Stereo Vision – Correspondence

Dr. Gerhard Roth

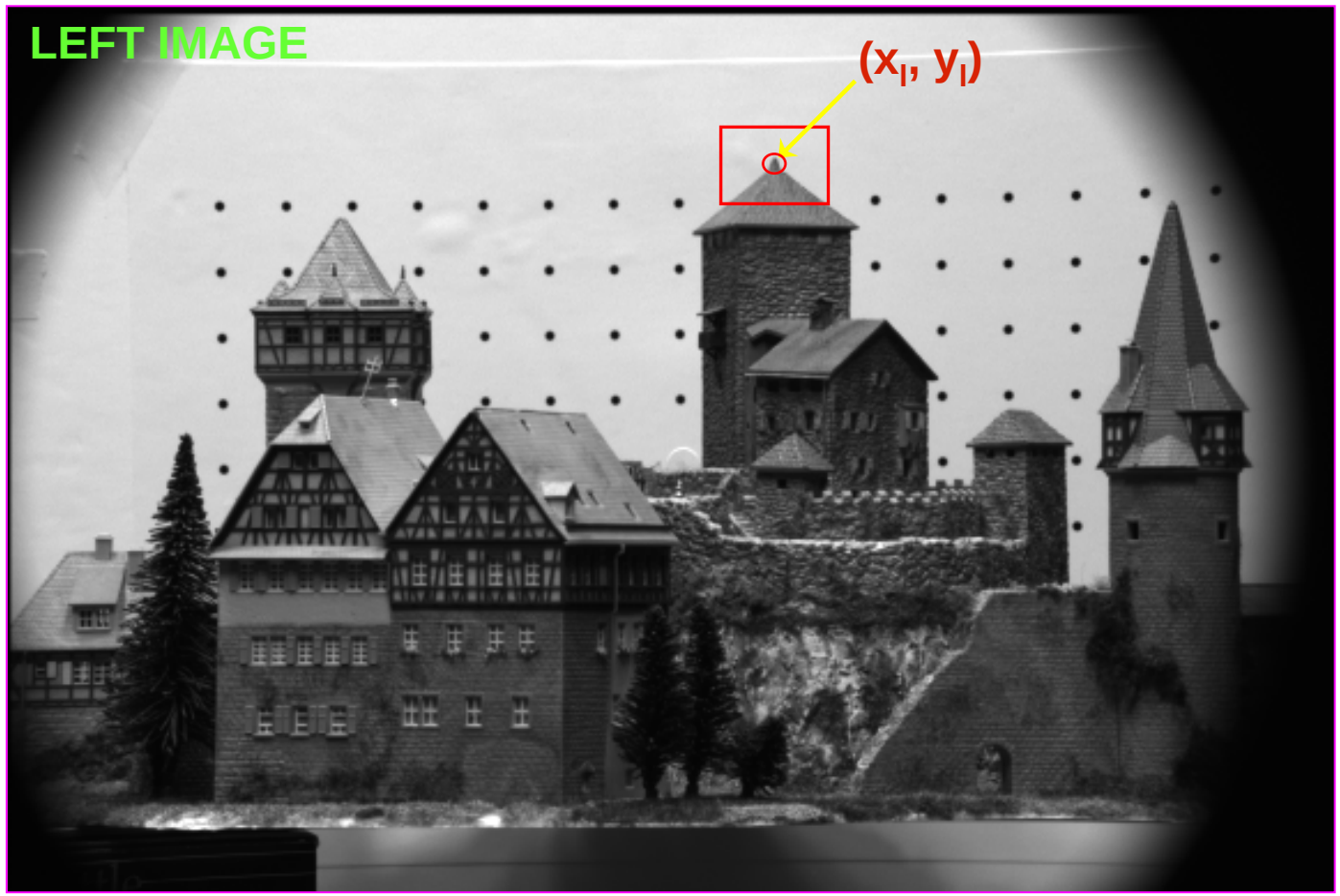
Problem Definition

- Correspondence problem
  - What parts of left and right image are projections of the same point in the 3D scene
- Simple stereo configuration
  - Corresponding points are on same horizontal line
- Assumptions
  - Most scene points are visible from both regions
  - Corresponding image regions are similar
- Search problem
  - Given scene element on left image search for
  - What parts of left and right images are parts of same object?
- Two decisions
  - Which element to match
  - Which similarity measure to adopt

Correspondence and Feature Methods

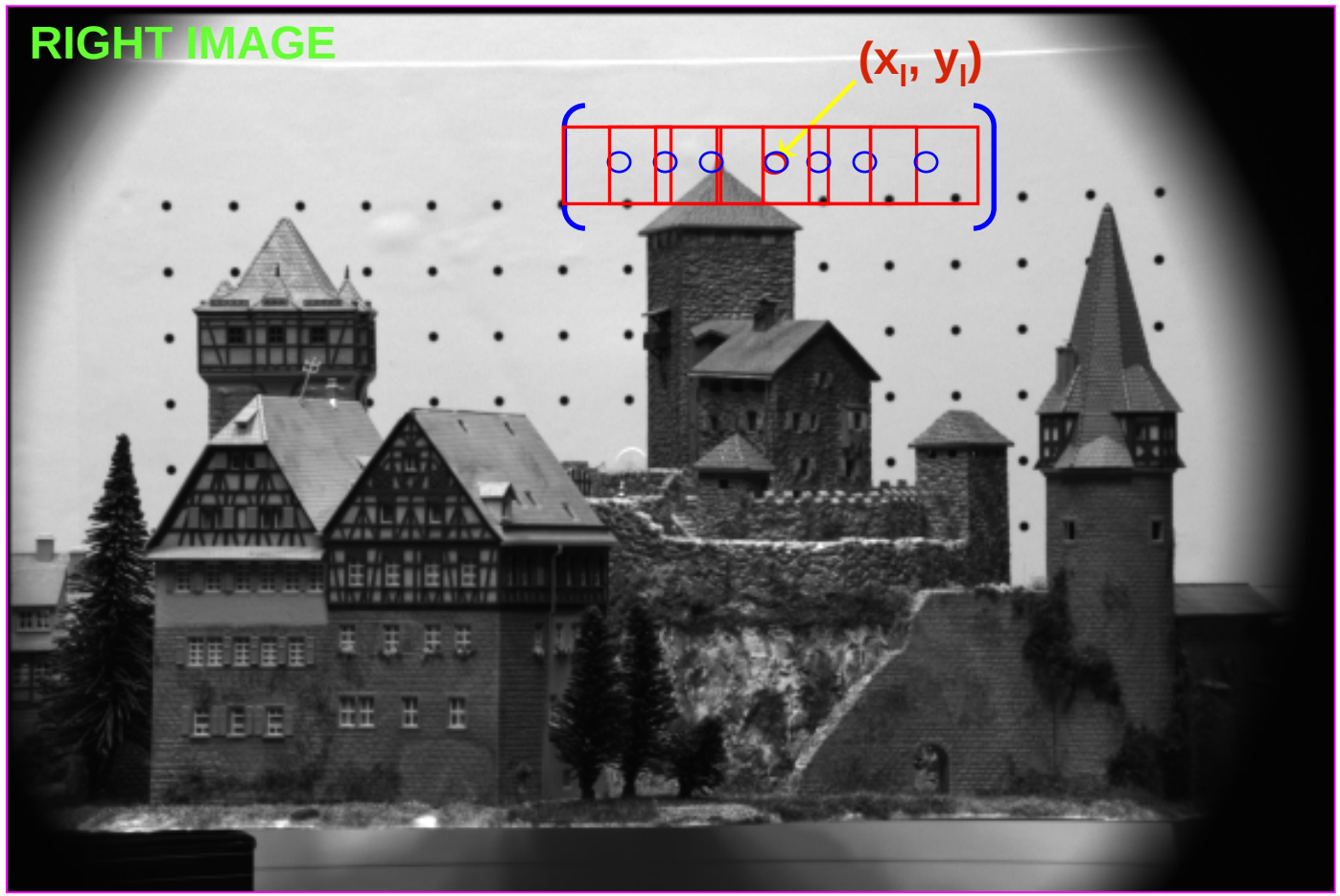
- Two basic approaches
- Correlation methods
  - Apply to all image points
  - Elements are image windows of fixed size
  - Similarity measure is correlation between two windows in the left and right images
  - Corresponding element is window that maximizes similarity criterion within a search window
- Feature methods
  - Apply only to a sparse set of feature points
  - Narrows down feasible matches by using constraints
  - Geometric constraints
  - Analytic constraints – uniqueness and continuity

Correlation Approach



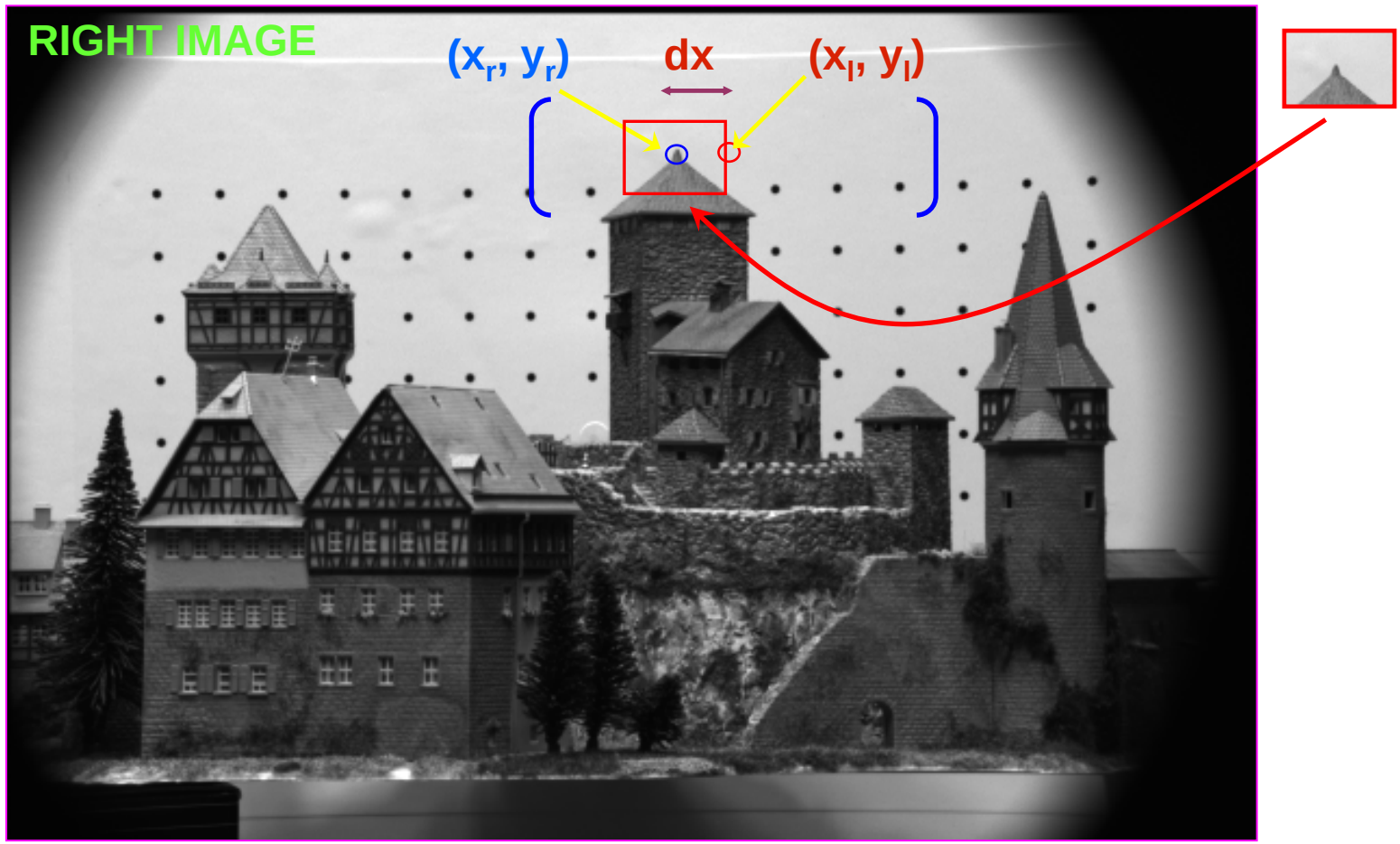
For Each point (x_l, y_l) in the left image, define a window centered at the point

Correlation Approach



… search its corresponding point within a search region in the right image

Correlation Approach



… the disparity (dx, dy) is the displacement when the correlation is maximum

Correlation Approach

Elements to be matched

- Image window of fixed size centered at each pixel in the left image

Similarity criterion

- A measure of similarity between windows in the two images
- The corresponding element is given by window that maximizes the similarity criterion within a search region

Search regions

- Theoretically, search region can be reduced to a 1-D segment, along the horizontal line (in future we will use term epipolar line), and within the disparity range.
- In practice, search a slightly larger region due to errors in calibration

Correlation Approach

Equations = w is the window size

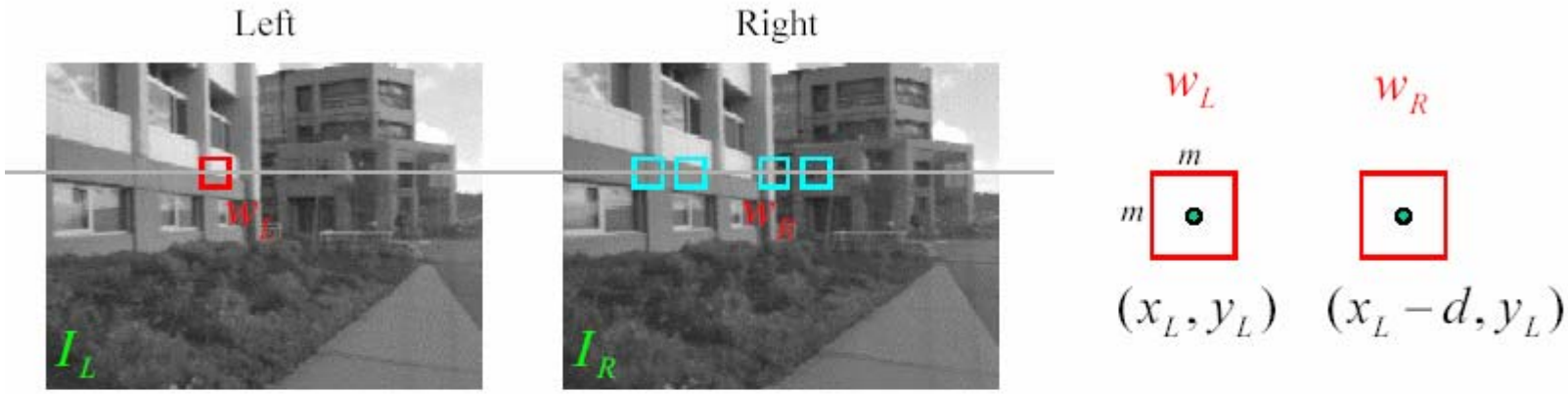
$$c(dx,dy) = \sum_{k=-W}^{W} \sum_{l=-W}^{W} \psi(I_l(x_l + k, y_l + l), I_r(x_l + dx + k, y_l + dy + l))$$

disparity $$\bar{\mathbf{d}} = (\bar{dx}, \bar{dy}) = \arg\max_{\mathbf{d} \in R} \{c(dx,dy)\}$$

Similarity criterion

- Cross-Correlation $\Psi(u,v) = uv$
- Sum of Square Difference (SSD) $\Psi(u,v) = -(u-v)^2$
- Sum of Absolute Difference(SAD) $\Psi(u,v) = -|u-v|$

Sum of Squared Differences (SSD)



w_L and w_R are corresponding m by m windows of pixels.

We define the window function :

$$W_m(x,y) = \{u,v \mid x - \tfrac{m}{2} \le u \le x + \tfrac{m}{2}, y - \tfrac{m}{2} \le v \le y + \tfrac{m}{2}\}$$

The SSD cost measures the intensity difference as a function of disparity :

$$C_r(x,y,d) = \sum_{(u,v)\in W_m(x,y)} [I_L(u,v) - I_R(u-d,v)]^2$$

Correlation Approach

PROS

- Easy to implement
- Produces dense disparity map
- Usually is slow

CONS

- Needs textured images to work well
- Inadequate for matching image pairs from very different viewpoints due to illumination changes
- Window may cover points with quite different disparities
- Inaccurate disparities on the occluding boundaries

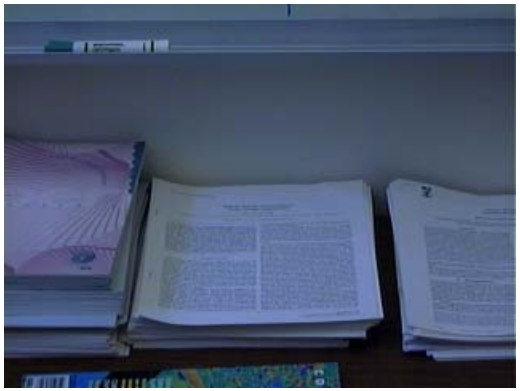
Correlation Approach

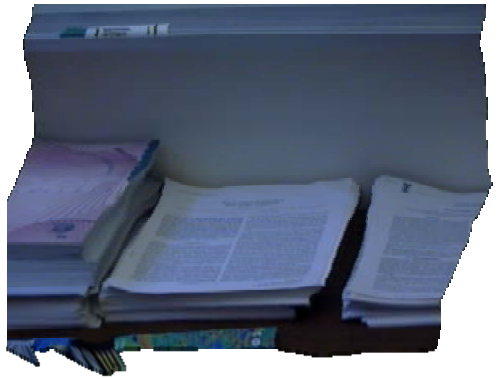
A Stereo Pair of UMass Campus – texture, boundaries and occlusion

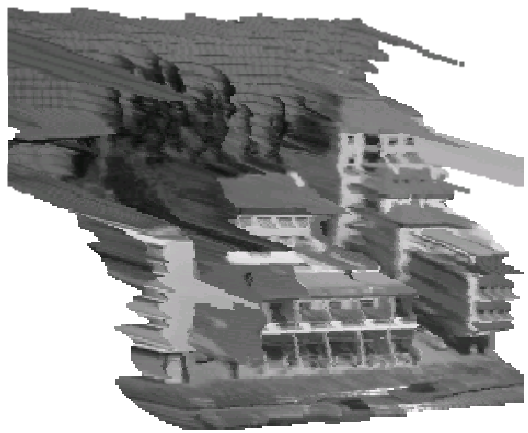
Disparity Map

- $D = ||x_1 – x_2||$ measures the distance between corresponding points in two images
  - Normally disparity is stated as number of pixels
  - Clearly a particular simple stereo configuration has a maximum and minimum possible disparity
- Depth is inversely proportional to disparity
- If we compute the disparity for the entire images then we have a disparity map
- Display it as an image
  - Bright points have highest disparity (closest)
  - Dark points have lowest disparity (farthest)
- Disparity map is a 3D image

Disparity Map





Correspondence Using Correlation

Left

Disparity Map

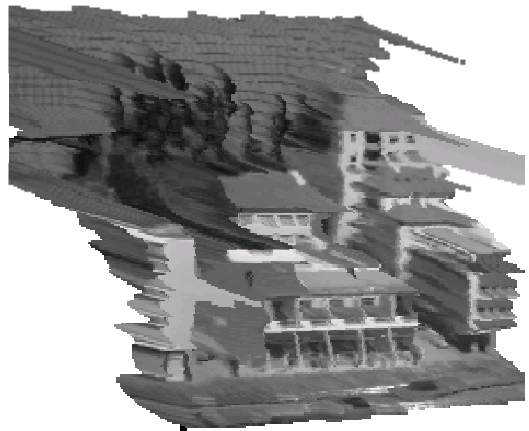
Images courtesy of Point Grey Research

Dense Stereo Matching

View extrapolation results

input

depth image



novel view

[Matthies,Szeliski,Kanade'88]

Feature-based Approach

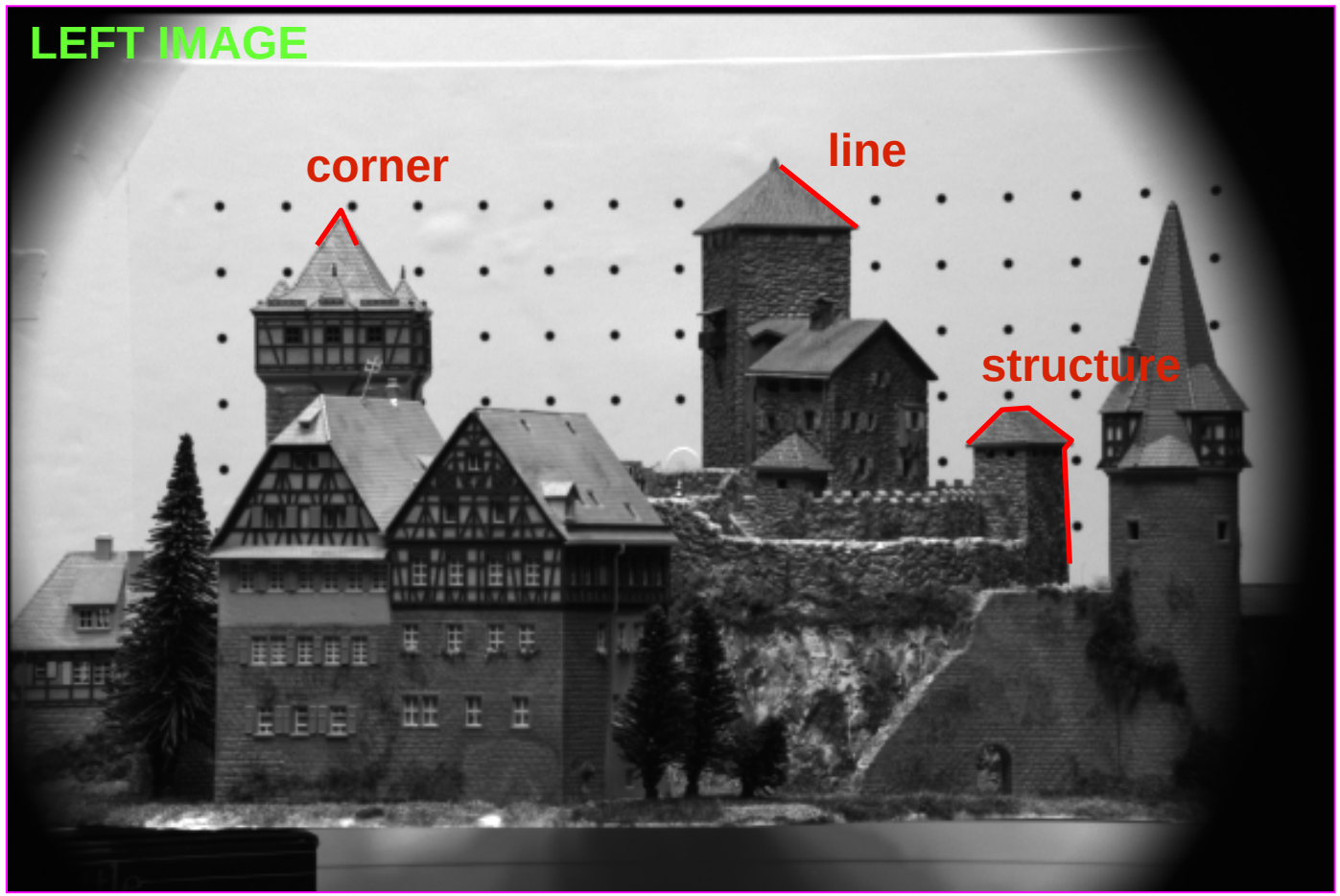
Features

- Edge points
- Lines (length, orientation, average contrast)
- Corners

Matching algorithm

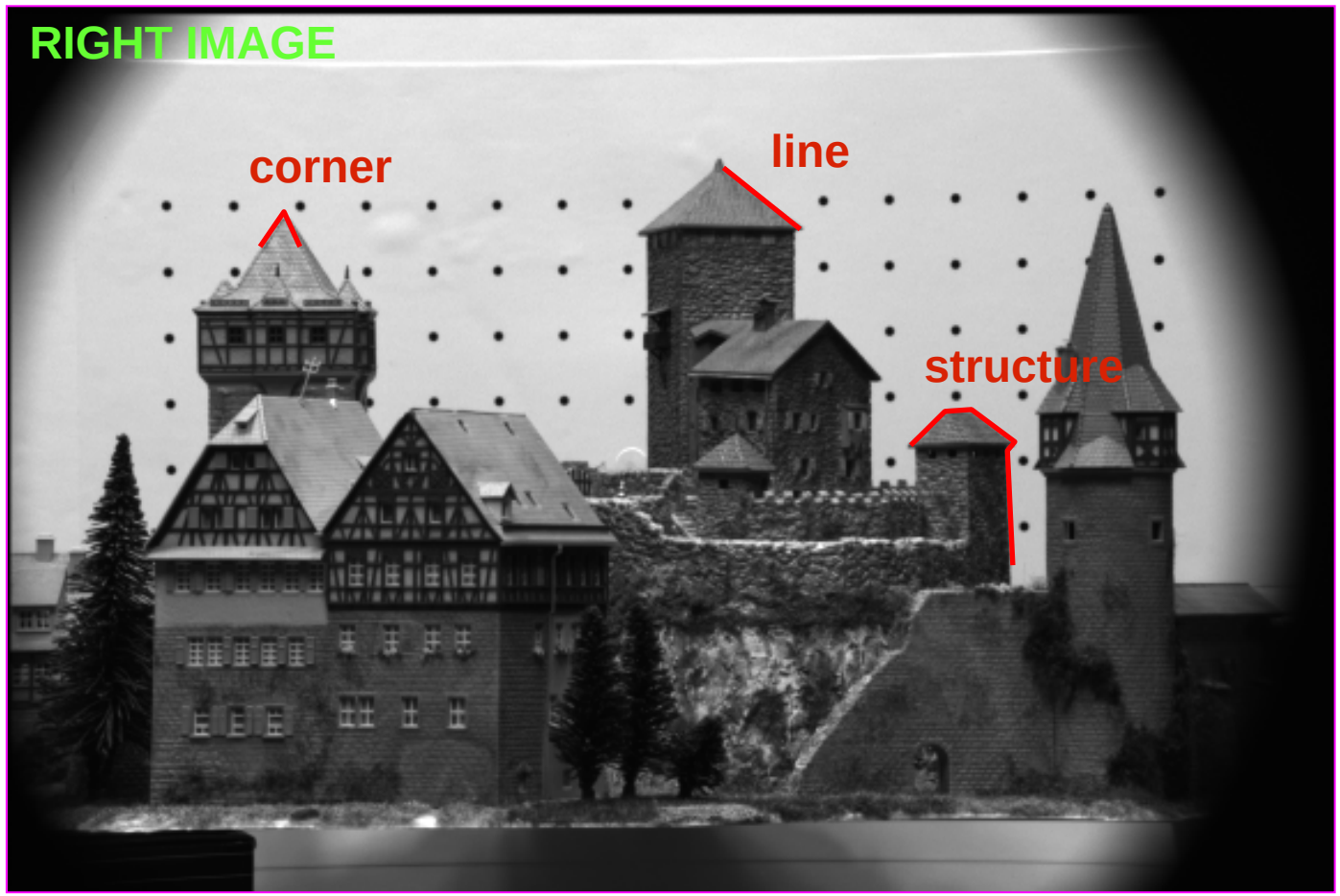
- Extract features in the stereo pair
- Define a suitable similarity measure for these features
- Use constraints to reduce number of matches
- Geometric constraints
  - Need only match features on same horizontal line
- Analytic constraints
  - Uniqueness – each feature has at most one match
    - » Often embedded into the left/right constraint
  - Continuity – disparity varies continuously almost everywhere across this image

Feature-based Approach



For each feature in the left image…

Feature-based Approach



Search in the right image… the disparity (dx, dy) is the displacement when the similarity measure is maximum

Feature-based Approach

PROS

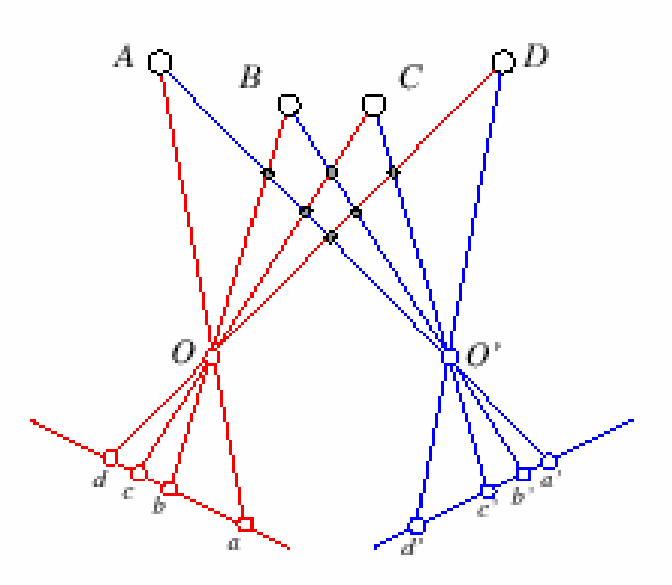
- Relatively insensitive to illumination changes
- Good for man-made scenes with strong lines but weak texture or textureless surfaces
- Work well on the occluding boundaries (edges)
- Could be faster than the correlation approach

CONS

- Only sparse depth map
- Feature extraction may be tricky for some features
  - Often uses corners as the features to match
  - Lines (Edges) might be partially extracted in one image
  - How to measure the similarity between two lines?

Correspondence

It is fundamentally ambiguous, even with stereo constraints



Ordering constraint…

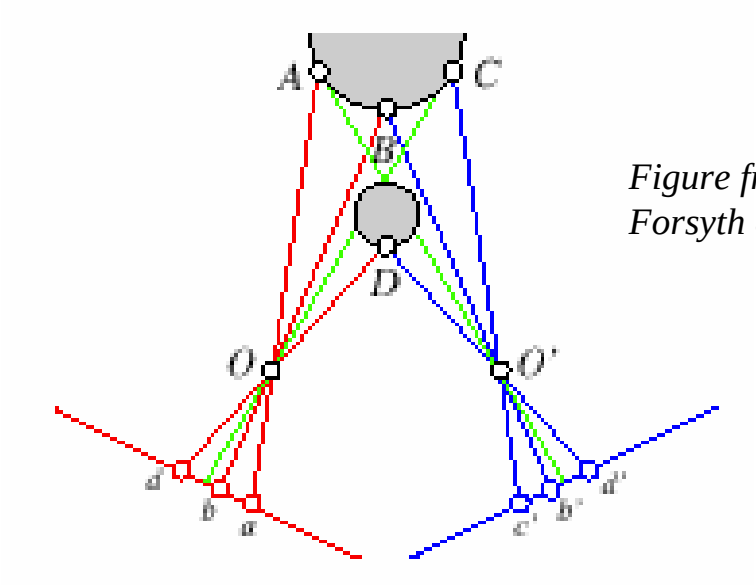
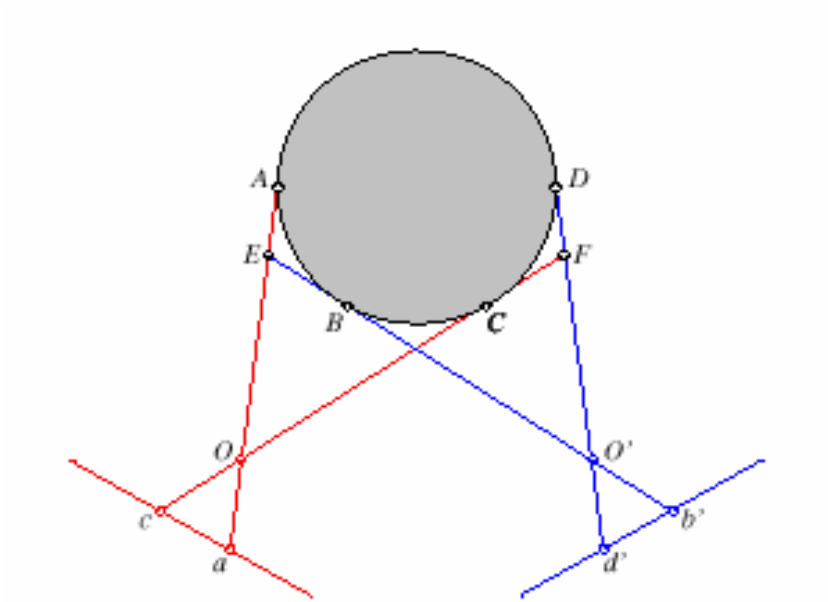


Figure from Forsyth & Ponce

…and its failure

A Last Word on Correspondences

Correspondence fail for smooth surfaces



There is currently no good solution to the correspondence problem

Problems for Correspondence

- Occlusions
  - Points with no counterpart in the other image
  - If algorithm produces a match this is an error
  - The wider the stereo baseline the more chance that there are occlusions
- Spurious matches
  - False correspondences produced for whatever reason
  - One reason is because of occlusions as described above
  - Another is that many elements are very similar