

Announcements

- Project 1 artifact winners
- Project 2 questions
- Project 2 extra signup slots
 - Can take a second slot if you'd like

3D shape from images

How might we do this automatically?

- What cues in the image provide 3D information?

Readings

- Trucco & Verri, Chapter 7
 - Read through 7.1, 7.2.1, 7.2.2, 7.3.1, 7.3.2, 7.3.7 and 7.4, 7.4.1. The rest is optional.

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

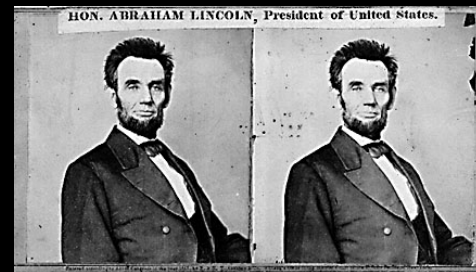
Motion

Others:

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

Shape From X

- X = shading, texture, focus, motion, ...
- In this class we'll focus on stereo: motion between two images





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



Teesta suspension bridge-Darjeeling, India



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



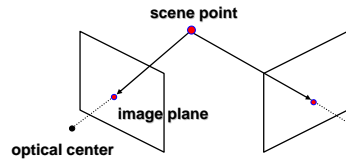
Mark Twain at Pool Table", no date, UCR Museum of Photography

Stereograms online

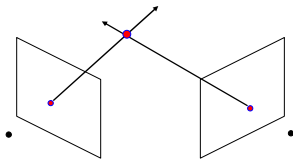
- UCR stereographs
 - <http://www.cmp.ucr.edu/site/exhibitions/stereo/>
- The Art of Stereo Photography
 - <http://www.photostuff.co.uk/stereo.htm>
- History of Stereo Photography
 - http://www.rpi.edu/~ruiz/stereo_history/text/historystereoq.html
- Double Exposure
 - <http://home.centurytel.net/s3dcor/index.html>
- 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



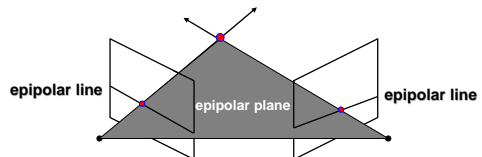
Basic Principle: Triangulation

- Gives reconstruction as intersection of two rays
- Requires
 - camera pose (calibration)
 - point correspondence**

Stereo correspondence

Determine Pixel Correspondence

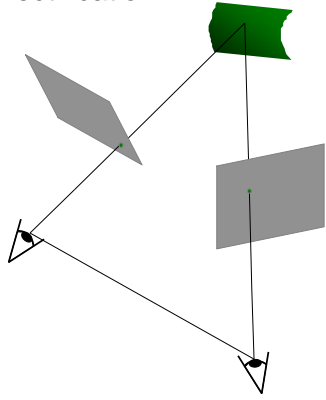
- Pairs of points that correspond to same scene point



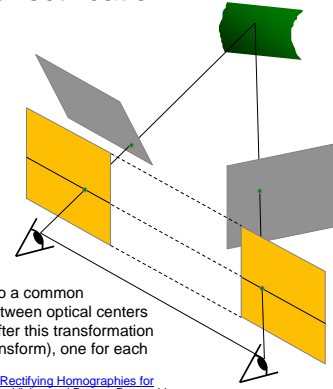
Epipolar Constraint

- 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



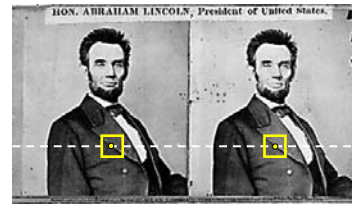
- reproject image planes onto a common plane parallel to the line between optical centers
 - pixel motion is horizontal after this transformation
 - two homographies (3x3 transform), one for each input image reprojection
- C. Loop and Z. Zhang: [Computing Rectifying Homographies for Stereo Vision](#). 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 familiar...
- Can use Lucas-Kanade or simple 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

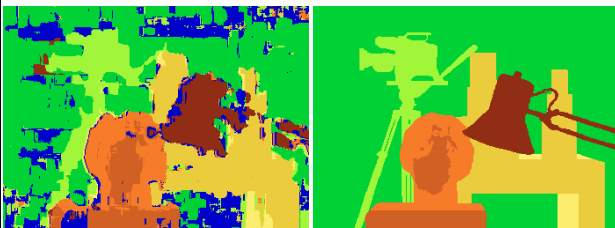


Scene



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.

For the latest and greatest: <http://www.middlebury.edu/stereo/>

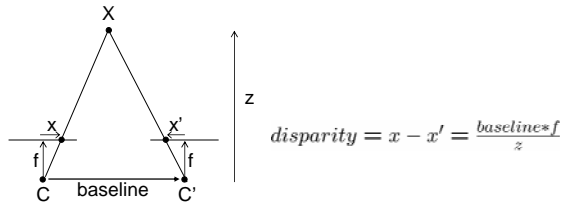
Depth from disparity



input image (1 of 2)

depth map
[Szeliski & Kang '95]

3D rendering



Video View Interpolation

<http://research.microsoft.com/users/larryz/videoviewinterpolation.htm>

Real-time stereo



[Nomad robot](http://www.frc.ri.cmu.edu/projects/meteorobot/index.html) searches for meteorites in Antarctica
<http://www.frc.ri.cmu.edu/projects/meteorobot/index.html>

Used for robot navigation (and other tasks)

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

Stereo reconstruction pipeline

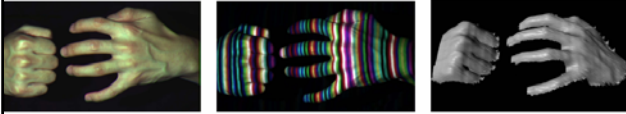
Steps

- 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



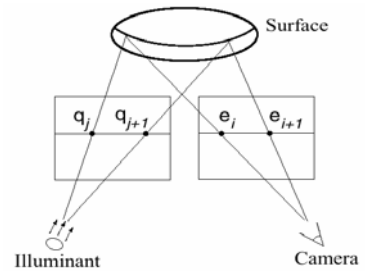
Li Zhang's one-shot stereo



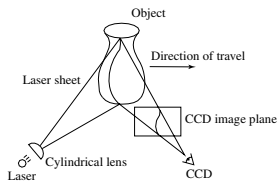
Project "structured" light patterns onto the object

- 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

Laser scanned models



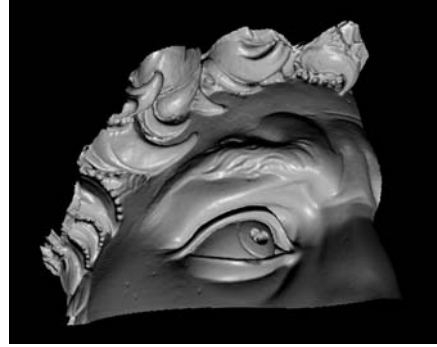
The Digital Michelangelo Project, Levoy et al.

Laser scanned models



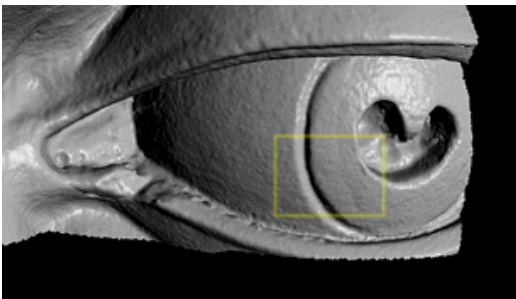
The Digital Michelangelo Project, Levoy et al.

Laser scanned models



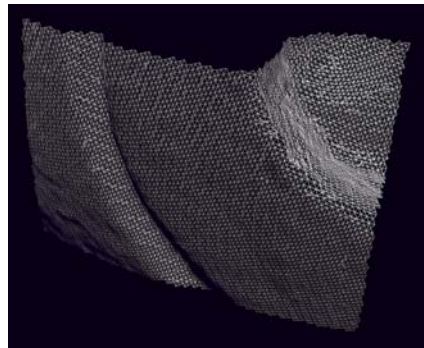
The Digital Michelangelo Project, Levoy et al.

Laser scanned models



The Digital Michelangelo Project, Levoy et al.

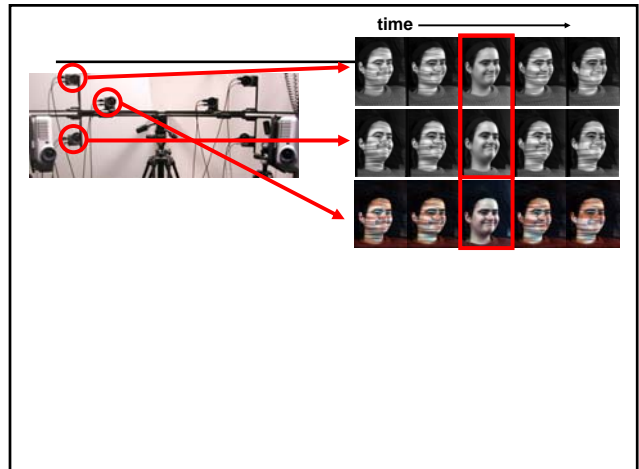
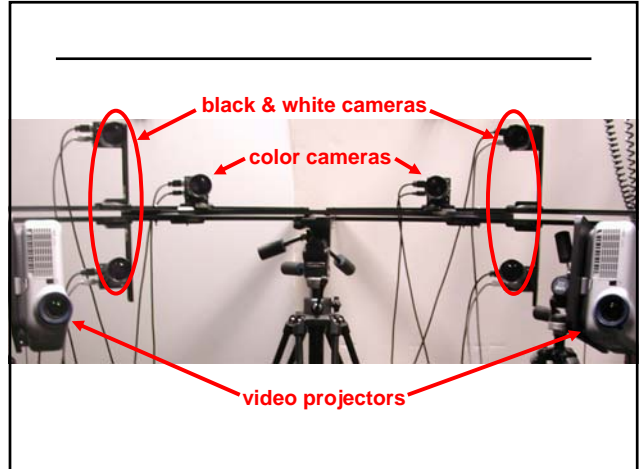
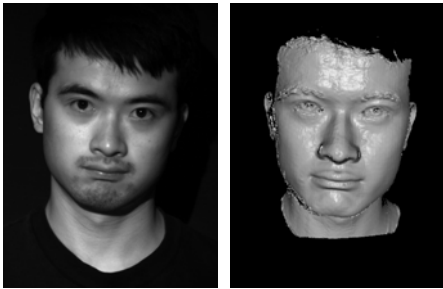
Laser scanned models

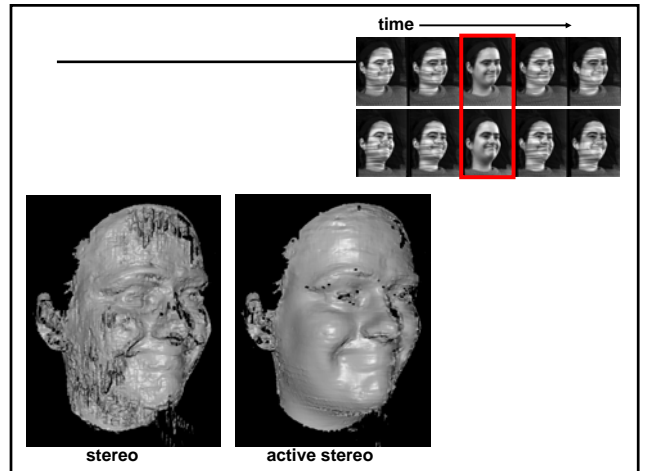
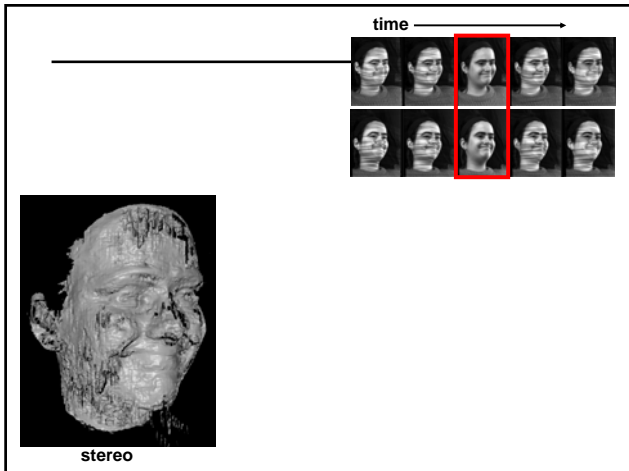
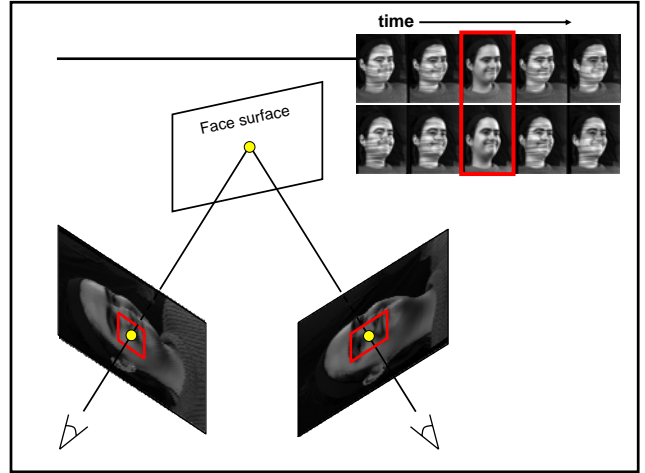
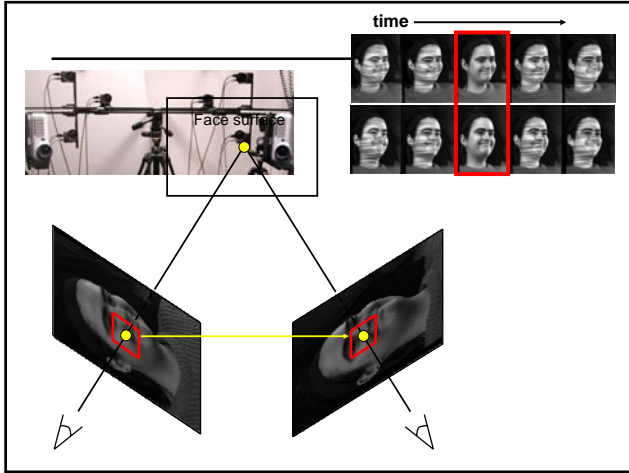


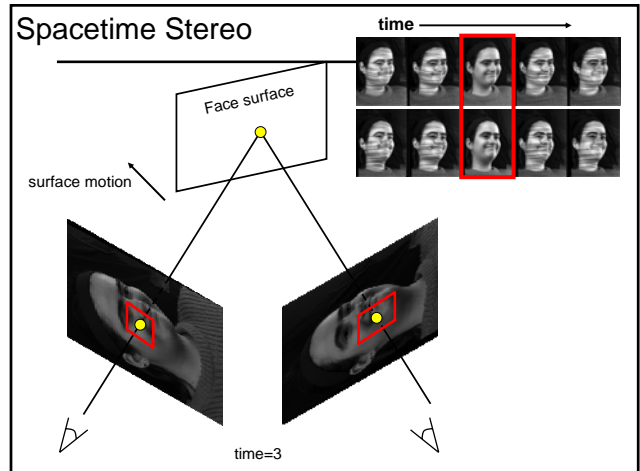
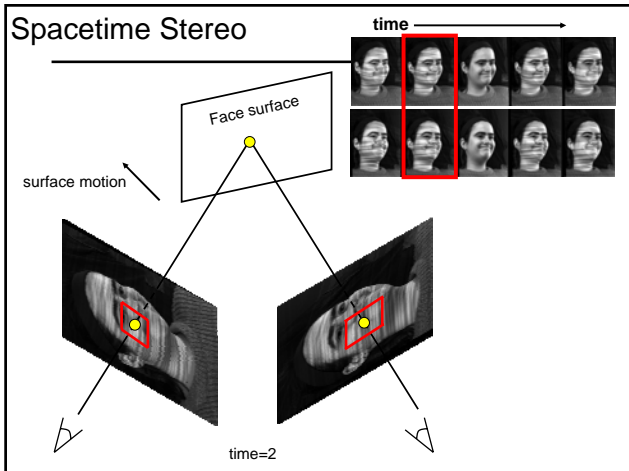
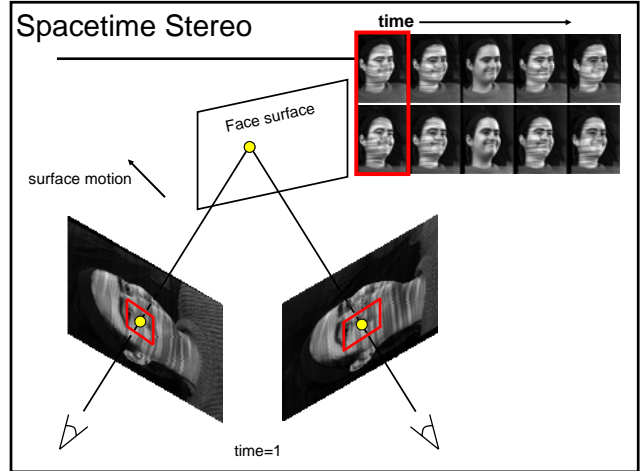
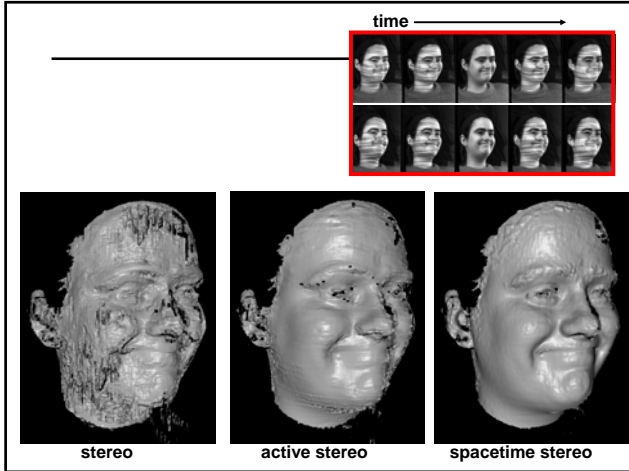
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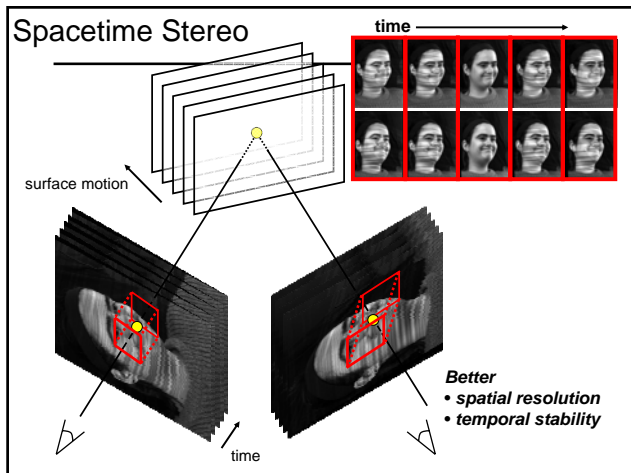
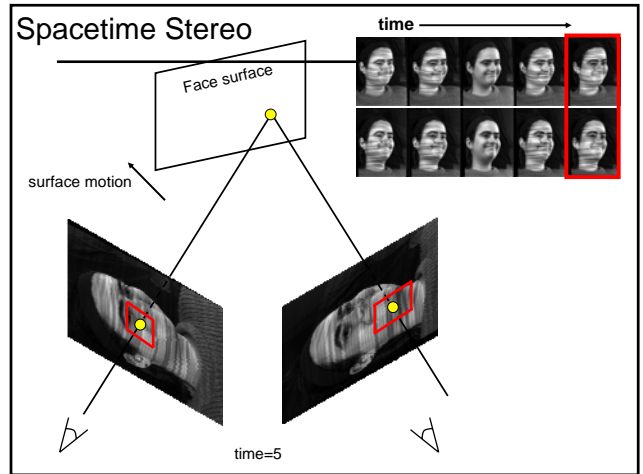
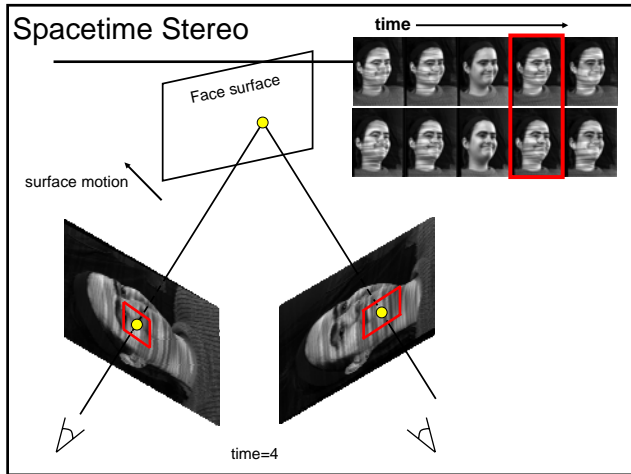
Moving scenes

with Noah Snavely,
Brian Curless, Steve Seitz









Demos

<http://grail.cs.washington.edu/projects/stereo/>