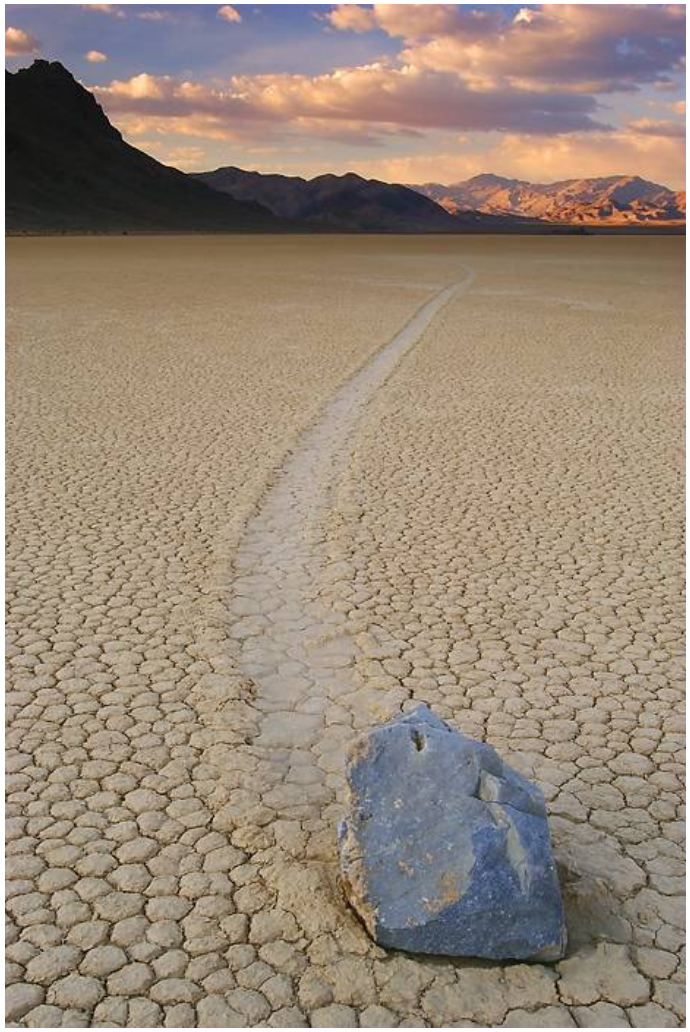
Multiple View Geometry



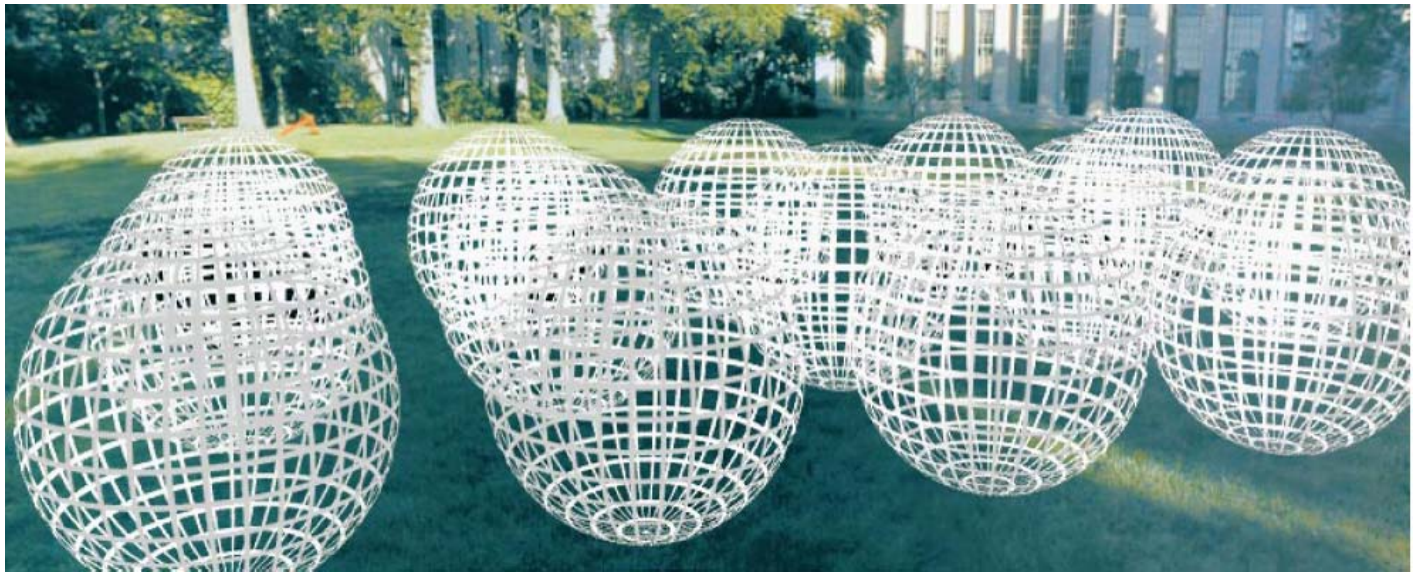
© Martin Quinn

15-463: Computational Photography
Alexei Efros, CMU, Fall 2006

…with a lot of slides stolen from Steve Seitz and Jianbo Shi

Our Goal

The Plenoptic Function



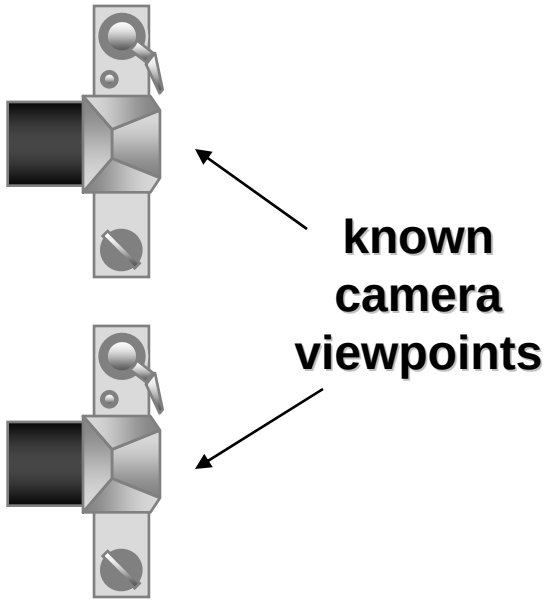
$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

How can we compress this into something manageable?

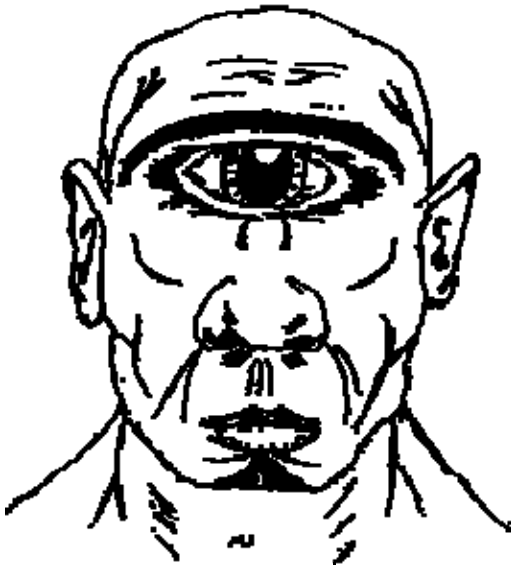
Stereo Reconstruction

The Stereo Problem

- Shape from two (or more) images
- Biological motivation

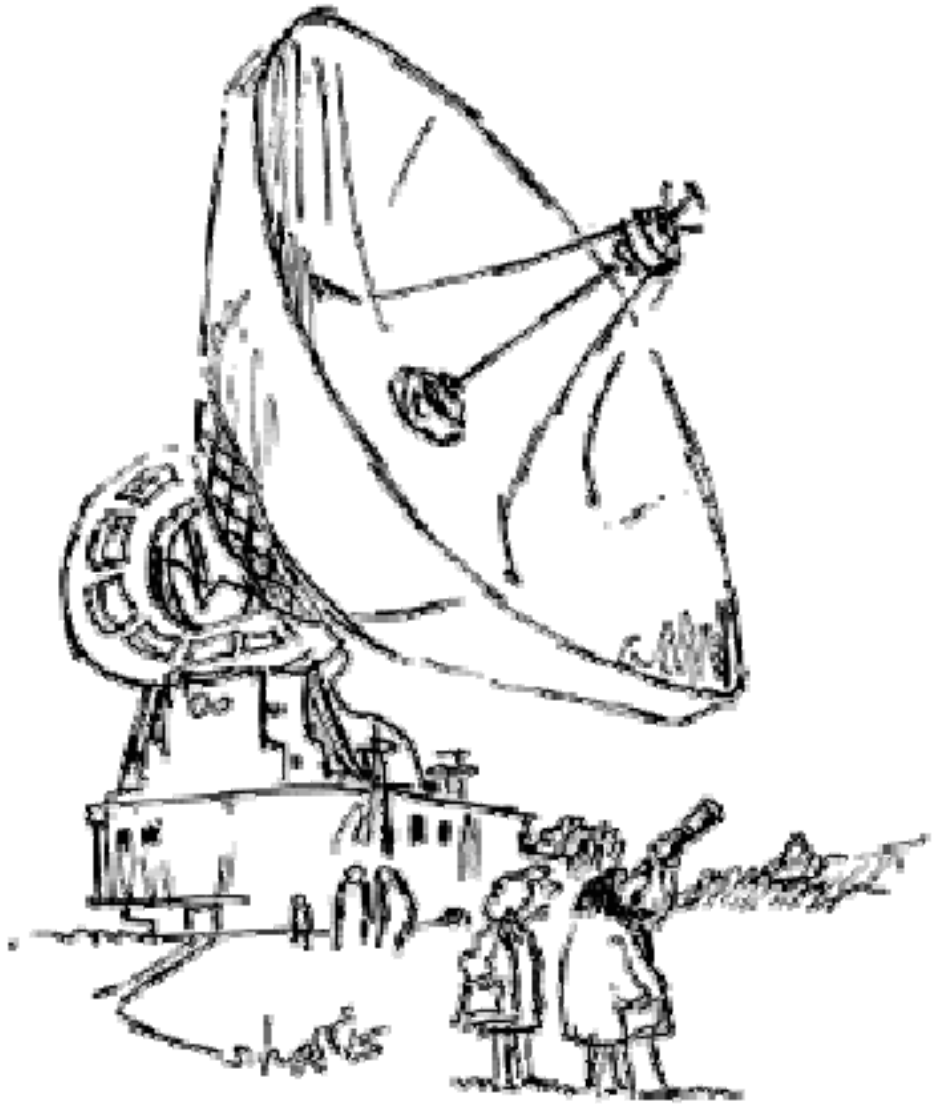


Why do we have two eyes?



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

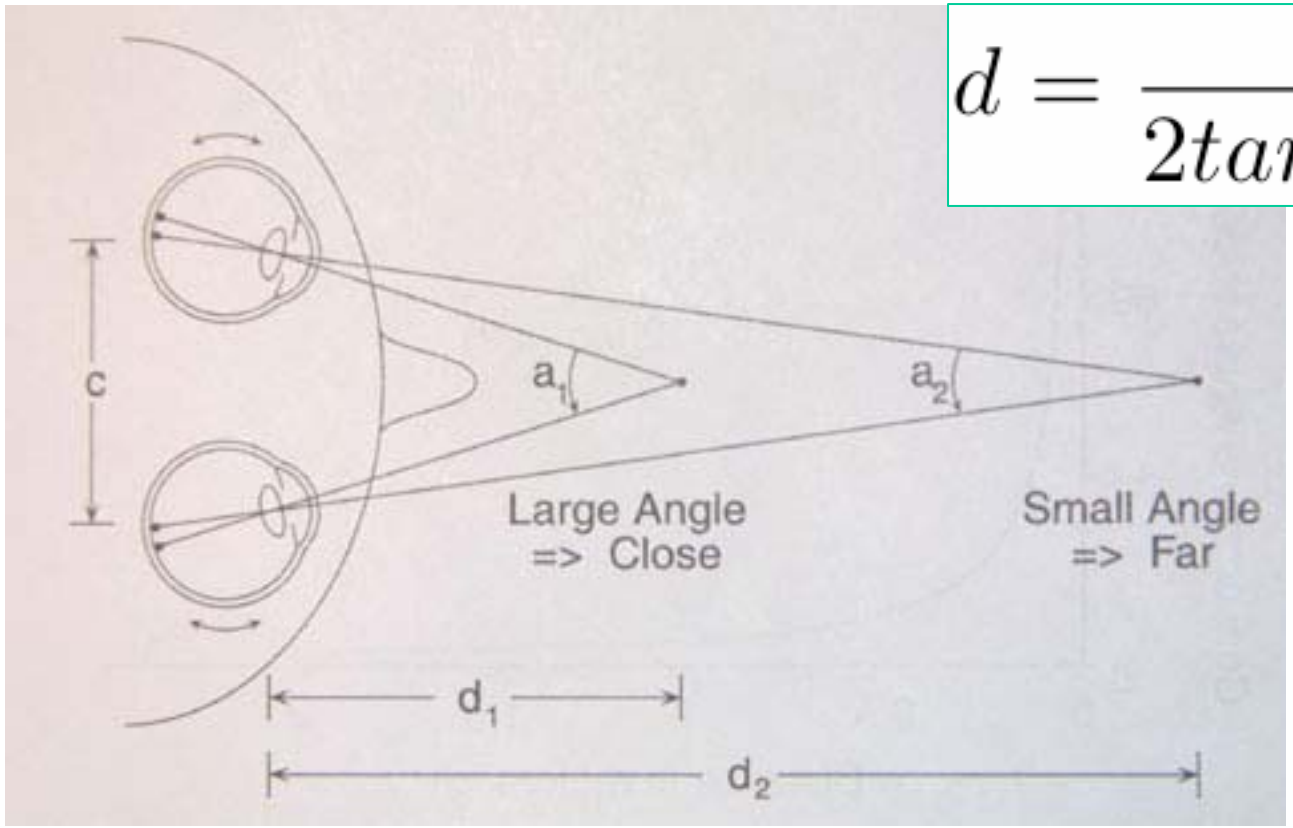
1. Two is better than one



"Just checking."

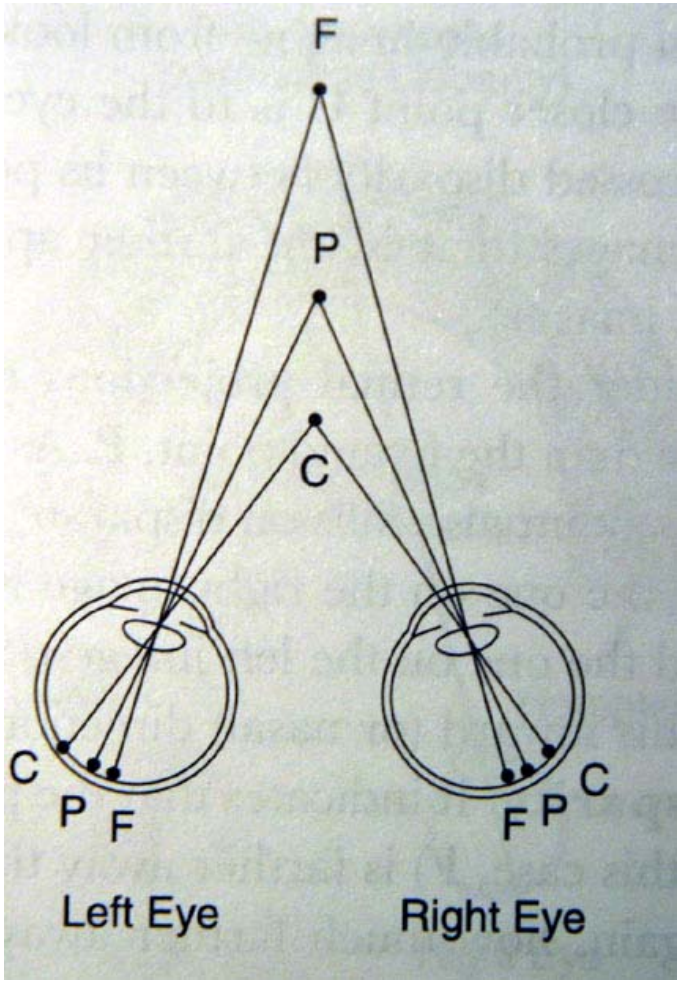
2. Depth from Convergence

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



Human performance: up to 6-8 feet

3. Depth from binocular disparity

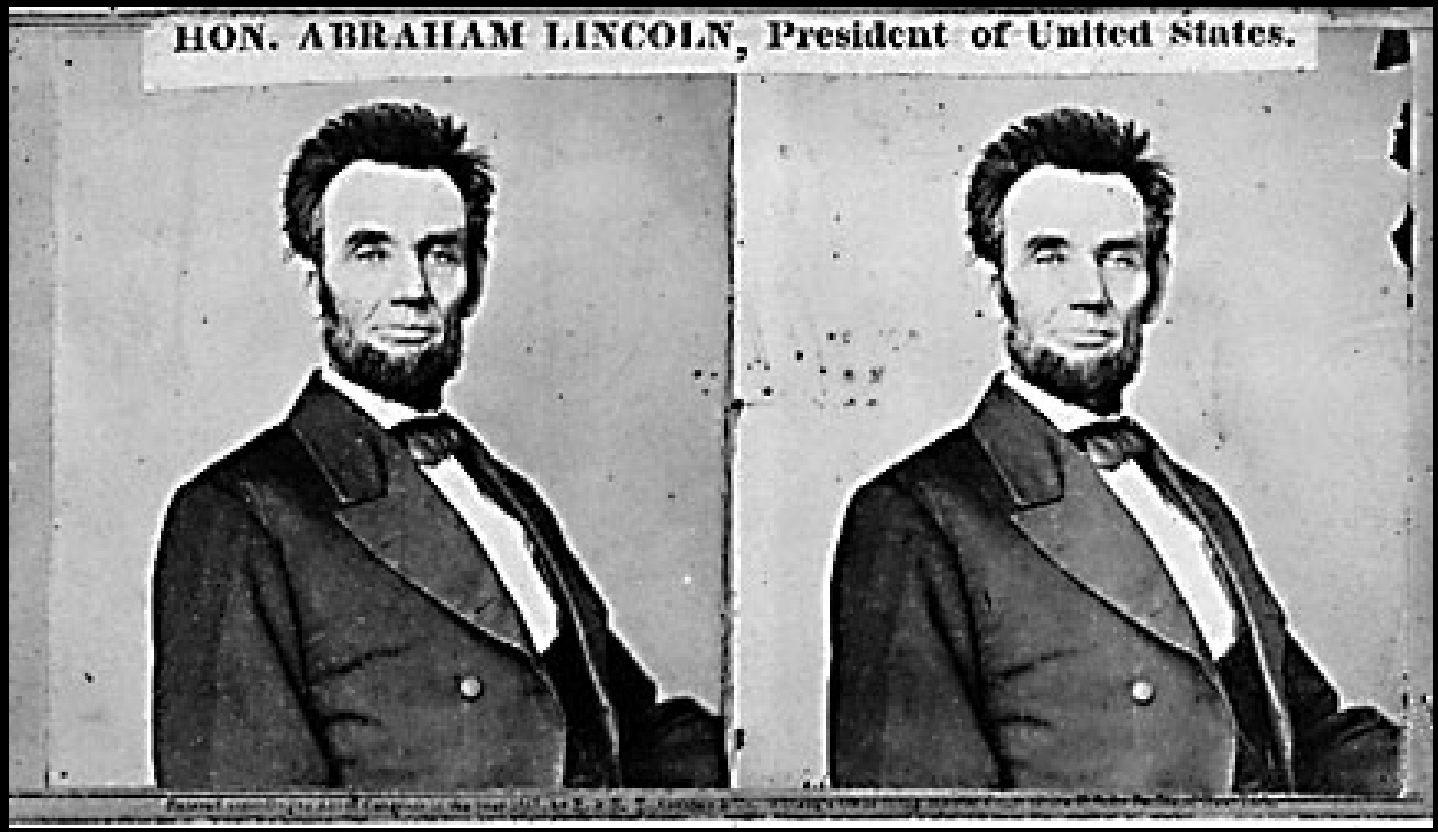


Sign and magnitude of disparity

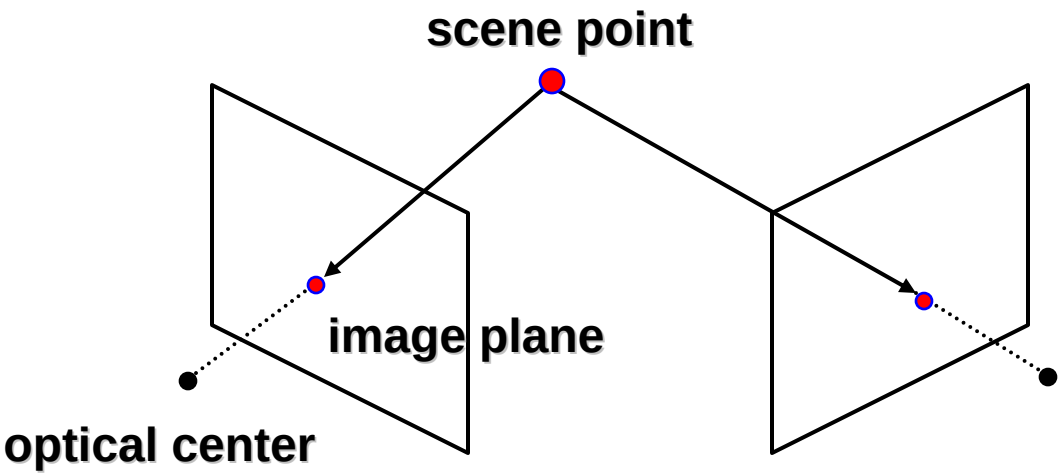
P: converging point

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

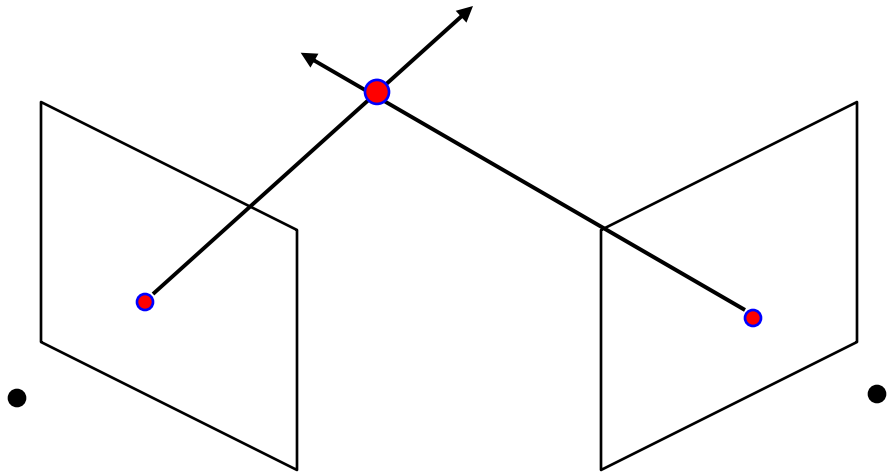
F: object farther projects to the inside of the P, disparity = -


HON. ABRAHAM LINCOLN, President of United States.

Stereo



Stereo



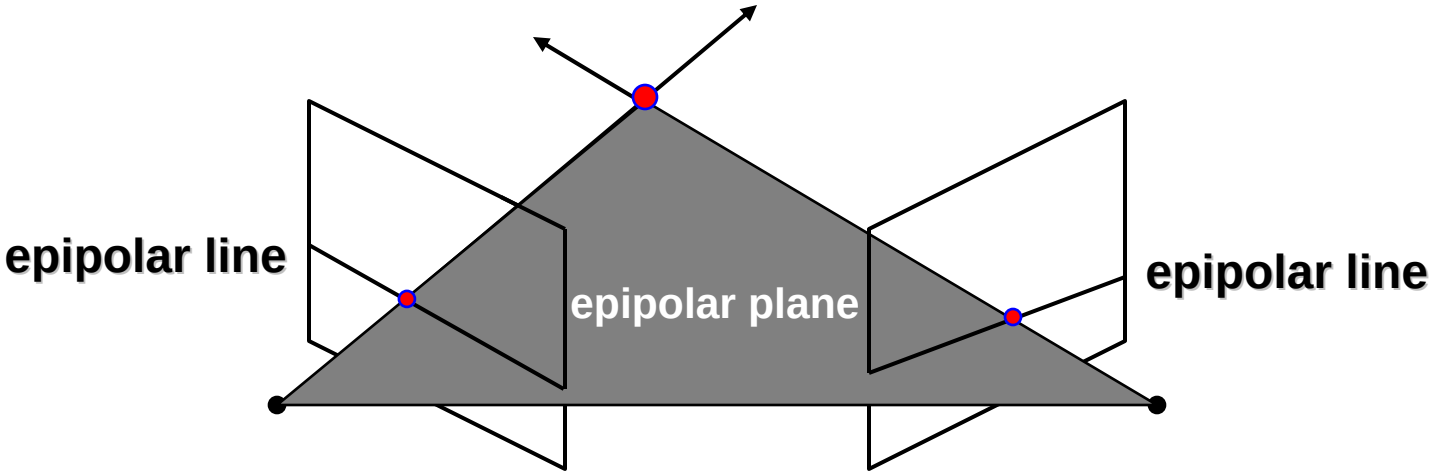
Basic Principle: Triangulation

- Gives reconstruction as intersection of two rays
- Requires
  - calibration
  - ***point correspondence***

Stereo correspondence

Determine Pixel Correspondence

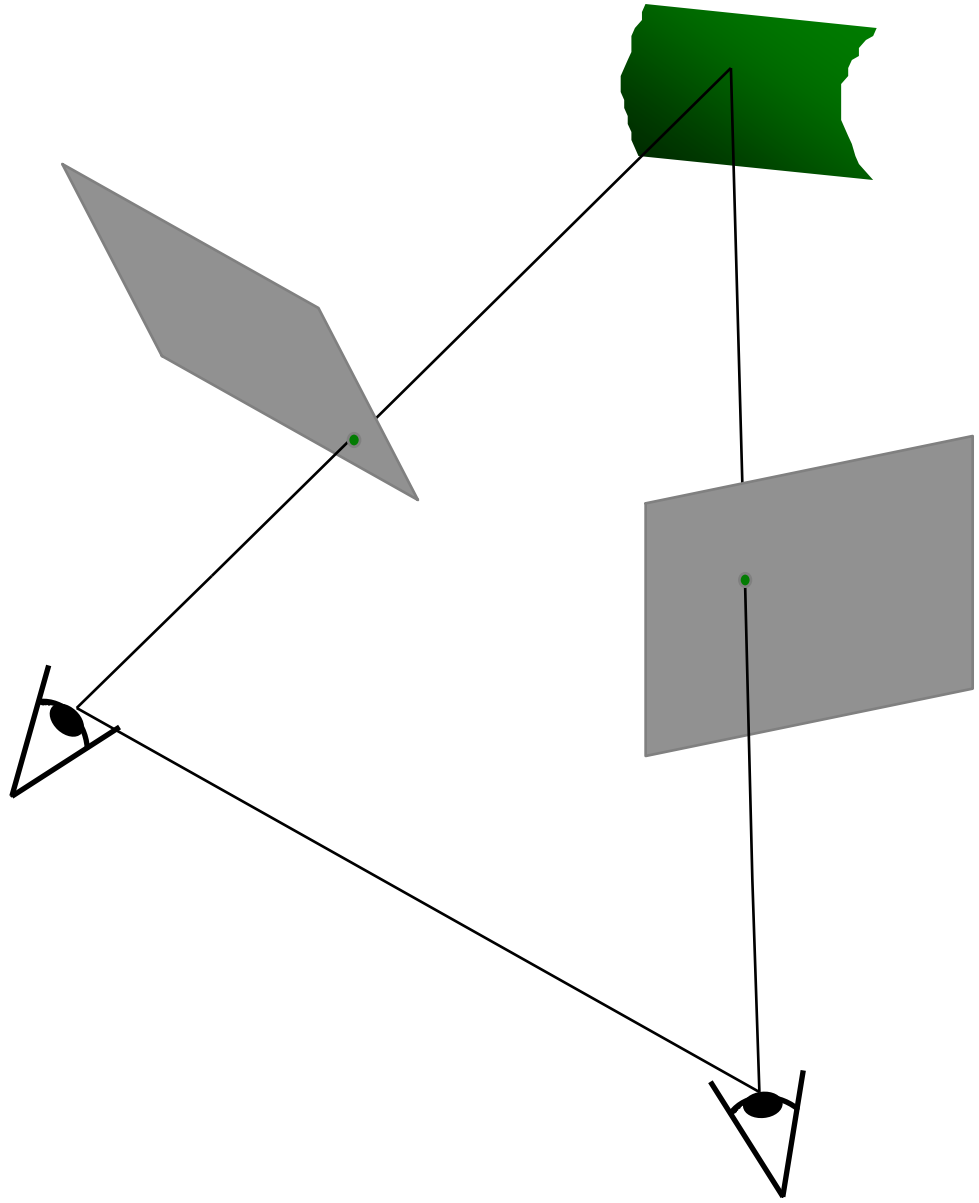
- Pairs of points that correspond to same scene point



Epipolar Constraint

- Reduces correspondence problem to 1D search along *conjugate epipolar lines*

Stereo image rectification



Stereo image rectification

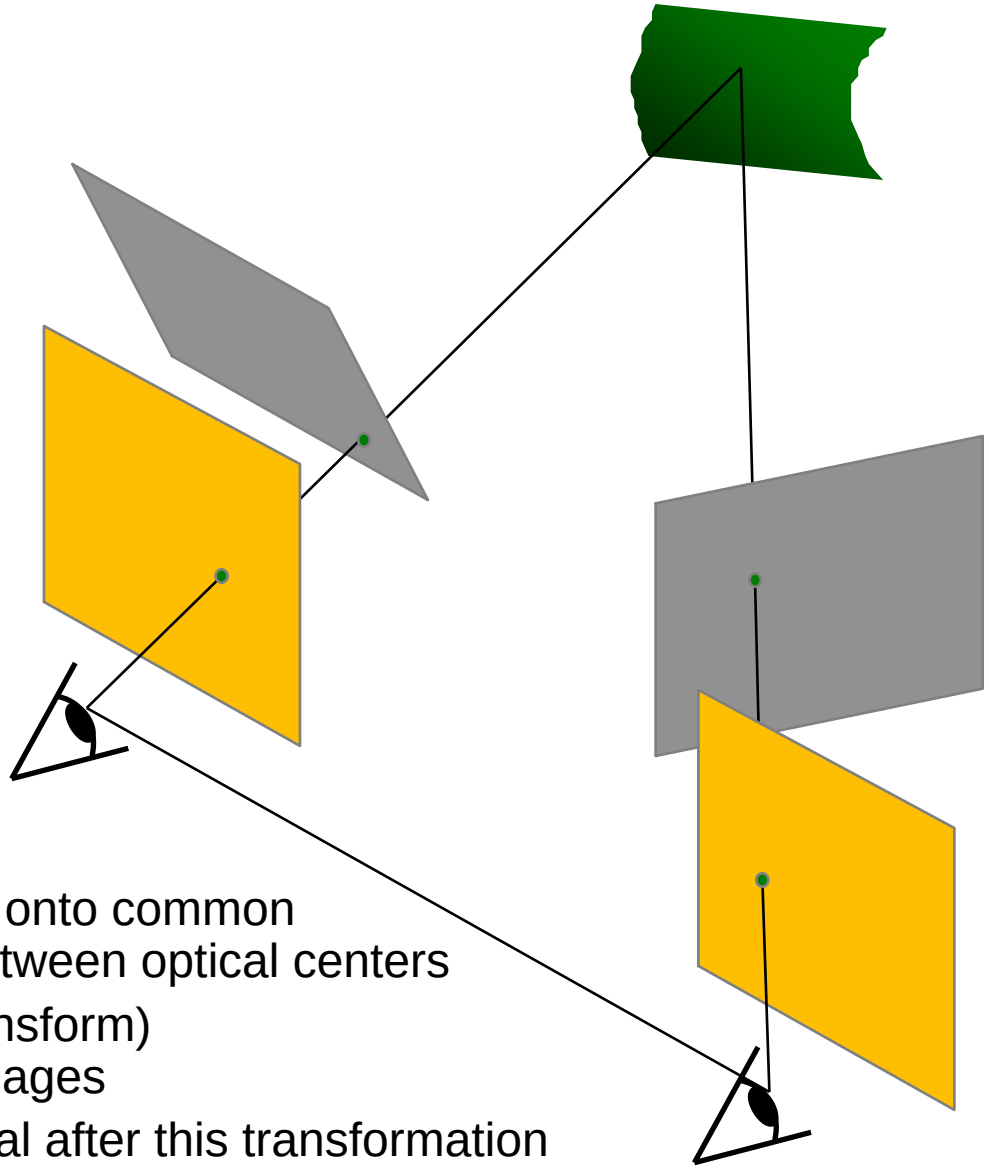
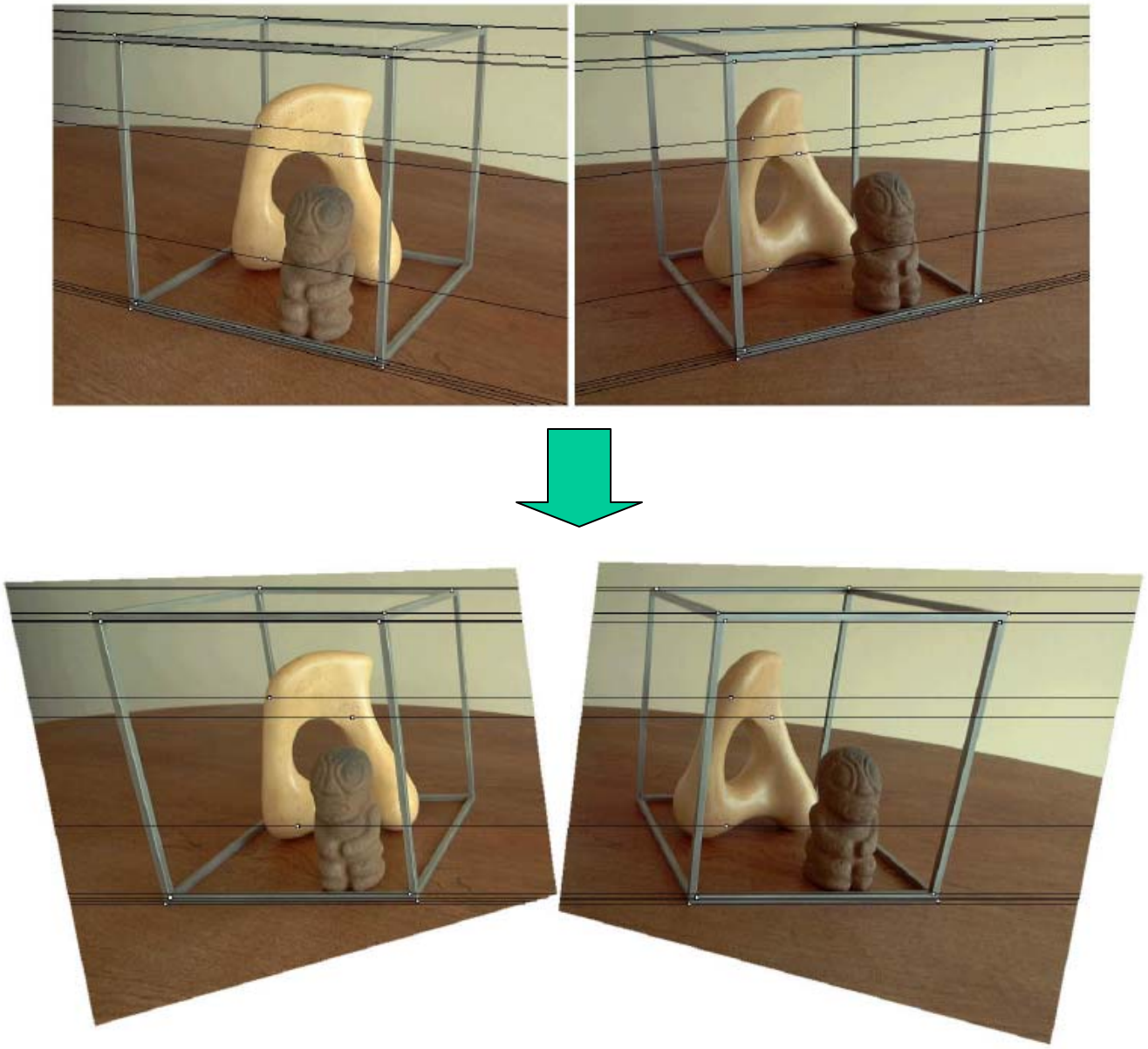


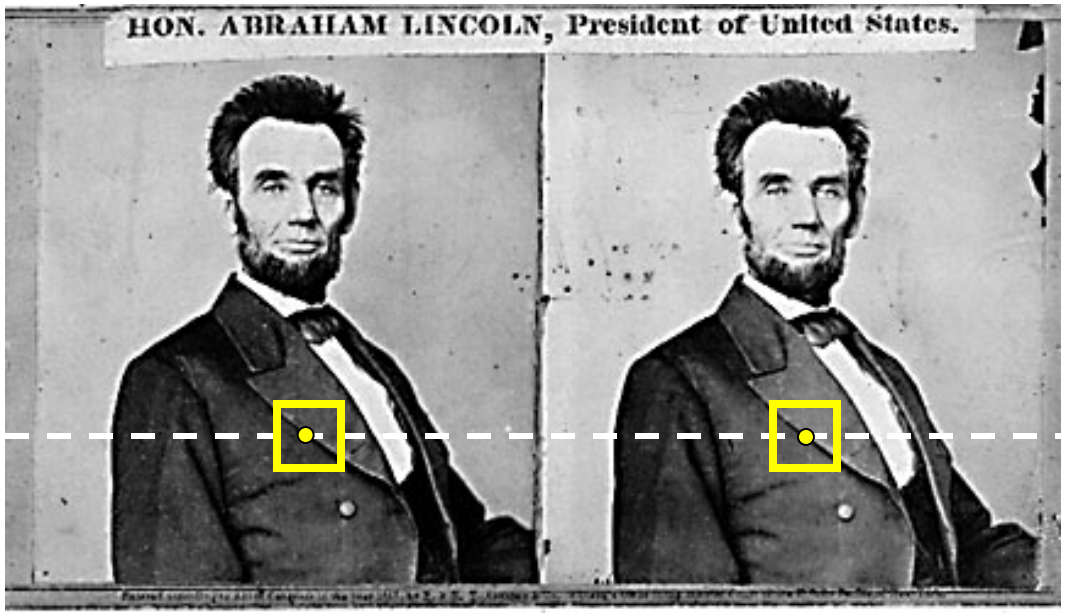
Image Reprojection

- 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 Rectification



Your basic stereo algorithm



For each epipolar line

For each pixel in the left image

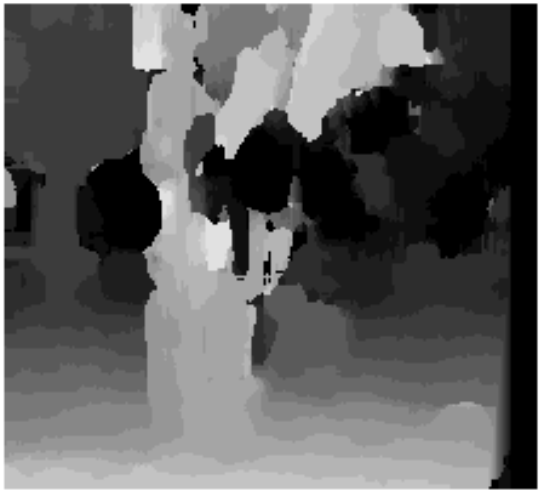
- compare with every pixel on same epipolar line in right image
- pick pixel with minimum match cost

Improvement: match ***windows***

- This should look familar...
- Can use Lukas-Kanade or discrete search (latter more common)

Window size

W = 3



W = 20

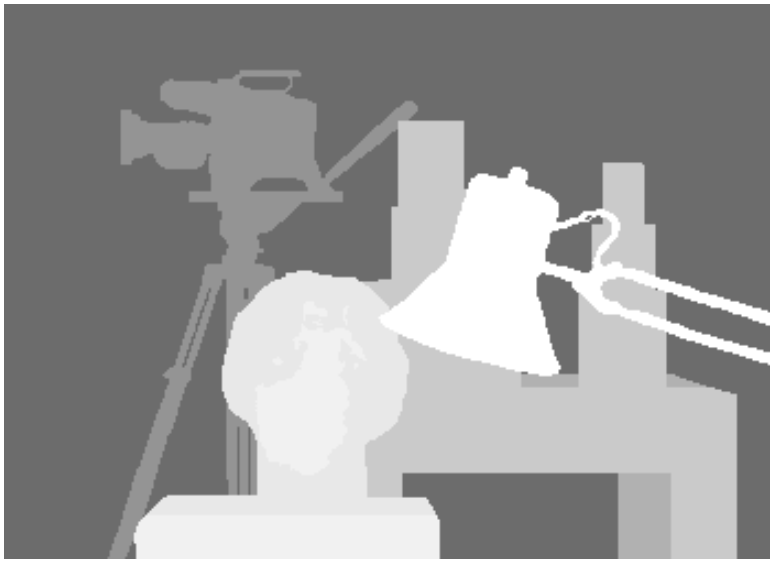
Effect of window size

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

Stereo results

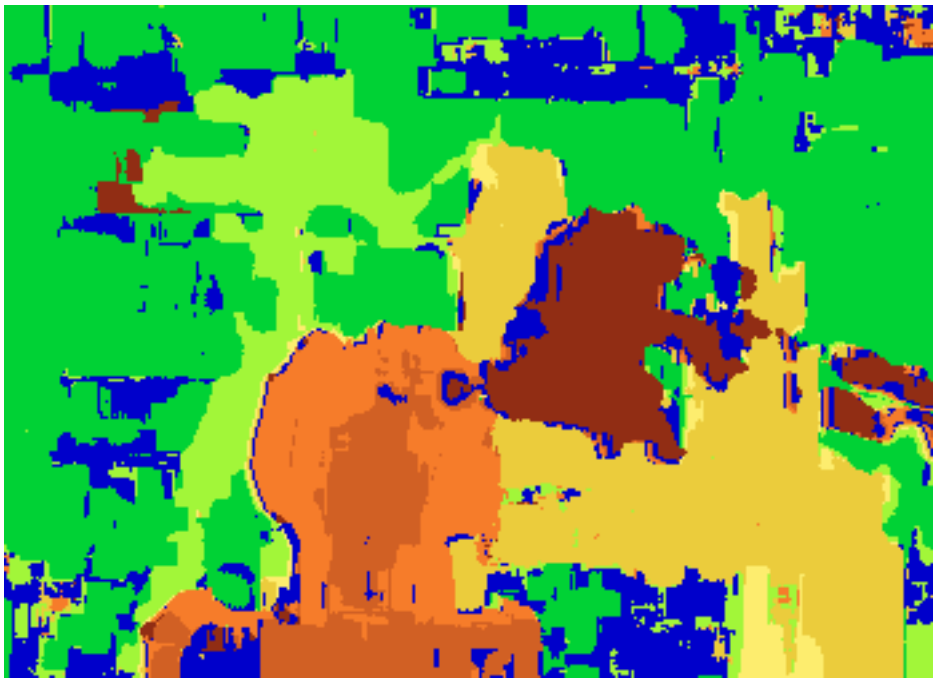
- Data from University of Tsukuba
- Similar results on other images without ground truth

Scene



Ground truth

Results with window search



Window-based matching
(best window size)

Ground truth

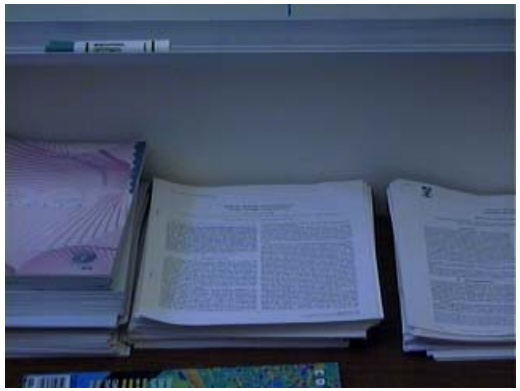
Better methods exist...

State of the art method

Ground truth

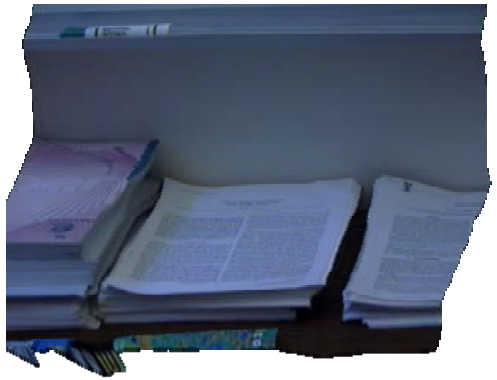
Boykov et al., Fast Approximate Energy Minimization via Graph Cuts, International Conference on Computer Vision, September 1999.

Depth from disparity

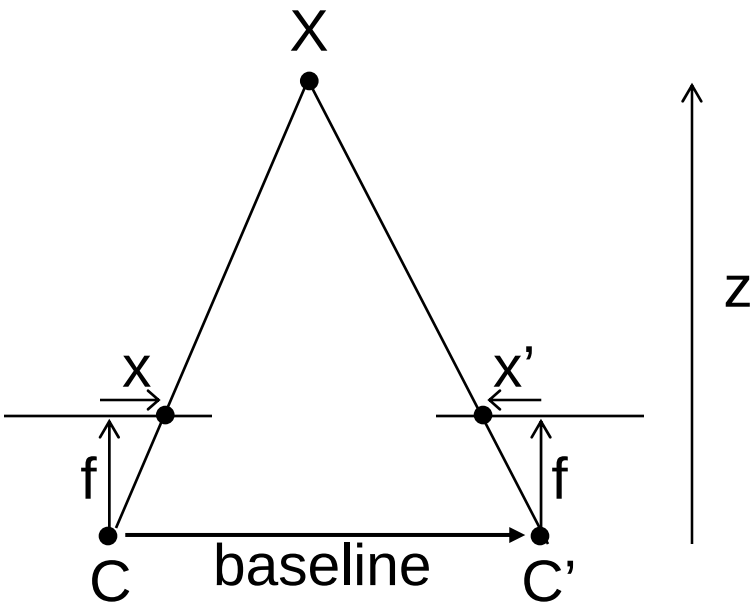


input image (1 of 2)

depth map
[Szeliski & Kang ‘95]



3D rendering



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

Stereo reconstruction pipeline

Steps

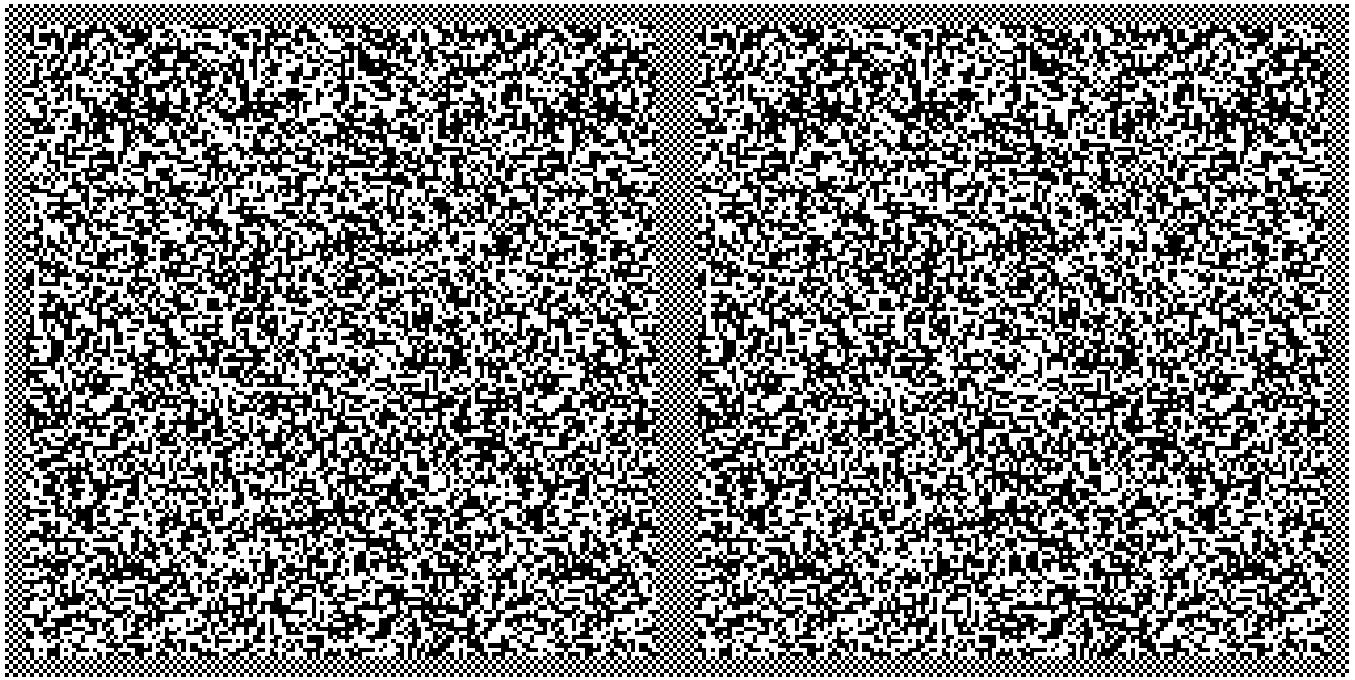
- Calibrate cameras
- Rectify images
- Compute disparity
- Estimate depth

What will cause errors?

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

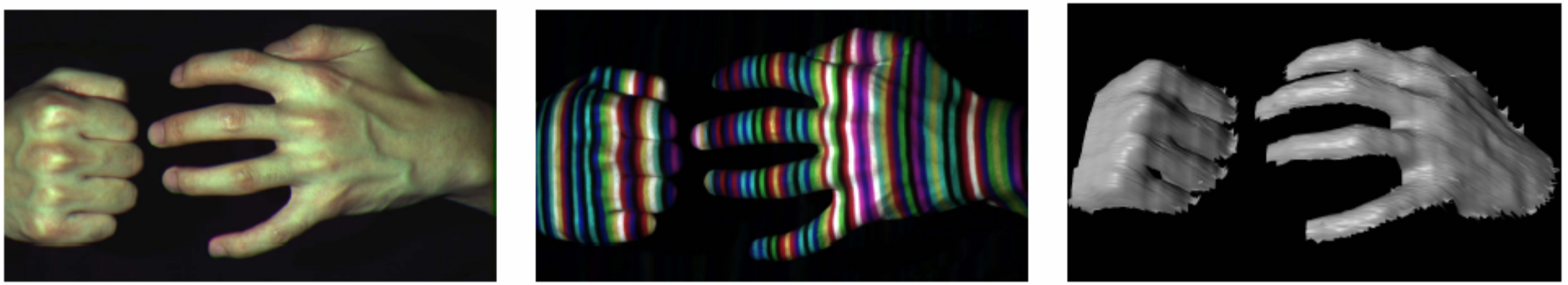
Stereo matching

Need texture for matching

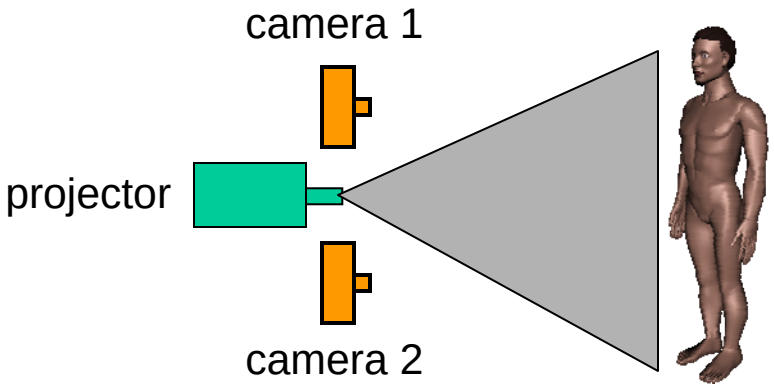


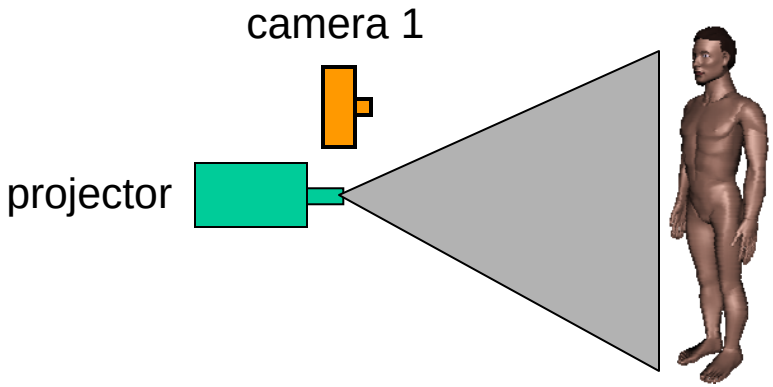
Julesz-style Random Dot Stereogram

Active stereo with structured light



Li Zhang's one-shot stereo

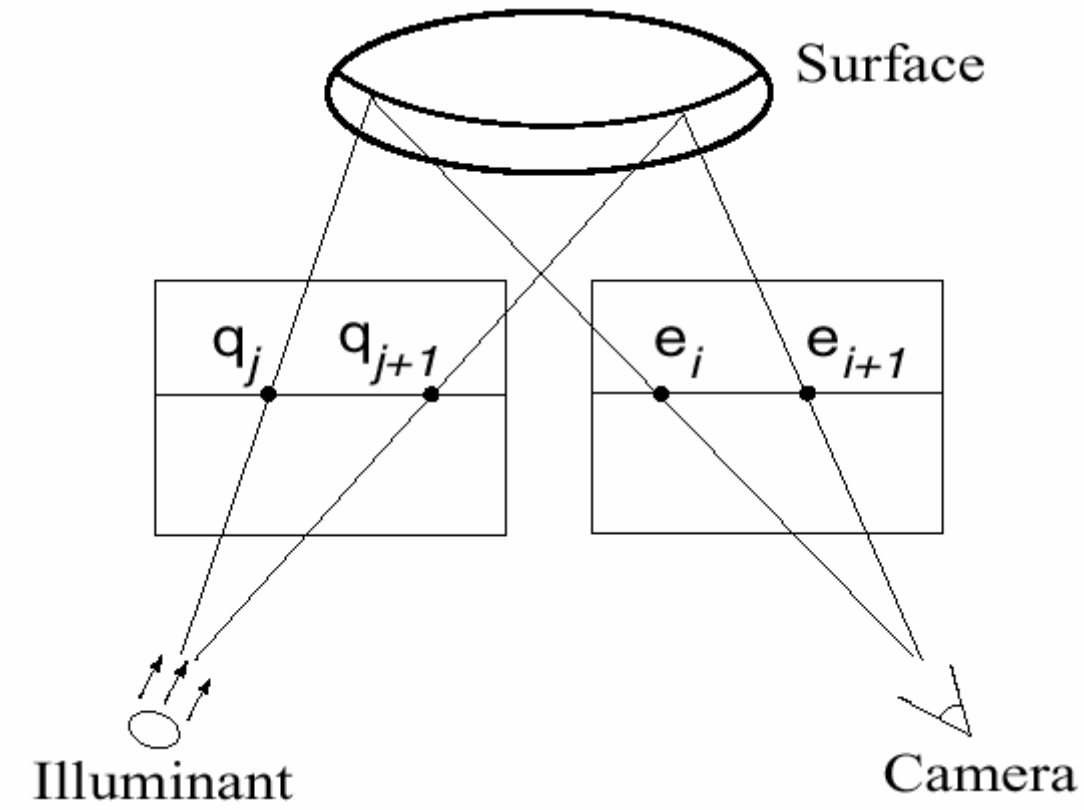




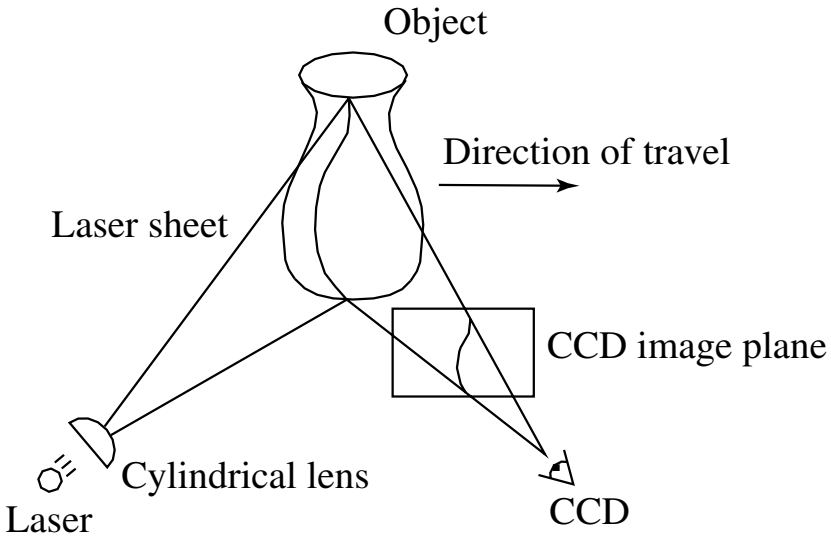
Project "structured" light patterns onto the object

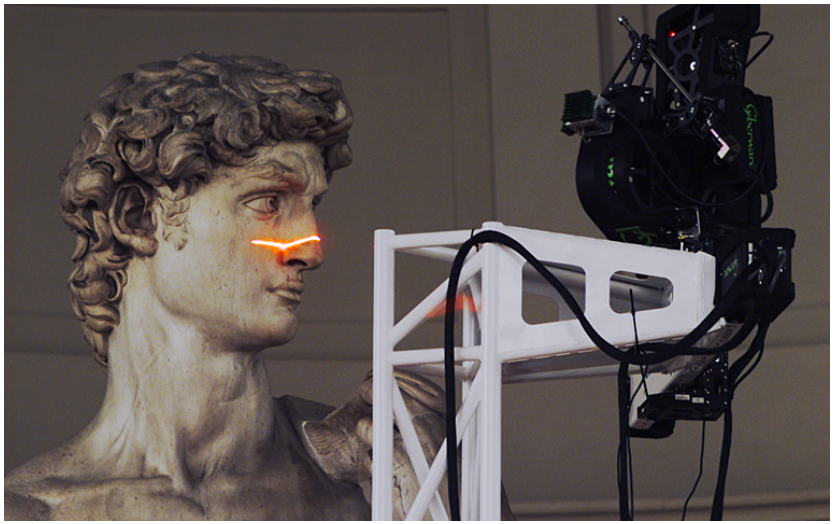
- simplifies the correspondence problem

Active stereo with structured light



Laser scanning



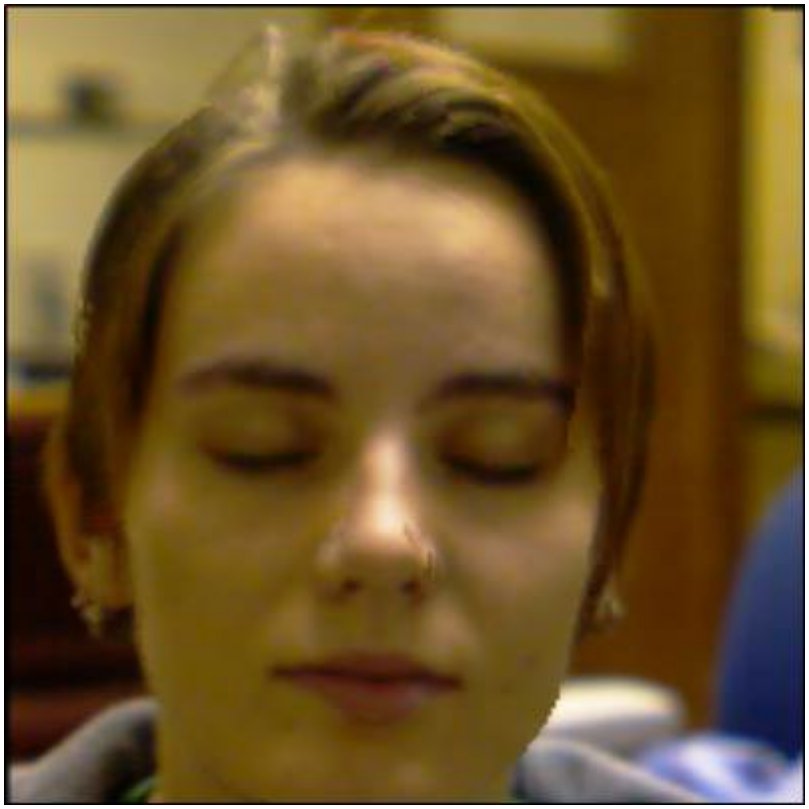


Digital Michelangelo Project
http://graphics.stanford.edu/projects/mich/

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)



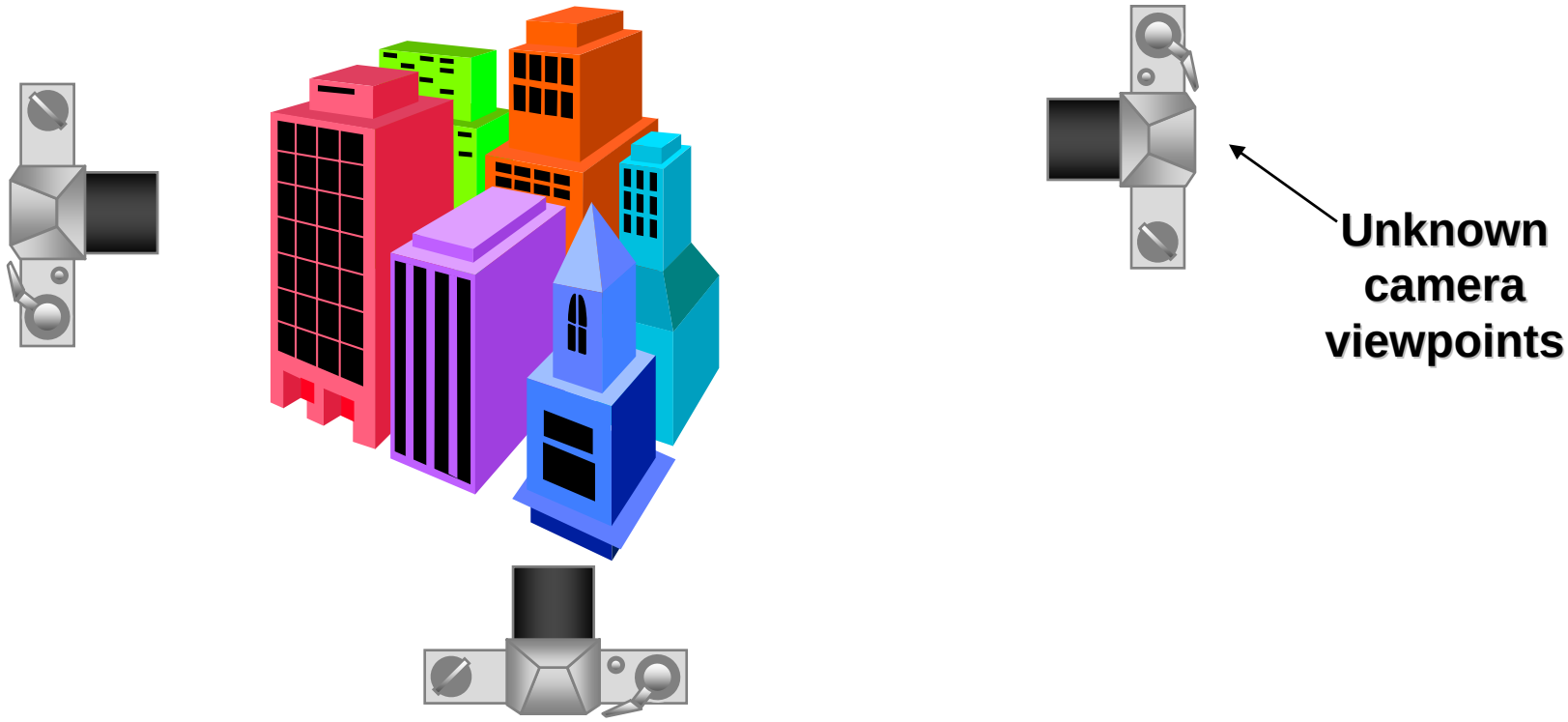
Real-time stereo

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

Used for robot navigation (and other tasks)

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

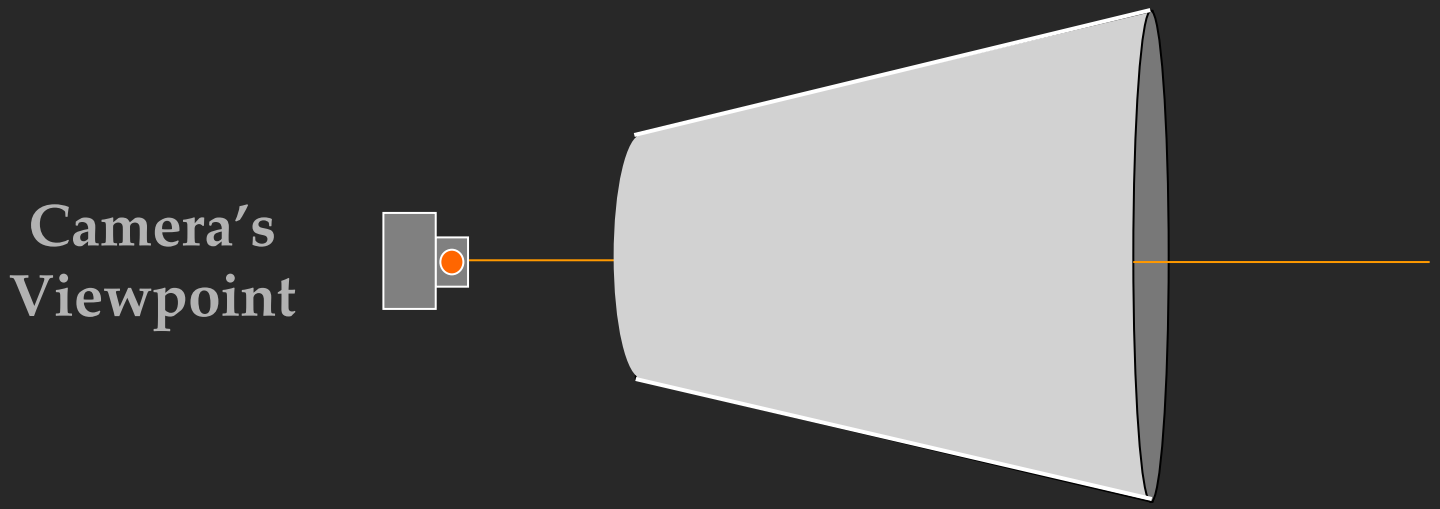
Structure from Motion



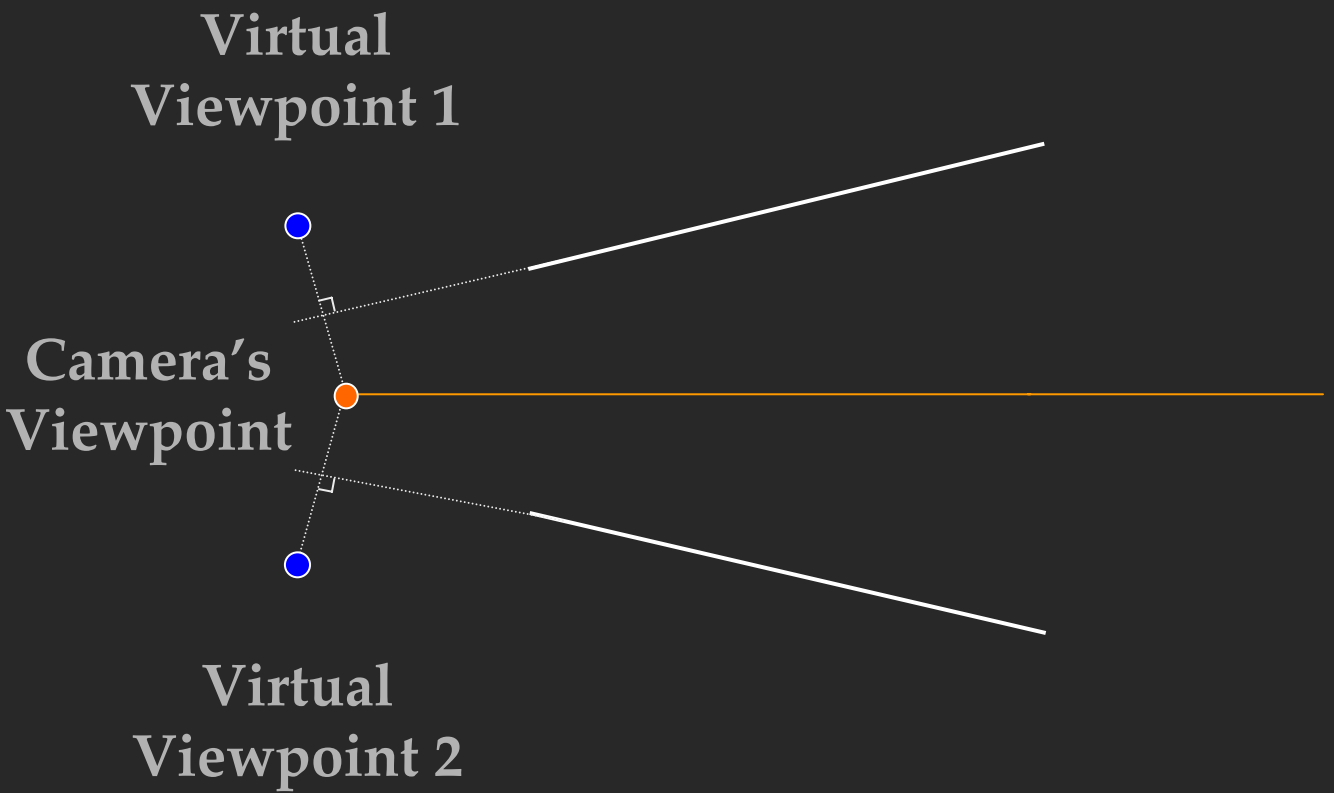
Reconstruct

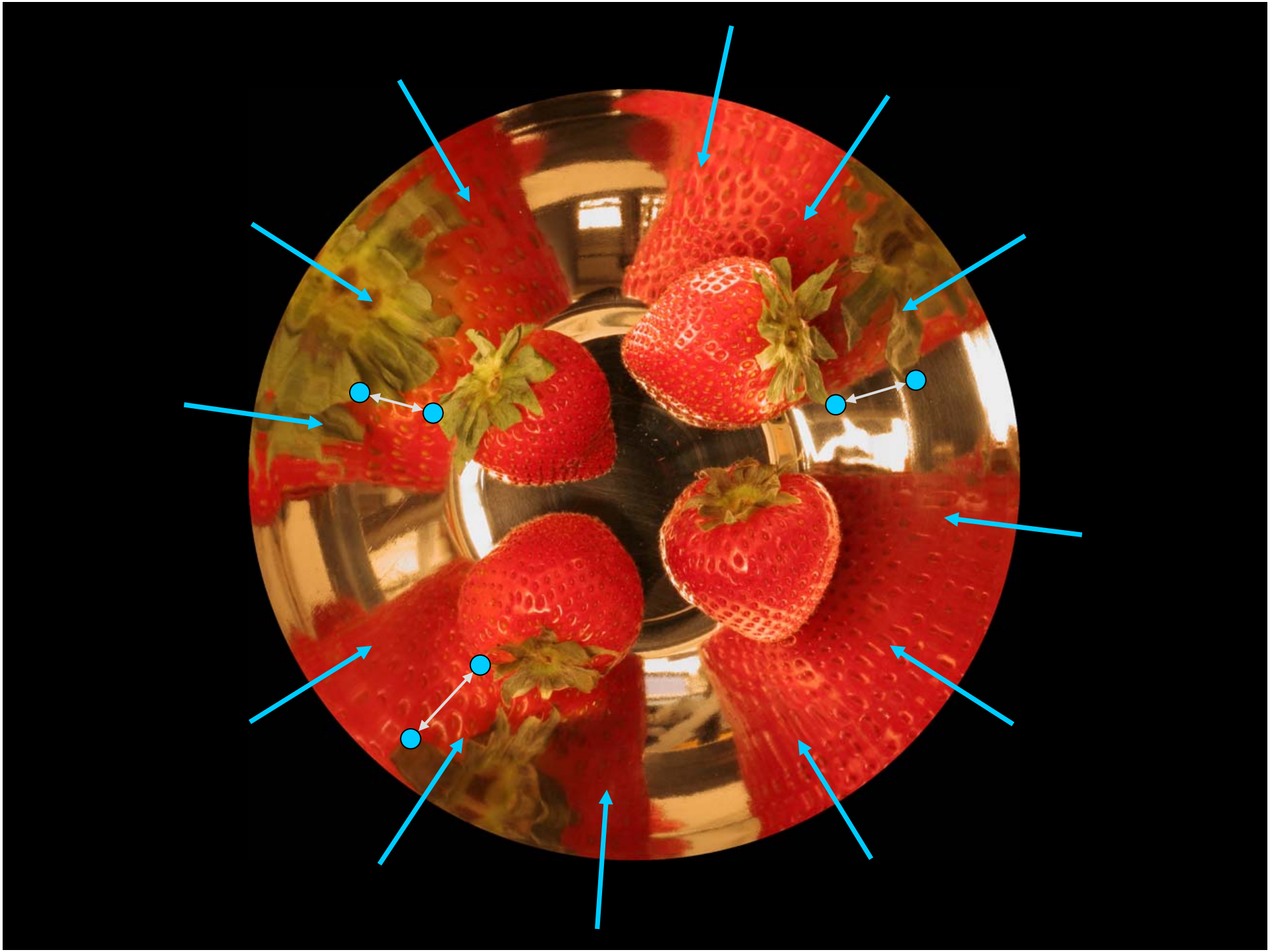
- Scene geometry
- Camera motion

Catadioptric Imaging

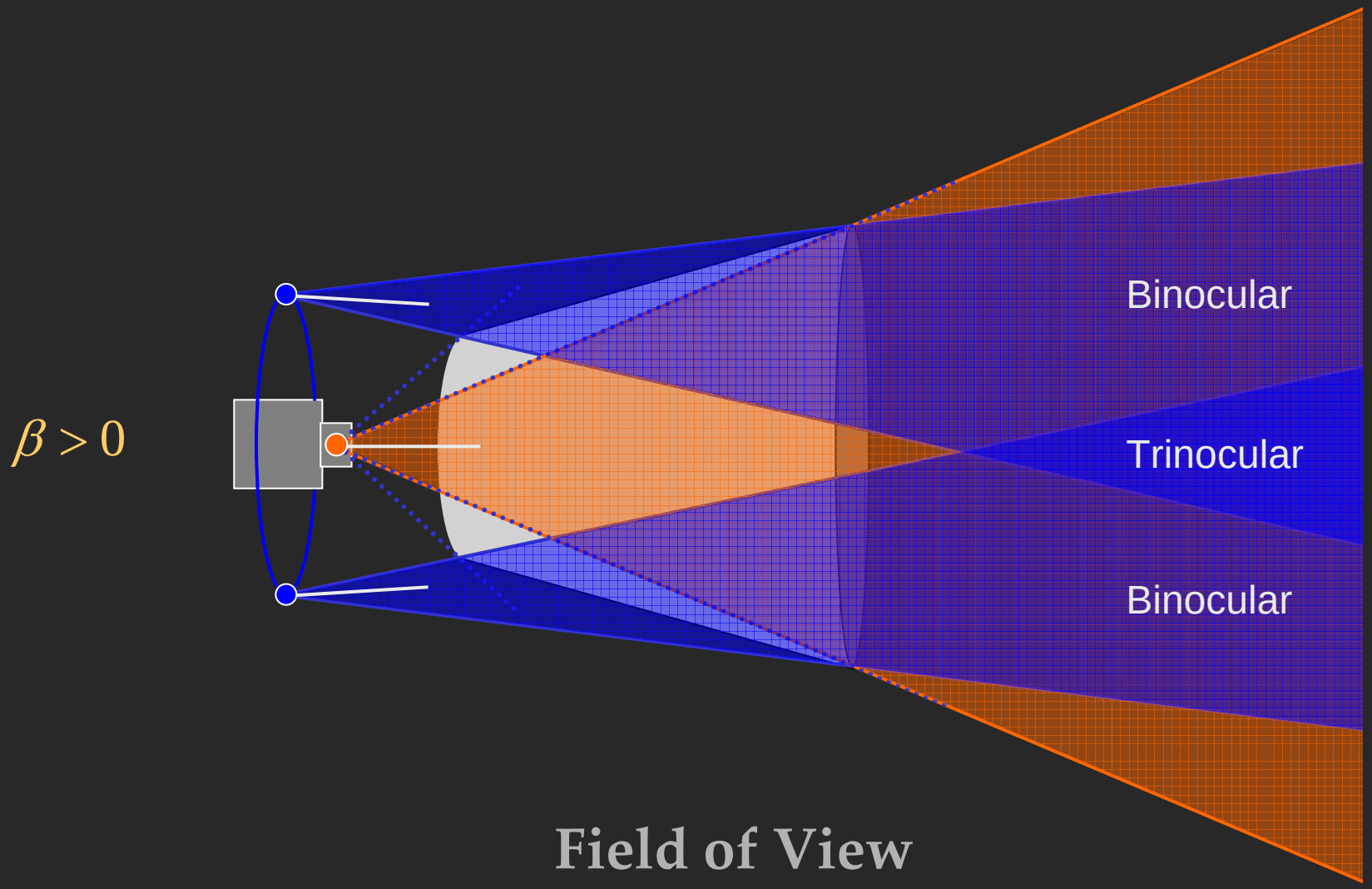


Multiview Catadioptric Imaging



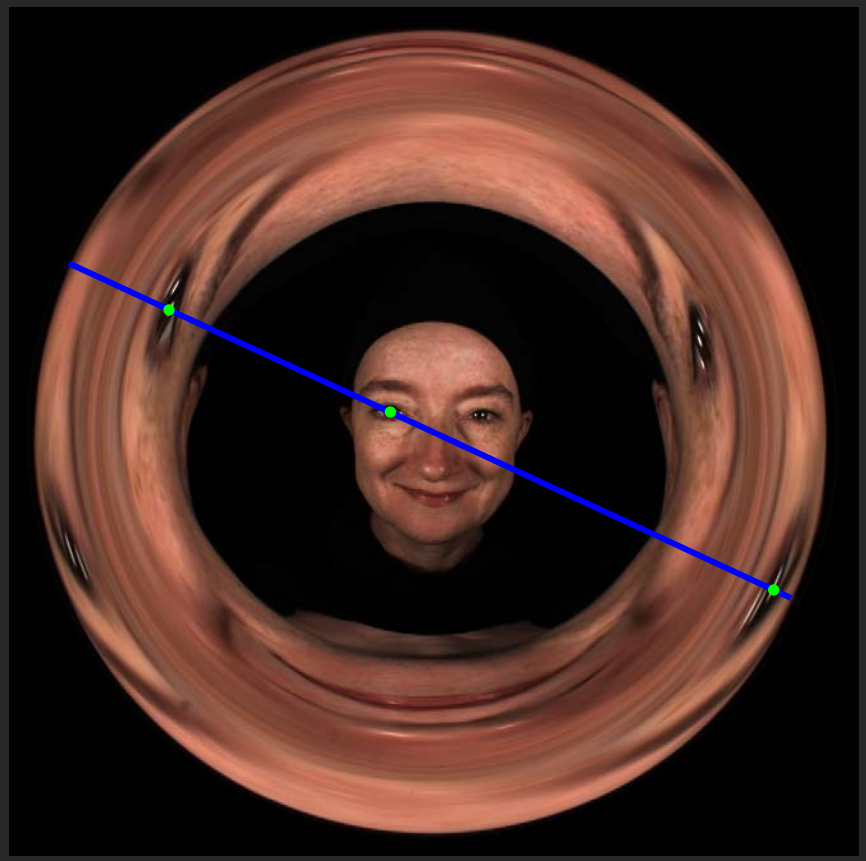


Reconstructing 3D Objects

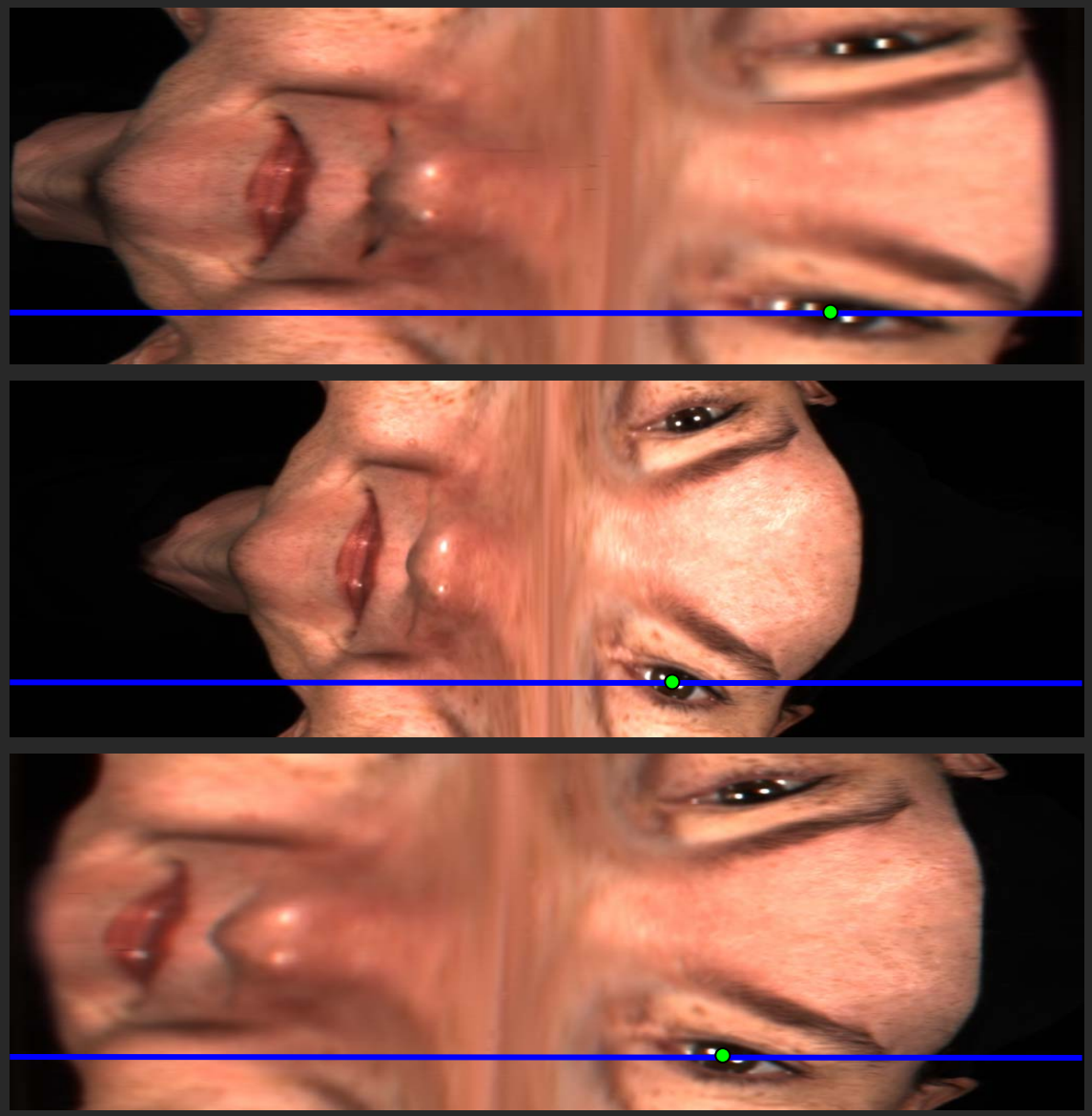


Reconstructing Faces

Reconstructing Faces

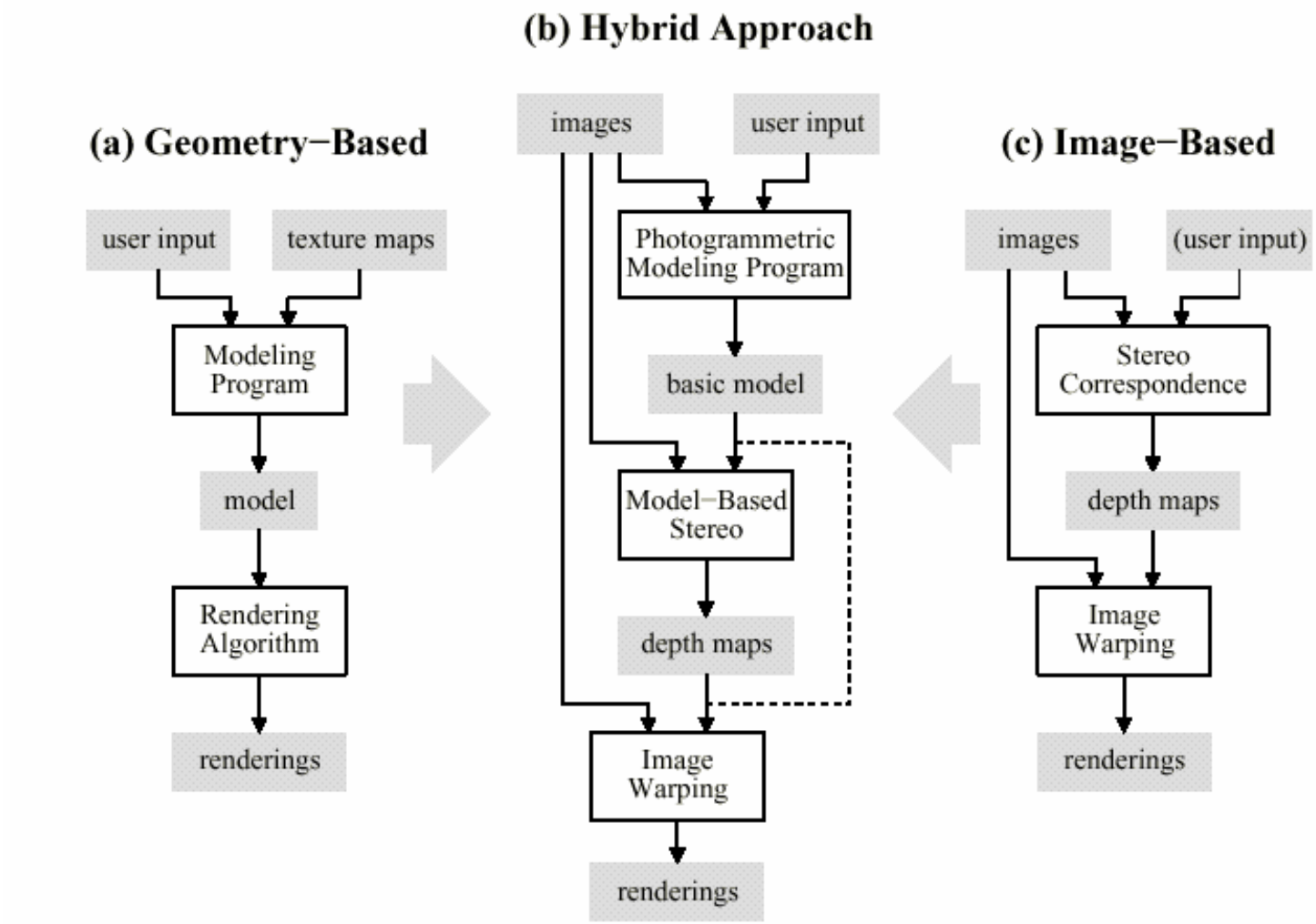


Stereo Views



Reconstructing Faces

Three approaches

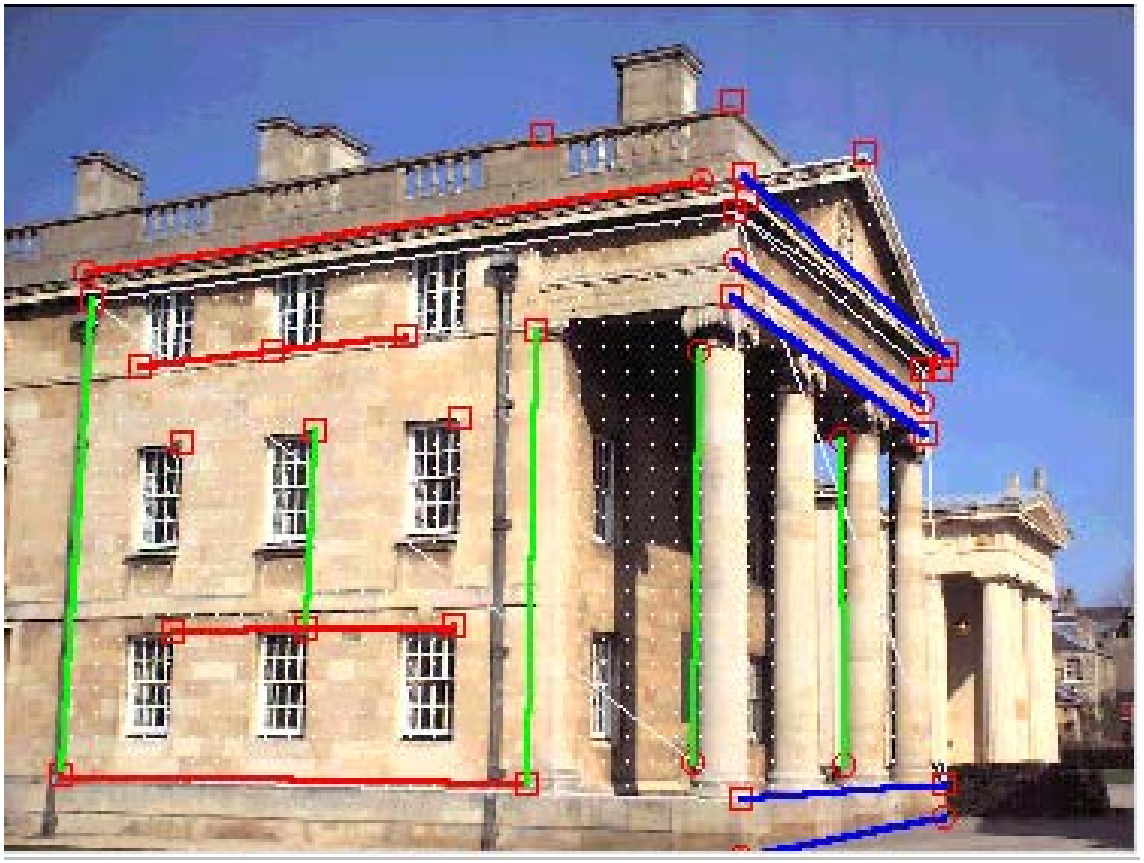


Outline of a simple algorithm (1)

- Based on constraints
- Input to the algorithm (1): two images

Outline of a simple algorithm (2)

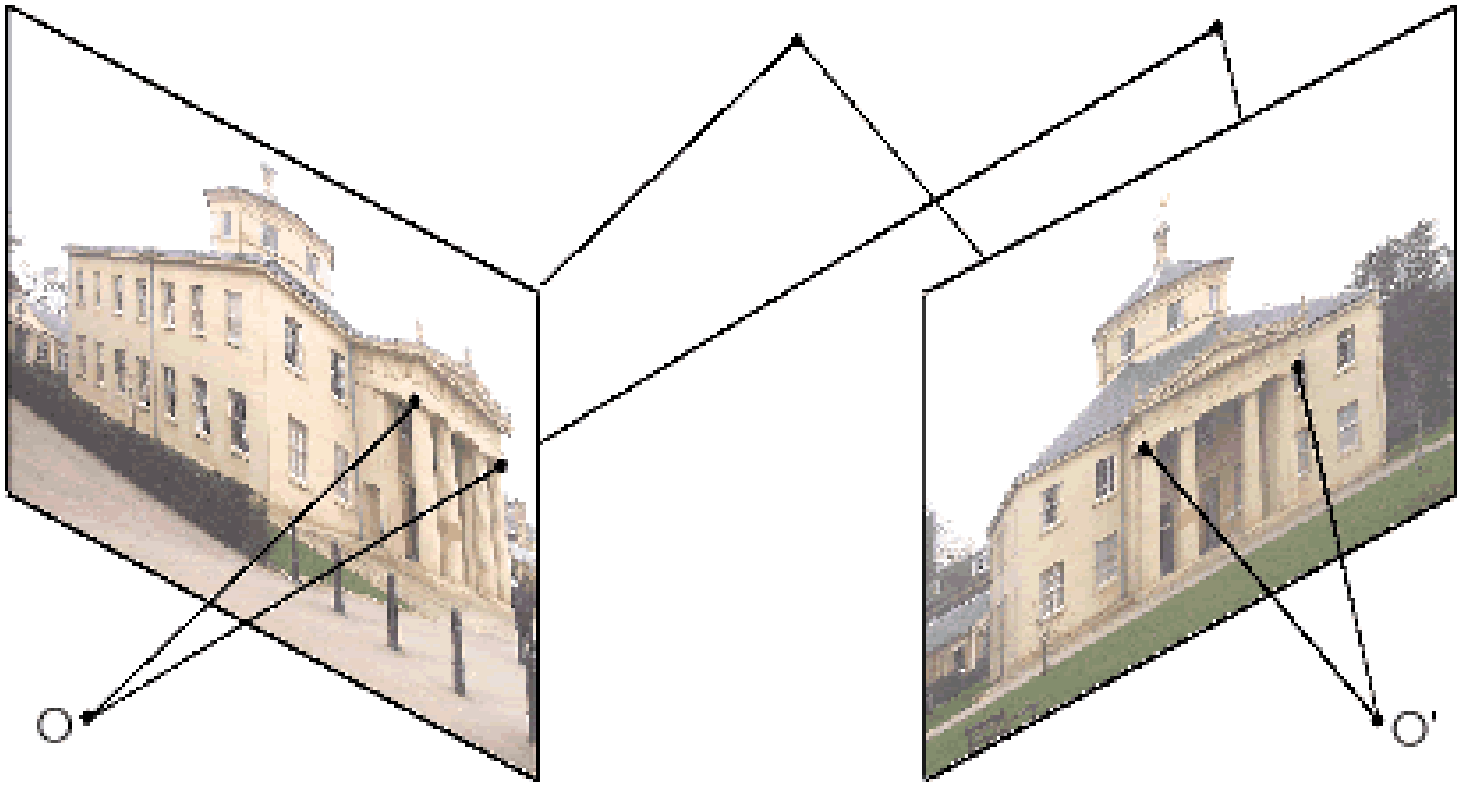
- Input to the algorithm (2):
  User select edges and corners



Outline of a simple algorithm (3)

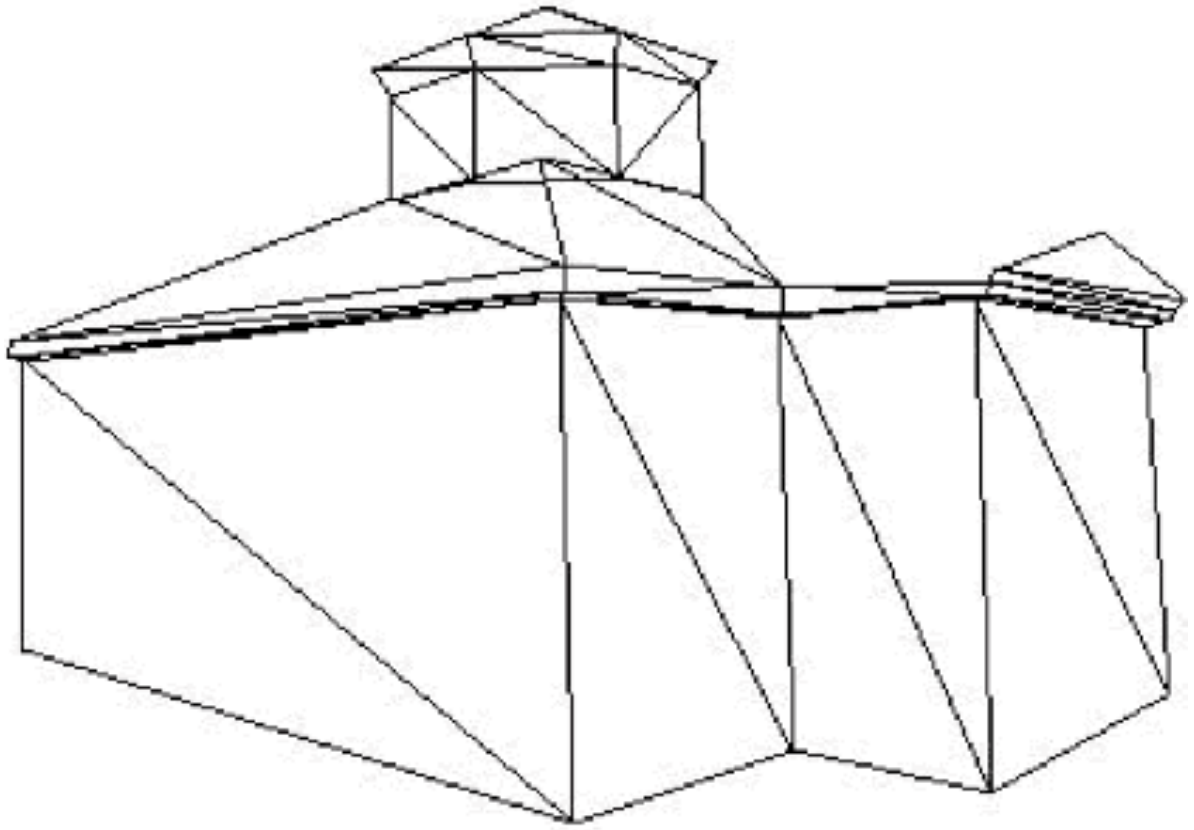
- Camera Position and Orientation

  Determine the position and orientation of camera



Outline of a simple algorithm (4)

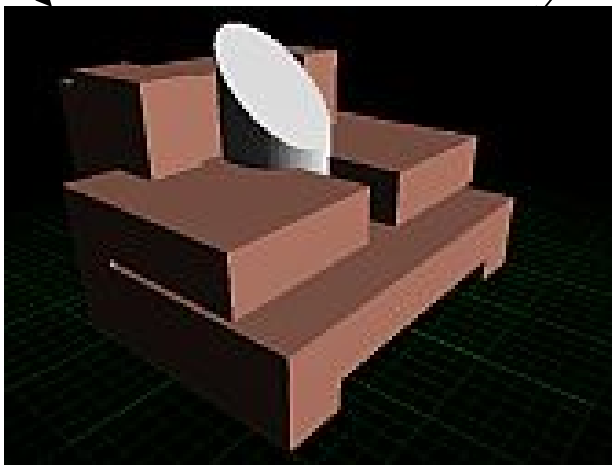
- Computing projection matrix and Reconstruction



Outline of a simple algorithm (5)

- Compute 3D textured triangles

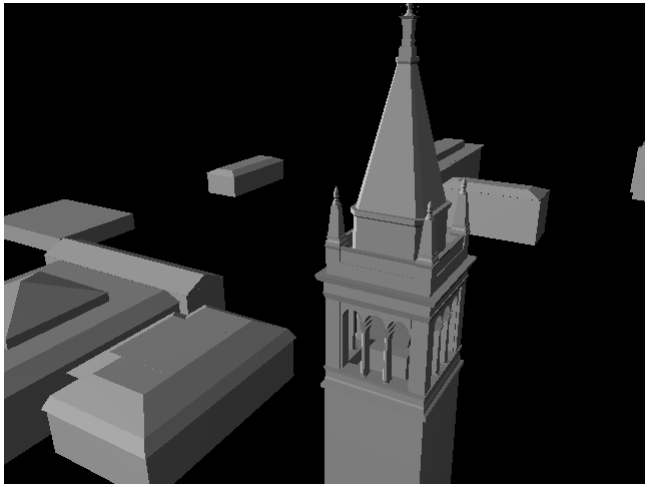
Facade

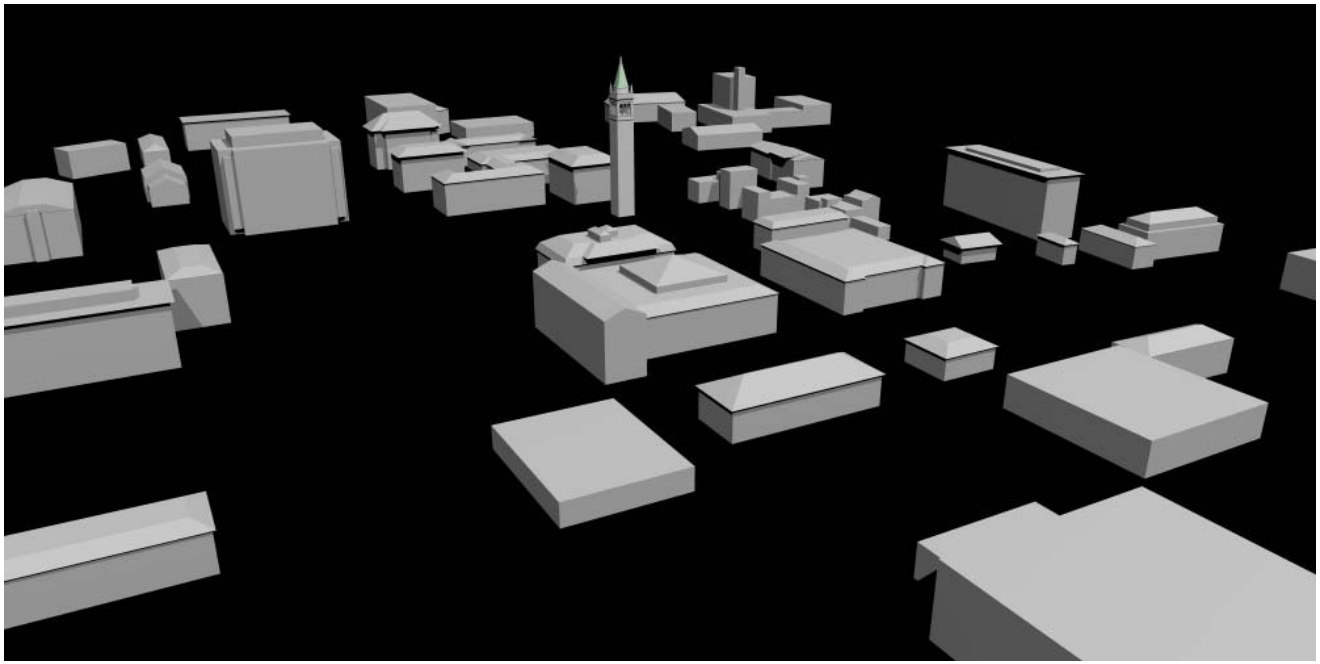


SFMOMA (San Francisco Museum of Modern Art) by Yizhou Yu,

Façade (Debevec et al) inputs

Façade (Debevec et al)





THANK YOU!