Stereo

Many slides adapted from Steve Seitz

Binocular stereo

- Given a calibrated binocular stereo pair, fuse it to produce a depth image

image 1

image 2

Dense depth map

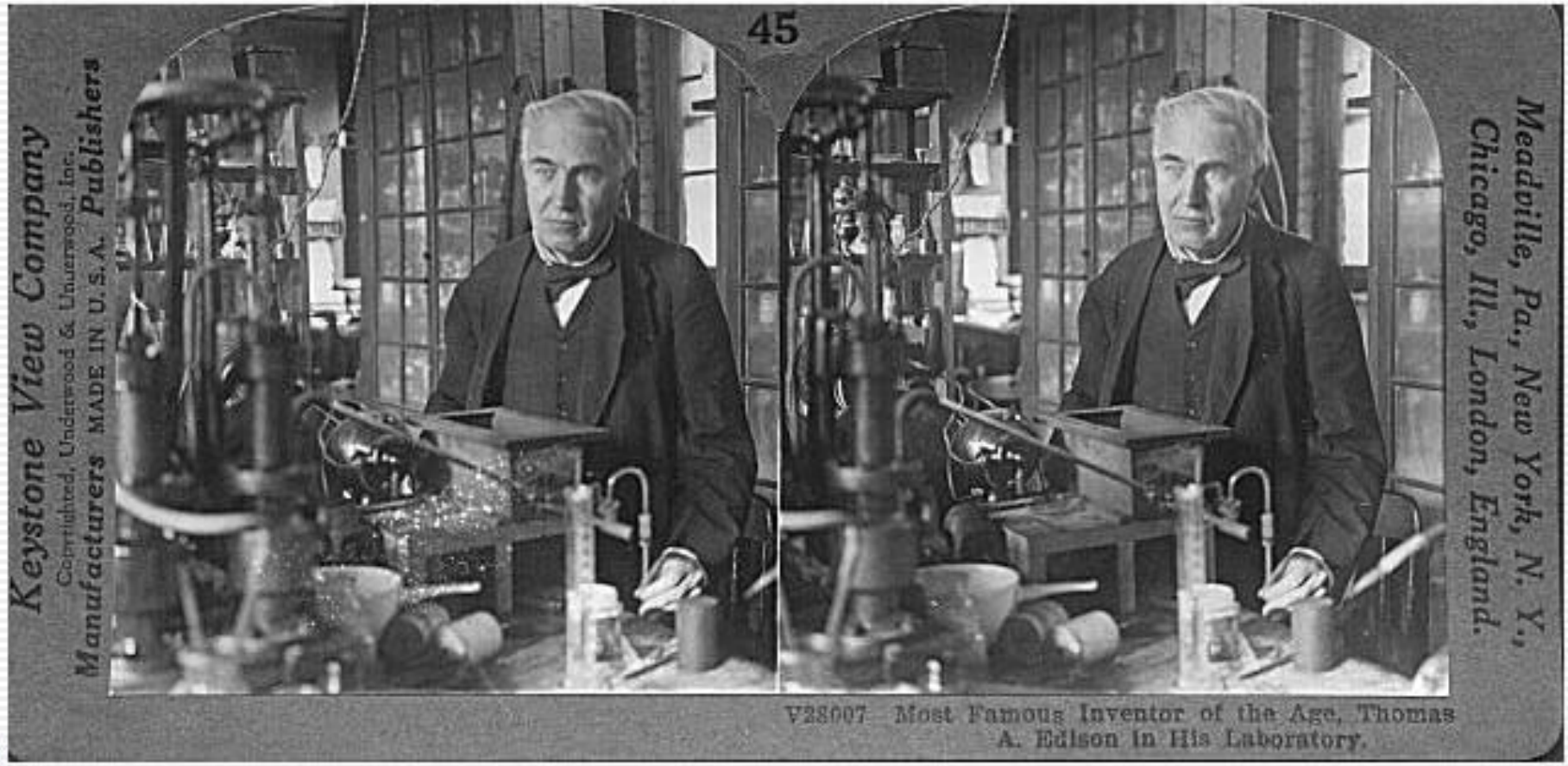
Binocular stereo

- Given a calibrated binocular stereo pair, fuse it to produce a depth image

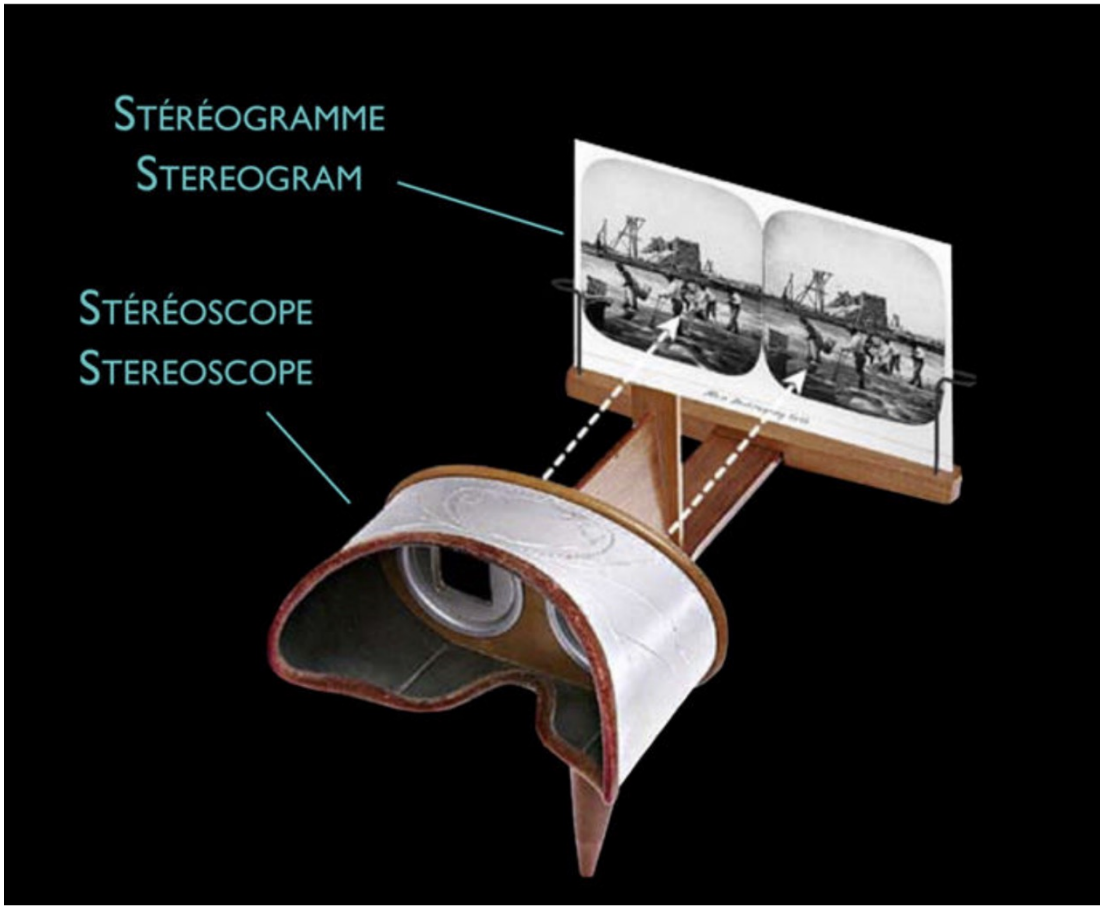
Where does the depth information come from?

Binocular stereo

- Given a calibrated binocular stereo pair, fuse it to produce a depth image
  - Humans can do it



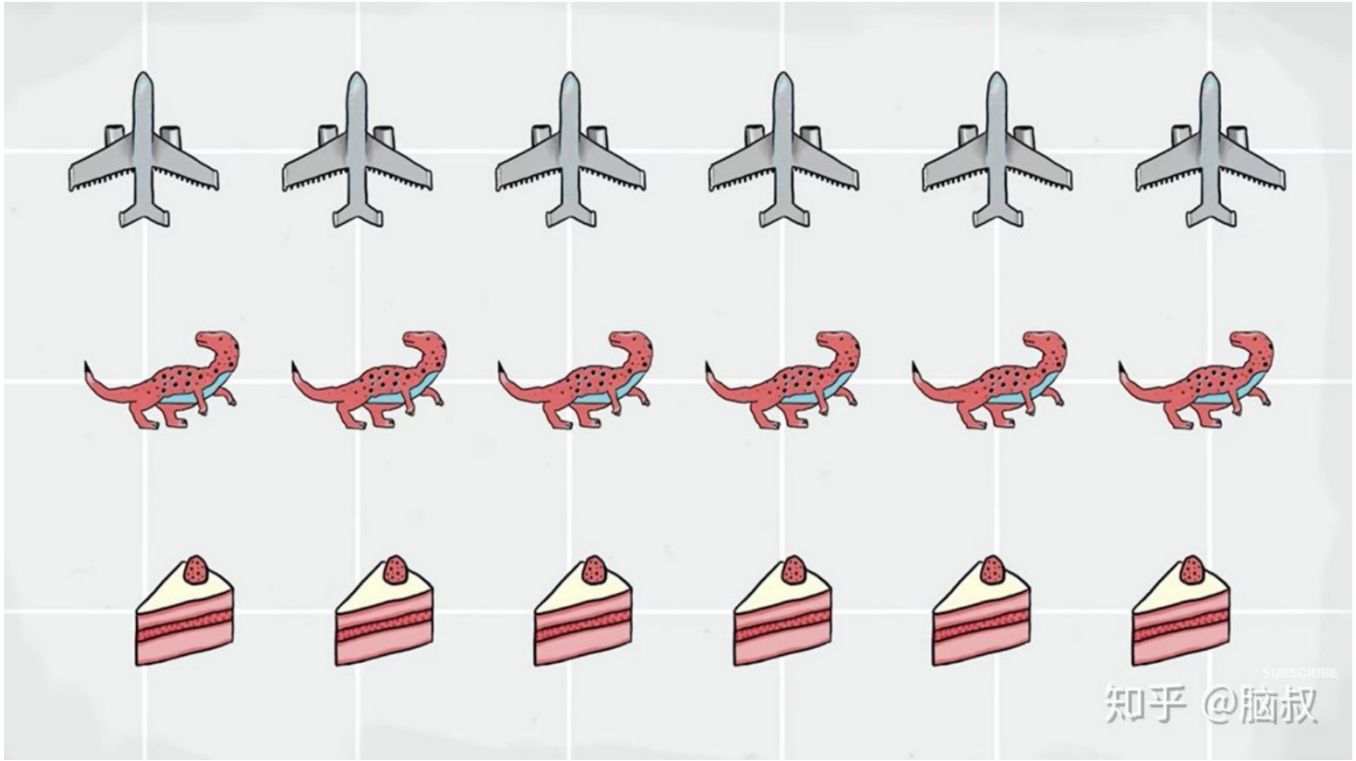
Stereograms: Invented by Sir Charles Wheatstone, 1838


STÉRÉOGRAMME
STEREOGRAM
STÉRÉOSCOPE
STEREOSCOPE

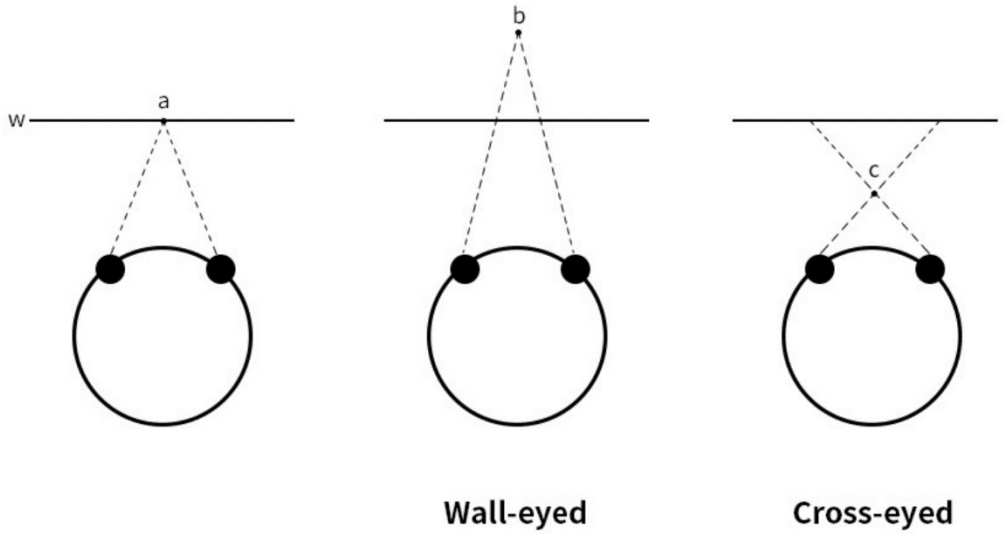

Underwood & Underwood, Publishers
2
Pyramid (N. W.), Egypt.

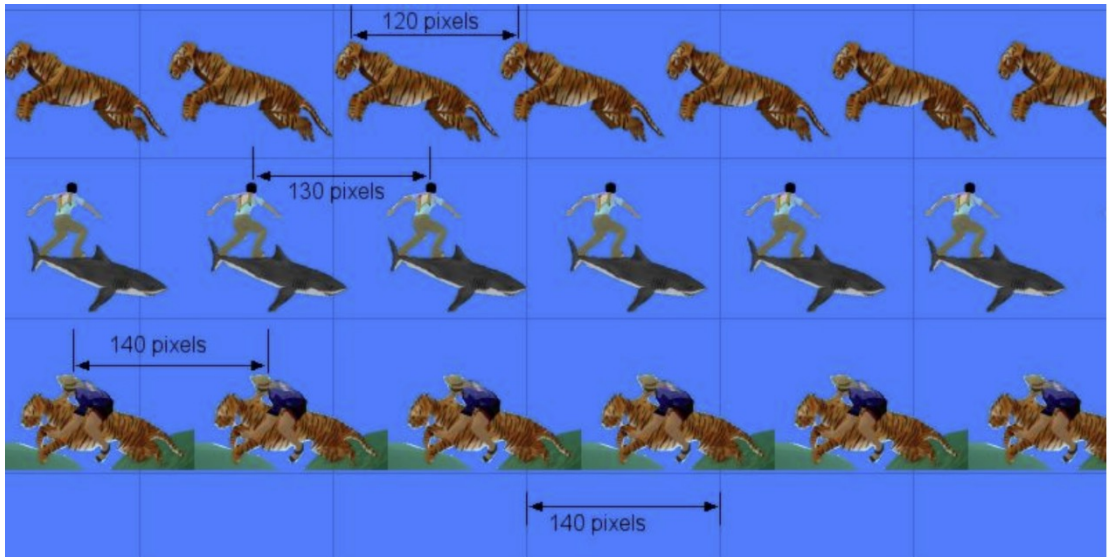
Binocular stereo

- Given a calibrated binocular stereo pair, fuse it to produce a depth image
  - Humans can do it

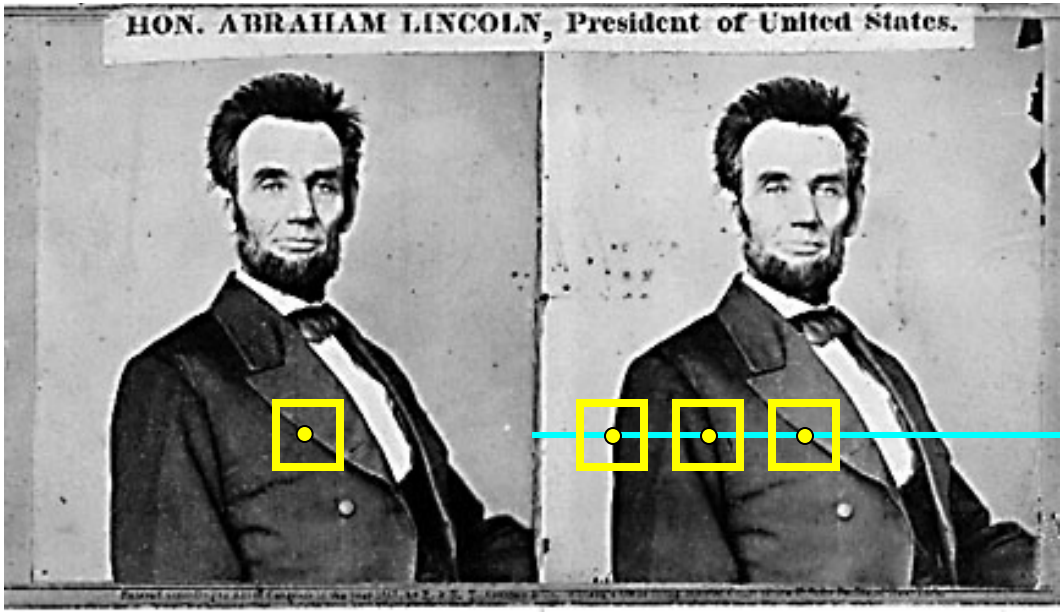


Autostereograms: www.magiceye.com


w
a
b
c
Wall-eyed
Cross-eyed


120 pixels
130 pixels
140 pixels
140 pixels

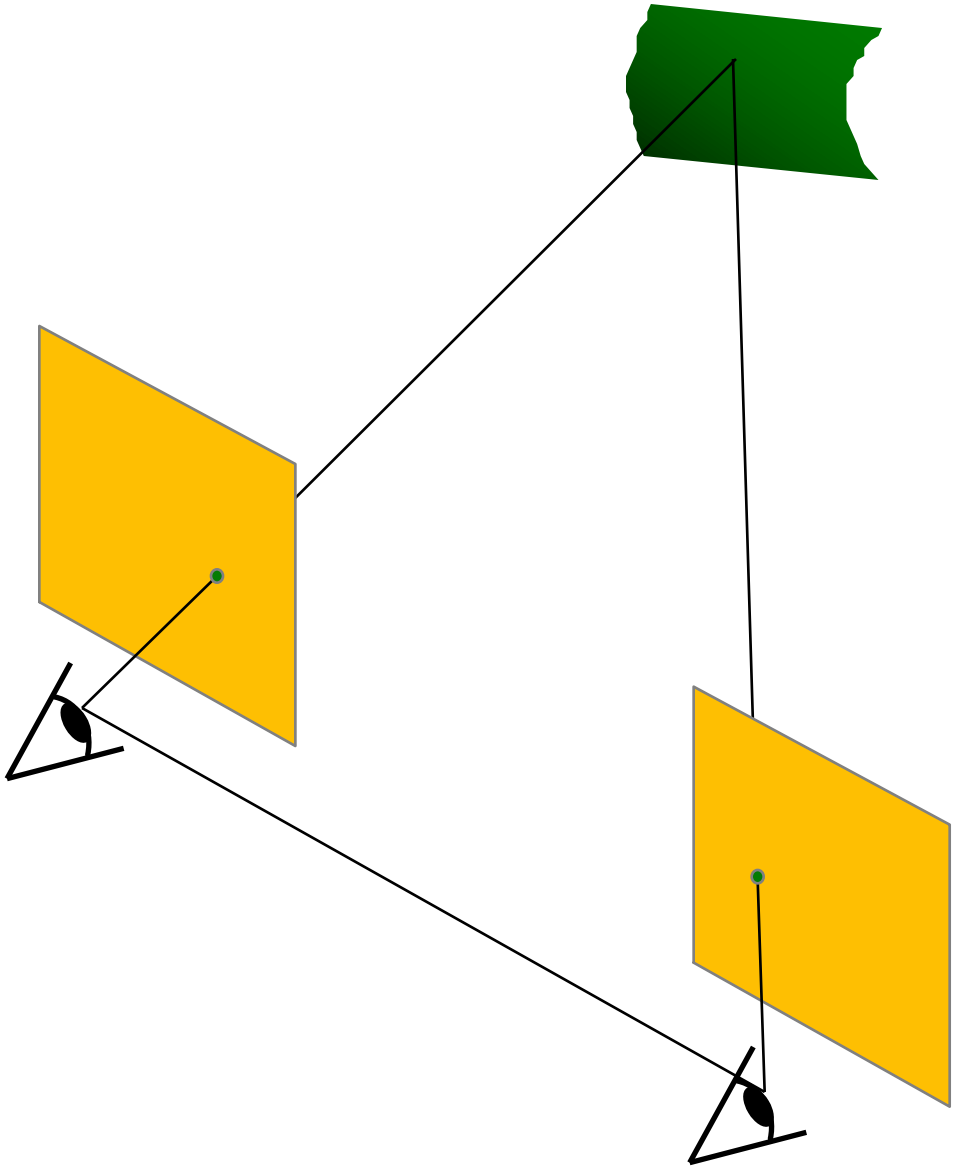
Basic stereo matching algorithm



- For each pixel in the first image
  - Find corresponding epipolar line in the right image
  - Examine all pixels on the epipolar line and pick the best match
  - Triangulate the matches to get depth information

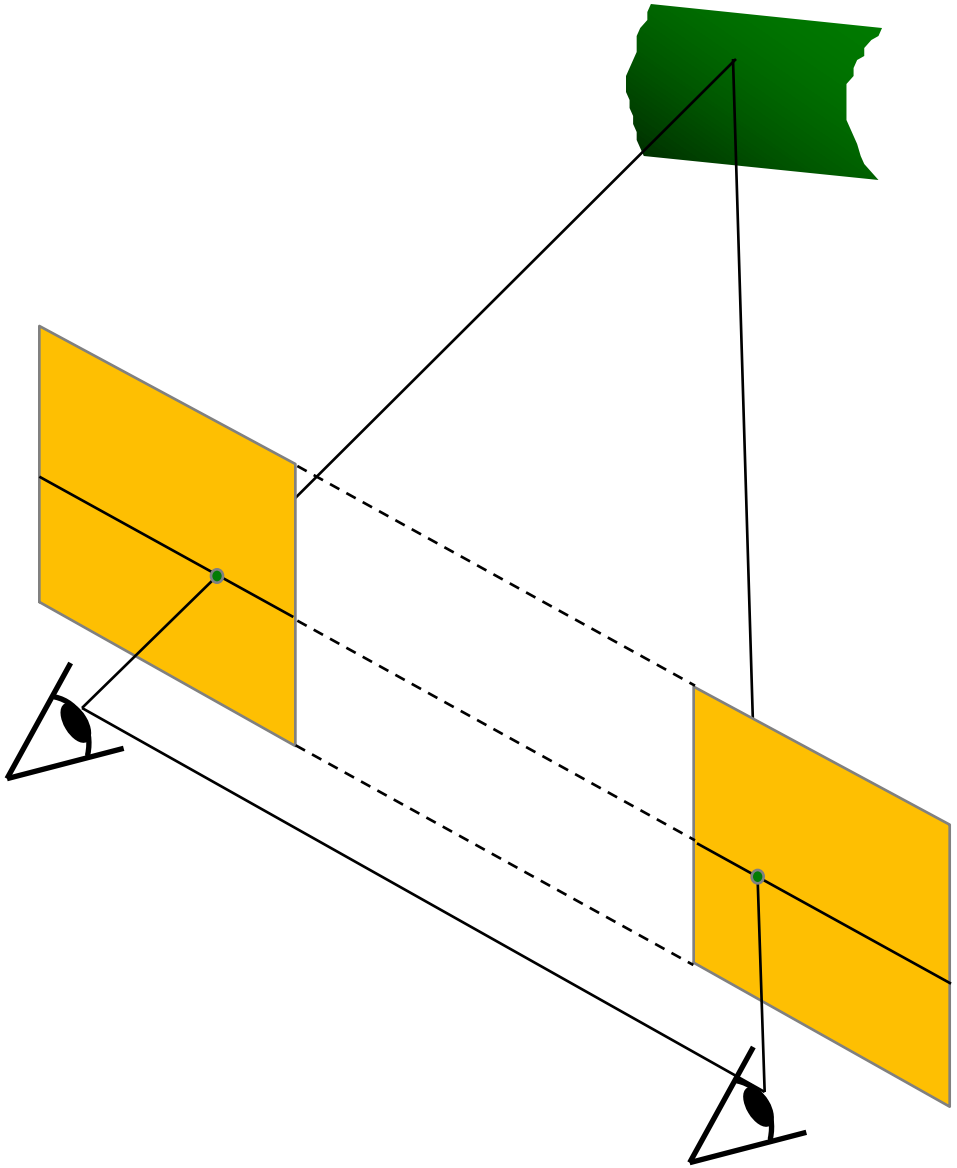
- Simplest case: epipolar lines are corresponding scanlines
  - When does this happen?

Simplest Case: Parallel images



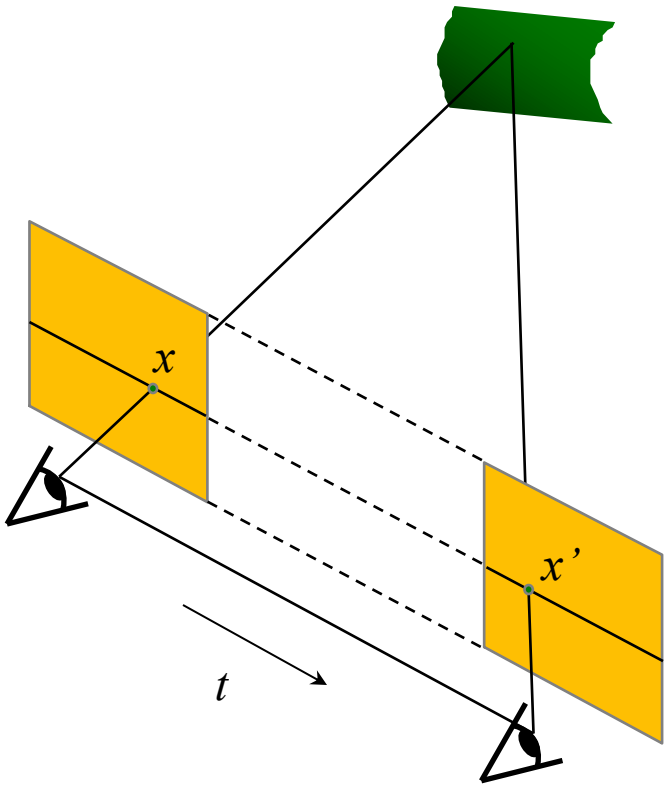
- Image planes of cameras are parallel to each other and to the baseline
- Camera centers are at same height
- Focal lengths are the same

Simplest Case: Parallel images



- Image planes of cameras are parallel to each other and to the baseline
- Camera centers are at same height
- Focal lengths are the same
- Then epipolar lines fall along the horizontal scan lines of the images

Essential matrix for parallel images



Epipolar constraint:

$$\boldsymbol{x}'^{T}\boldsymbol{E}\boldsymbol{x}=0, \quad \boldsymbol{E}=[\boldsymbol{t}_{\times}]\boldsymbol{R}$$

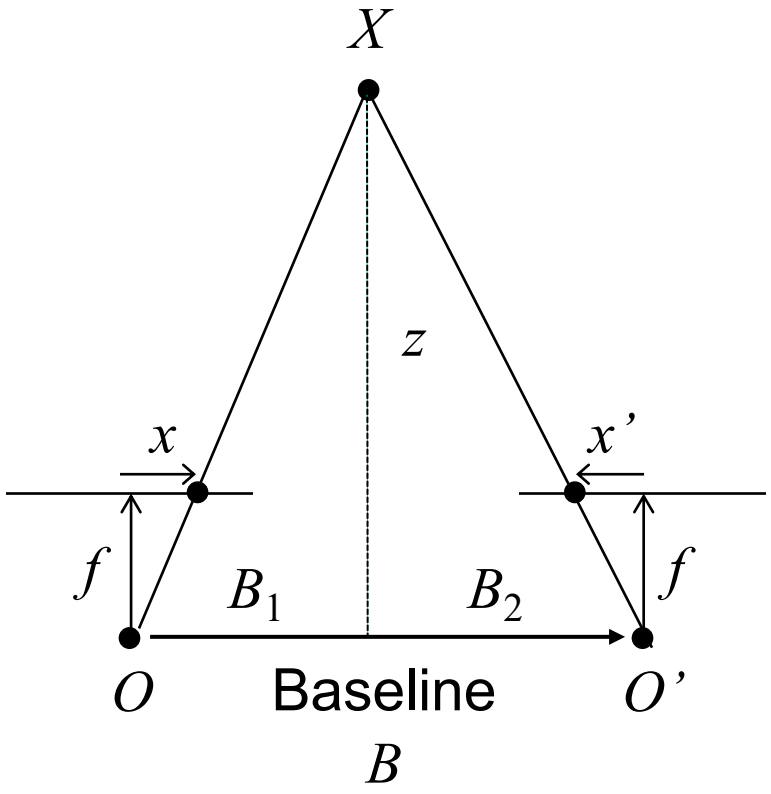
$$\boldsymbol{R}=\boldsymbol{I} \qquad \boldsymbol{t}=(T,0,0)$$

$$\boldsymbol{E}=[\boldsymbol{t}_{\times}]\boldsymbol{R}=\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & -T\\ 0 & T & 0\end{bmatrix}$$

$$\begin{pmatrix}u' & v' & 1\end{pmatrix}\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & -T\\ 0 & T & 0\end{bmatrix}\begin{pmatrix}u\\ v\\ 1\end{pmatrix}=0 \qquad \begin{pmatrix}u' & v' & 1\end{pmatrix}\begin{pmatrix}0\\ -T\\ Tv\end{pmatrix}=0 \qquad Tv'=Tv$$

The y-coordinates of corresponding points are the same!

Depth from disparity



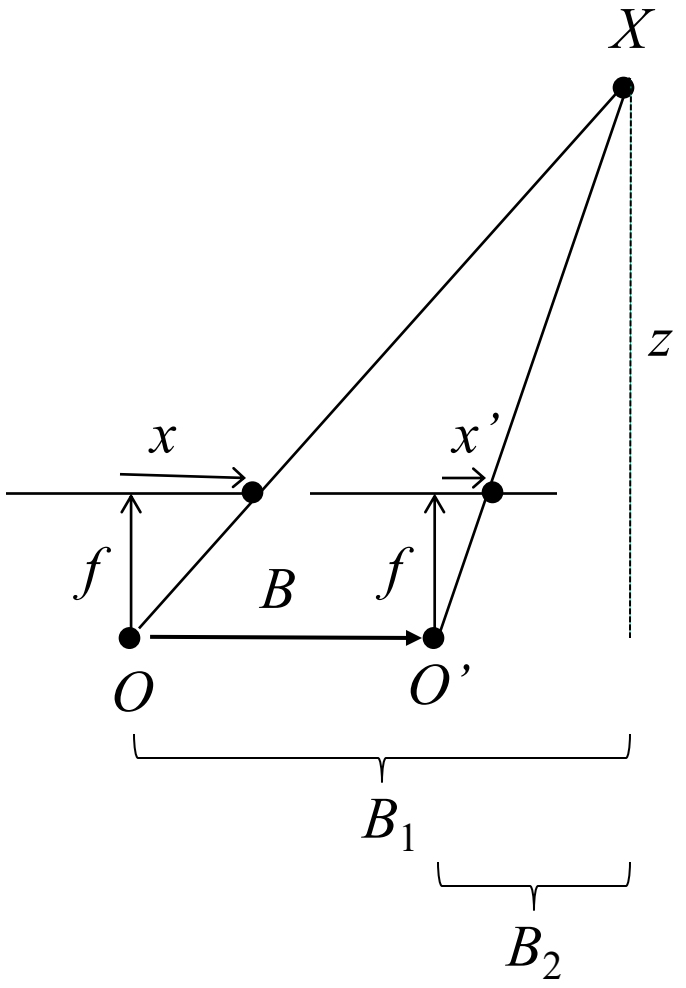
$$\frac{x}{f} = \frac{B_1}{z} \qquad \frac{-x'}{f} = \frac{B_2}{z}$$

$$\frac{x - x'}{f} = \frac{B_1 + B_2}{z}$$

$$disparity = x - x' = \frac{B \cdot f}{z}$$

Disparity is inversely proportional to depth!

Depth from disparity

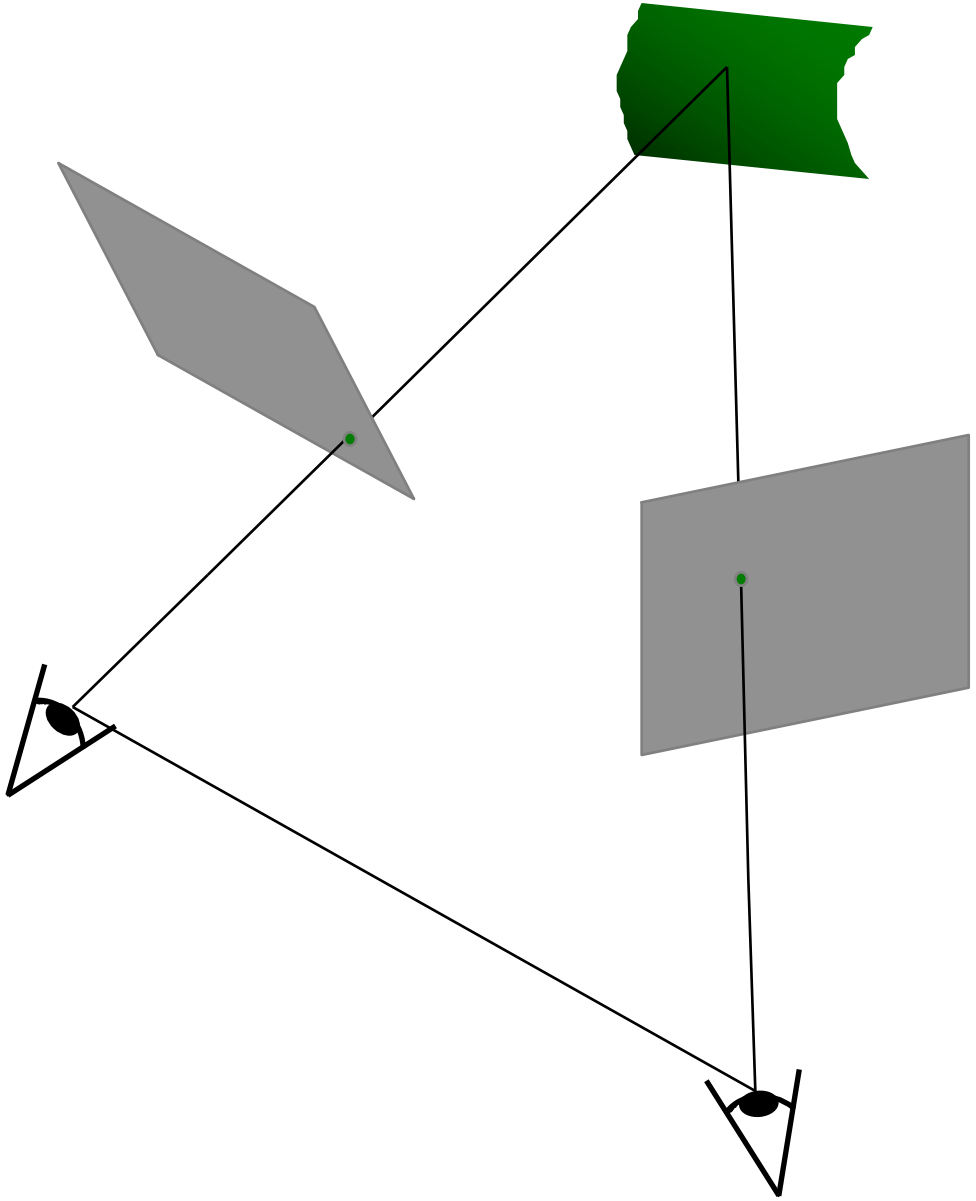


$$\frac{x}{f} = \frac{B_1}{z} \qquad \frac{x'}{f} = \frac{B_2}{z}$$

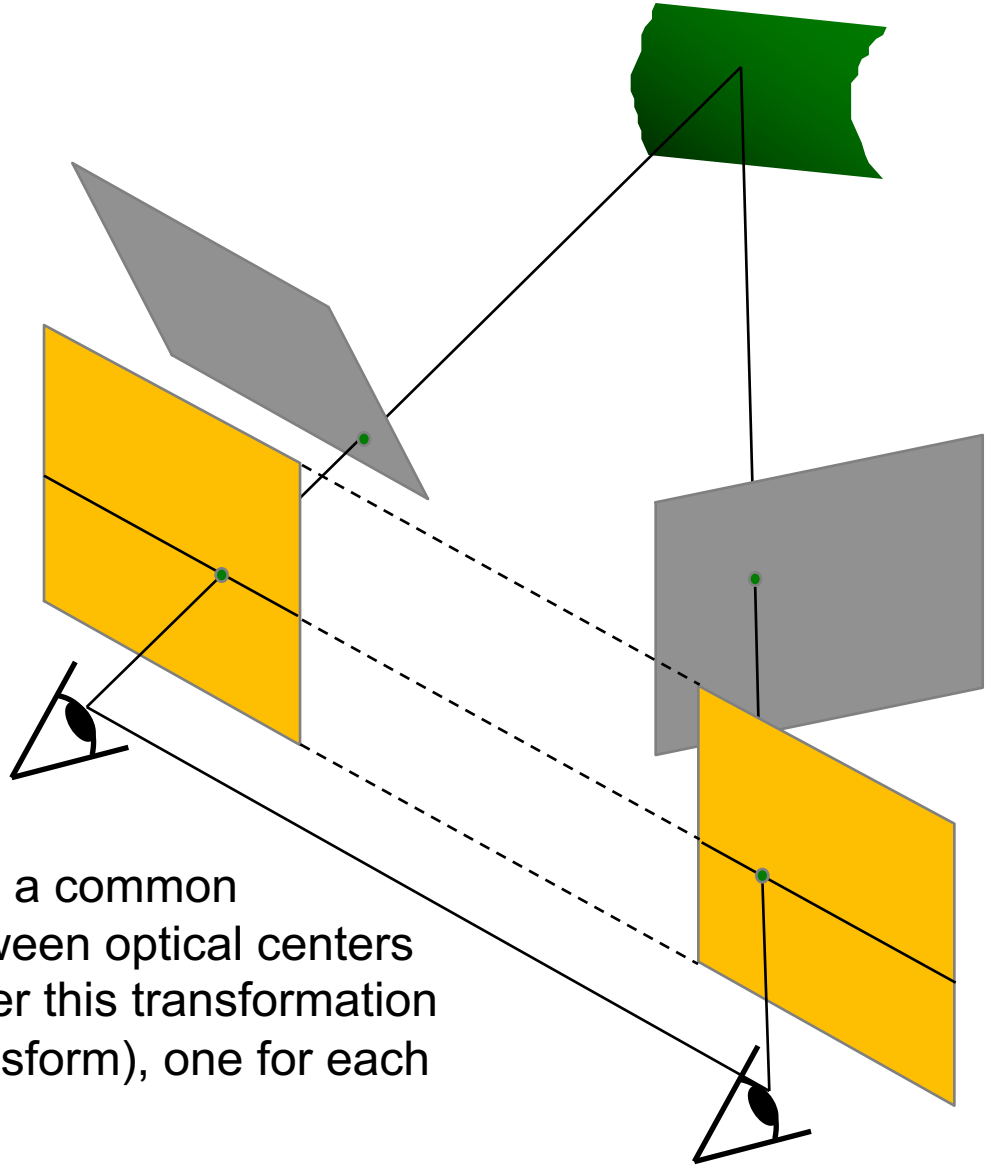
$$\frac{x - x'}{f} = \frac{B_1 - B_2}{z}$$

$$disparity = x - x' = \frac{B \cdot f}{z}$$

Stereo image rectification



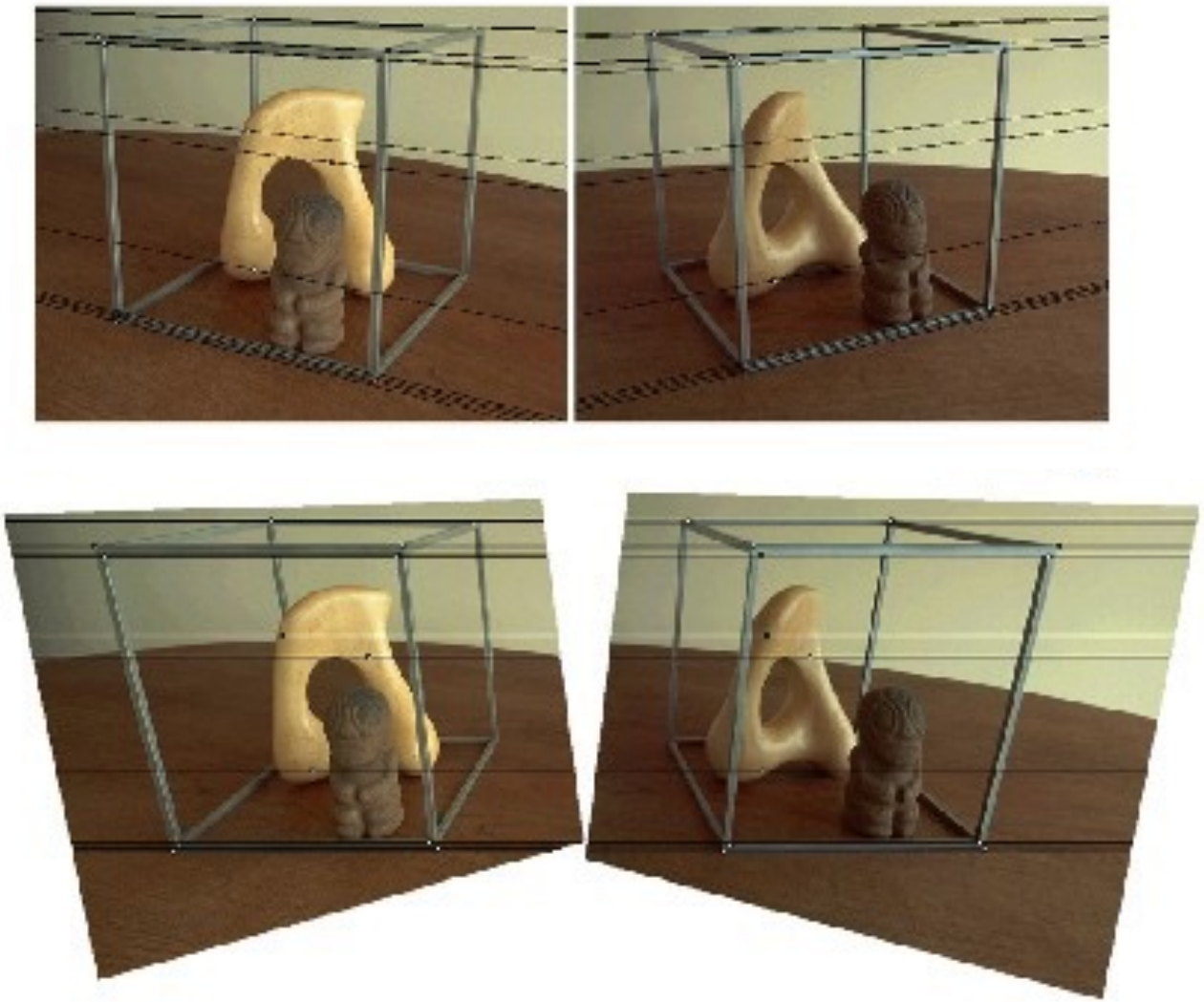
Stereo image rectification



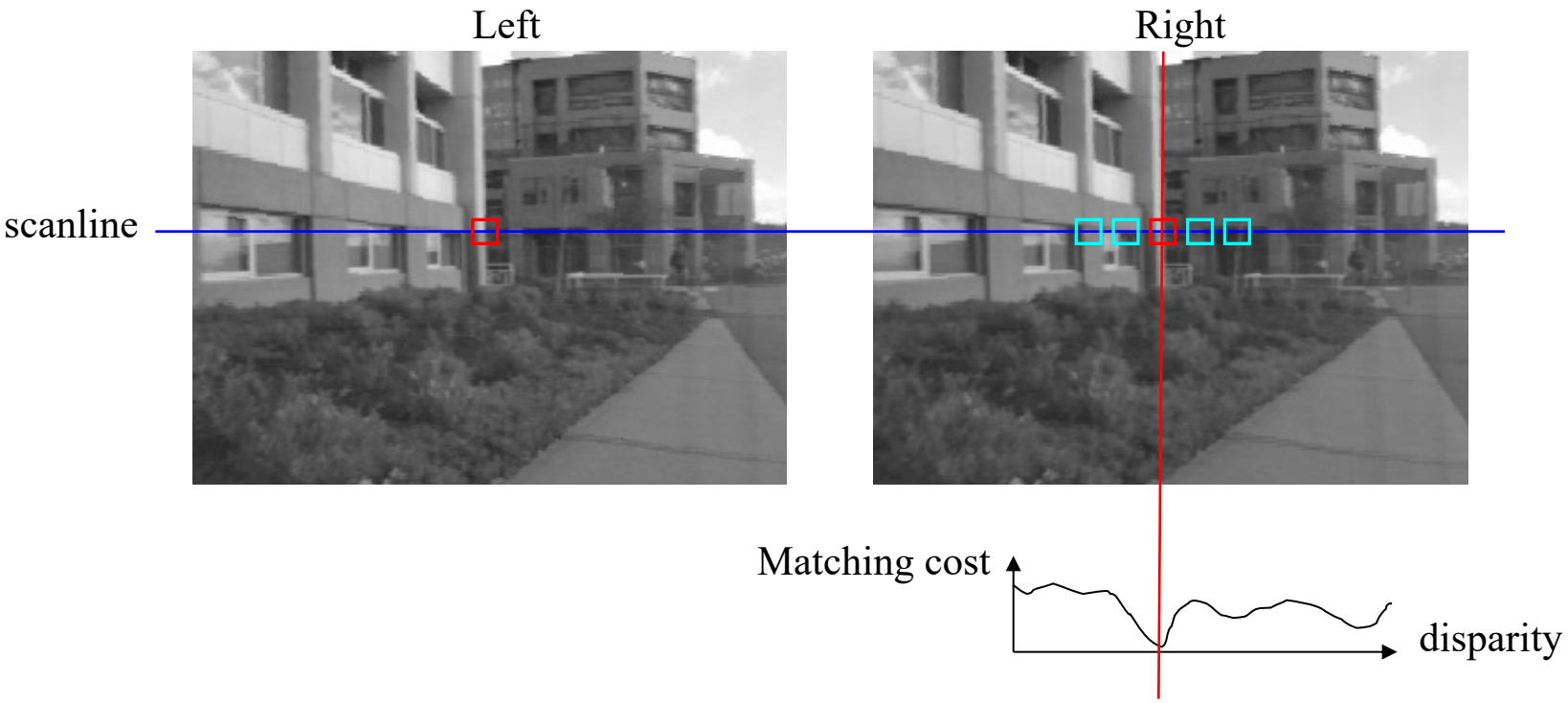
- Reproject image planes onto a common plane parallel to the line between optical centers
- Pixel motion is horizontal after this transformation
- Two homographies (3x3 transform), one for each input image reprojection

C. Loop and Z. Zhang. Computing Rectifying Homographies for Stereo Vision. IEEE Conf. Computer Vision and Pattern Recognition, 1999.

Rectification example

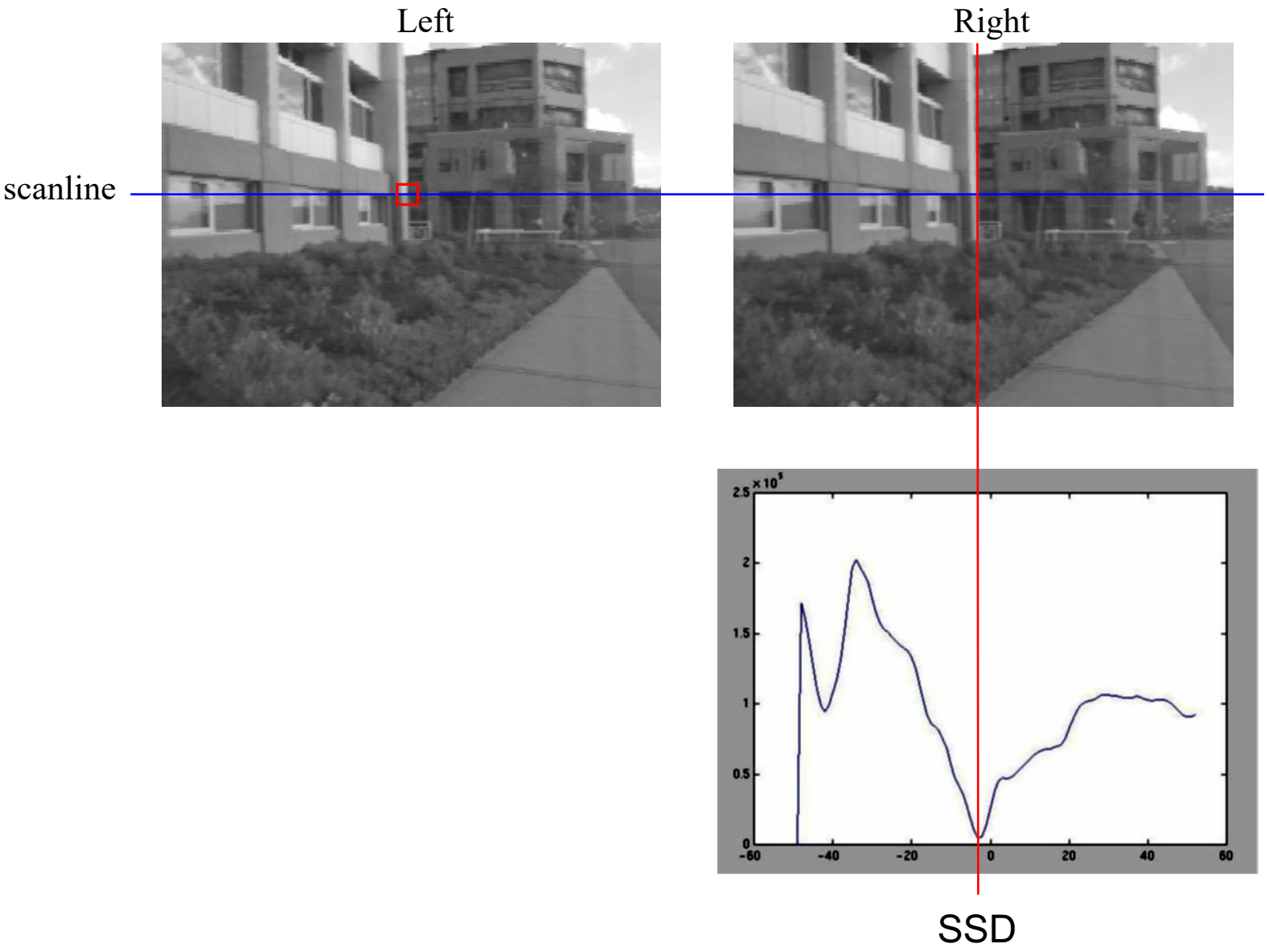


Correspondence search

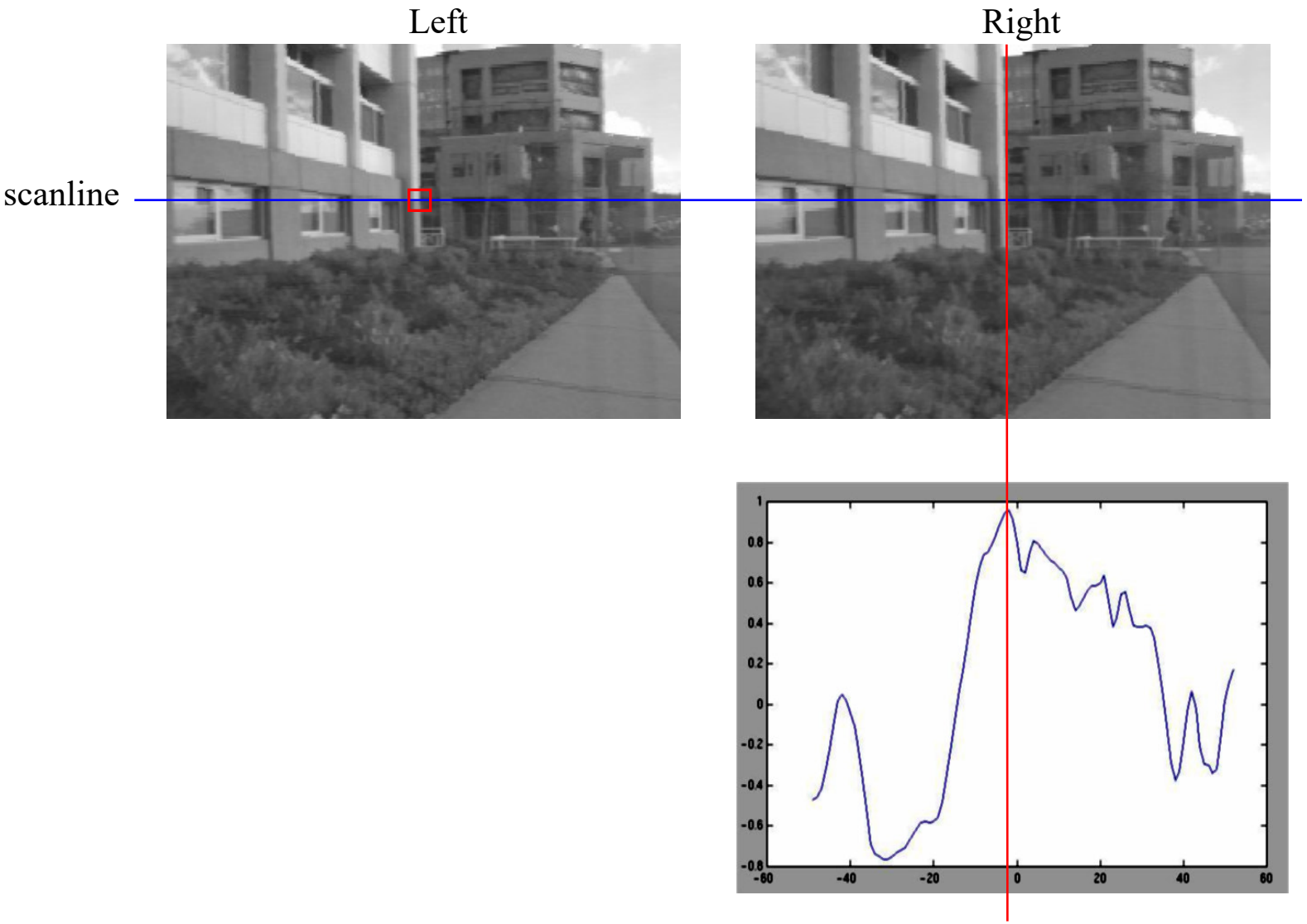


- Slide a window along the right scanline and compare contents of that window with the reference window in the left image
- Matching cost: SSD or normalized correlation

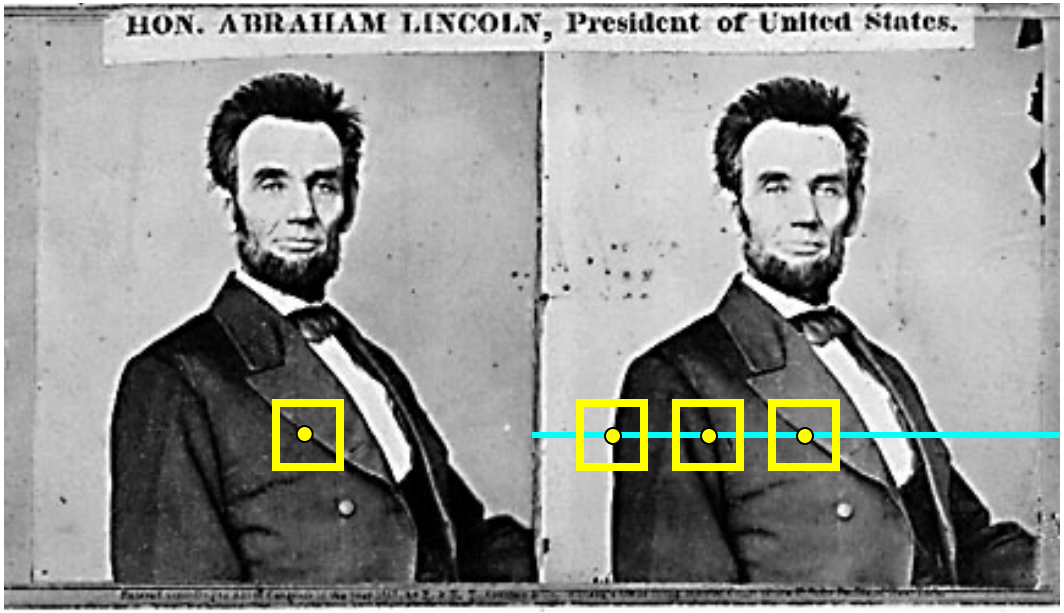
Correspondence search



Correspondence search

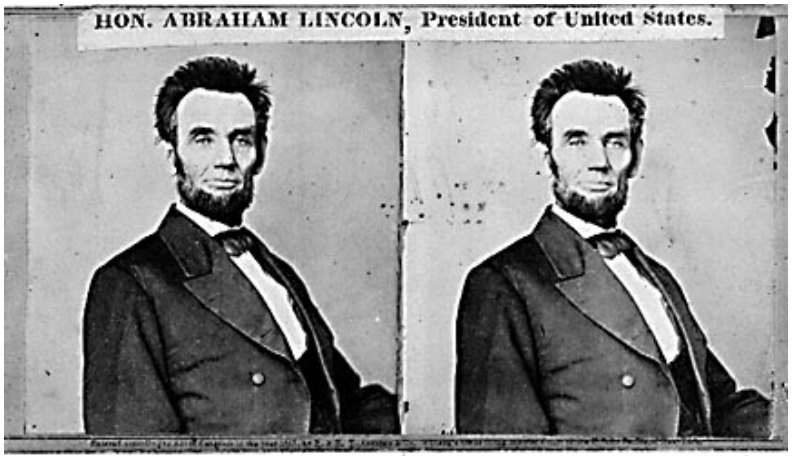


Basic stereo matching algorithm



- If necessary, rectify the two stereo images to transform epipolar lines into scanlines
- For each pixel *x* in the first image
  - Find corresponding epipolar scanline in the right image
  - Examine all pixels on the scanline and pick the best match *x'*
  - Compute disparity *x–x'* and set depth(*x*) = *B*f*/(*x–x'*)

Failures of correspondence search



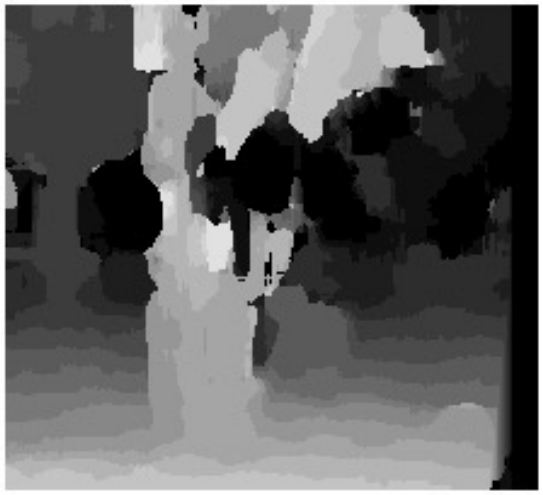
Textureless surfaces

Occlusions, repetition

Non-Lambertian surfaces, specularities

Effect of window size

W = 3



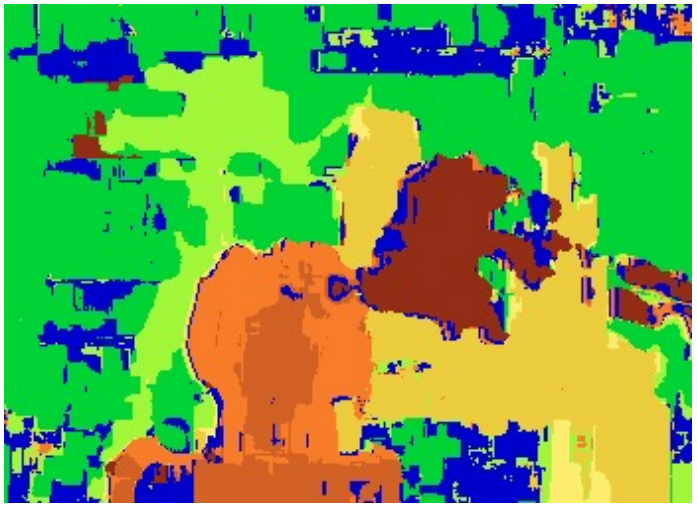
W = 20

- Smaller window
  - \+ More detail
  - – More noise
- Larger window
  - \+ Smoother disparity maps
  - – Less detail

Results with window search

Data

Window-based matching



Ground truth

Better methods exist...

Graph cuts

Ground truth

Y. Boykov, O. Veksler, and R. Zabih, Fast Approximate Energy Minimization via Graph Cuts, PAMI 2001

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