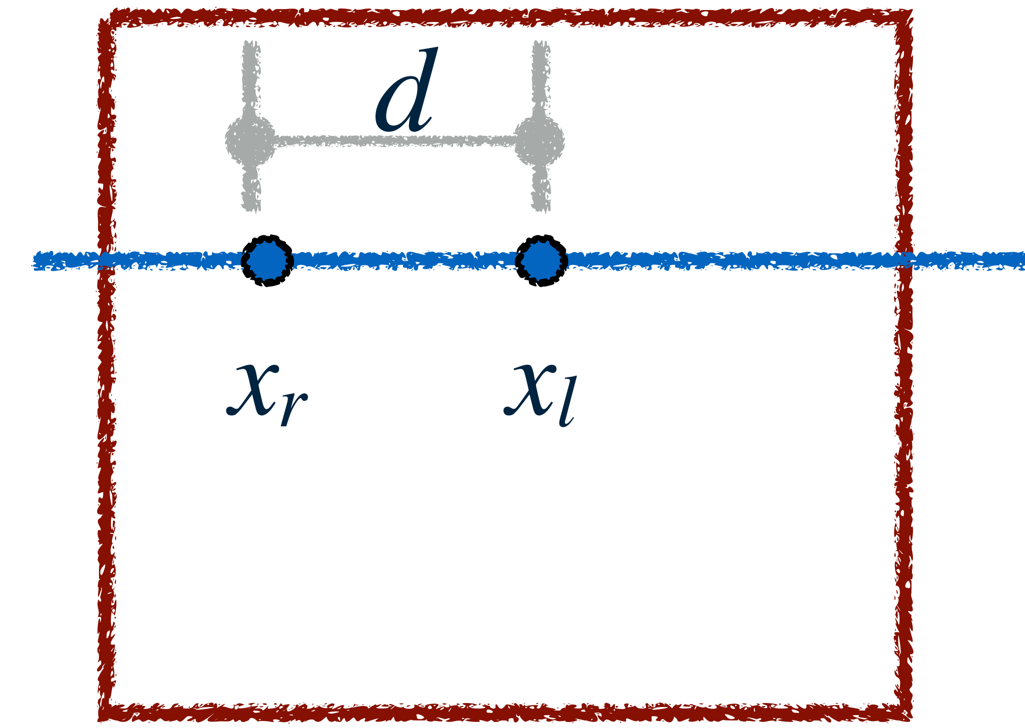


Disparity is larger for closer surfaces

Slide adapted from Bob Collins

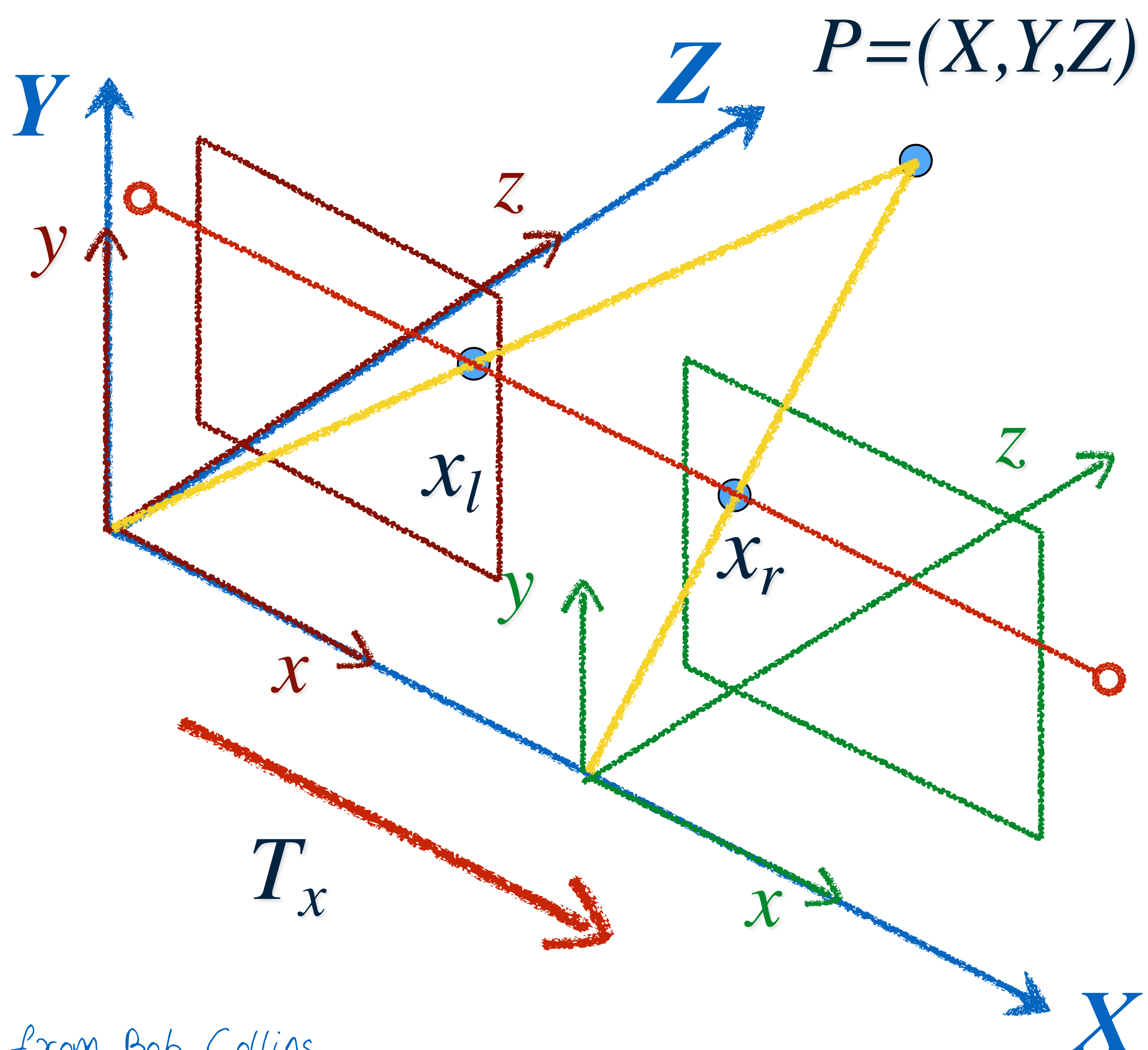
Computing Disparity

$$d = x_l - x_r$$



* Correspondence
  * Which pixel in the right image corresponds to each pixel in the left
* Epipolar Constraint
  * No need to search the whole 2D right image
  * The epipolar constraint reduces the search space to a one-dimensional line

Recall: A Simple Stereo System



left camera

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

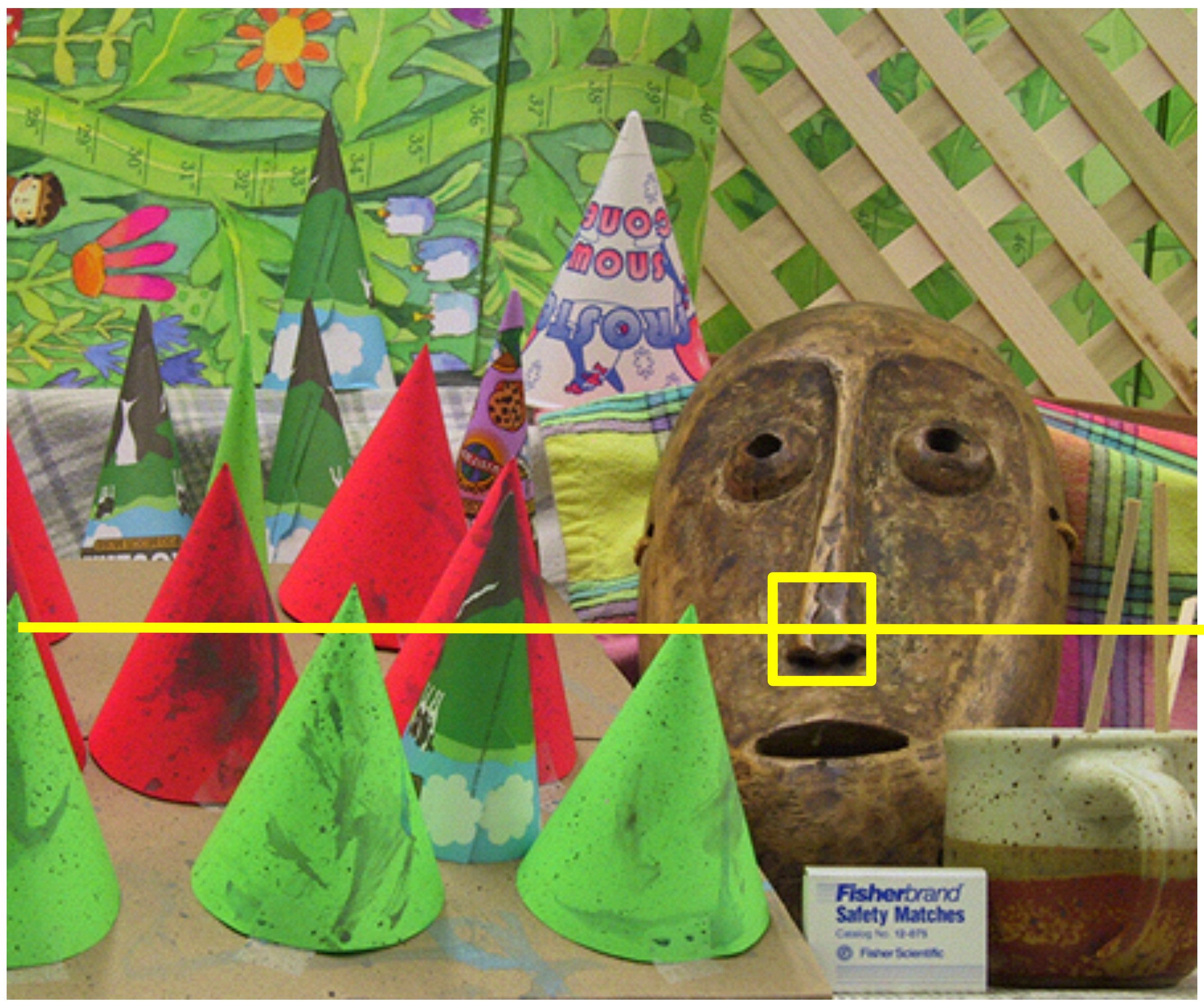
right camera

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

Slide adapted from Bob Collins

Matching Using Epipolar Lines

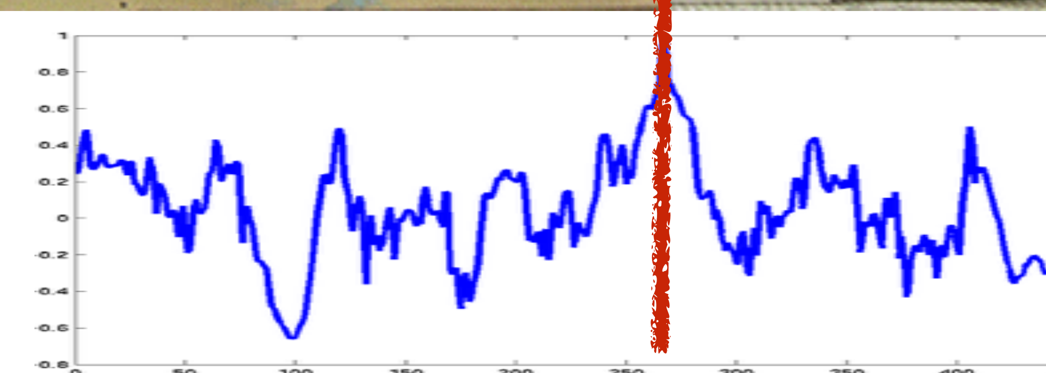
Left Image



Right Image

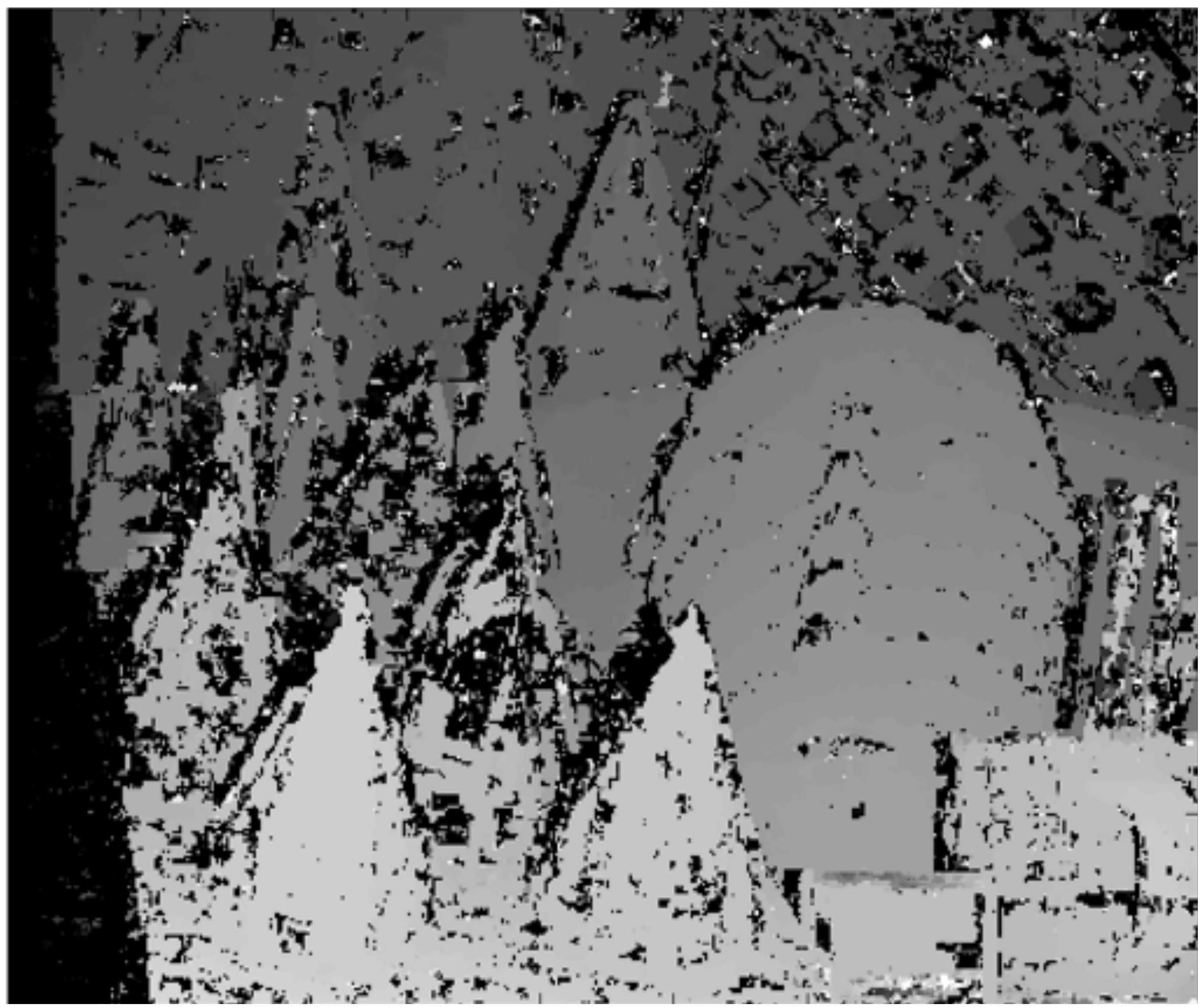
For a patch in left image

Compare with patches along same row in right image

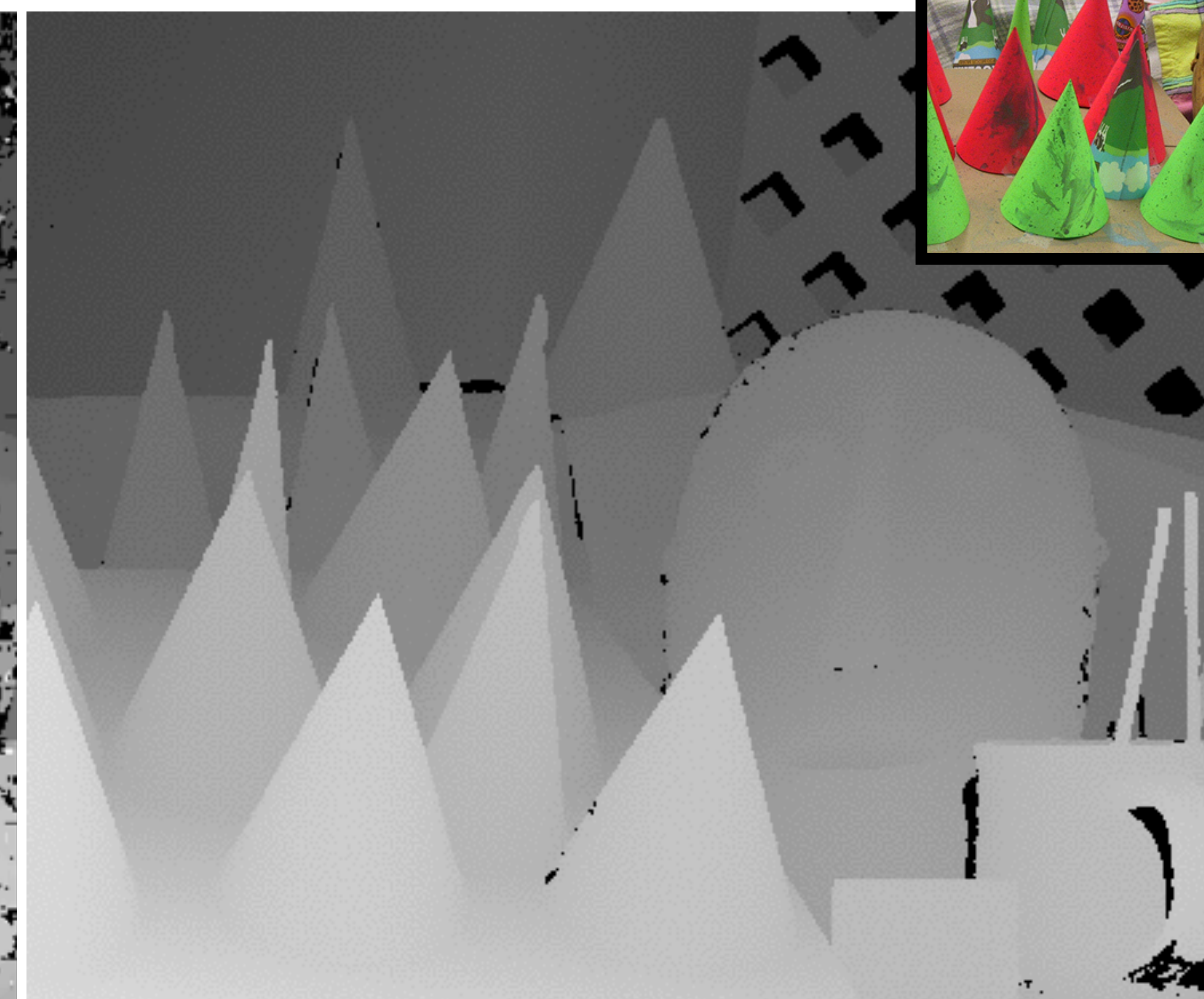


Match Score Values

No Matches



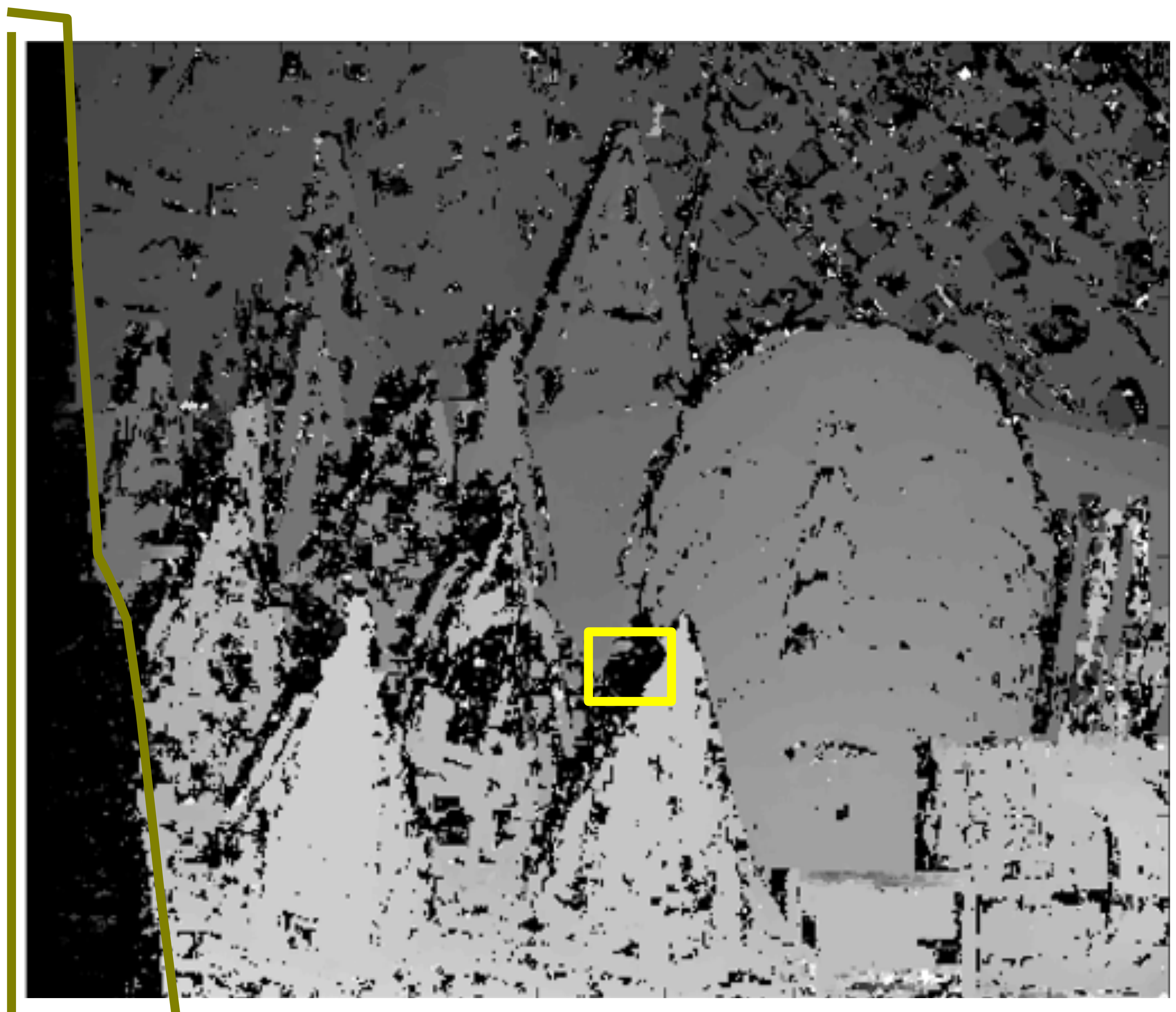
Computed disparities



Ground truth

Black pixels: bad disparity values, or no matching patch in right image

Occlusions: No Matches



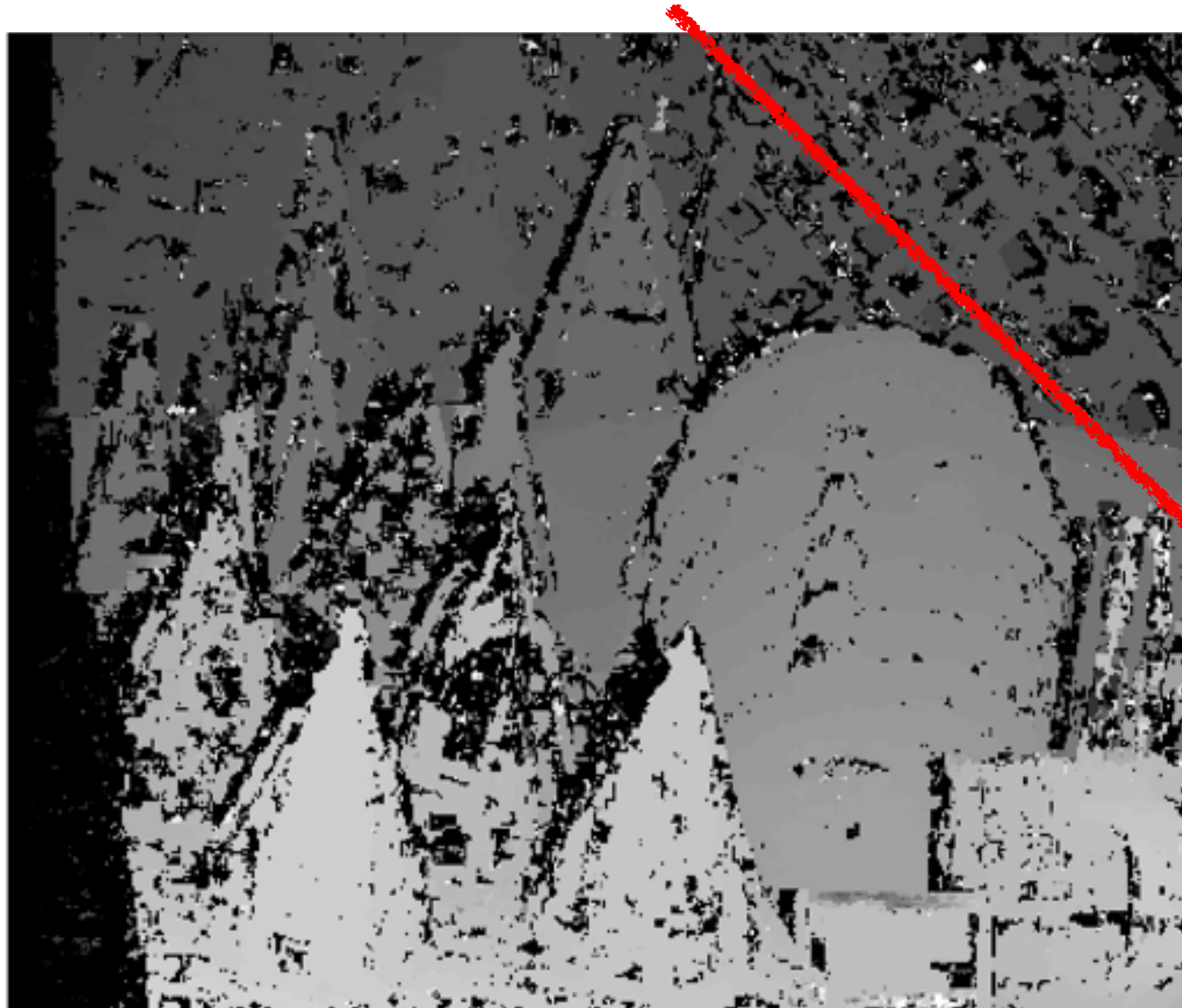
Left Image

Right Image

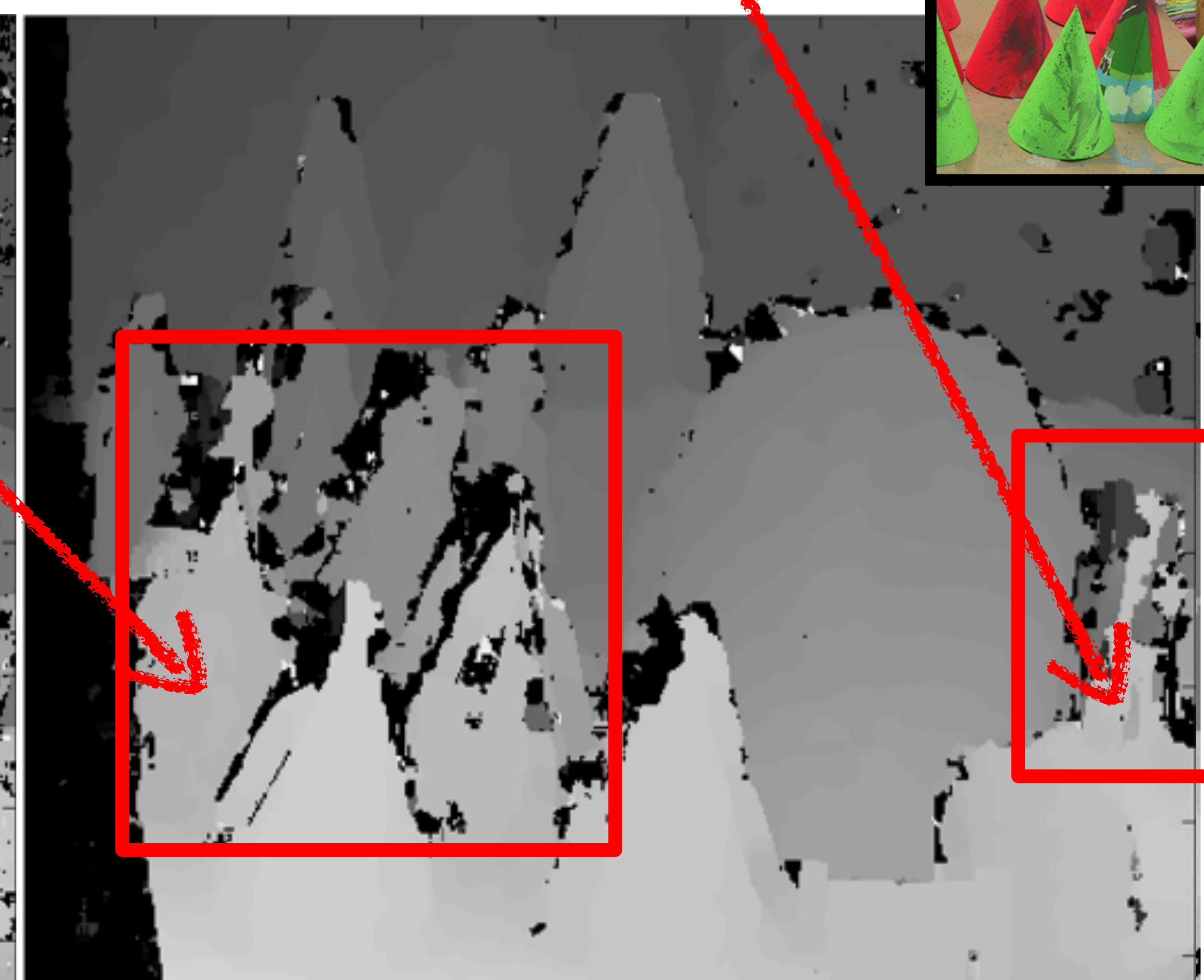
Effects of Patch Size

Smoother in some areas

Loss of finer details

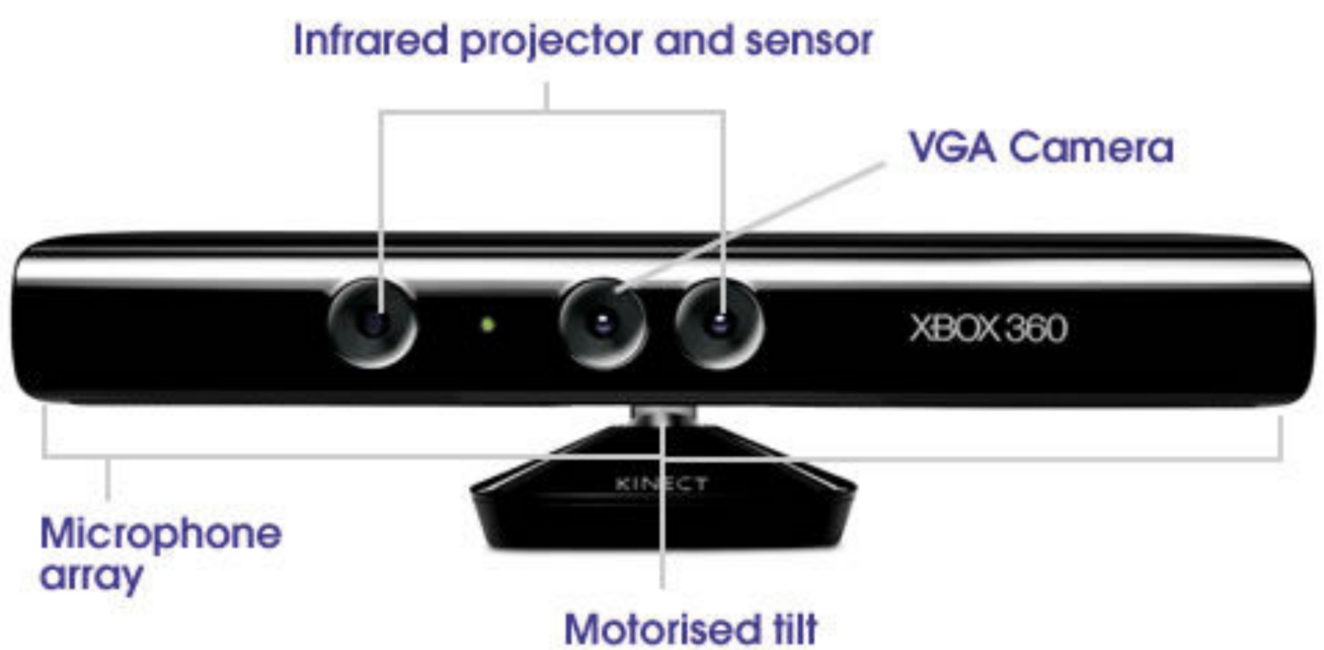


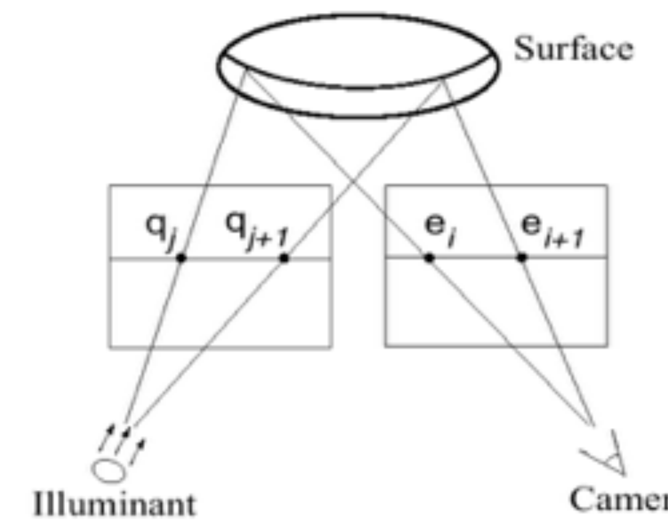
5 X 5 patches

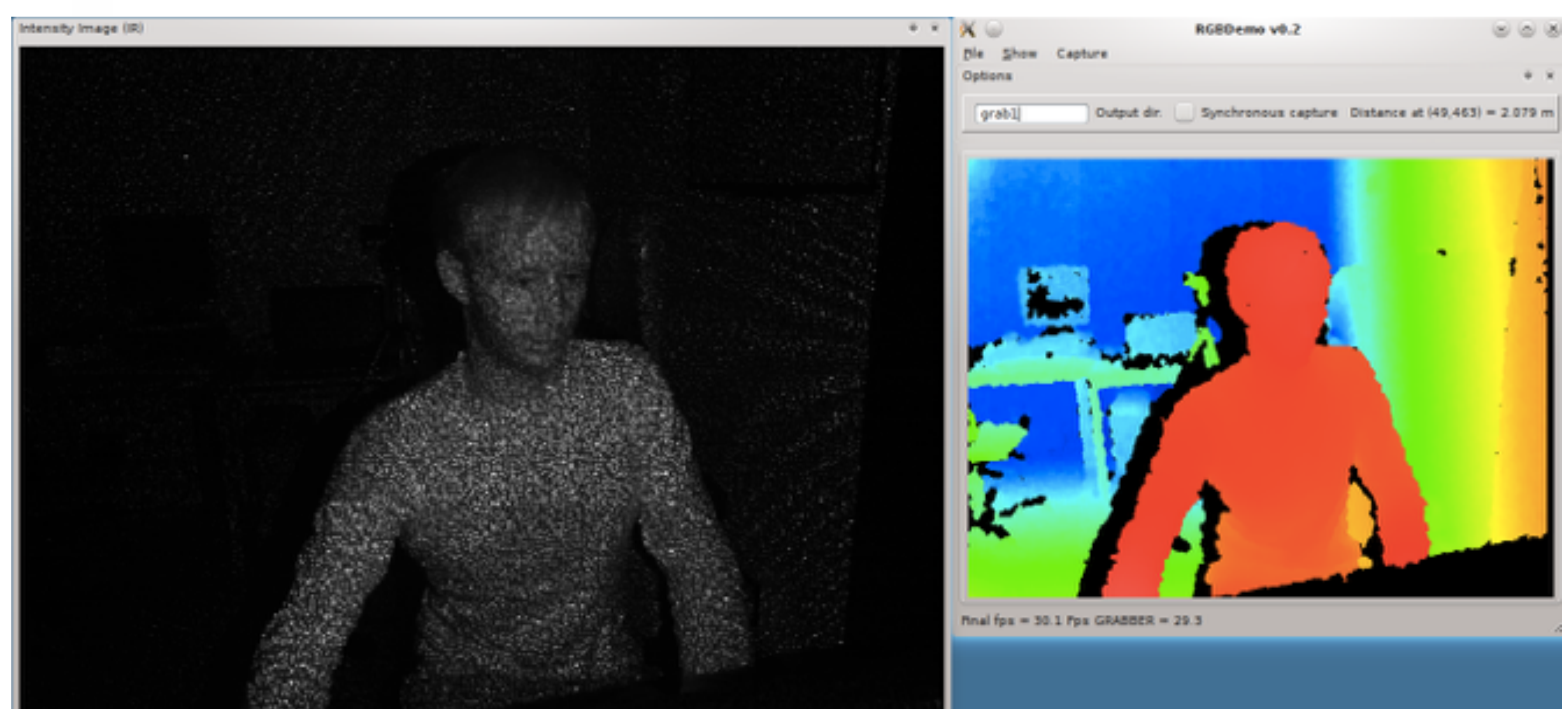


11 X 11 patches

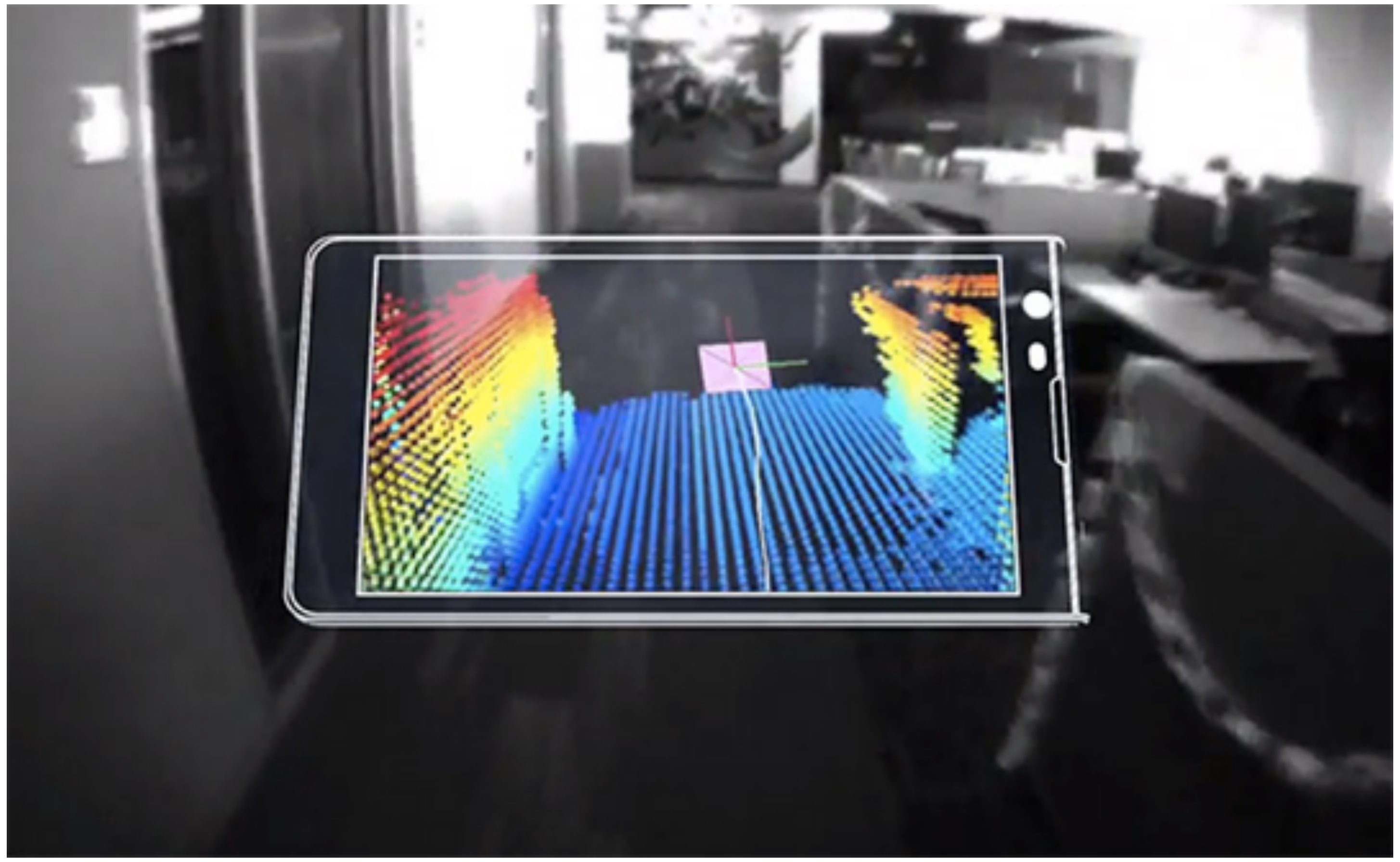
Some well known RGBD Cameras







http://nicolas.burrus.name/



Google Project Tango

Amazon Fire

5 Cameras

Kinect For Windows 1

Processed Image From Kinect

Kinect For Windows 2

Image via http://blogs.msdn.com

zugara

Kinect 1 to Kinect 2: Time of Flight Camera

Summary

* Shape/Structure/Geometry from X methods
* Stereo Imaging
* Compute depth from a Stereo image pair

Further Reading

* McMillan & Gortler (1999) "Image-Based Rendering: A New Interface Between Computer Vision and Computer Graphics" Applications of Computer Vision to Computer Graphics Vol 33, No 2 1999 [Link]
* Szeliski (2010)
* Hartley & Zisserman (2004)


To-Do List
Rewrite
Finish
Write
Write
Make
Move
facebook

Credits

* For more information, see:
  * Richard Szeliski (2010) Computer Vision: Algorithms and Applications, Springer (Chapter 3)
* Some concepts in slides motivated by similar slides by James Hays Alyosha Efros, Svetlana Lazebnik, Bob Collins, and Greg Turk
* Grant Schindler,
  * http://www.trimensional.com/
* Additional list will be available on website

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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