Announcements

- Midterms graded (handed back at end of lecture)
- Handout (Chap 7, Trucco & Verri)
- Questions on project?
- http://www.dartfish.com/technologies/technologies_stromotion.html

Recovering 3D from images

So far, we've relied on a human to provide depth cues

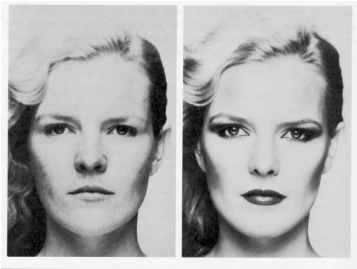
- parallel lines, reference points, etc.

How might we do this automatically?

- What cues in the image provide 3D information?

Visual cues

Shading



Merle Norman Cosmetics, Los Angeles

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

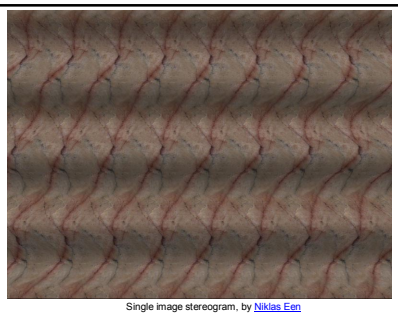
Others:

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

Shape From X

- X = shading, texture, focus, motion, ...
- In this class we'll focus on the motion cue

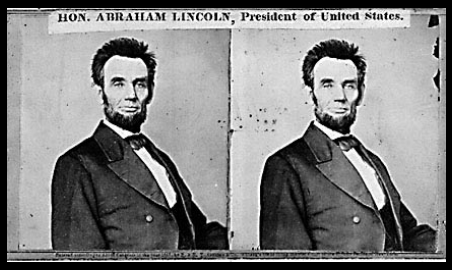
Stereo



Single image stereogram, by Niklas Een

Readings

- Trucco & Verri, Chapter 7 (handout)
  - Read through 7.3.2, also 7.3.7 and 7.4, 7.4.1. The rest is optional.



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

Teesta suspension bridge-Darjeeling, India

Mark Twain at Pool Table", no date, UCR Museum of Photography

Woman getting eye exam during immigration procedure at Ellis Island, c. 1905 - 1920 , UCR Museum of Phography

Stereograms online

UCR stereographs
- http://www.cmp.ucr.edu/site/exhibitions/stereo/

The Art of Stereo Photography
- http://www.photostuff.co.uk/stereo.htm

History of Stereo Photography
- http://www.rpi.edu/~ruiz/stereo_history/text/historystereog.html

Double Exposure
- http://home.centurytel.net/s3dcor/index.html

Stereo Photography
- http://www.shortcourses.com/book01/chapter09.htm

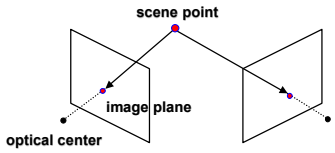
3D Photography links
- http://www.studyweb.com/links/5243.html

National Stereoscopic Association
- http://204.248.144.203/3dLibrary/welcome.html

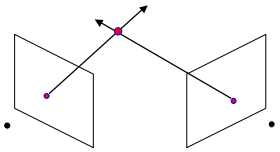
Books on Stereo Photography
- http://userwww.sfsu.edu/~hl/3d.biblio.html

A free pair of red-blue stereo glasses can be ordered from Rainbow Symphony Inc
- http://www.rainbowsymphony.com/freestuff.html

Stereo



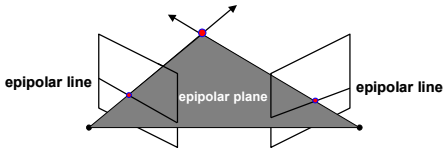
Stereo



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

Stereo correspondence

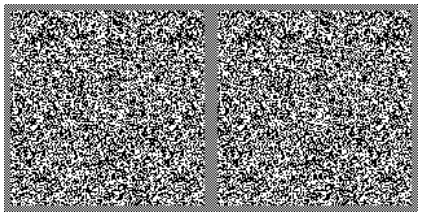
Determine Pixel Correspondence
- Pairs of points that correspond to same scene point



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

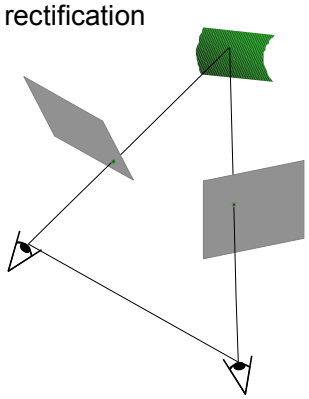
Stereo matching

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



Julesz-style Random Dot Stereogram

Stereo image rectification



Stereo image rectification

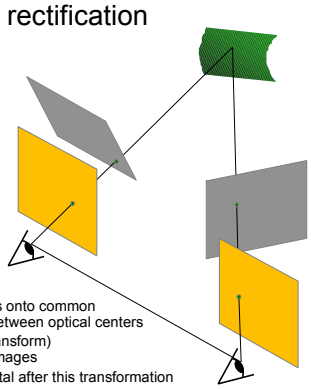


Image Reprojection

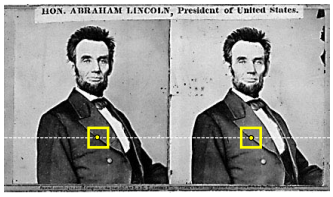
- reproject image planes onto common plane parallel to line between optical centers
- a homography (3x3 transform) applied to both input images
- pixel motion is horizontal after this transformation
- C. Loop and Z. Zhang. Computing Rectifying Homographies for Stereo Vision. IEEE Conf. Computer Vision and Pattern Recognition, 1999.

Stereo matching algorithms

Match Pixels in Conjugate Epipolar Lines

- Assume brightness constancy
- This is a tough problem
- Numerous approaches
  - dynamic programming [Baker 81,Ohta 85]
  - smoothness functionals
  - more images (trinocular, N-ocular) [Okutomi 93]
  - graph cuts [Boykov 00]

Your 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...
- Can use Lukas-Kanade or discrete search (latter more common)

Window size

W = 3 W = 20

Effect of window size

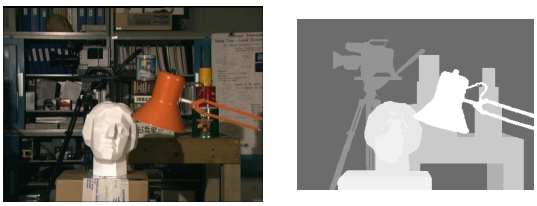
- Smaller window
  - more details
  - more noise
- Larger window
  - less noise
  - less detail

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

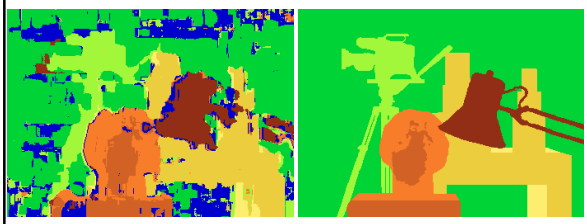
Stereo results

- Data from University of Tsukuba
- Similar results on other images without ground truth



Scene Ground truth

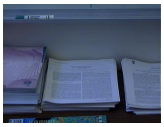
Results with window correlation



Window-based matching (best window size)

Ground truth

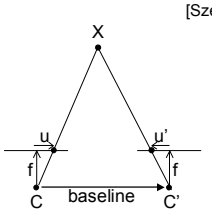
Depth from disparity



input image (1 of 2)

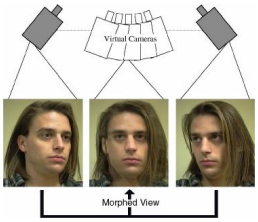
depth map [Szeliski & Kang '95]

3D rendering



$$disparity = u - u' = \frac{baseline * f}{z}$$

Image-based rendering



Render new views from raw disparity

- S. M. Seitz and C. R. Dyer, View Morphing, *Proc. SIGGRAPH 96*, 1996, pp. 21-30.
- L. McMillan and G. Bishop. Plenoptic Modeling: An Image-Based Rendering System, *Proc. of SIGGRAPH 95*, 1995, pp. 39-46.

Stereo reconstruction pipeline

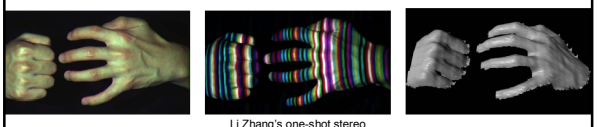
Steps

- Calibrate cameras
- Rectify images
- Compute disparity
- Estimate depth

What will cause errors?

- Camera calibration errors
- Poor image resolution
- Occlusions
- Violations of brightness constancy (specular reflections)
- Large motions
- Low-contrast image regions

Active stereo with structured light

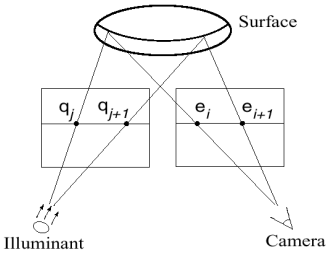


Li Zhang's one-shot stereo

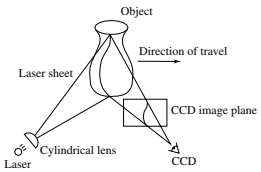
Project "structured" light patterns onto the object

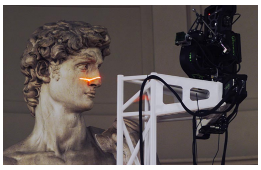
- simplifies the correspondence problem

Active stereo with structured light



Laser scanning





Digital Michelangelo Project
http://graphics.stanford.edu/projects/mich/

Optical triangulation

- Project a single stripe of laser light
- Scan it across the surface of the object
- This is a very precise version of structured light scanning

Real-time stereo

Nomad robot searches for meteorites in Antartica
http://www.frc.ri.cmu.edu/projects/meteorobot/index.html

real-time stereo video

Used for robot navigation (and other tasks)

- Several software-based real-time stereo techniques have been developed (most based on simple discrete search)

Summary

Things to take away from this lecture

- Cues for 3D inference, shape from X
- Epipolar geometry
- Stereo image rectification
- Stereo matching
  - window-based epipolar search
  - effect of window size
  - sources of error
- Active stereo
  - structured light
  - laser scanning