Computer Vision

Spring 2006 15-385,-685

Instructor: S. Narasimhan

Wean 5403
T-R 3:00pm – 4:20pm

Lecture #14

Announcements

Homework 4 went out Tuesday. Due April 4.

Start early.

Course Schedule – Done!

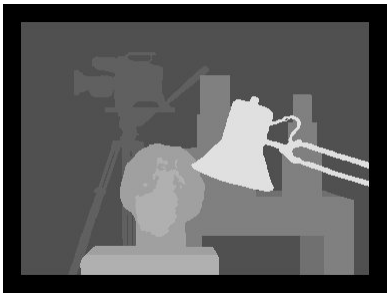
1/17/2006:	Introduction and Course Fundamentals	
PART 1 : Cameras and Imaging		
1/19/2006:	Image Formation and Projection	
1/24/2006:	Matlab Review	
1/26/2006:	Image Sensing	[Homework 1 OUT]
PART 2 : Signal and Image Processing		
1/31/2006:	Binary Image Processing	
2/2/2006:	1D Signal Processing	[Homework 1 DUE; Homework 2 OUT]
2/7/2006:	2D Image Processing	
2/9/2006:	Edge Detection	
2/14/2006:	Image Pyramids	
2/16/2006:	Hough Transform	[Homework 2 DUE; Homework 3 OUT]
PART 3: Physics of the World		
2/21/2006:	Basic Principles of Radiometry	
2/23/2006:	Retinex Theory	
2/28/2006:	Surface Reflectance and BRDF	
3/2/2006:	Photometric Stereo	[Homework 3 DUE]
3/7/2006:	**Midterm Review**	
3/9/2006:	**Midterm Exam**	
3/13/2006:	**Midterm Grades Due**	
3/21/2006:	Shape from Shading	[Homework 4 OUT]

Course Schedule

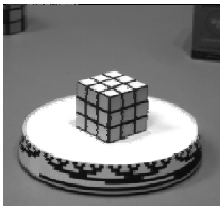
PART 4 : 3D Geometry		
3/23/2006:	Binocular Stereo 1	
3/28/2006:	Binocular Stereo 2	
3/30/2006:	Motion and Optical Flow	
4/4/2006:	Line Drawing	[Homework 4 DUE; Homework 5 OUT]
4/6/2006:	Structured Light	
PART 5 : Statistical Techniques		
4/11/2006:	Linear Least Squares	
4/13/2006:	Principle Components Analysis	
4/18/2006:	Applications of PCA	[Homework 5 DUE; Homework 6 OUT]
PART 6: Current Trends and Challenges in Vision Research		
4/27/2006:	Novel Cameras and Displays	
5/2/2006:	Open challenges in vision research	
5/4/2006:	Review Class	[Homework 6 DUE]
5/9/2006:	**Final Exam**	
5/18/2006:	**Final Grades Due**	

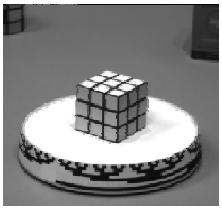
*** Use as a guide…changes possible

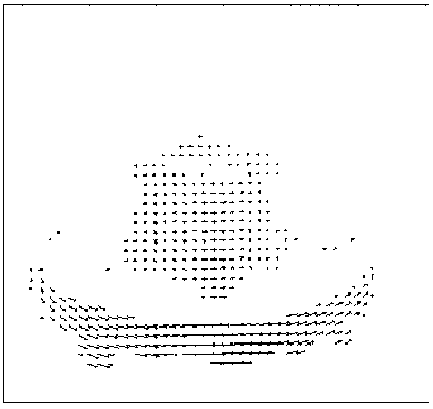
Binocular Stereo



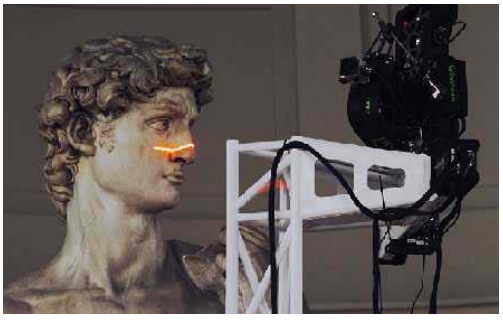
Optical Flow

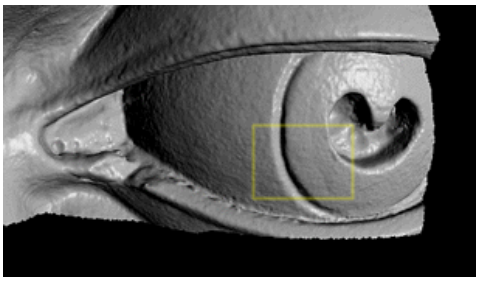






Range Scanning and Structured Light





Binocular Stereo

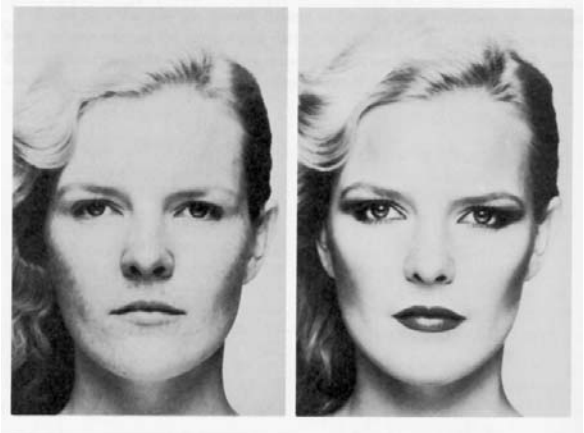
Lecture #14

Recovering 3D from Images

- How can we automatically compute 3D geometry from images?
  - What cues in the image provide 3D information?

Visual Cues for 3D

- Shading



Merle Norman Cosmetics, Los Angeles

Visual Cues for 3D

- Shading
- Texture

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

Visual Cues for 3D

- Shading
- Texture
- Focus

From *The Art of Photography*, Canon

Visual Cues for 3D

- Shading
- Texture
- Focus
- Motion

Visual Cues for 3D

- Shading
- Texture
- Focus
- Motion

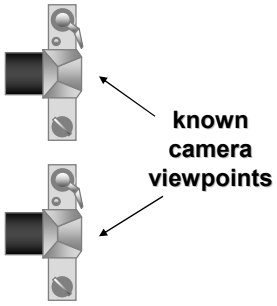
- Others:
  - Highlights
  - Shadows
  - Silhouettes
  - Inter-reflections
  - Symmetry
  - Light Polarization
  - ...

Shape From X

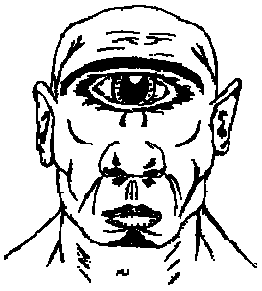
- X = shading, texture, focus, motion, ...
- We'll focus on the motion cue

Stereo Reconstruction

- The Stereo Problem
  - Shape from two (or more) images
  - Biological motivation

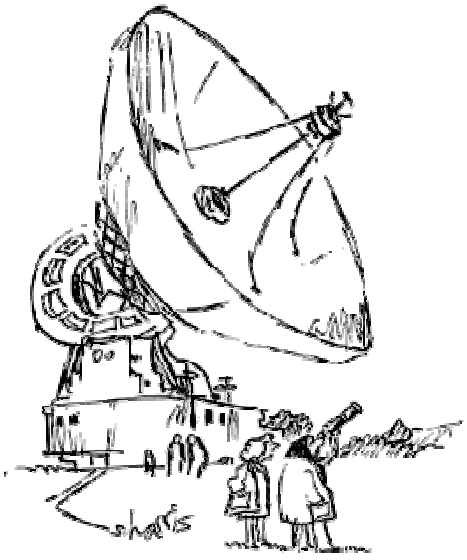


Why do we have two eyes?



Cyclope **vs.** **Odysseus**

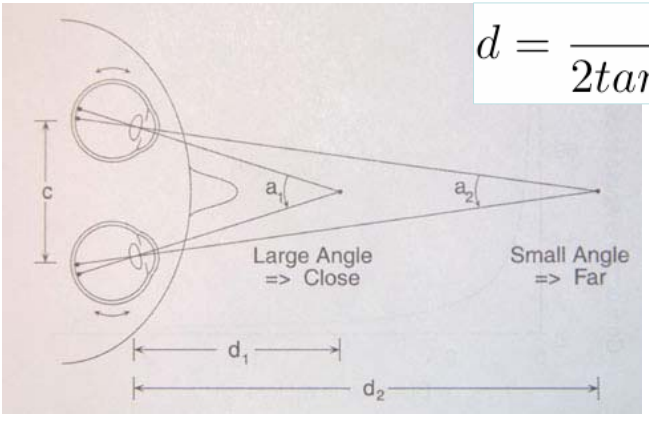
1. Two is better than one



"Just checking."

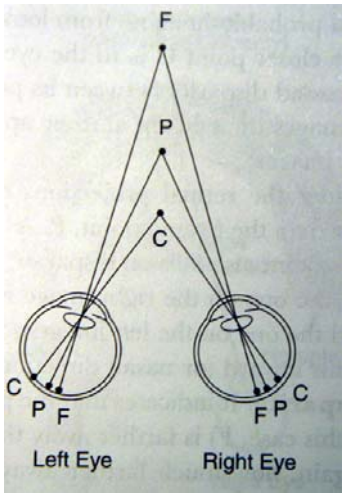
2. Depth from Convergence

$$d = \frac{c}{2tan(a/2)}$$



Human performance: up to 6-8 feet

3. Depth from binocular disparity

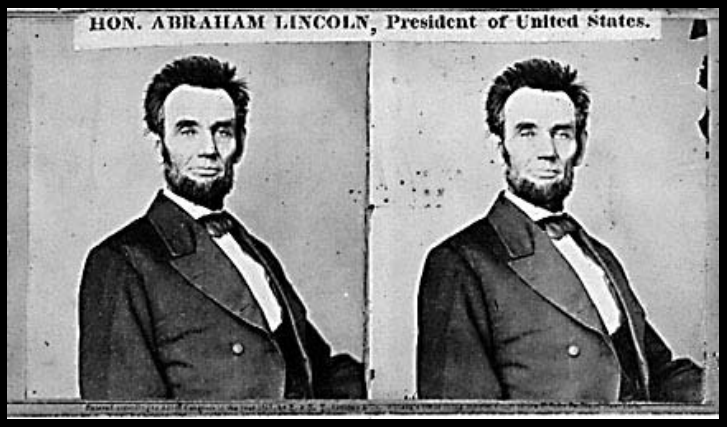


P: converging point

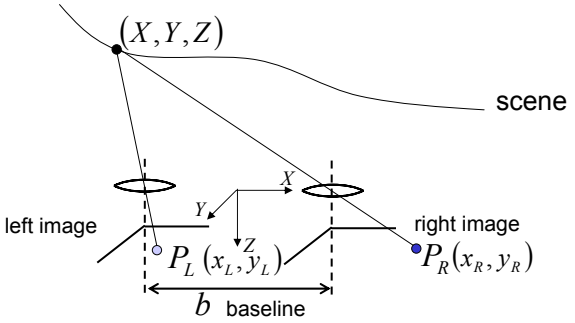
C: object nearer projects to the outside of the P, disparity = +

F: object farther projects to the inside of the P, disparity = -

Sign and magnitude of disparity



Disparity and Depth

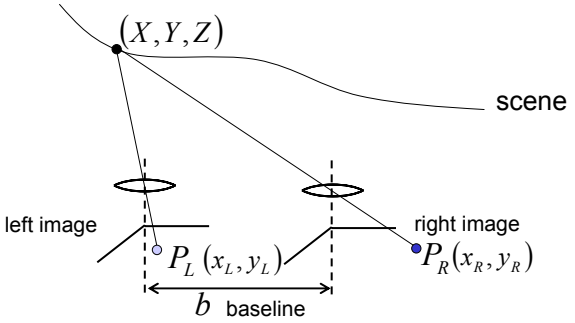


Assume that we know P_L corresponds to P_R

From perspective projection (define the coordinate system as shown above)

$$\frac{x_L}{f} = \frac{X + b/2}{Z} \qquad \frac{x_R}{f} = \frac{X - b/2}{Z} \qquad \frac{y_L}{f} = \frac{y_R}{f} = \frac{Y}{Z}$$

Disparity and Depth



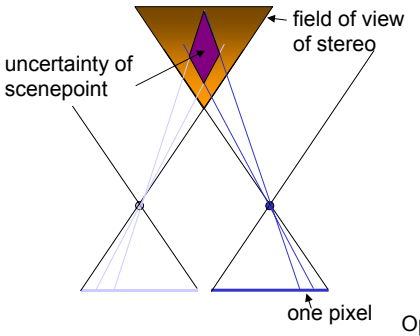
$$\frac{x_L}{f} = \frac{X + b/2}{Z} \qquad \frac{x_R}{f} = \frac{X - b/2}{Z} \qquad \frac{y_L}{f} = \frac{y_R}{f} = \frac{Y}{Z}$$

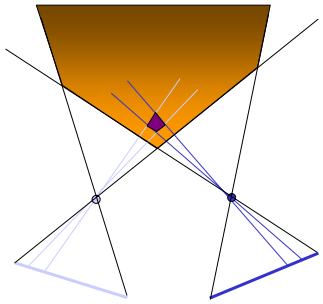
$$\Rightarrow \quad X = \frac{b(x_L + x_R)}{2(x_L - x_R)} \qquad Y = \frac{b(y_L + y_R)}{2(x_L - x_R)} \qquad Z = \frac{bf}{(x_L - x_R)}$$

$d = x_L - x_R$ is the **disparity** between corresponding left and right image points

- inverse proportional to depth
- disparity increases with baseline **b**

Vergence

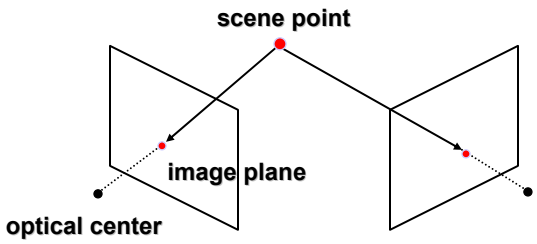




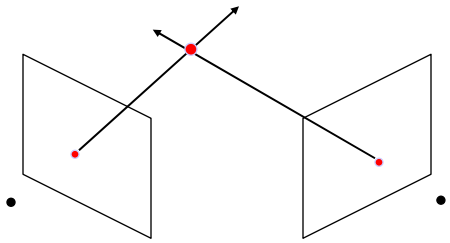
Optical axes of the two cameras need not be parallel

- Field of view decreases with increase in baseline and vergence
- Accuracy increases with baseline and vergence

Binocular Stereo



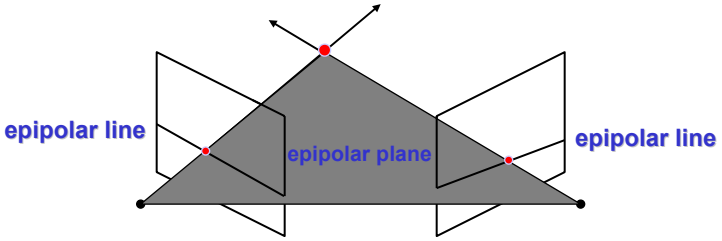
Binocular Stereo



- Basic Principle: Triangulation
  - Gives reconstruction as intersection of two rays
  - Requires
    - calibration
    - ***point correspondence***

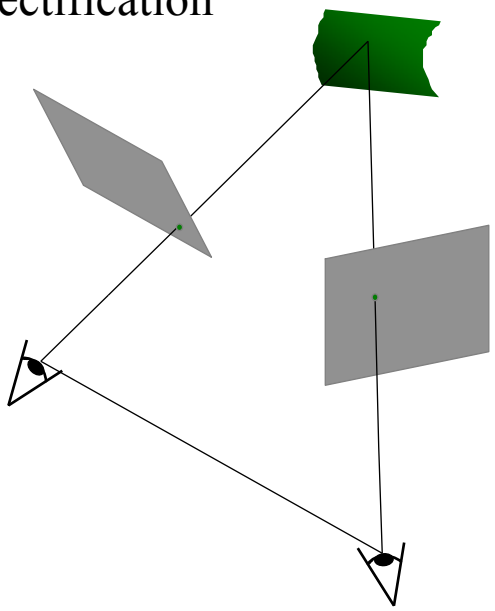
Stereo Correspondence

- Determine Pixel Correspondence
  - Pairs of points that correspond to same scene point

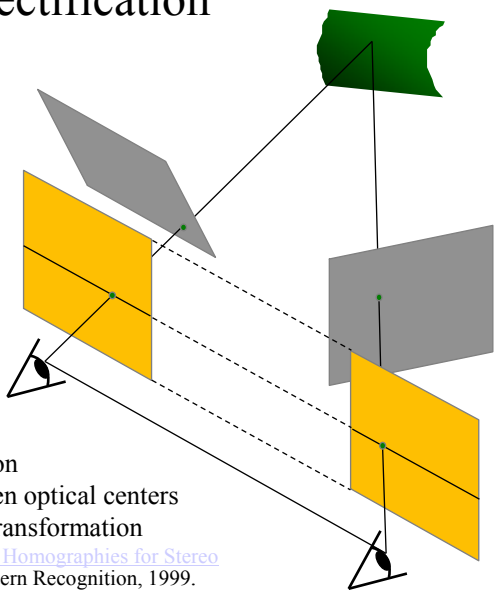


- Epipolar Constraint
  - Reduces correspondence problem to 1D search along *conjugate epipolar lines*
  - Java demo: http://www.ai.sri.com/~luong/research/Meta3DViewer/EpipolarGeo.html

Stereo Image Rectification



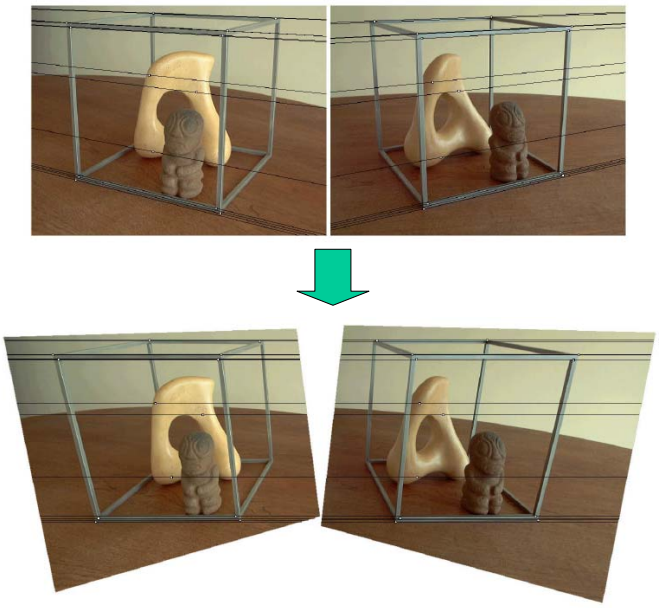
Stereo Image Rectification



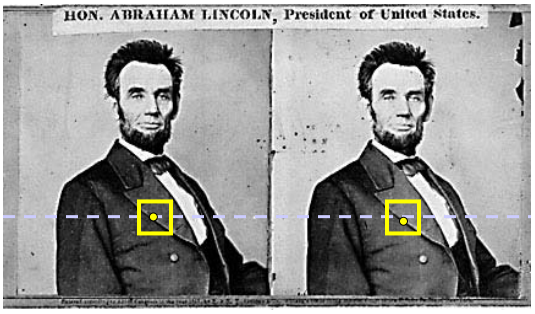
- reproject image planes onto a common
- plane parallel to the line between optical centers
- pixel motion is horizontal after this transformation

➢ C. Loop and Z. Zhang. Computing Rectifying Homographies for Stereo Vision. IEEE Conf. Computer Vision and Pattern Recognition, 1999.

Stereo Rectification



Basic Stereo Algorithm



For each epipolar line

For each pixel in the left image

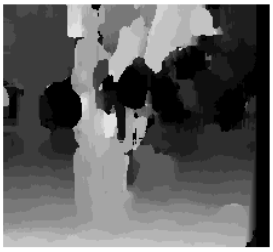
- compare with every pixel on same epipolar line in right image
- pick pixel with minimum match cost

Improvement: match ***windows***

- This should look familar...
- Correlation, Sum of Squared Difference (SSD), etc.

Size of Matching window

W = 3



W = 20

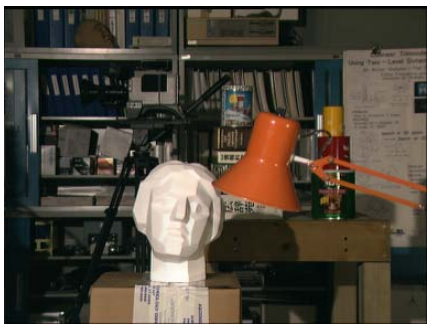
- Effect of window size
  - Smaller window
    Good/bad ?
  - Larger window
    Good/bad ?

Better results with *adaptive window*

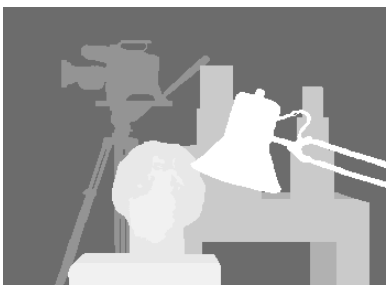
- T. Kanade and M. Okutomi, *A Stereo Matching Algorithm with an Adaptive Window: Theory and Experiment*,, Proc. International Conference on Robotics and Automation, 1991.
- D. Scharstein and R. Szeliski. Stereo matching with nonlinear diffusion. International Journal of Computer Vision, 28(2):155-174, July 1998

Stereo Results

- Data from University of Tsukuba

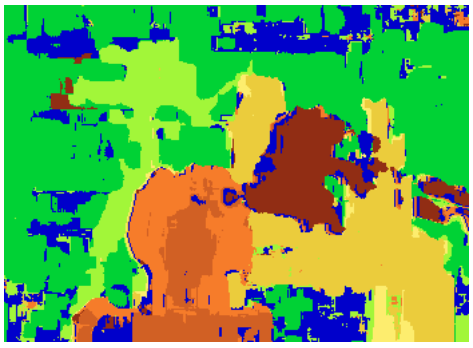


Scene



Ground truth

Results with Window Search



Window-based matching
(best window size)

Ground truth

Better methods exist...

State of the art method

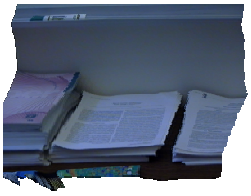
Ground truth

Boykov et al., Fast Approximate Energy Minimization via Graph Cuts,
International Conference on Computer Vision, September 1999.

Stereo Example

input image (1 of 2)

depth map
[Szeliski & Kang '95]



3D rendering

Stereo Example

left image

right image

depth map

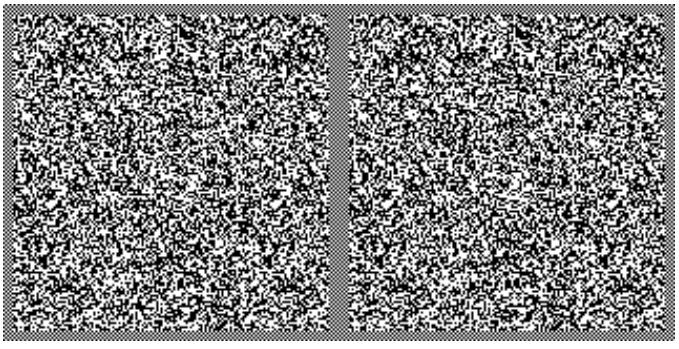
H. Tao et al. "Global matching criterion and color segmentation based stereo"

Stereo Example

H. Tao et al. "Global matching criterion and color segmentation based stereo"

Stereo Matching

- Features vs. Pixels?
  - Do we extract features prior to matching?



Julesz-style Random Dot Stereogram

Next Class

- Binocular Stereo (relative and absolute orientation)
- Reading: Horn, Chapter 13.