

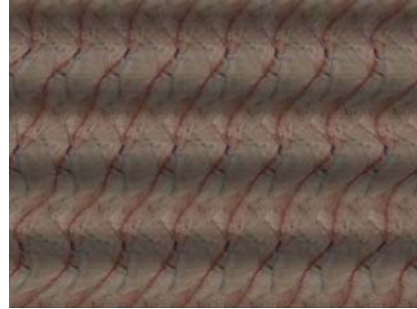
## Announcements

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- Project 2 code & artifact due Friday
- Midterm out tomorrow (check your email), due next Fri

## Stereo

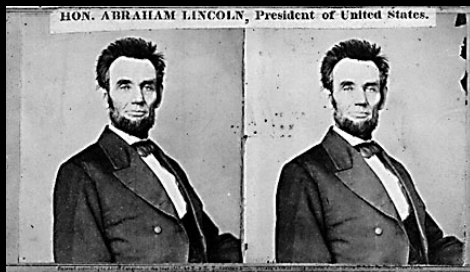
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Single image stereogram, by [Niklas Een](#)

### 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.



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 Photography



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

## Anaglyphs online

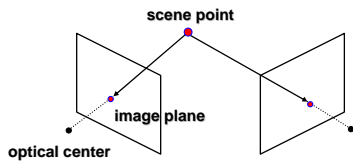
I used to maintain a list of sites, but too hard to keep up to date. Instead, see wikipedia page:

[http://en.wikipedia.org/wiki/Anaglyph\\_image](http://en.wikipedia.org/wiki/Anaglyph_image)

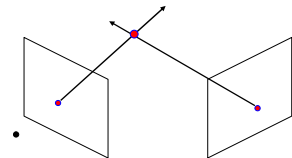
A free pair of red-blue stereo glasses can be ordered from [Rainbow Symphony Inc](http://www.rainbowsymphony.com/freestuff.html)

- <http://www.rainbowsymphony.com/freestuff.html>

## Stereo



## Stereo



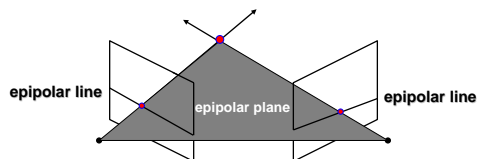
### Basic Principle: Triangulation

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

## Stereo correspondence

### Determine Pixel Correspondence

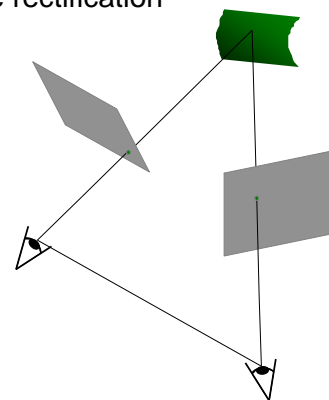
- Pairs of points that correspond to same scene point



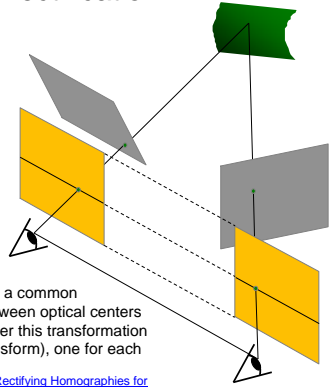
### Epipolar Constraint

- 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



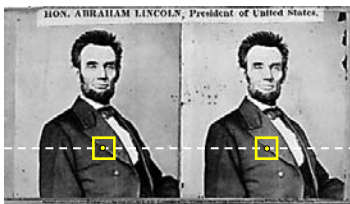
- reproject image planes onto a common plane parallel to the line between optical centers
  - pixel motion is horizontal after this transformation
  - two homographies (3x3 transform), one for each input image reprojection
- C. Loop and Z. Zhang. [Computing Rectifying Homographies for Stereo Vision](#). IEEE Conf. Computer Vision and Pattern Recognition, 1999.

## Stereo matching algorithms

### Match Pixels in Conjugate Epipolar Lines

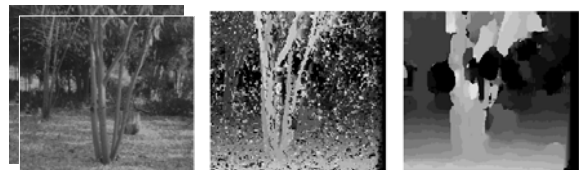
- Assume brightness constancy
- This is a tough problem
- Numerous approaches
  - A good survey and evaluation: <http://www.middlebury.edu/stereo/>

## 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...

## 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

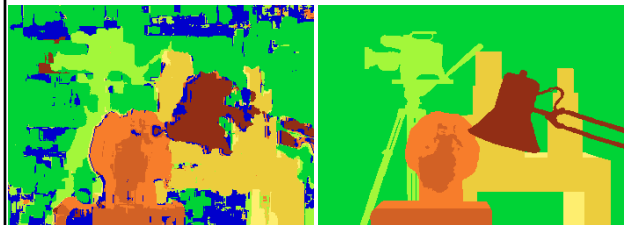


Scene



Ground truth

## Results with window search



Window-based matching  
(best window size)

Ground truth

## Better methods exist...



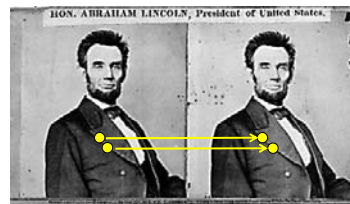
State of the art method

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/>

## Stereo as energy minimization



What defines a good stereo correspondence?

1. Match quality
  - Want each pixel to find a good match in the other image
2. Smoothness
  - If two pixels are adjacent, they should (usually) move about the same amount

## Stereo as energy minimization

Expressing this mathematically

### 1. Match quality

- Want each pixel to find a good match in the other image

$$\text{matchCost} = \sum_{x,y} \|I(x,y) - J(x + d_{xy}, y)\|$$

### 2. Smoothness

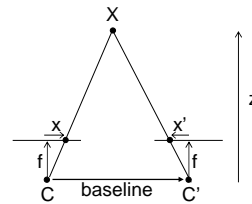
- If two pixels are adjacent, they should (usually) move about the same amount

$$\text{smoothnessCost} = \sum_{\text{neighbor pixels } p,q} |d_p - d_q|$$

We want to minimize  $\text{Energy} = \text{matchCost} + \text{smoothnessCost}$

- This is a special type of energy function known as an MRF (Markov Random Field)
- Effective and fast algorithms have been recently developed:
  - » Graph cuts, belief propagation....
  - » for more details (and code): <http://vision.middlebury.edu/MRF/>

## Depth from disparity



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

## Video View Interpolation

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

## Real-time stereo



Nomad robot 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

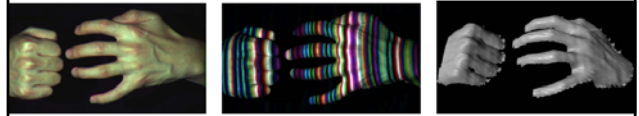
### Steps

- 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



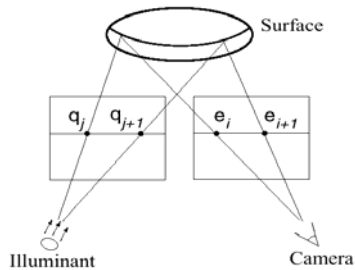
Li Zhang's one-shot stereo



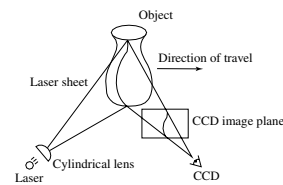
Project "structured" light patterns onto the object

- 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

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*The Digital Michelangelo Project, Levoy et al.*

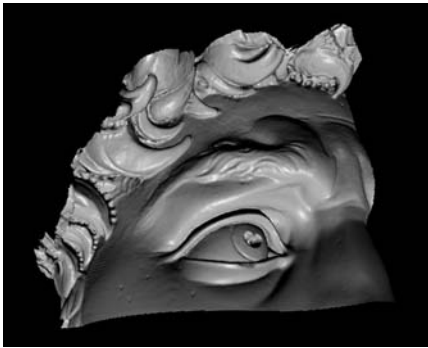
Laser scanned models



*The Digital Michelangelo Project, Levoy et al.*

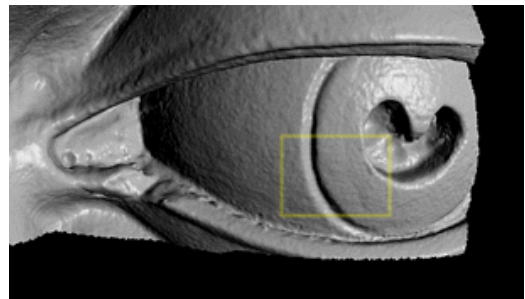
Laser scanned models

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*The Digital Michelangelo Project, Levoy et al.*

Laser scanned models

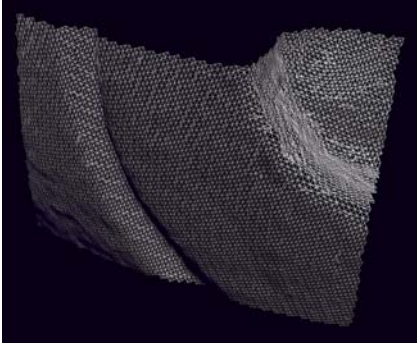


*The Digital Michelangelo Project, Levoy et al.*



## Laser scanned models

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*The Digital Michelangelo Project, Levoy et al.*

## Spacetime Stereo

Li Zhang, Noah Snavely,  
Brian Curless, Steve Seitz



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