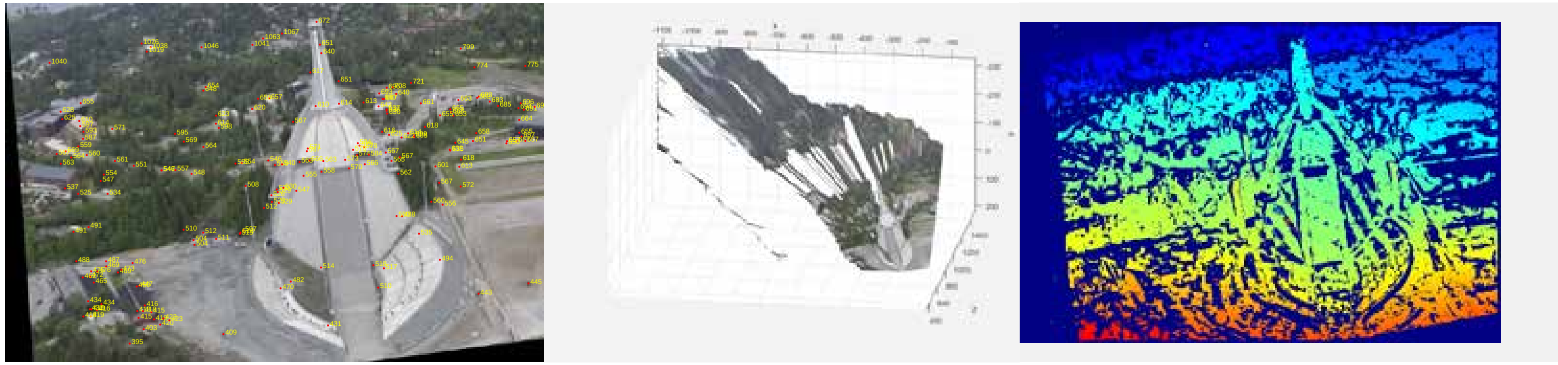
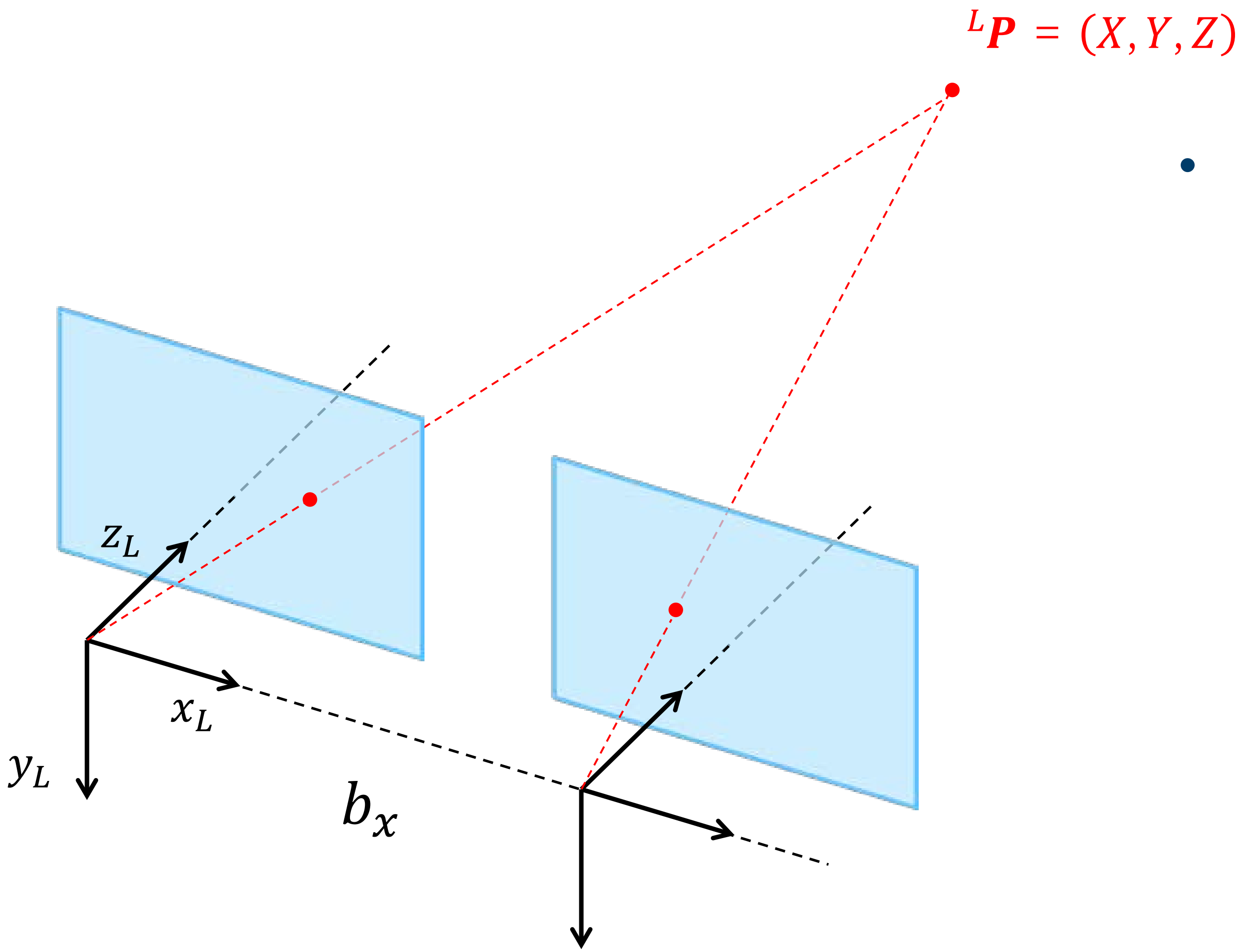


Lecture 6.3
Stereo processing

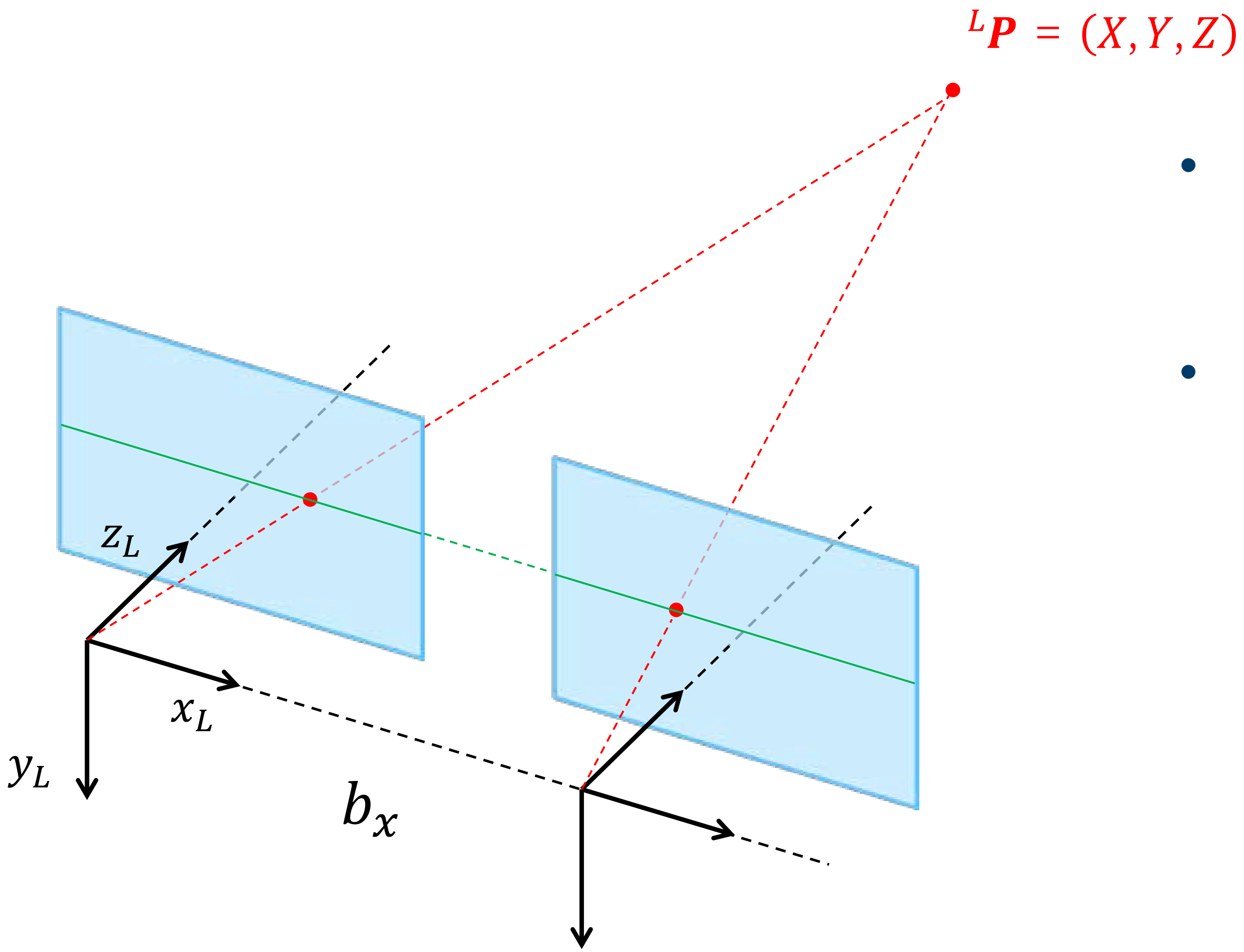
Trym Vegard Haavardsholm

Stereo geometry



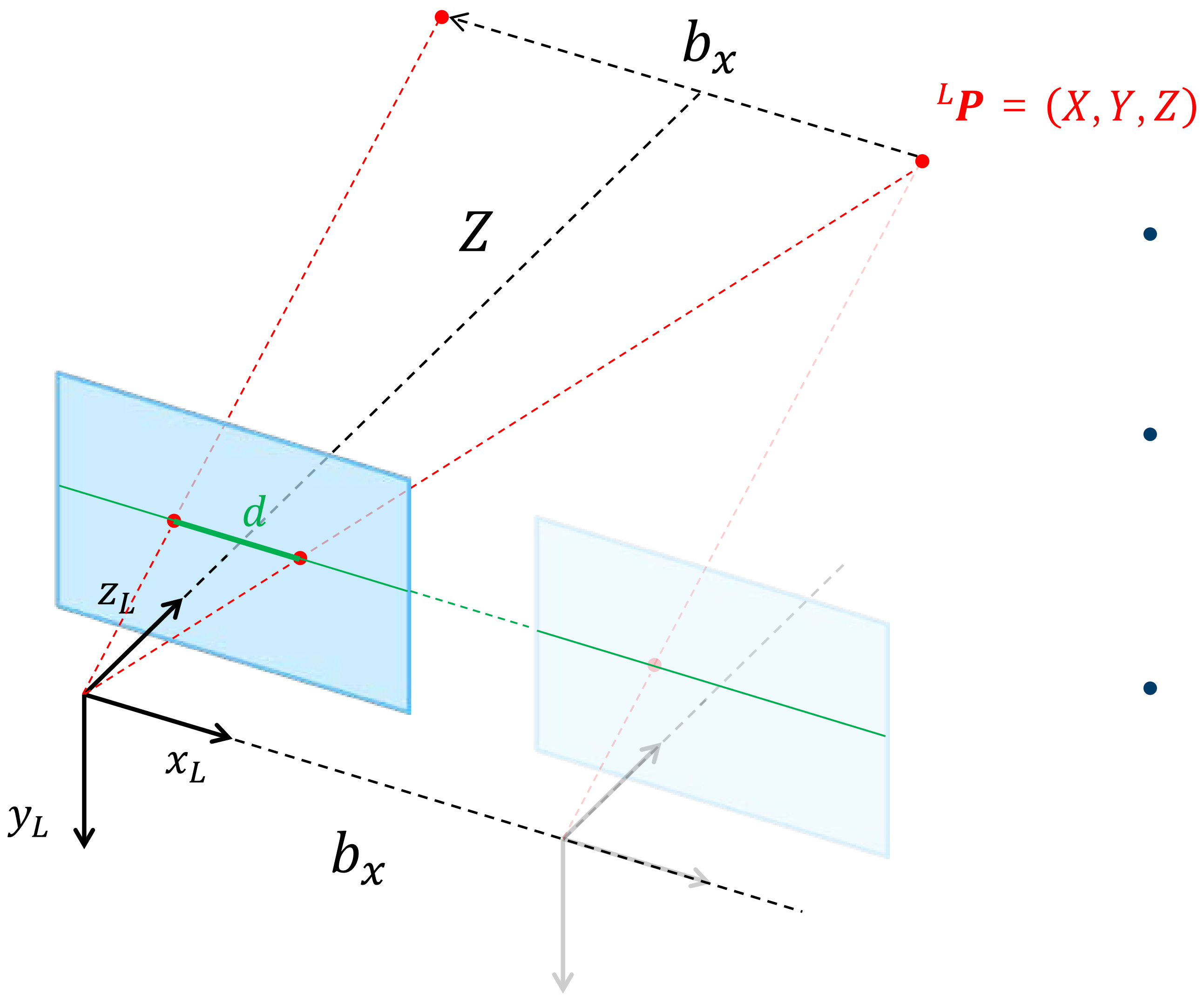
- Parallel identical cameras
  - Translated along *x*-axis

Stereo geometry

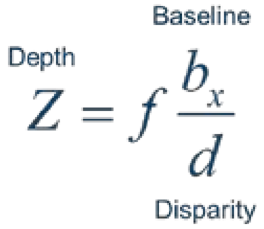


- Parallel identical cameras
  - Translated along *x*-axis
- Horizontal epipolar lines
  - Corresponding points lie along the same row in the two images

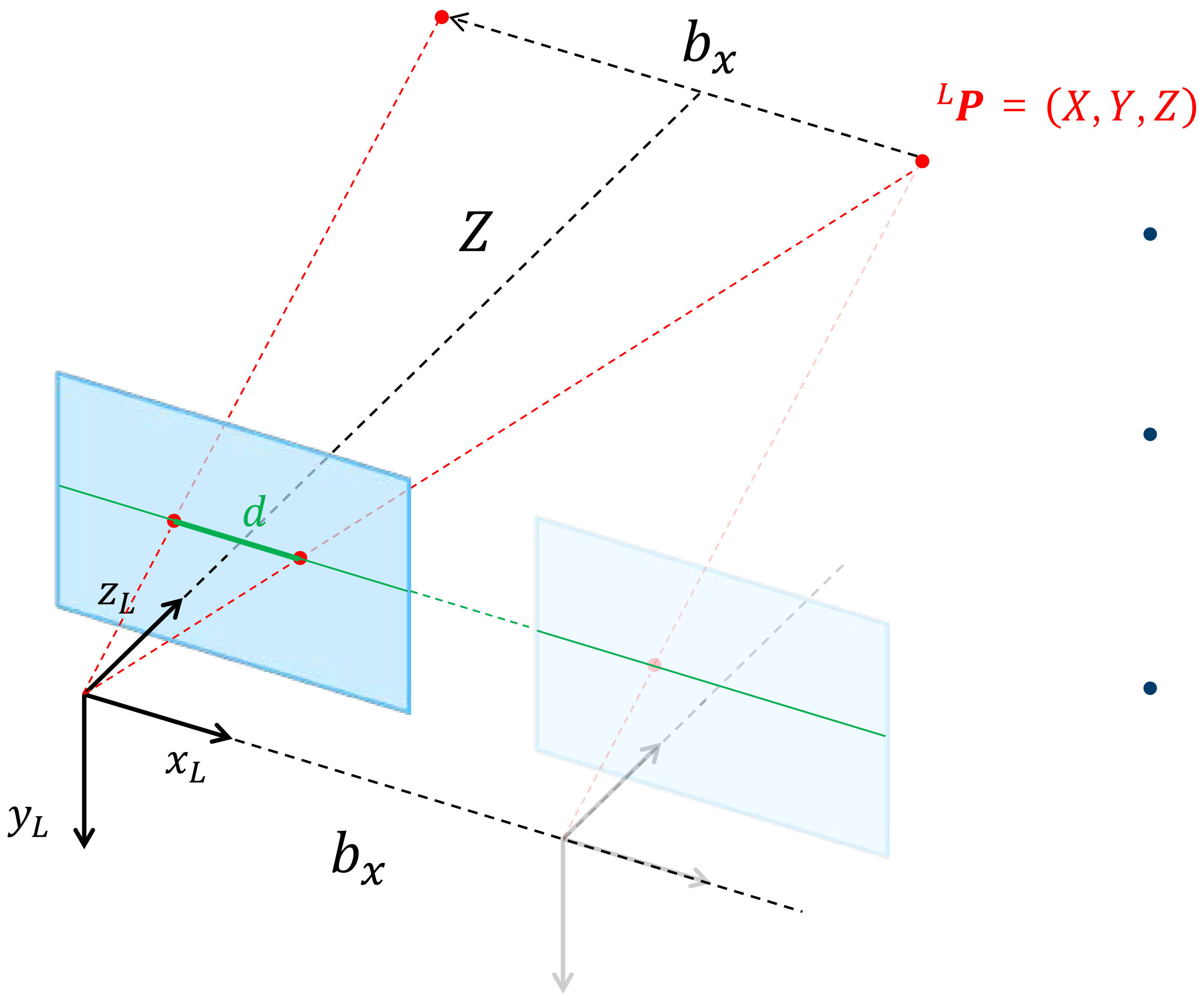
Stereo geometry



- Parallel identical cameras
  - Translated along *x*-axis
- Horizontal epipolar lines
  - Corresponding points lie along the same row in the two images
- Depth from disparity



Stereo geometry



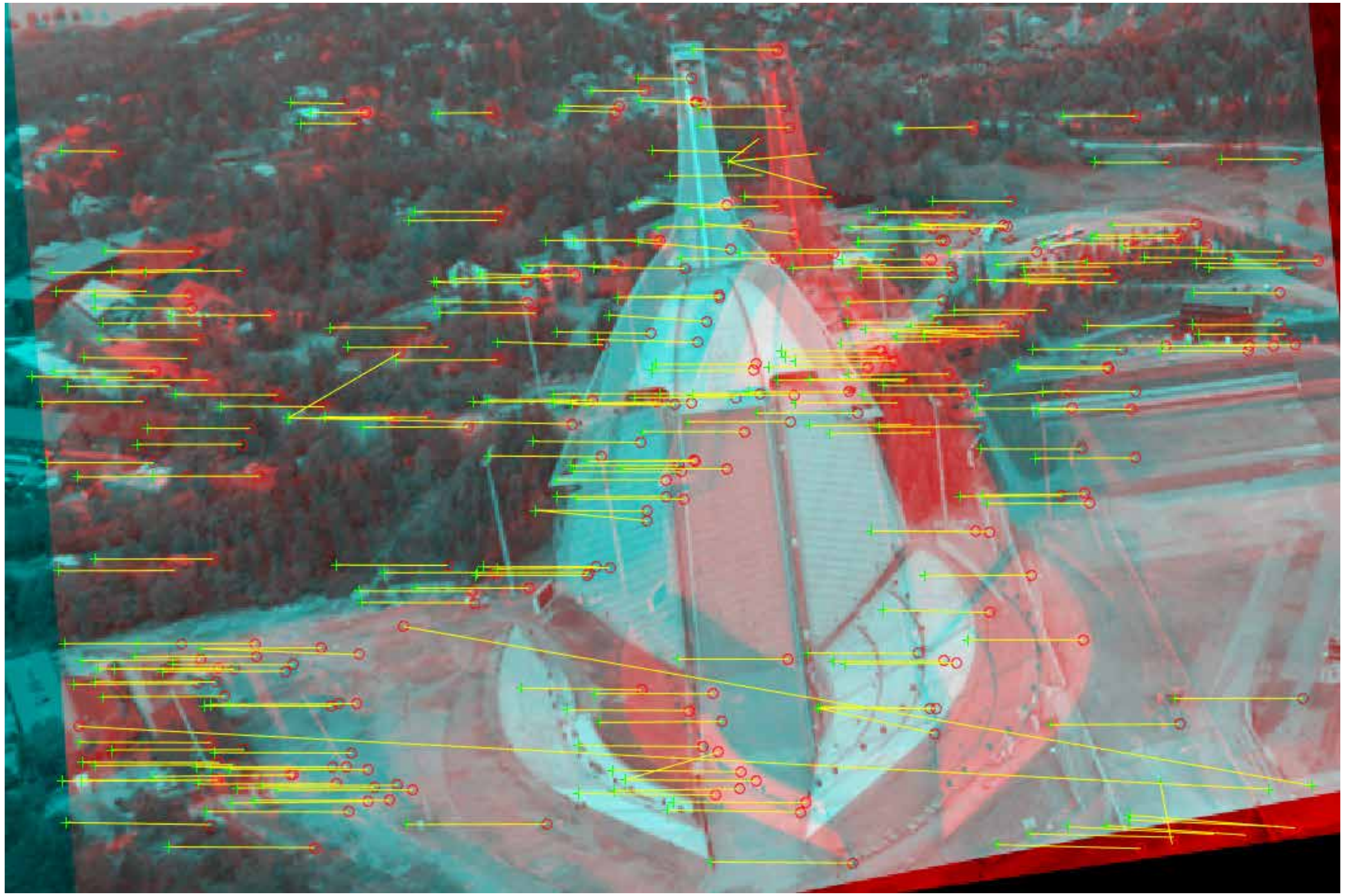
- Parallel identical cameras
  - Translated along *x*-axis
- Horizontal epipolar lines
  - Corresponding points lie along the same row in the two images
- 3D from disparity

Baseline
Depth
$$Z = f\frac{b_x}{d} \qquad X = x_L\frac{b_x}{d} \qquad Y = y_L\frac{b_x}{d}$$
Disparity

Stereo processing

- Sparse stereo
  - Extract keypoints
  - Match keypoints along the same row
  - Compute 3D from disparity

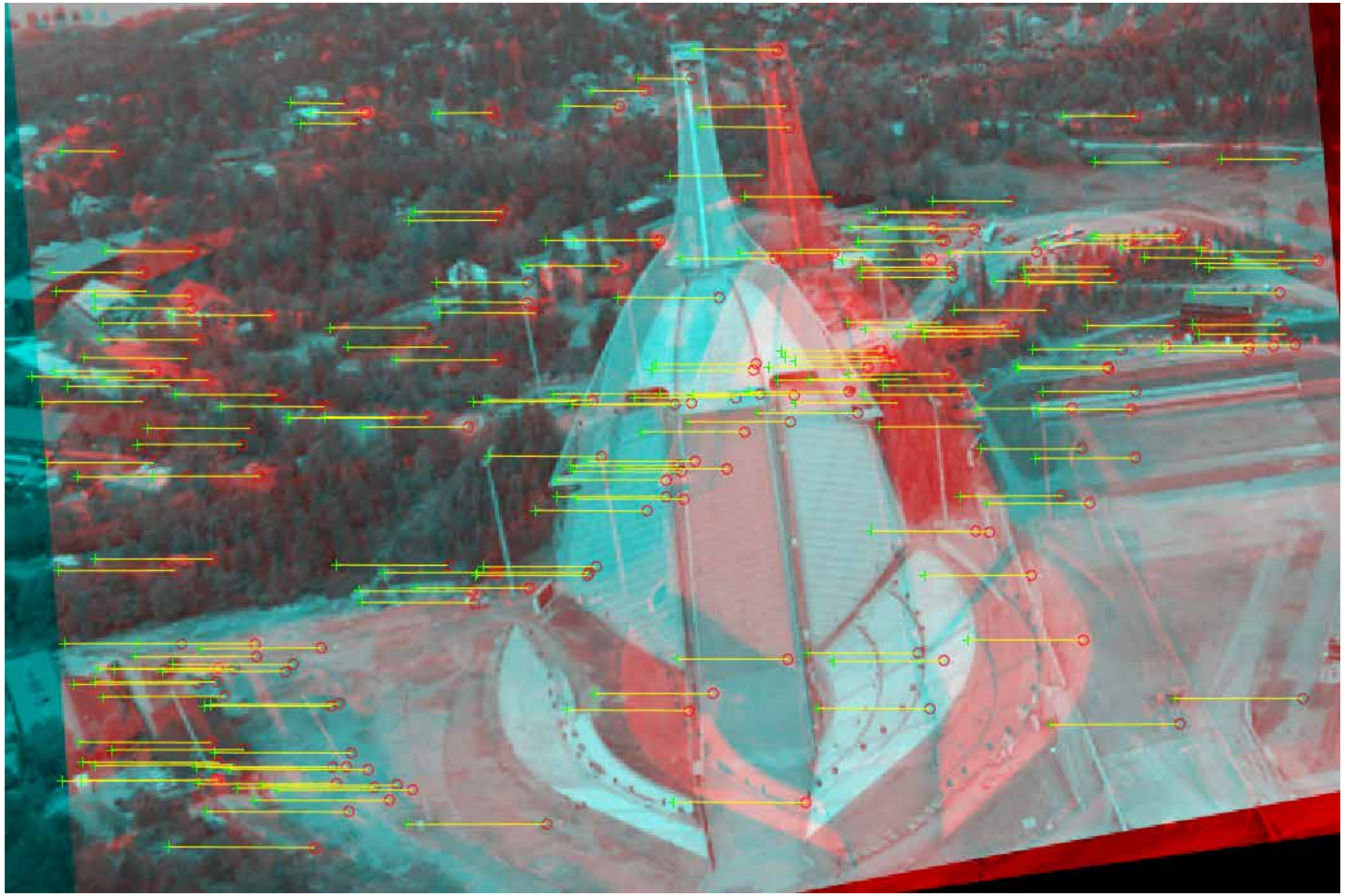
Sparse stereo matching



Example

- Putative matches

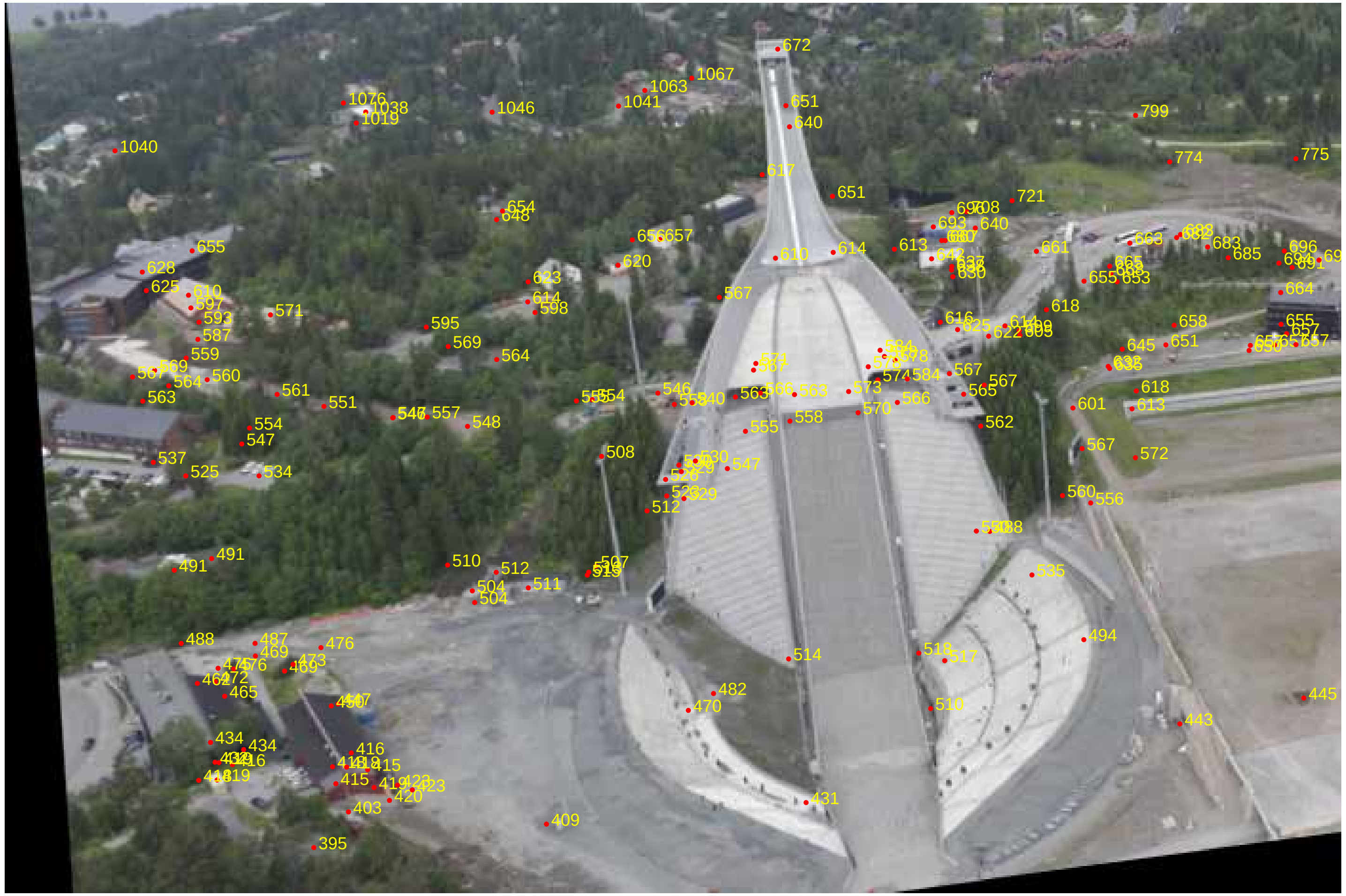
Sparse stereo matching



Example

- Matches consistent with epipolar line
- Length of yellow lines corresponds to disparity

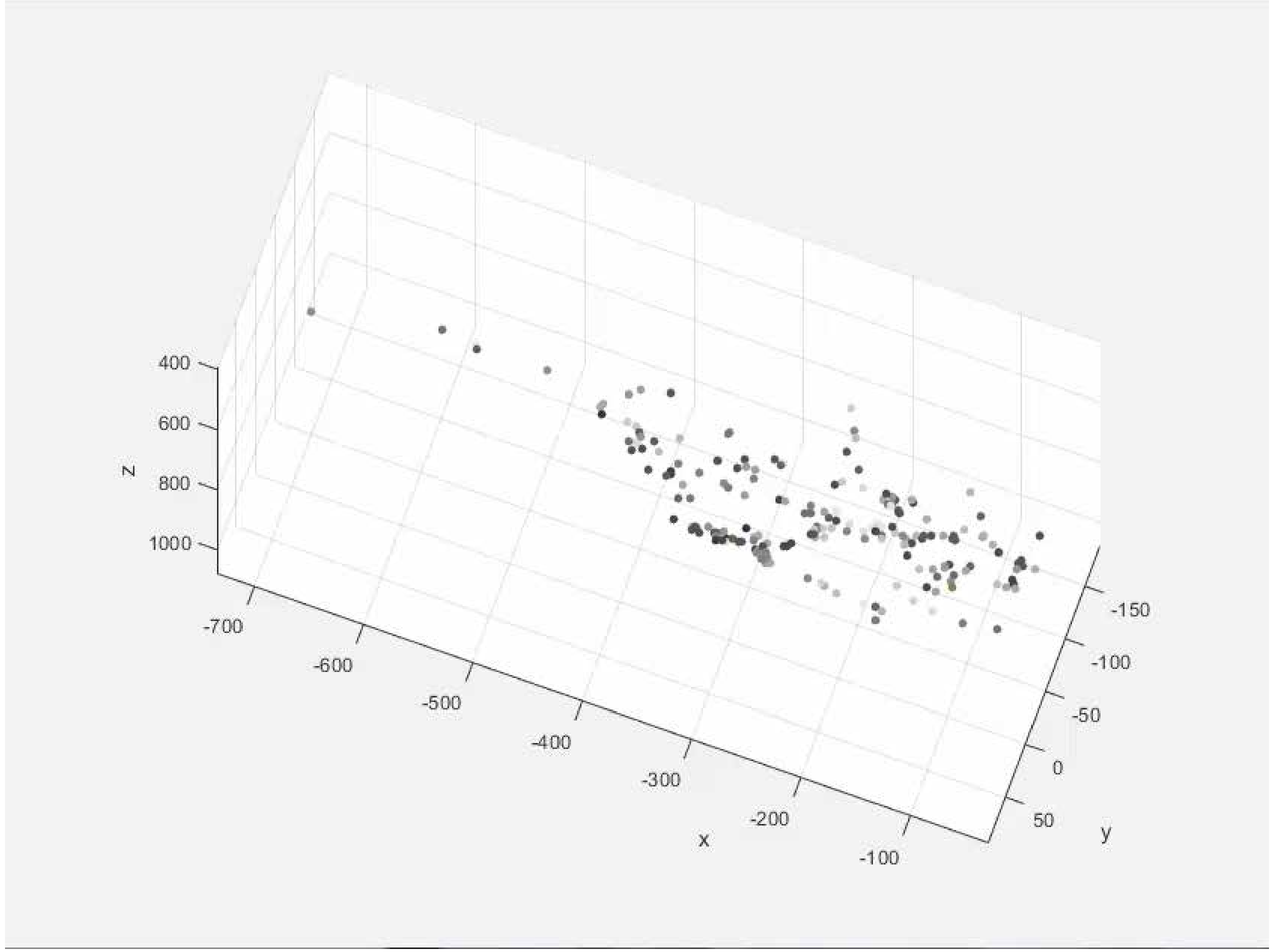
Sparse stereo matching



Example

- Depth in meters for each matched point
- Computed directly from disparity

Sparse stereo matching

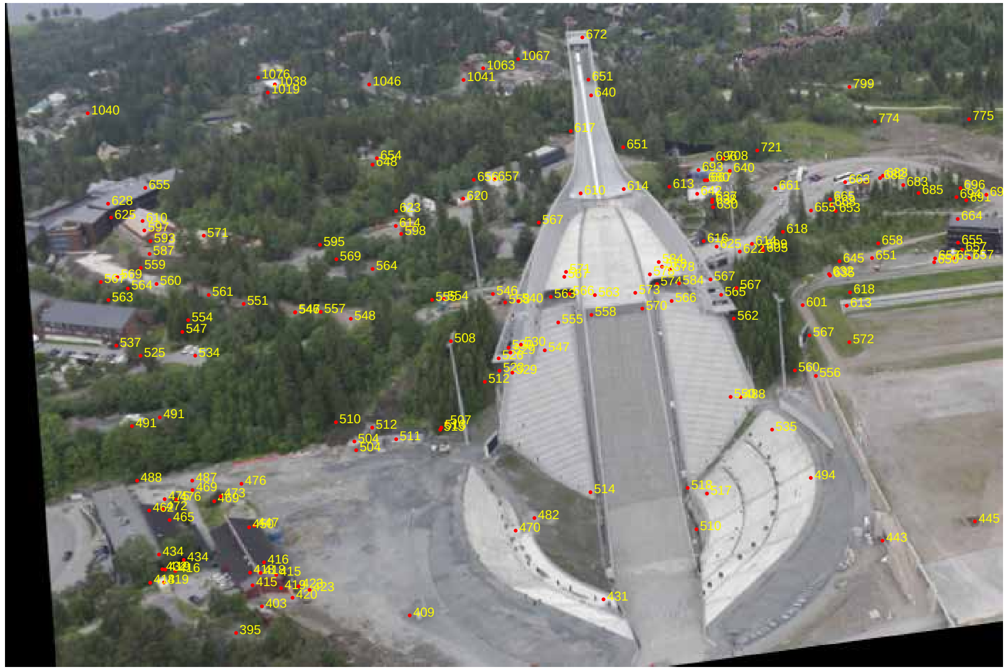


Example

- Sparse 3D point cloud
- Each point has two descriptors
  – Map for pose estimation with PnP!

Stereo processing

- Sparse stereo
  - Extract keypoints
  - Match keypoints along the same row
  - Compute 3D from disparity



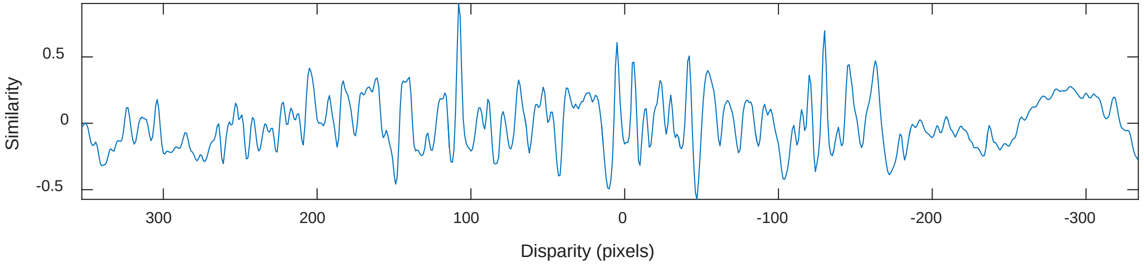
- Dense stereo
  - Try to match all pixels along rows
  - Compute disparity image by finding the best disparity for each pixel
  - Refine and clean disparity image
  - Compute dense 3D point cloud or surface from disparity

Dense stereo matching

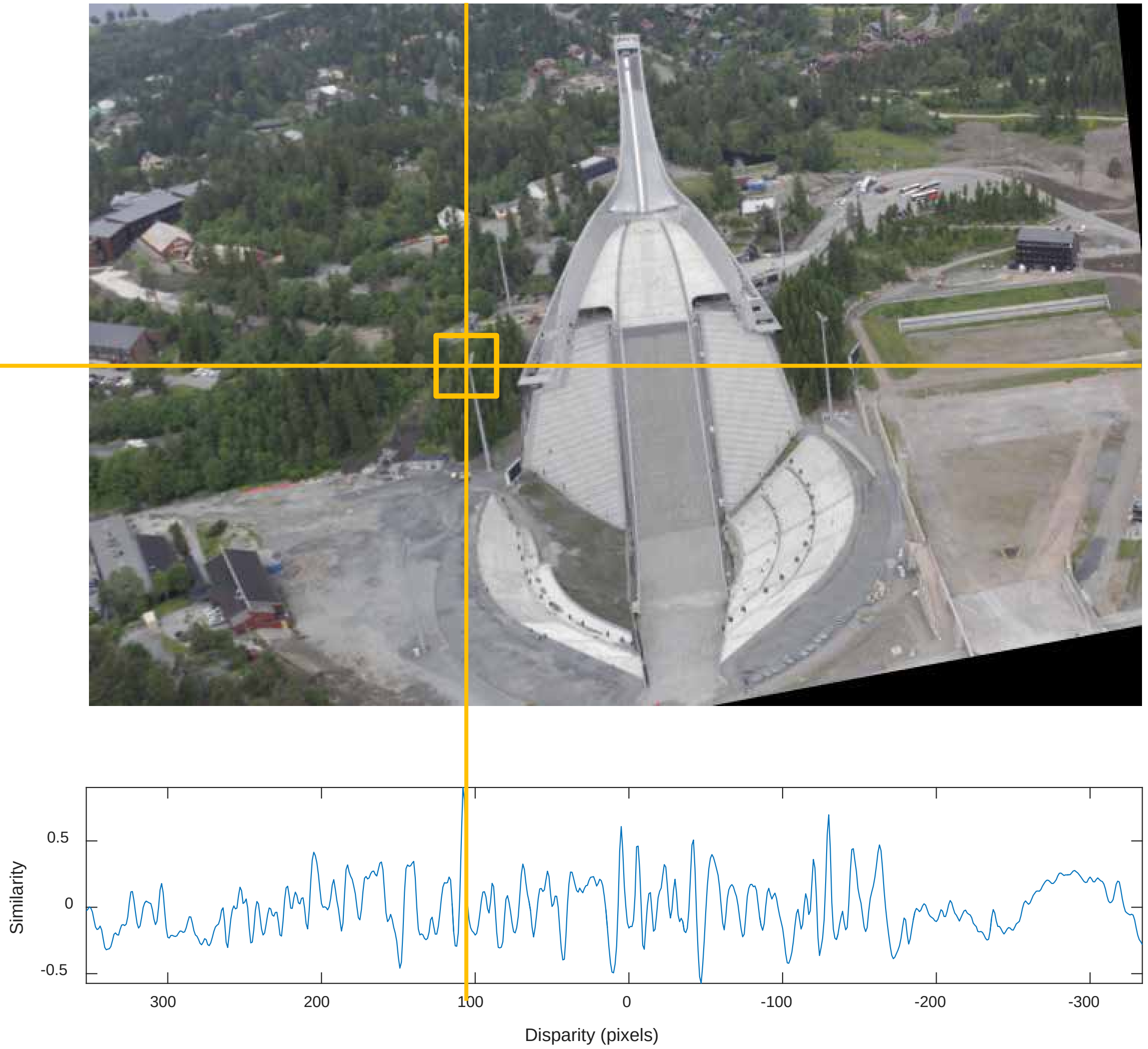
- For a patch in the left image
  - Compare with patches along the same row in the right image

Dense stereo matching

- For a patch in the left image
  - Compare with patches along the same row in the right image



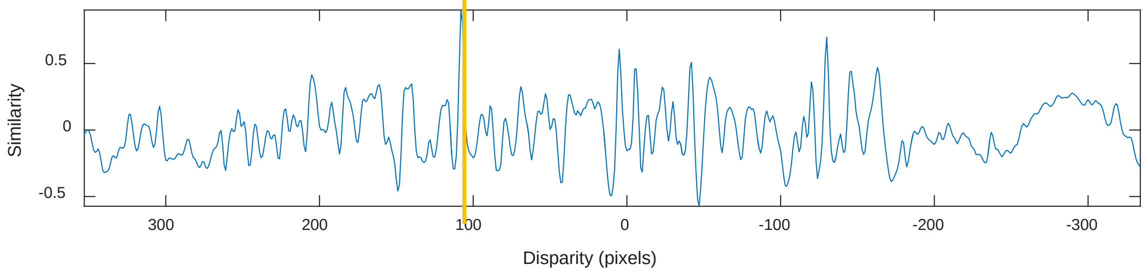
Dense stereo matching



- For a patch in the left image
  - Compare with patches along the same row in the right image
  - Select patch with highest score

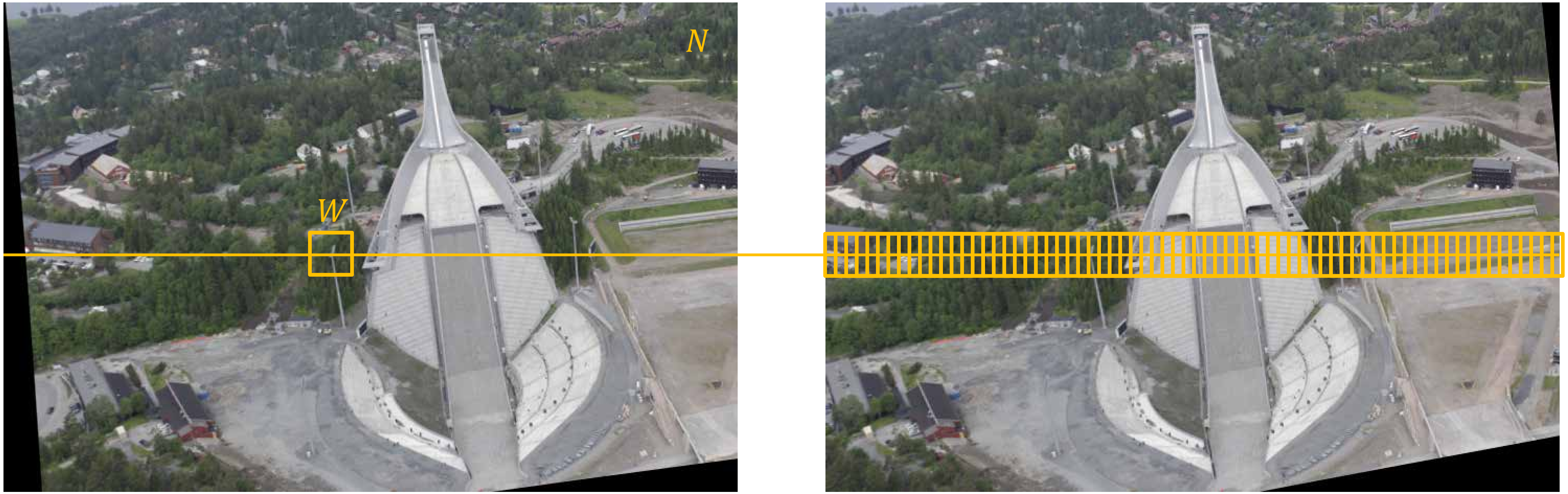
Dense stereo matching

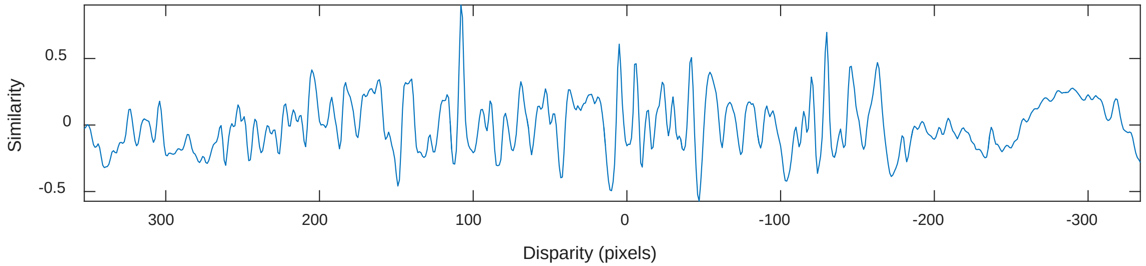
- For a patch in the left image
  - Compare with patches along the same row in the right image
  - Select patch with highest score



- Repeat for all pixels in the left image

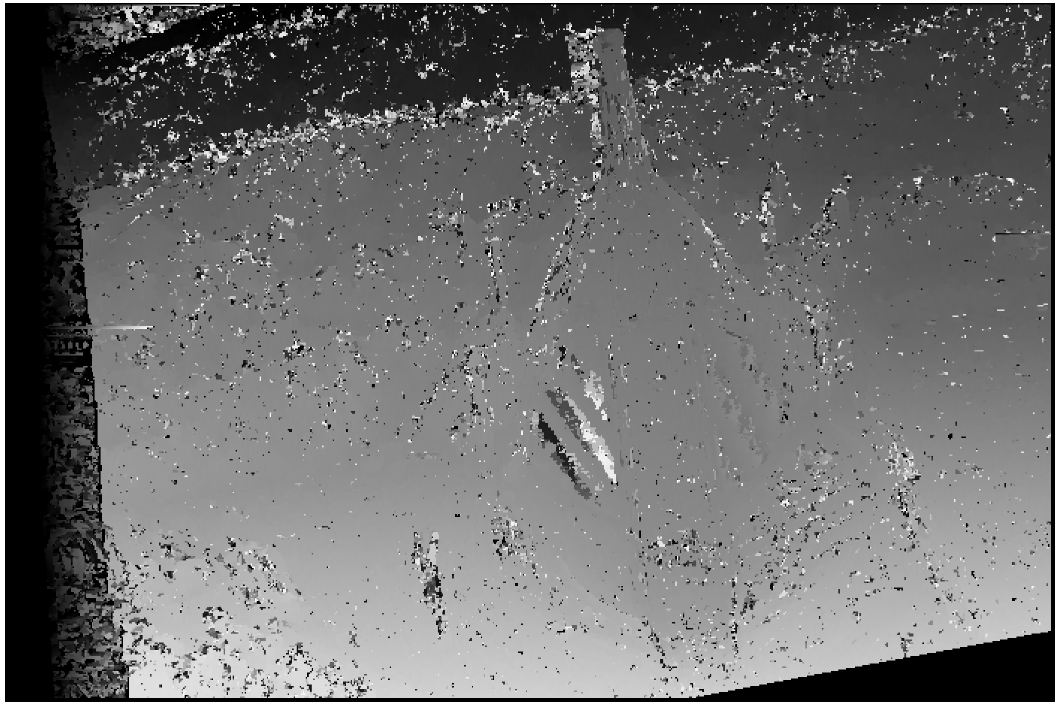
Dense stereo matching





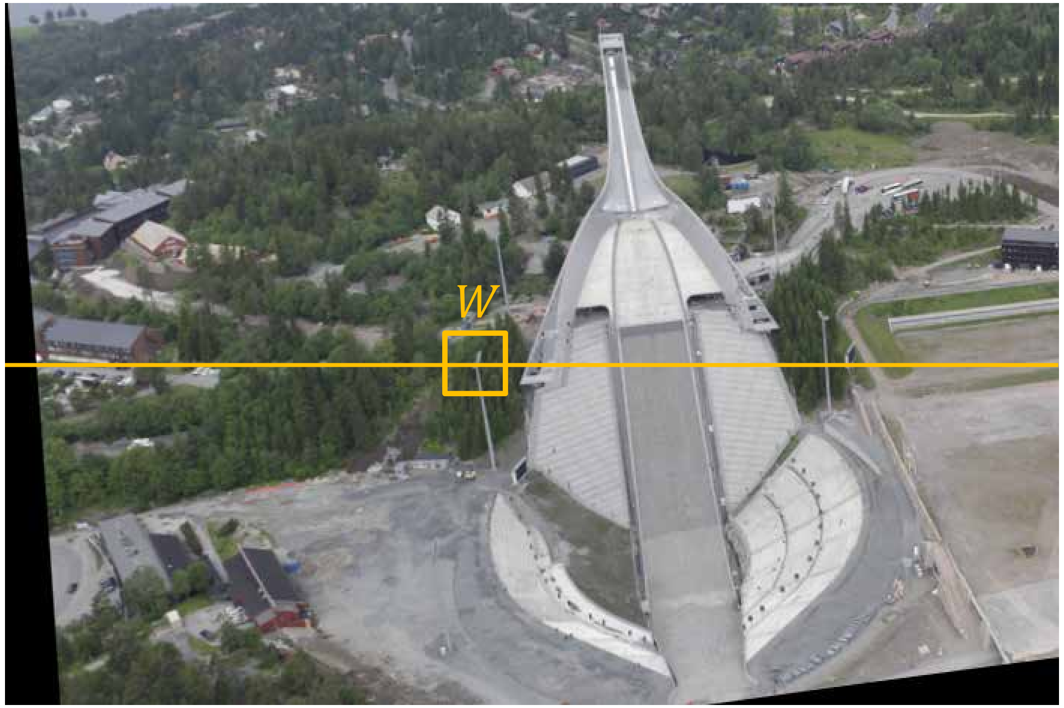
- Computational cost
  - $O(DW^2N^2)$

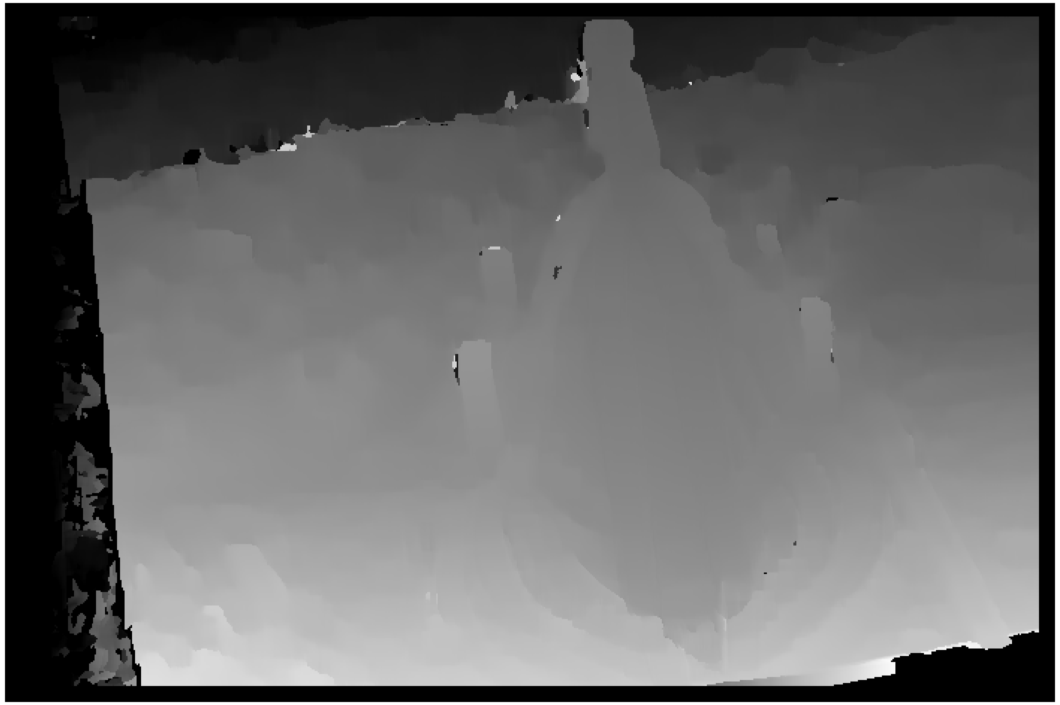
Dense stereo matching



- Size of window
  - Small: More difficult to match, noisy

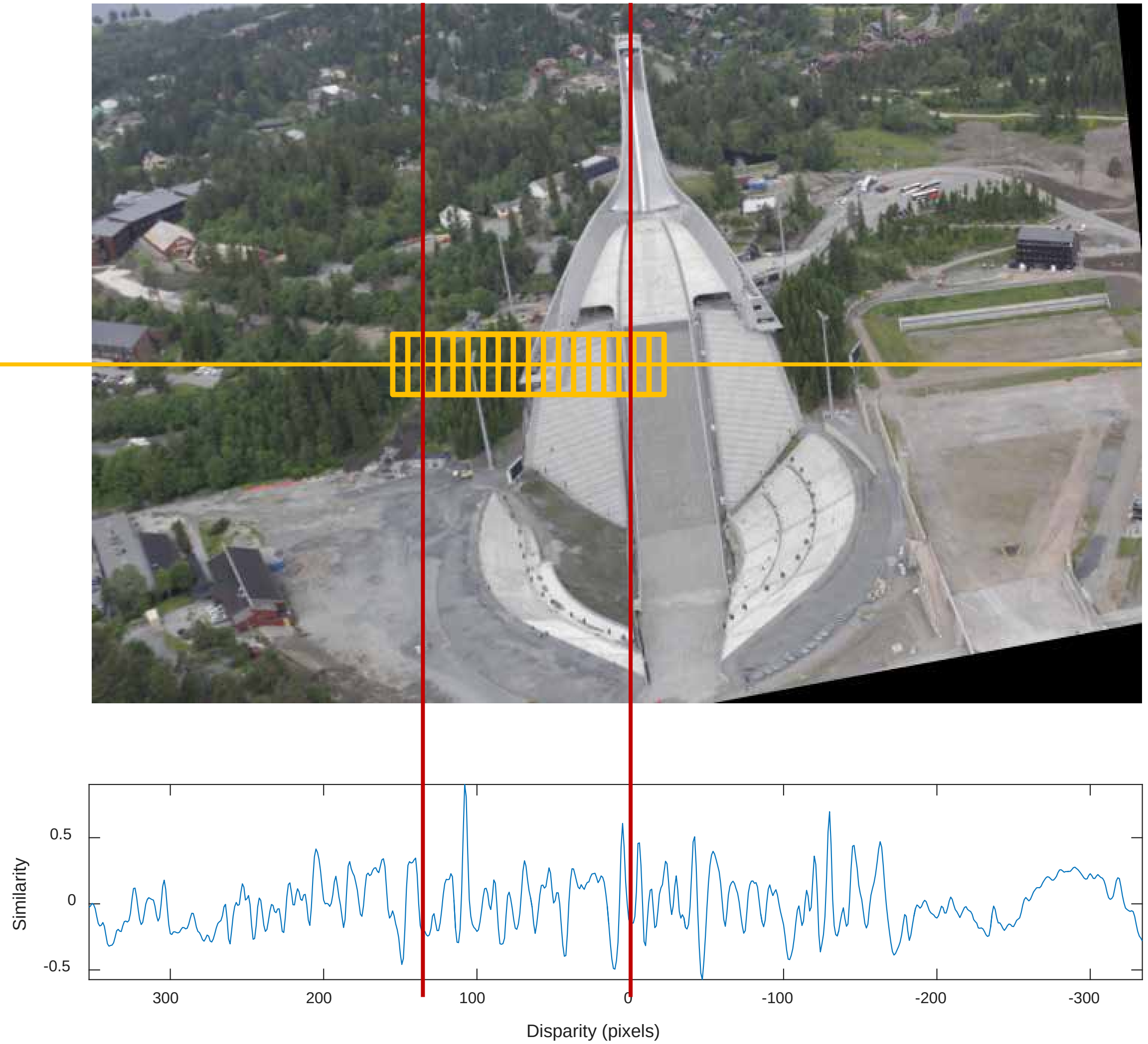
Dense stereo matching





- Size of window
  - Small: More difficult to match, noisy
  - Large: Loss of detail, smooth, slow

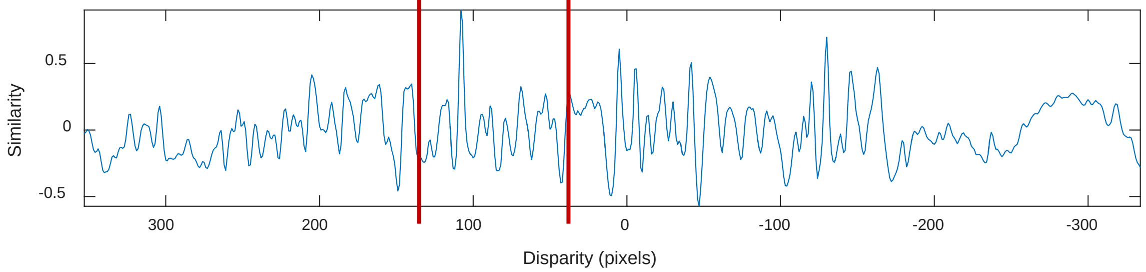
Dense stereo matching



- Restrict disparity range
  - Less computation
  - Less memory
  - Less matching errors

Dense stereo matching

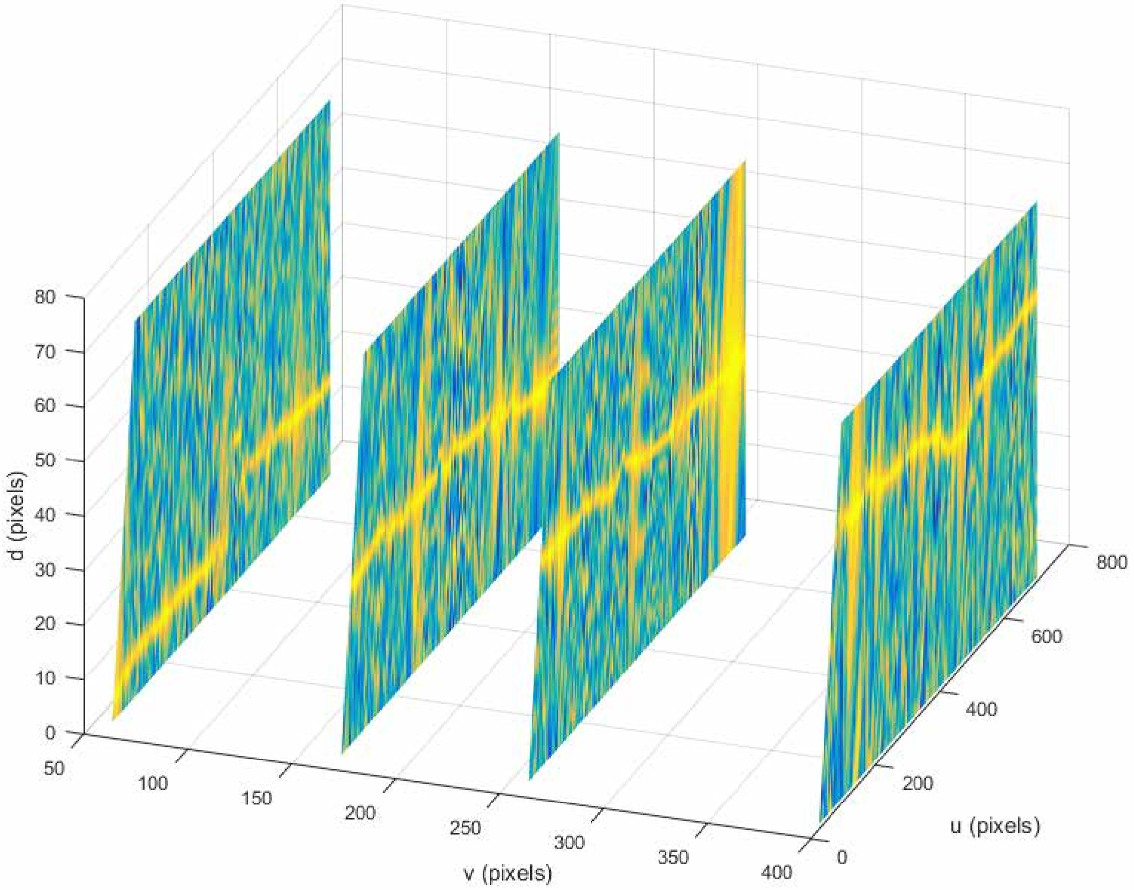
- Restrict disparity range
  - Less computation
  - Less memory
  - Less matching errors



Disparity Space Image (DSI)

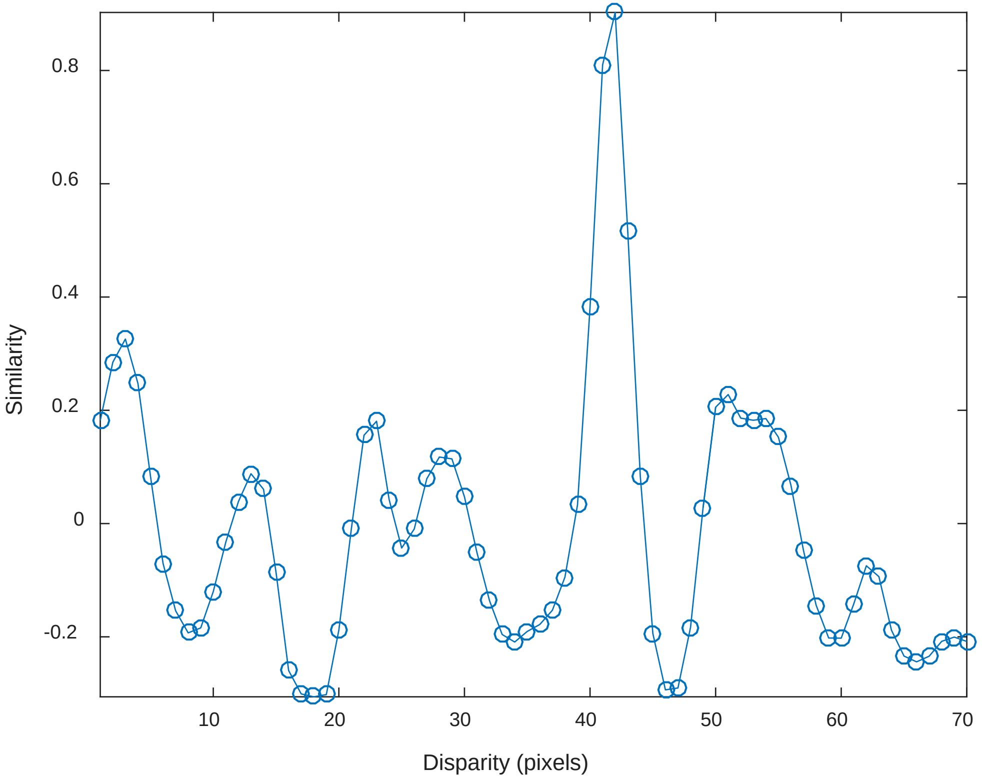
- The element $D(u, v, d)$ is the similarity between the support regions centered at (u_L, v_L) in the left image and $(u_L - d, v_L)$ in the right image

Disparity Space Image (DSI)



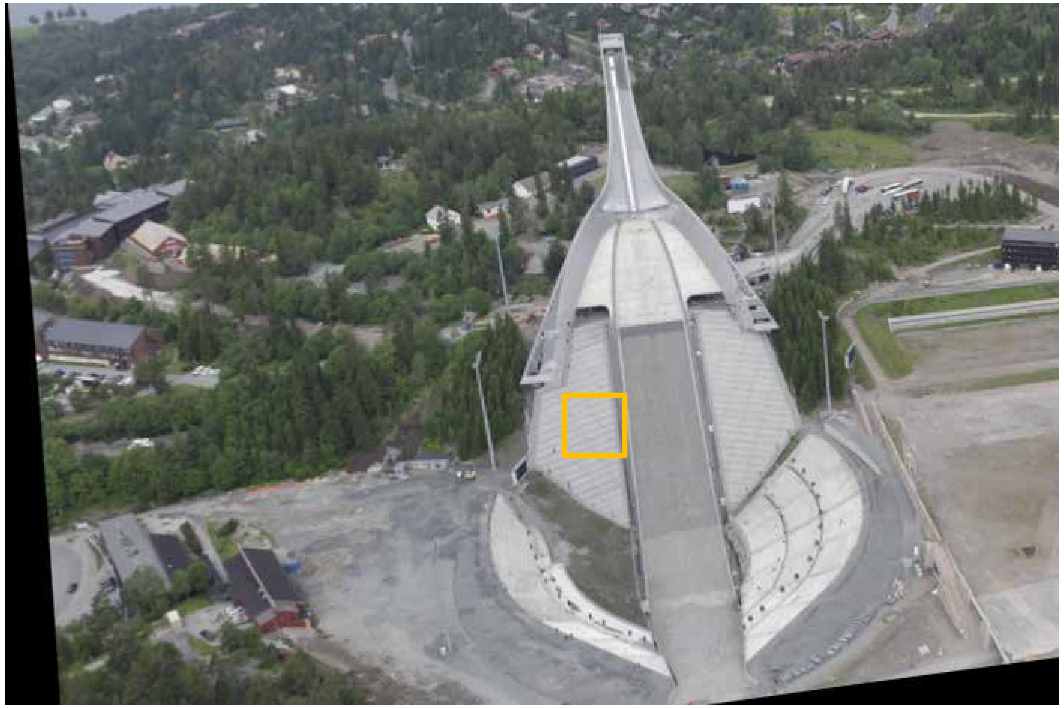
- The element $D(u, v, d)$ is the similarity between the support regions centered at (u_L, v_L) in the left image and $(u_L - d, v_L)$ in the right image

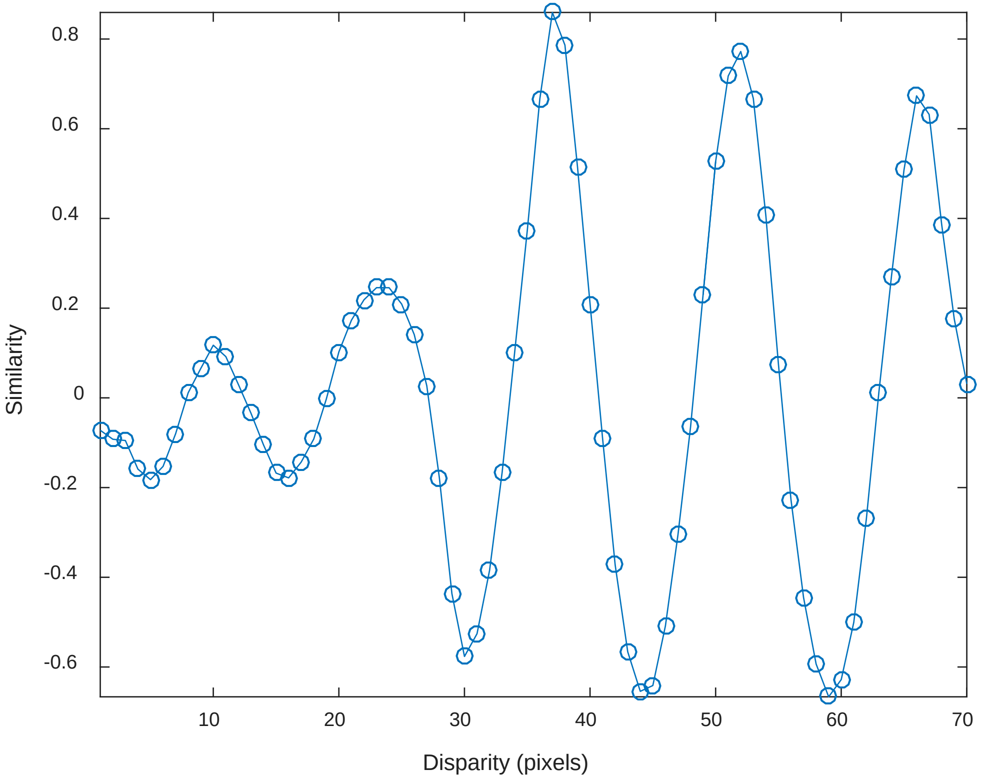
Stereo matching failures



- Single strong unambiguous peak

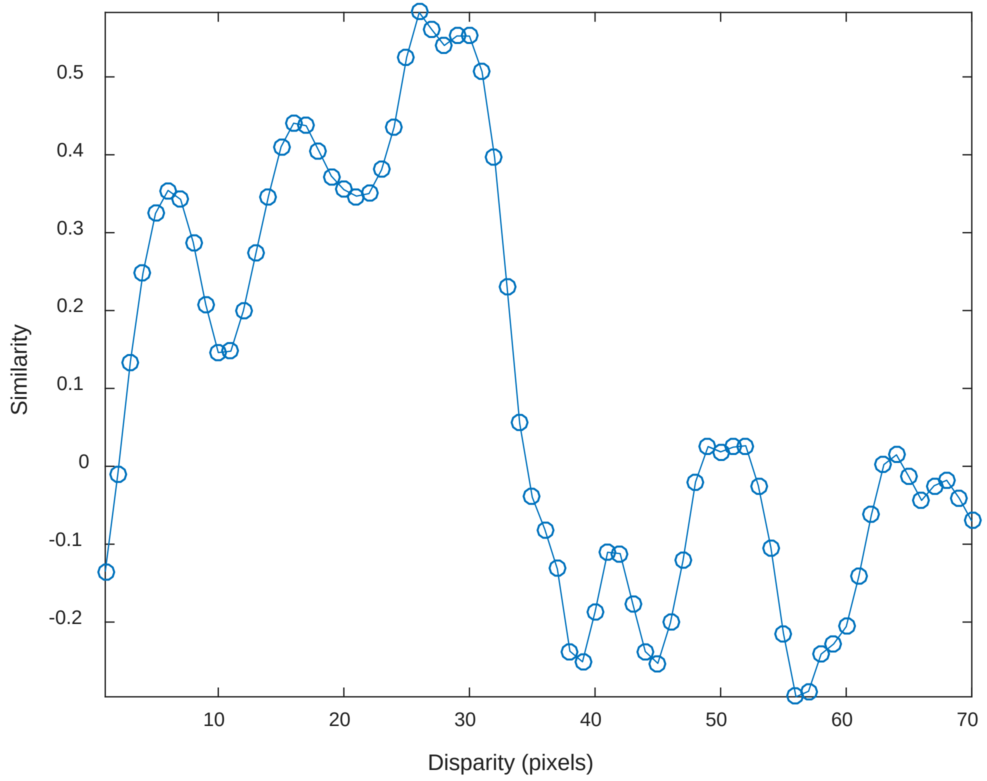
Stereo matching failures





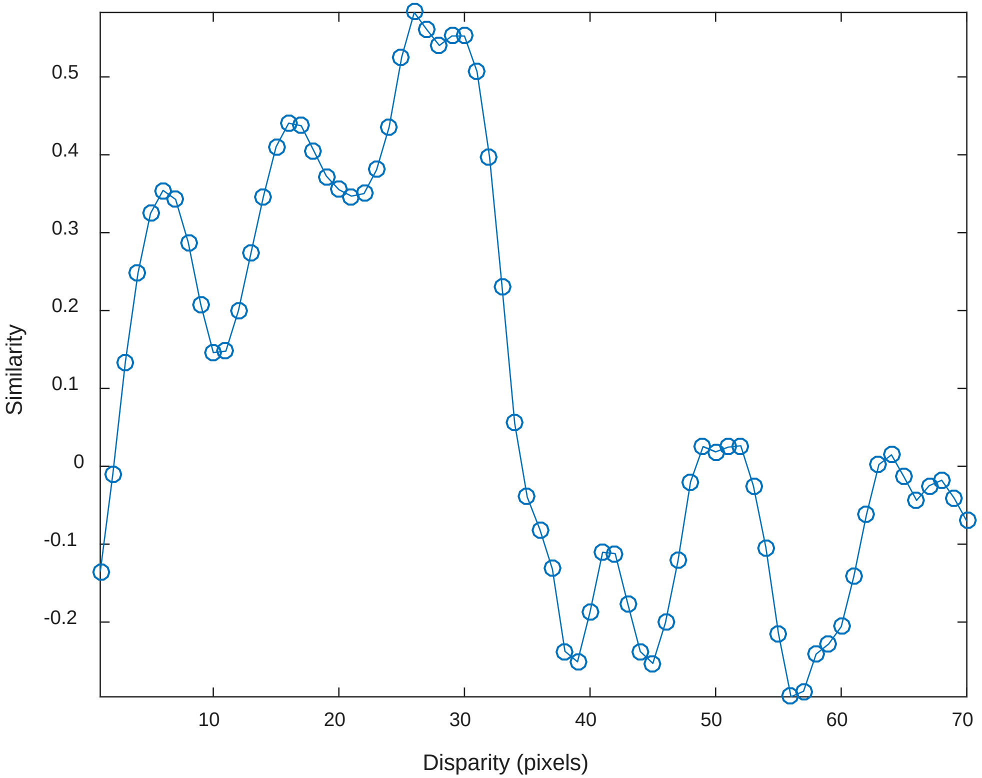
- Several ambiguous peaks
  - Which is the correct peak?
  - Repeating patterns
  - Detect with ratio test

Stereo matching failures



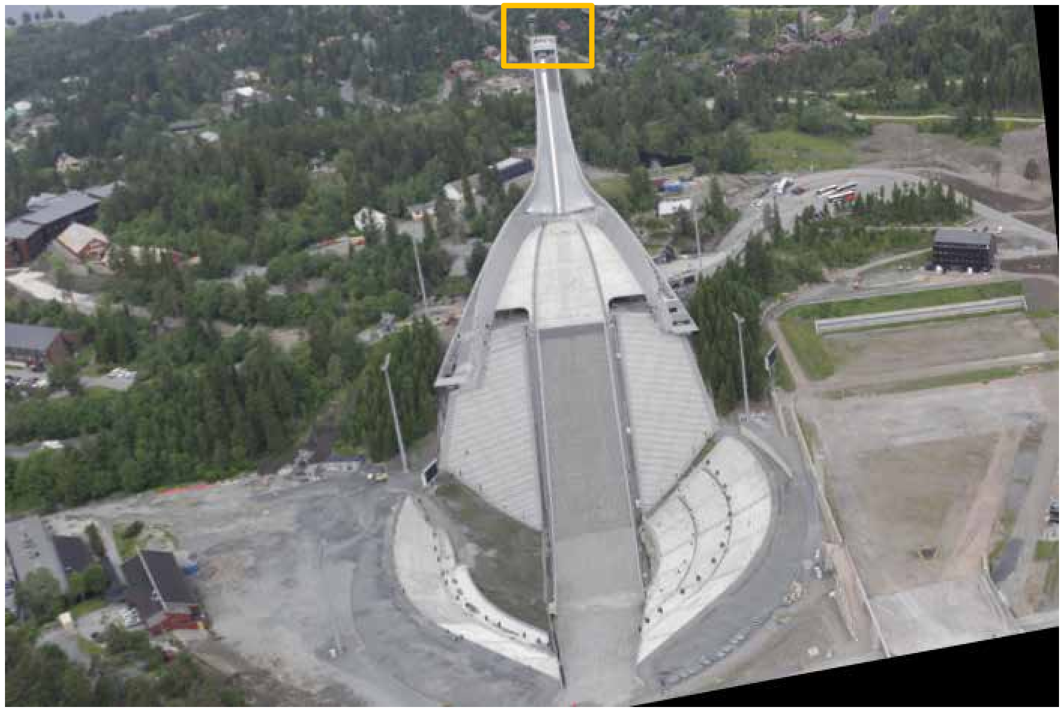
- A weak peak
  - Often occlusion, parallax

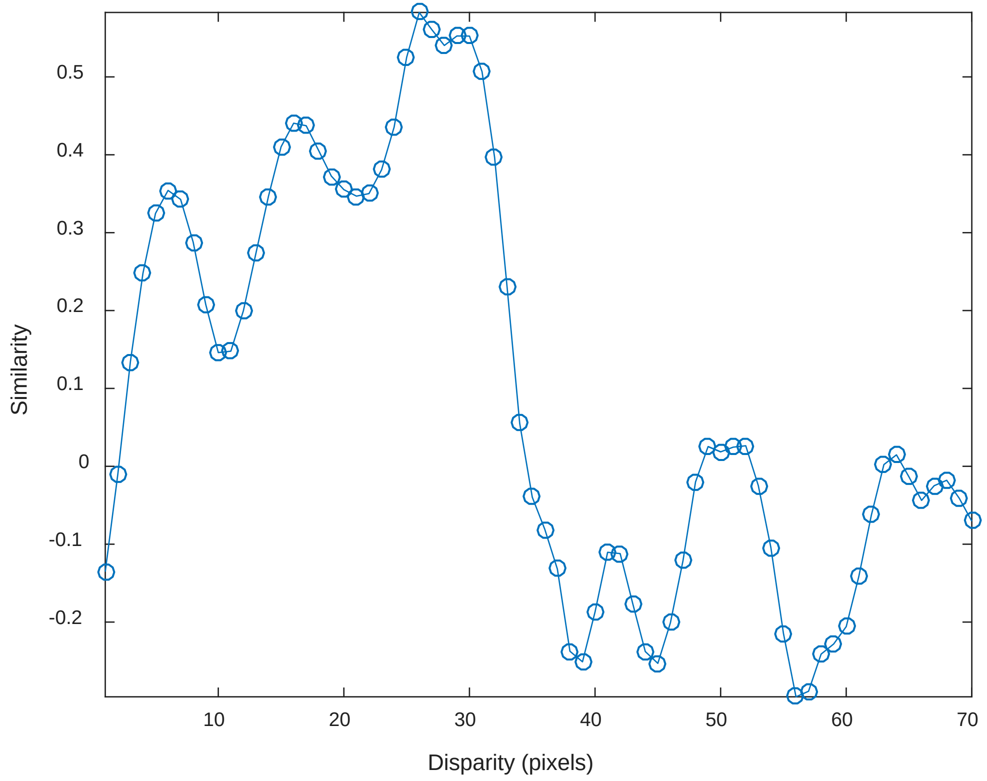
Stereo matching failures



- A weak peak
  - Often occlusion, parallax

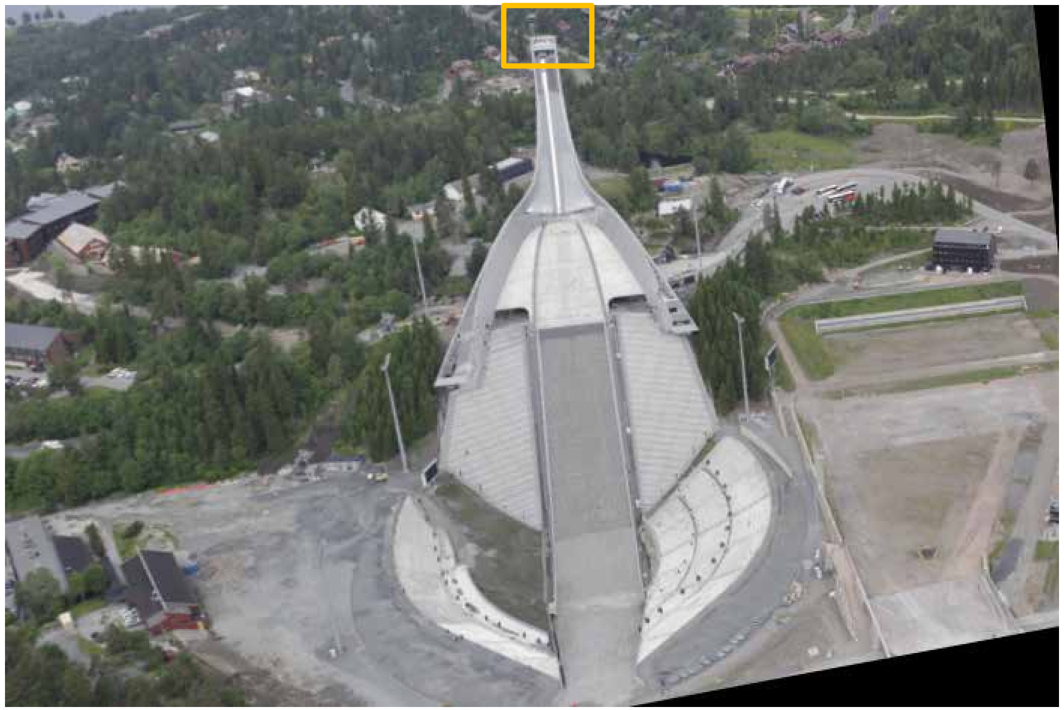
Stereo matching failures

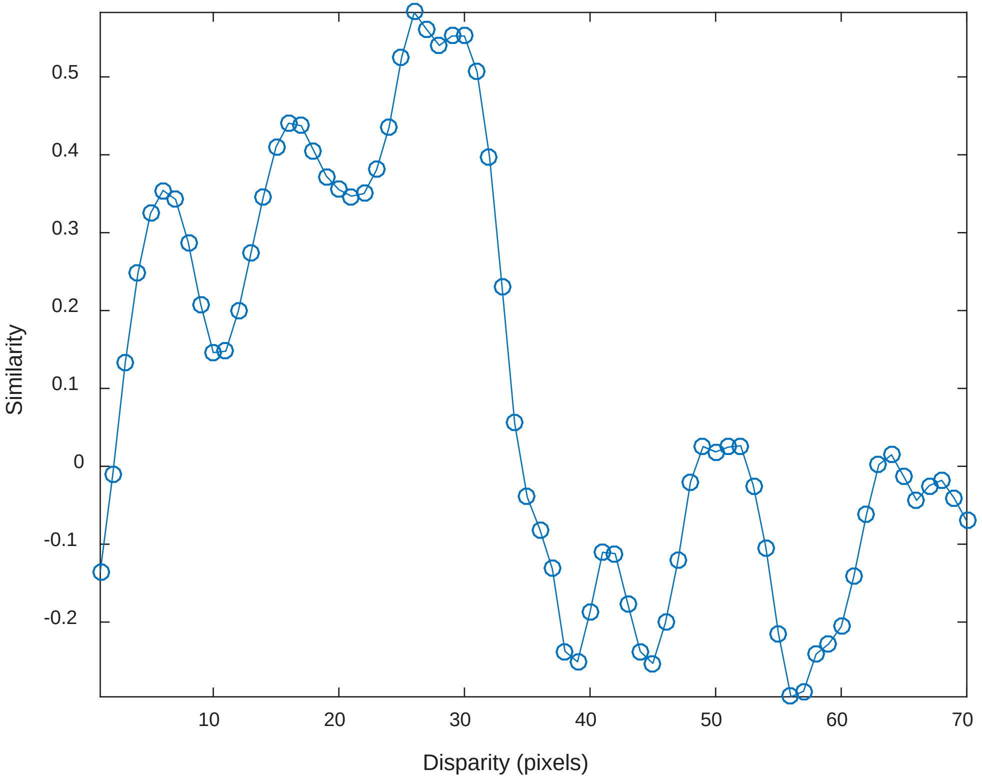




- A weak peak
  - Often occlusion, parallax

Stereo matching failures



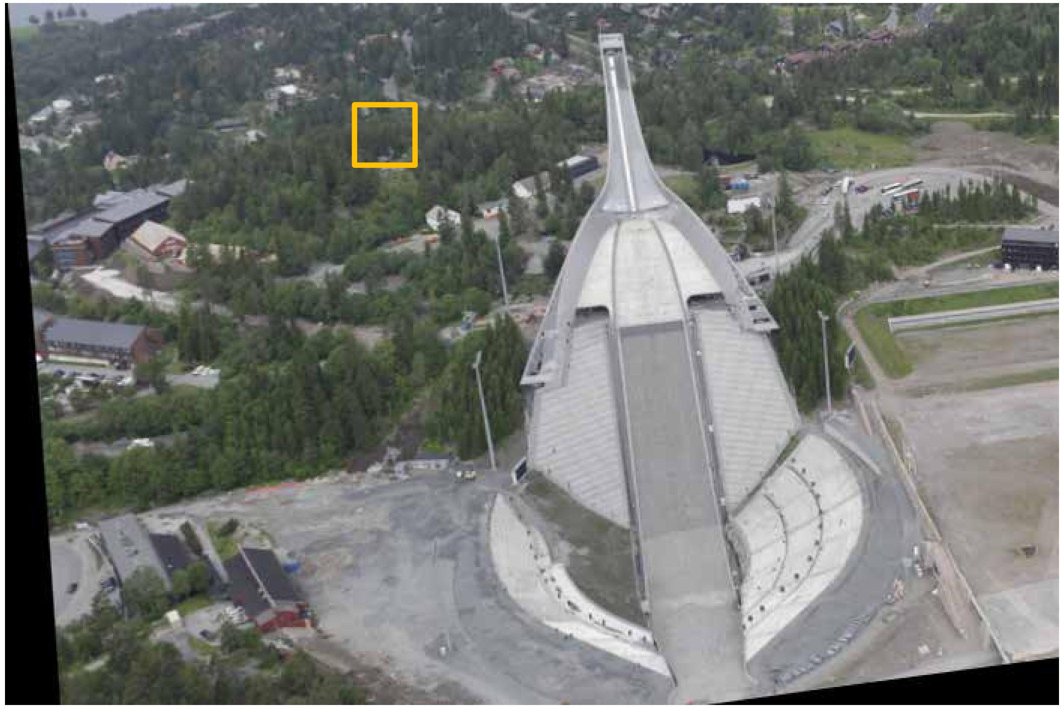


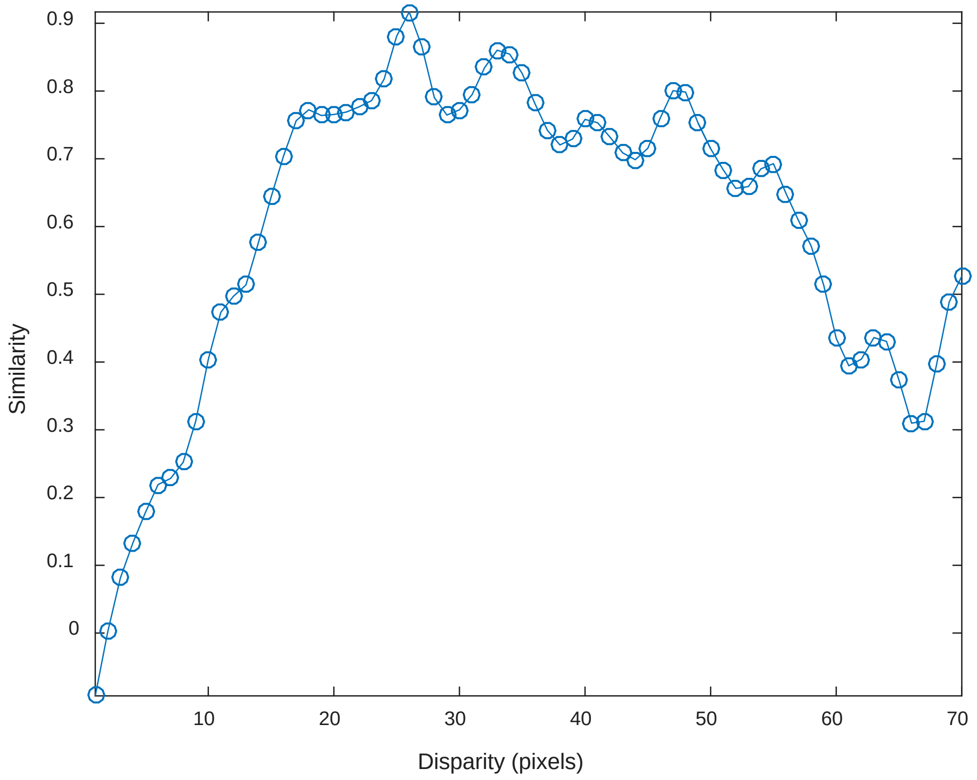
- A weak peak
  - Often occlusion, parallax
  - Worse with larger baseline
  - Detect by thresholding similarity score

Stereo matching failures

- A weak peak
  - Often occlusion, parallax
  - Worse with larger baseline
  - Detect by thresholding similarity score

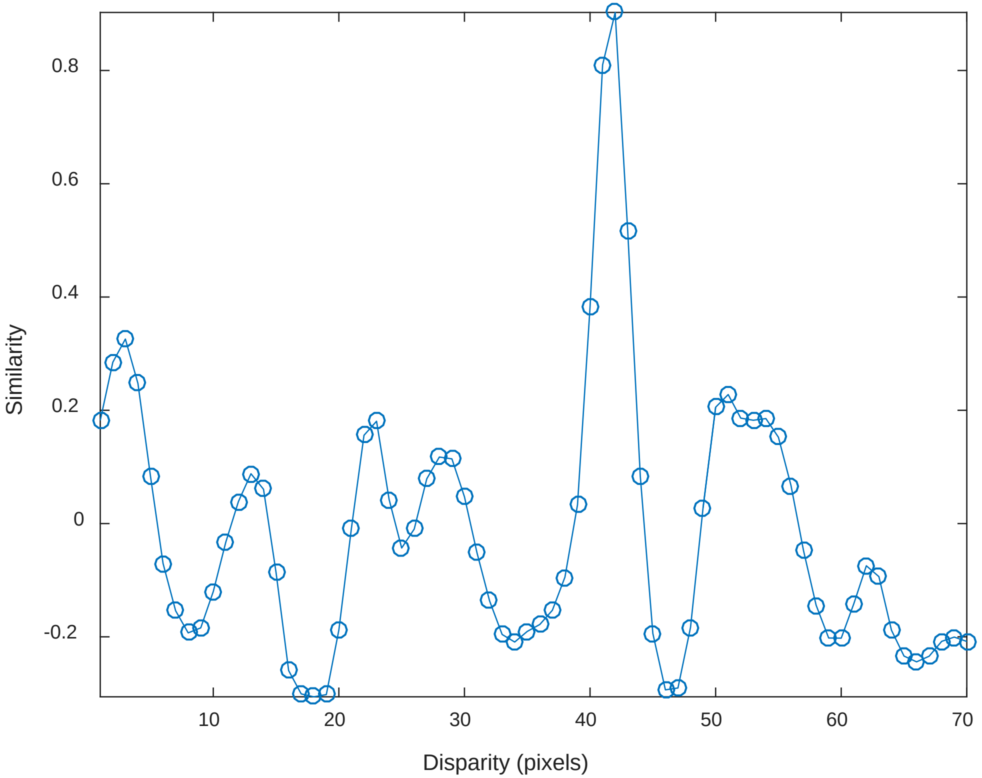
Stereo matching failures





- A broad peak
  - Little texture
  - Detect with texture metrics or from peak estimates

Determining position of peaks

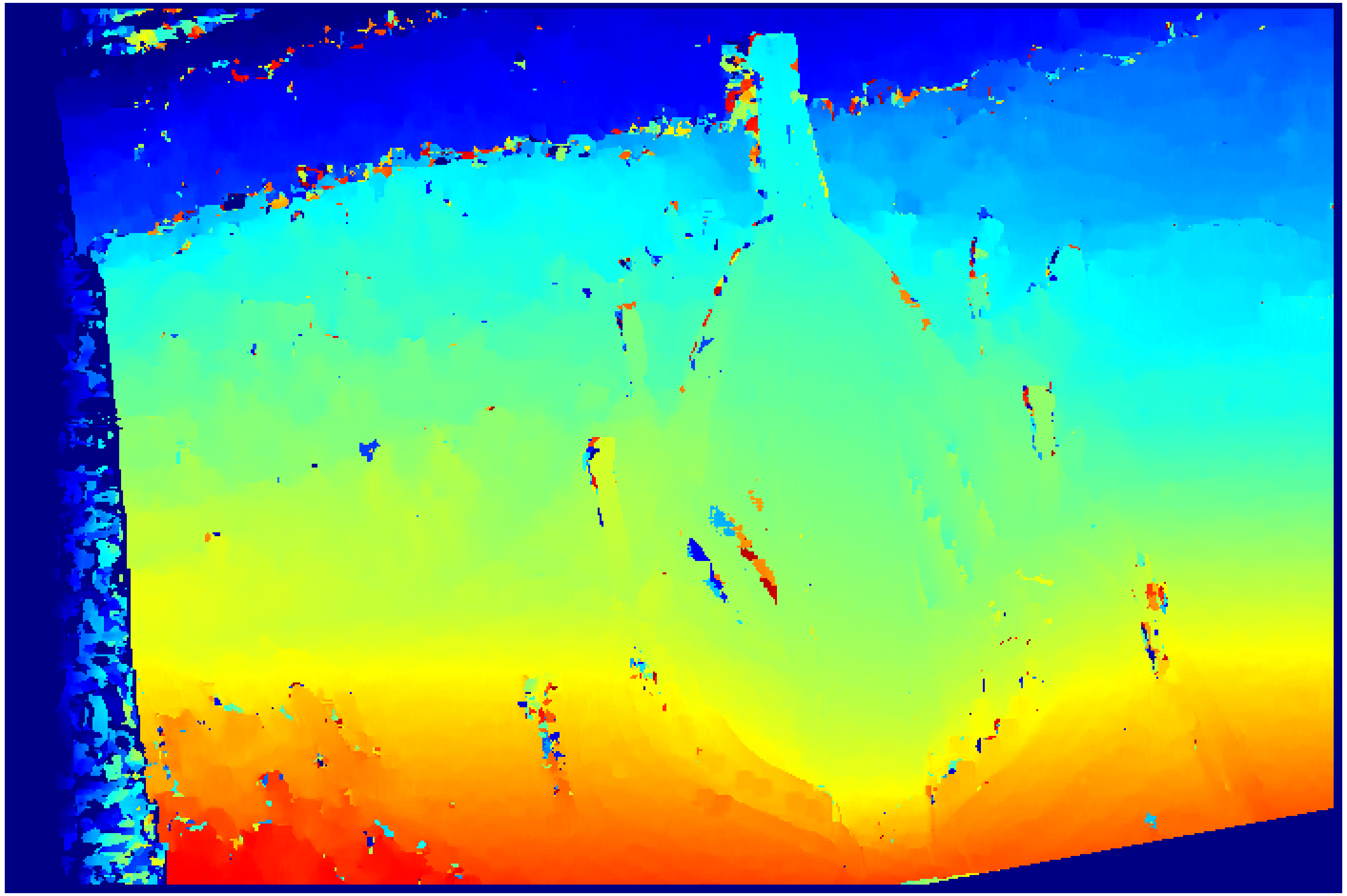


- Fit a parabola to the peak and its neighbors
  - $s = Ad^2 + Bd + C$
  - $\hat{d} = \frac{-B}{2A}$

- Avoids steps in depth

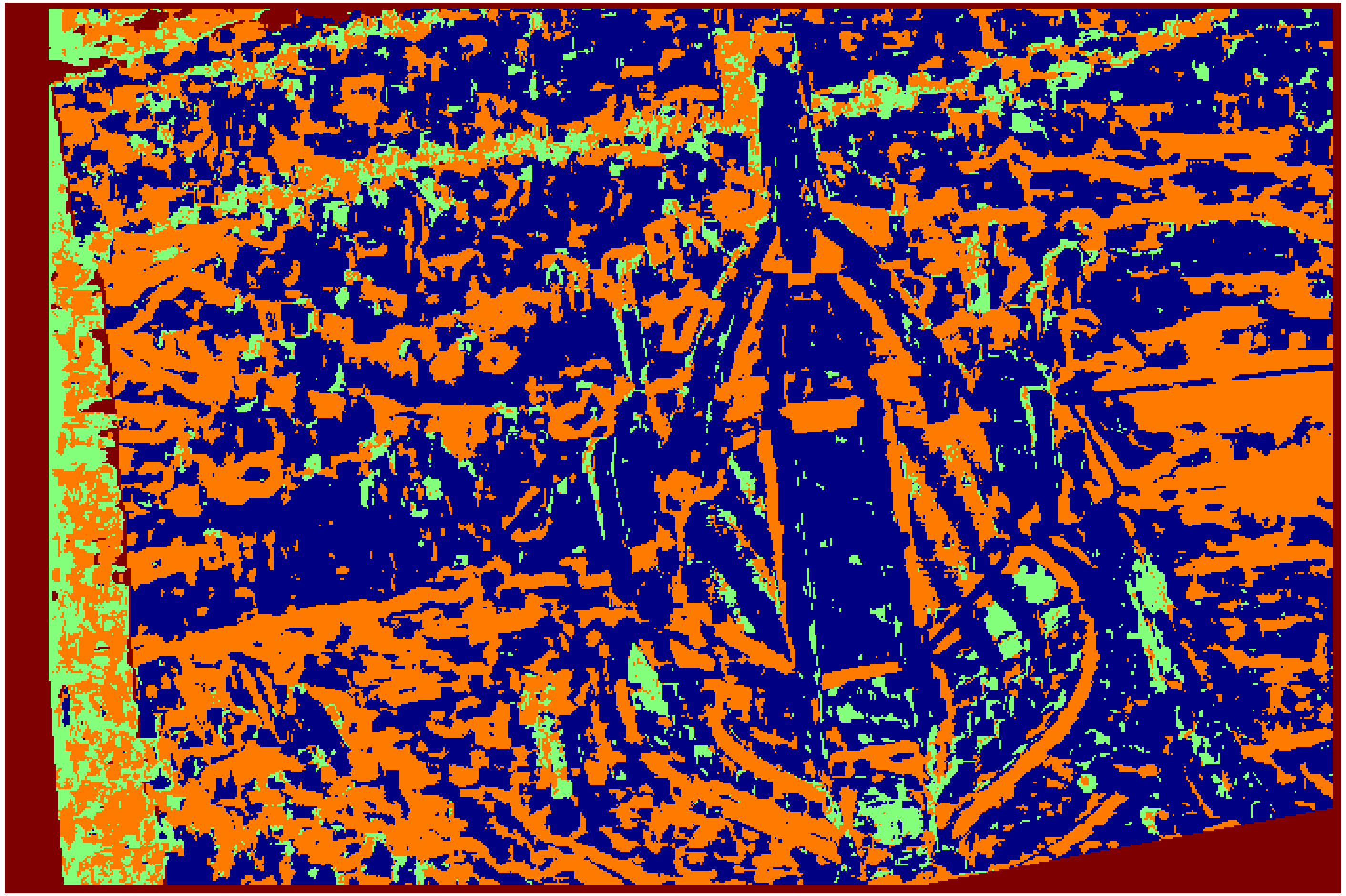
Dense stereo example

Dense stereo example



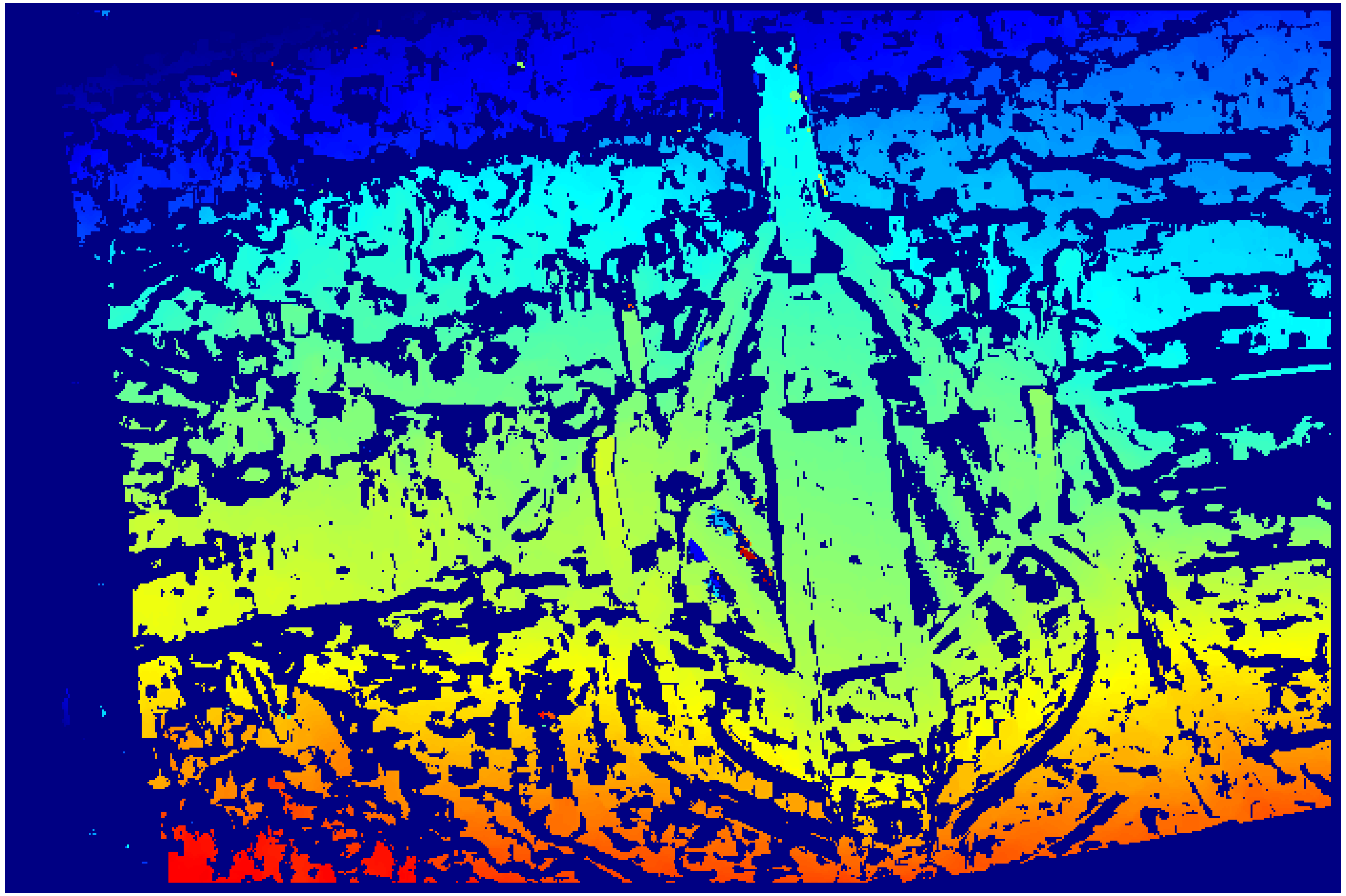
- Raw disparity image

Dense stereo example



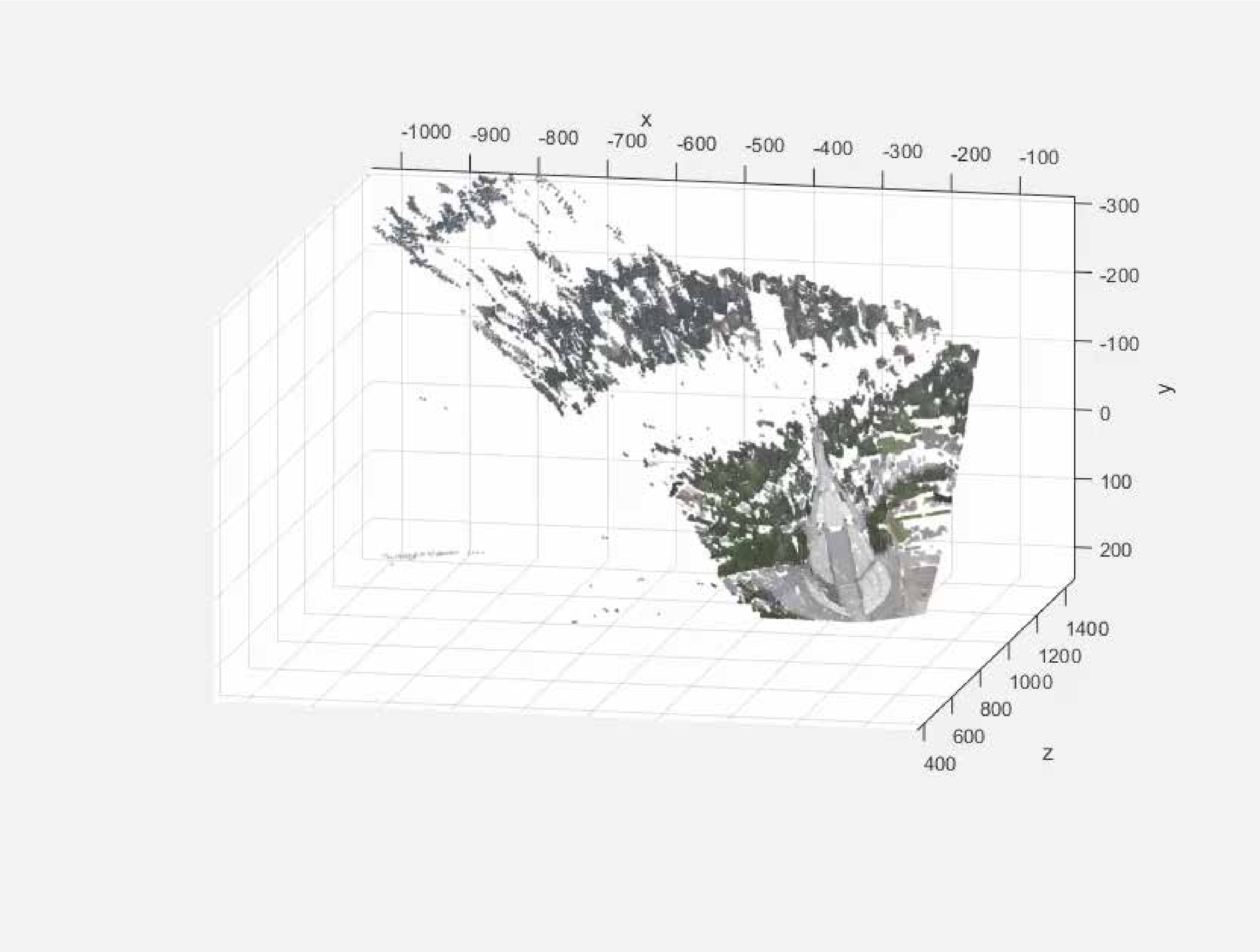
- Detection of failures
  - Blue: Ok
  - Red: Outside image
  - Orange: Broad peaks
  - Green: Low similarity
- In computer vision in general:
  - Smooth and fill holes
- In robotics:
  - Typically better to remove uncertain points

Dense stereo example



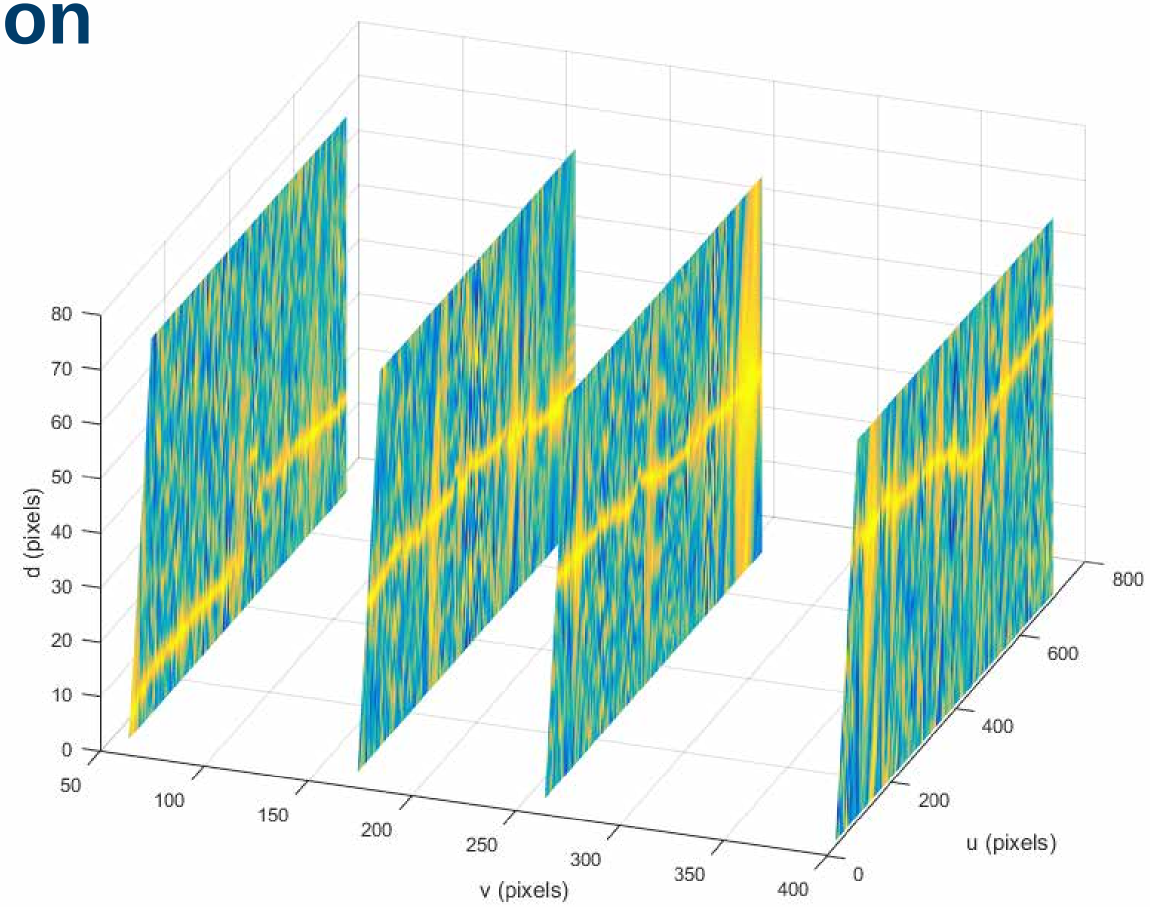
- Disparity image
  - Failures removed

Dense stereo example



- Dense 3D point cloud

Smooth stereo: Global optimization



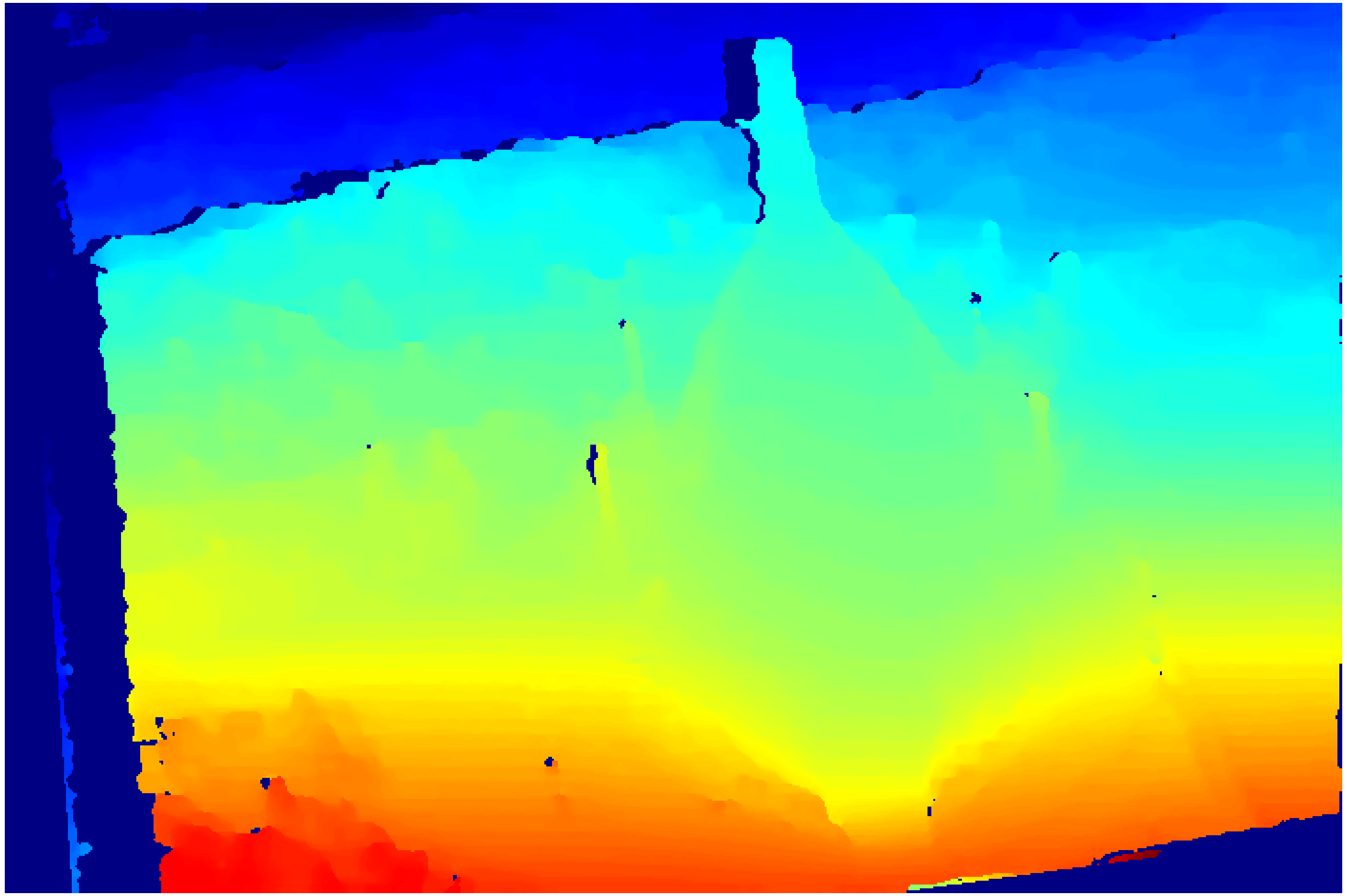
- Instead of finding best disparity for each pixel, find d so that global energy is minimum:

$$E(d) = E_d(d) + \lambda E_s(d)$$

Semi Global Matching example

- SGBM
  Heiko Hirschmuller, “Stereo processing by semiglobal matching and mutual information”. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 30(2):328–341, 2008

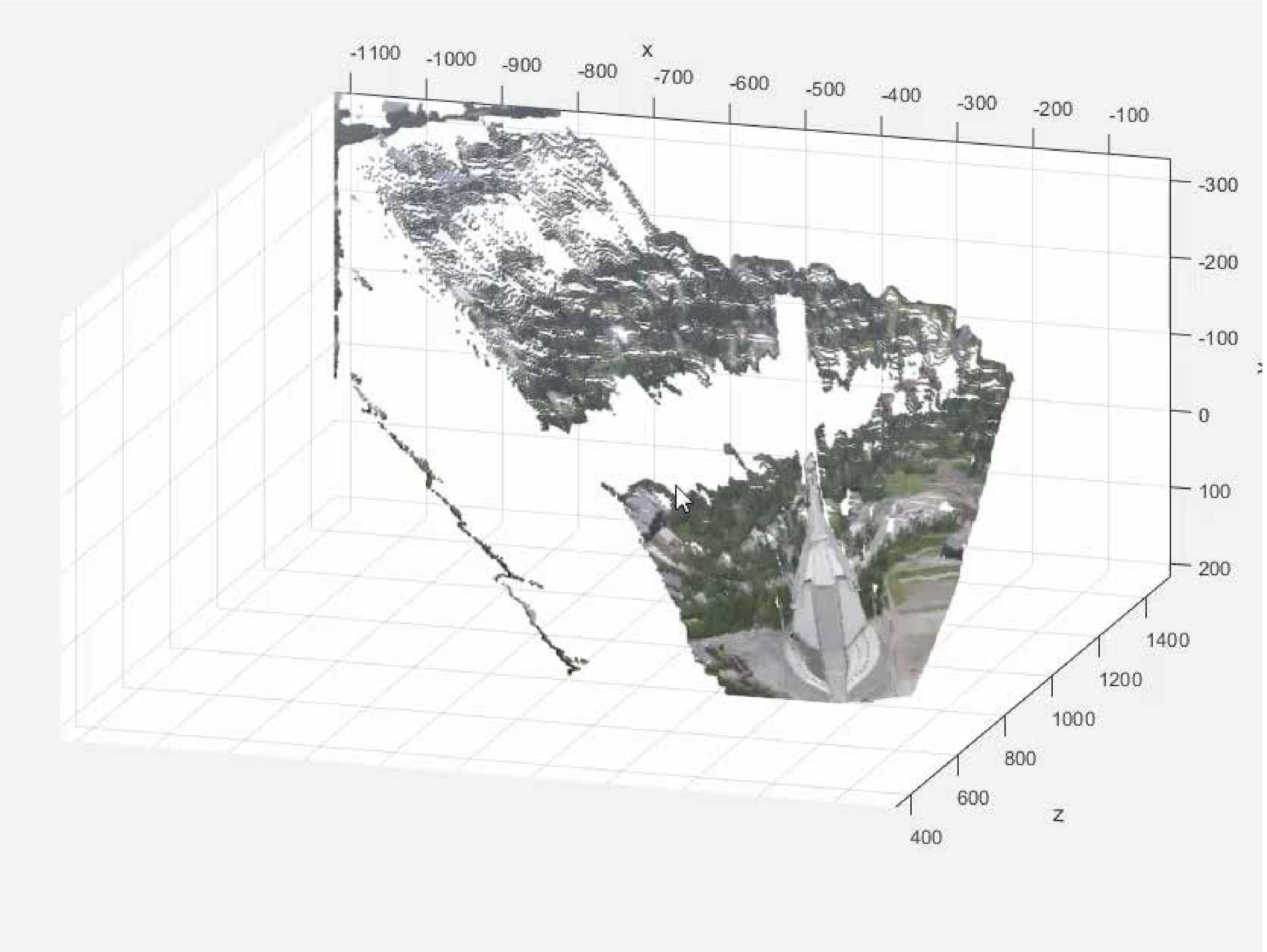
Semi Global Matching example



- SGBM
  Heiko Hirschmuller, “Stereo processing by semiglobal matching and mutual information”. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 30(2):328–341, 2008

- Disparity image

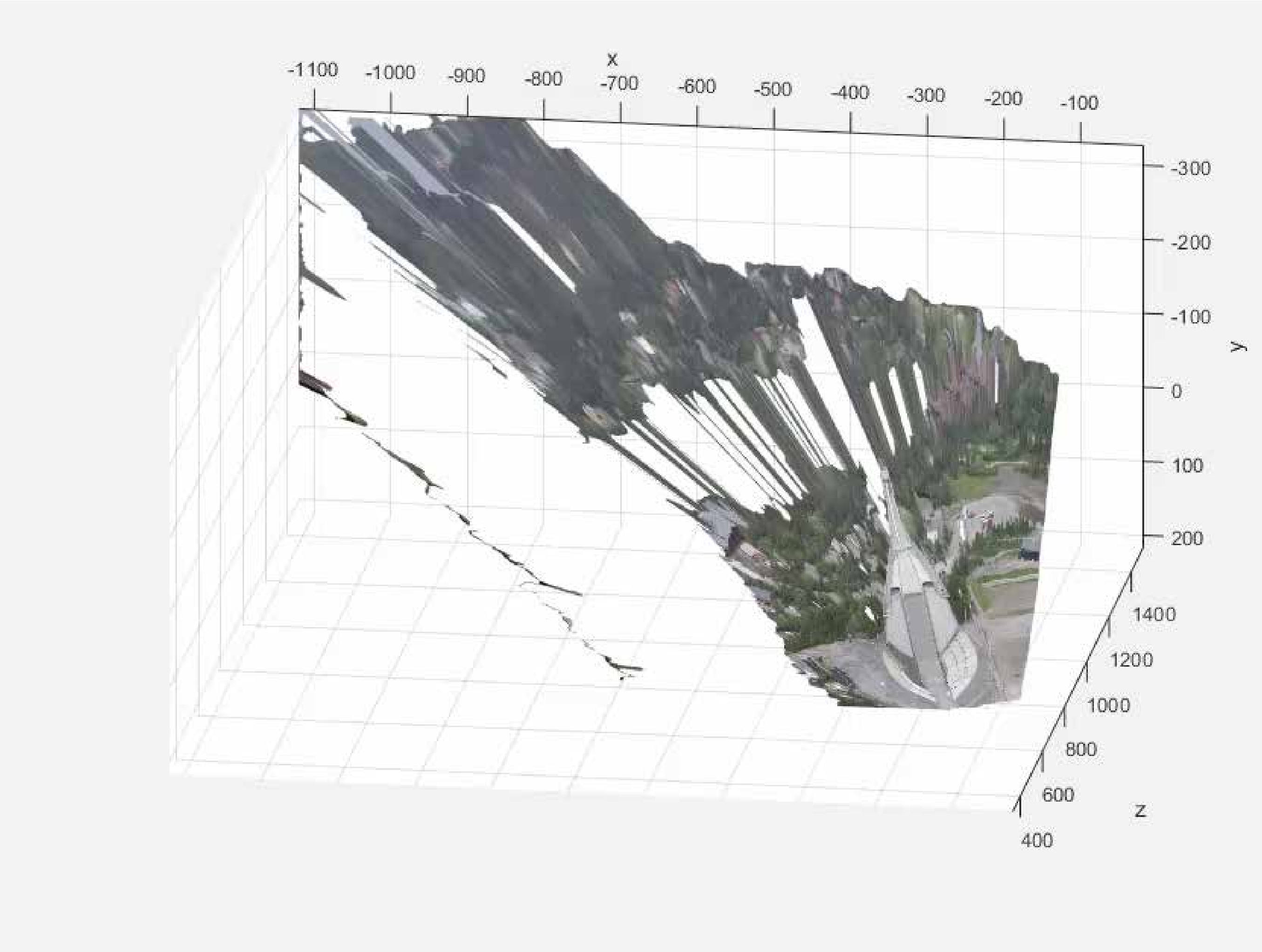
Semi Global Matching example



- SGBM
  Heiko Hirschmuller, “Stereo processing by semiglobal matching and mutual information”. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 30(2):328–341, 2008

- 3D point cloud

Semi Global Matching example



- SGBM
  Heiko Hirschmuller, “Stereo processing by semiglobal matching and mutual information”. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 30(2):328–341, 2008

- Textured surface

Summary

- Stereo imaging
  - Horizontal epipolar lines
  - Disparity
  - 3D from disparity
  - Stereo rectification

- Stereo processing
  - Sparse vs dense matching
  - DSI
  - Typical failures
  - Removing failures vs smoothness

- Additional reading
  - Szeliski: 11.2-11.5
  - http://vision.middlebury.edu/stereo/

- Matlab toolkit:
  - Peter Corke's Robotics Toolbox and Machine Vision Toolbox http://www.petercorke.com/Toolboxes.html

- Lab:
  - Make your own stereo camera!