Announcements

- Project 1 artifact winners
- Project 2 questions
- Project 2 extra signup slots

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

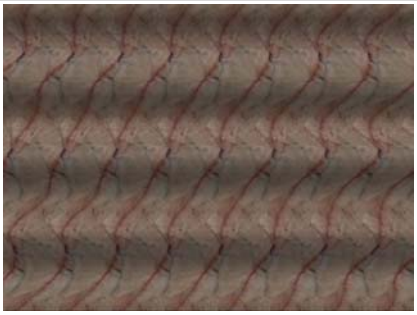
Others:

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

Shape From X

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

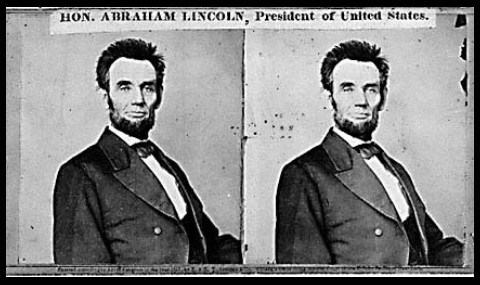
Stereo



Single image stereogram, by Niklas Een

Readings

- Trucco & Verri, Chapter 7
  - 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

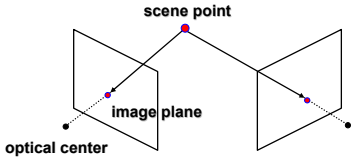
3D Photography links
- http://www.studyweb.com/links/5243.html

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

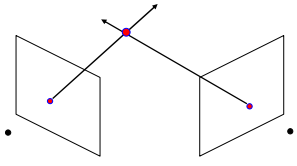
Books on Stereo Photography
- http://userwww.sfsu.edu/~hl/3d.biblio.html

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

Stereo



Stereo

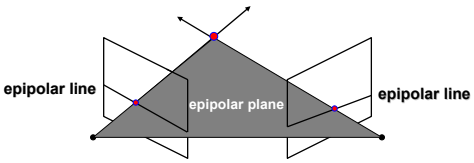


Basic Principle: Triangulation
- Gives reconstruction as intersection of two rays
- Requires
  - calibration
  - ***point correspondence***

Stereo correspondence

Determine Pixel Correspondence

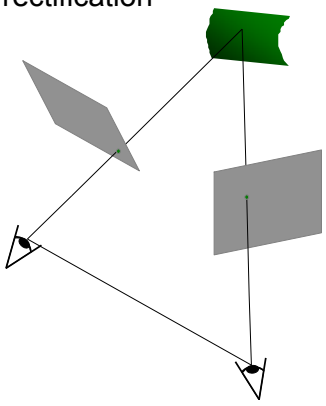
- Pairs of points that correspond to same scene point



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 image rectification



Stereo image rectification

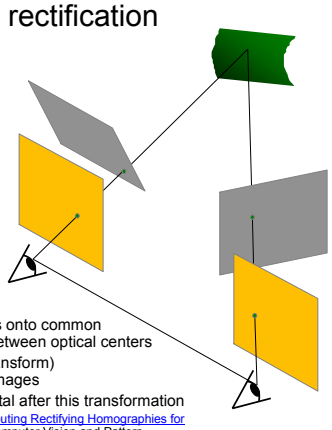


Image Reprojection

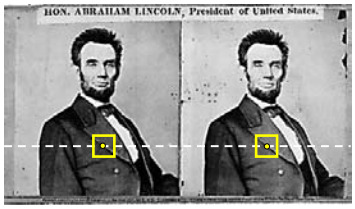
- reproject image planes onto common plane parallel to line between optical centers
- a homography (3x3 transform) applied to both input images
- pixel motion is horizontal after this transformation
- C. Loop and Z. Zhang. Computing Rectifying Homographies for Stereo Vision. IEEE Conf. Computer Vision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

Stereo matching algorithms

Match Pixels in Conjugate Epipolar Lines

- Assume brightness constancy
- This is a tough problem
- Numerous approaches
  - A good survey and evaluation: http://www.middlebury.edu/stereo/

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
  - \+
  - –
- Larger window
  - \+
  - –

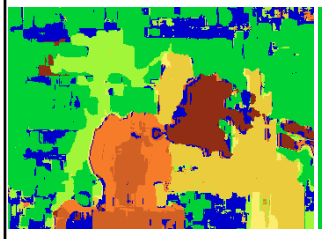
Stereo results

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

Scene

Ground truth

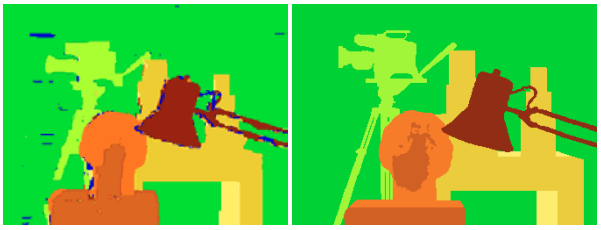
Results with window search



Window-based matching (best window size)

Ground truth

Better methods exist...



State of the art method

Ground truth

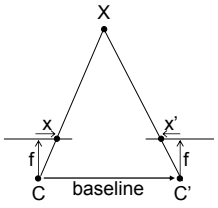
Boykov et al., Fast Approximate Energy Minimization via Graph Cuts, International Conference on Computer Vision, September 1999.

Depth from disparity

input image (1 of 2)

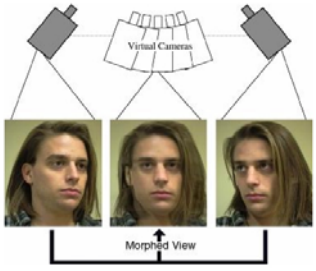
depth map
[Szeliski & Kang '95]

3D rendering



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

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

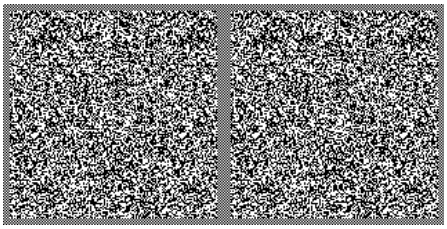
What will cause errors?

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

Stereo matching

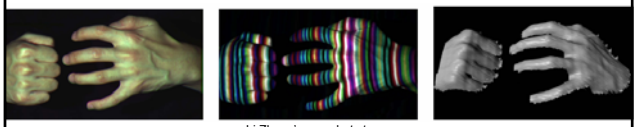
Features vs. Pixels?

- Do we extract features prior to matching?



Julesz-style Random Dot Stereogram

Active stereo with structured light

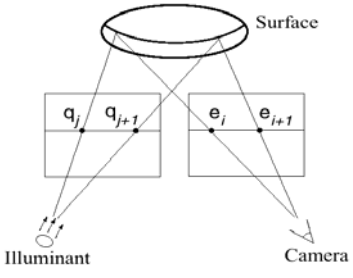


Li Zhang's one-shot stereo

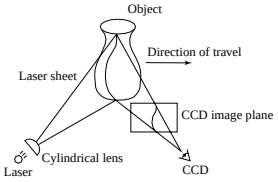
Project "structured" light patterns onto the object

- simplifies the correspondence problem

Active stereo with structured light



Laser scanning

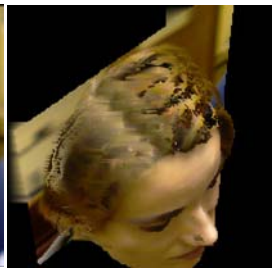


Digital Michelangelo Project
http://graphics.stanford.edu/projects/mich/

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

Portable 3D laser scanner (this one by Minolta)



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)