Digital Image Processing ECE 566

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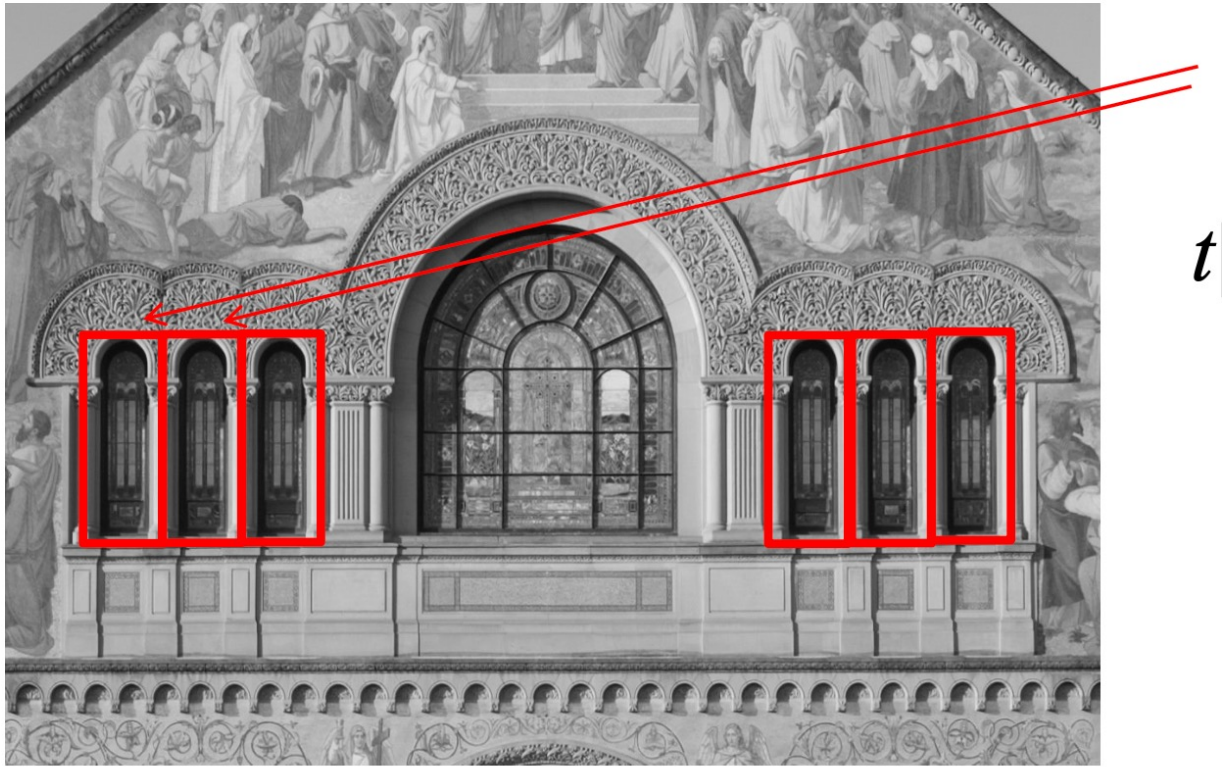
Template Matching

Problem: locate an object, described by a template $t[x,y]$, in the image $s[x,y]$

Face recognition and medical image processing

Example



$t[x,y]$

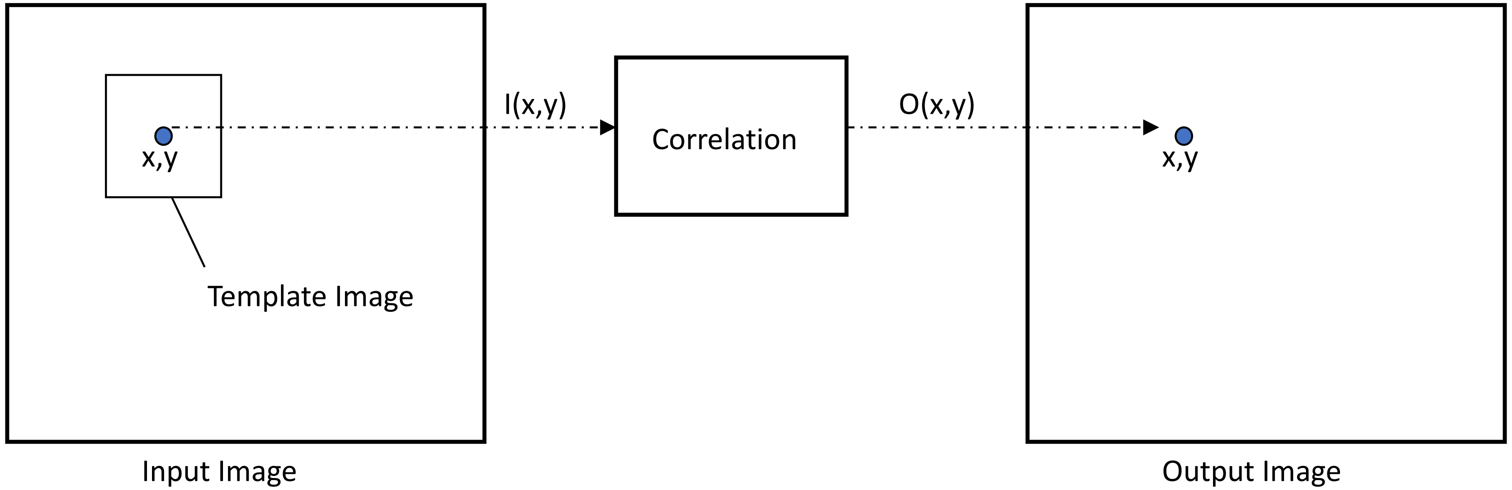
$s[x,y]$

Credit: DIP, Stanford University

Template Matching: Appearance-based Matching

Moving $t[x,y]$ to all possible positions in $s[x,y]$ and computes a numerical index that indicates how well the template matches the image in that position.

Match is done on a pixel-by-pixel basis.



Credit: Longin Jan Latecki, Temple University

Appearance-based Matching: Euclidean Distance

Let I be a gray level image and g be a gray-value template of size n×m.

$$d(I,g,r,c)=\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}\big(I(r+i,c+j)-g(i,j)\big)^{2}}$$

In this formula (r,c) denotes the top left corner of template g.

Credit: Longin Jan Latecki, Temple University

Appearance-based Matching: Correlation

$$cor = \frac{\sum_{i=0}^{N-1}(x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum_{i=0}^{N-1}(x_i - \bar{x})^2 \cdot \sum_{i=0}^{N-1}(y_i - \bar{y})^2}}$$

x is the template gray level image

$\bar{x}$ is the average grey level in the template image

y is the source image section

$\bar{y}$ is the average grey level in the source image

N is the number of pixels in the template image (N= columns * rows)

The value cor is between –1 and +1, with larger values representing a stronger relationship between the two images.

Credit: Longin Jan Latecki, Temple University

Appearance-based Matching: Correlation

Correlation is a measure of the degree to which two variables agree, not necessary in actual value but in general behavior.

It is computationally intensive.

Appearance-based Matching: Correlation

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Example:

Template image size: 53×48. Source image size: 177×236

Assumption: template image is inside the source image (No padding).

Correlation (search) matrix size: 124×188 $(177 - 53 \times 236 - 48)$

Computation count: $124 \times 188 \times 53 \times 48 = 59{,}305{,}728$

Credit: Longin Jan Latecki, Temple University

Appearance-based Matching: Metrics

- Euclidean distance (Sum of squared differences)
- Correlation (like convolution, however kernel is not flipped)
- Sum of absolute differences

Template Matching Metrics in OpenCV

Template Image

Source Image

Template Matching Metrics in OpenCV

1. **method=TM_SQDIFF**

$$R(x,y) = \sum_{x',y'} (T(x',y') - I(x+x',y+y'))^2$$

2. **method=TM_SQDIFF_NORMED**

$$R(x,y) = \frac{\sum_{x',y'} (T(x',y') - I(x+x',y+y'))^2}{\sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x+x',y+y')^2}}$$

3. **method=TM_CCORR**

$$R(x,y) = \sum_{x',y'} (T(x',y') \cdot I(x+x',y+y'))$$

4. **method=TM_CCORR_NORMED**

$$R(x,y) = \frac{\sum_{x',y'} (T(x',y') \cdot I(x+x',y+y'))}{\sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x+x',y+y')^2}}$$

5. **method=TM_CCOEFF**

$$R(x,y) = \sum_{x',y'} (T'(x',y') \cdot I'(x+x',y+y'))$$

where

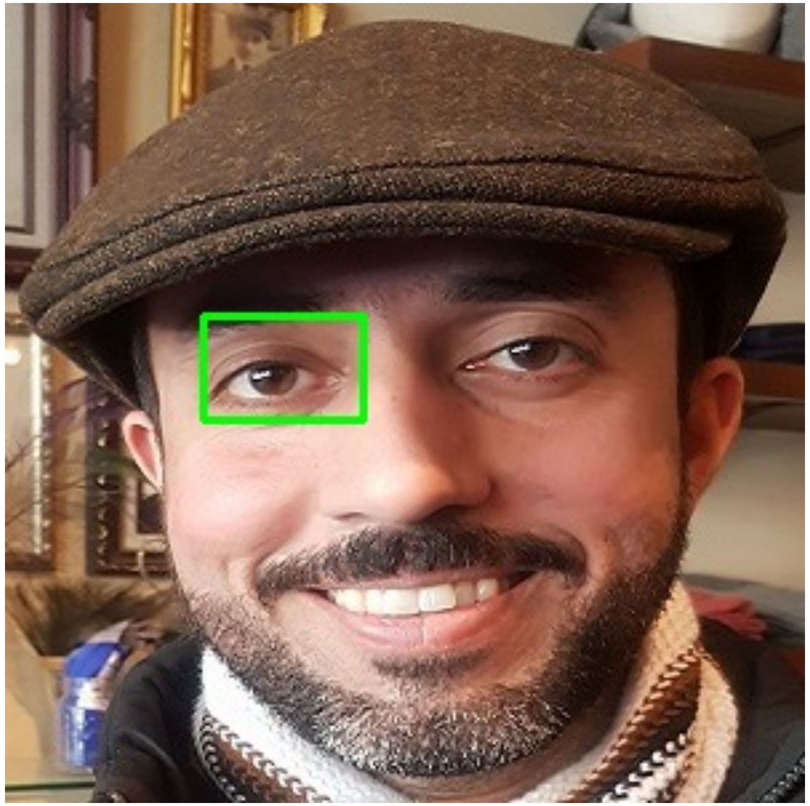
$$T'(x',y') = T(x',y') - 1/(w \cdot h) \cdot \sum_{x'',y''} T(x'',y'')$$
$$I'(x+x',y+y') = I(x+x',y+y') - 1/(w \cdot h) \cdot \sum_{x'',y''} I(x+x'',y+y'')$$

6. **method=TM_CCOEFF_NORMED**

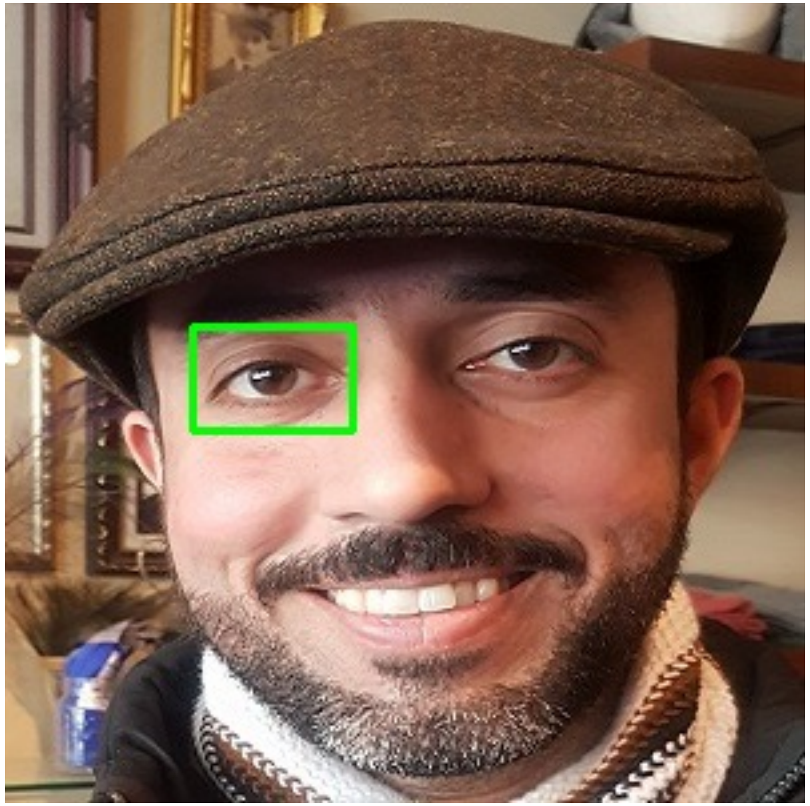
$$R(x,y) = \frac{\sum_{x',y'} (T'(x',y') \cdot I'(x+x',y+y'))}{\sqrt{\sum_{x',y'} T'(x',y')^2 \cdot \sum_{x',y'} I'(x+x',y+y')^2}}$$

Credit: https://docs.opencv.org/3.4/de/da9/tutorial_template_matching.html

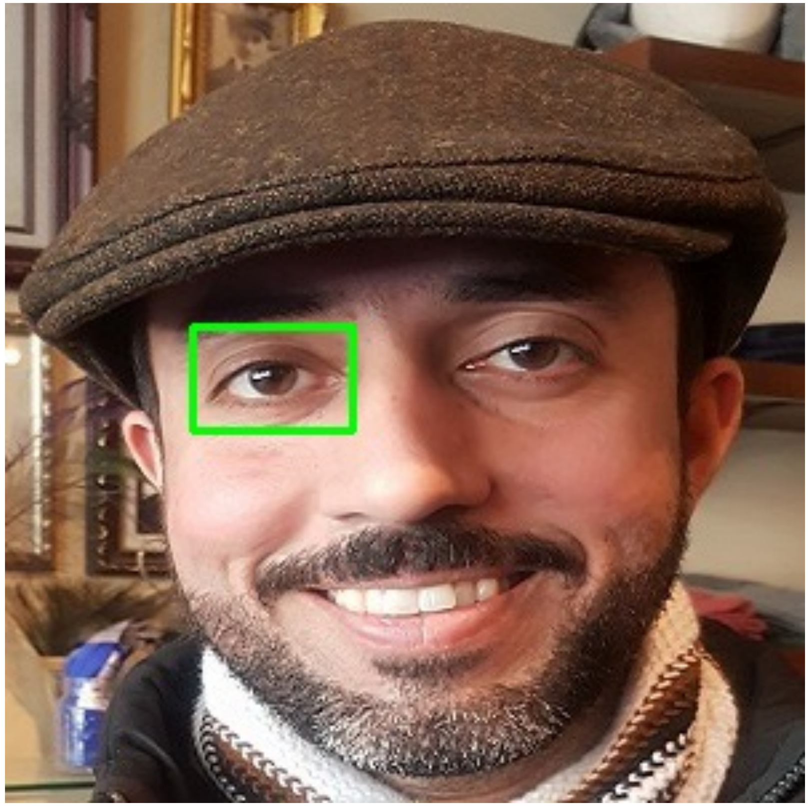
Template Matching Metrics in OpenCV



cv2.TM_SQDIFF



cv2.TM_CCORR



cv2.TM_CCOEFF

Appearance-based Matching: Metrics

- Euclidean distance (Sum of squared differences)
- Correlation (like convolution, however kernel is not flipped)
- Sum of absolute differences

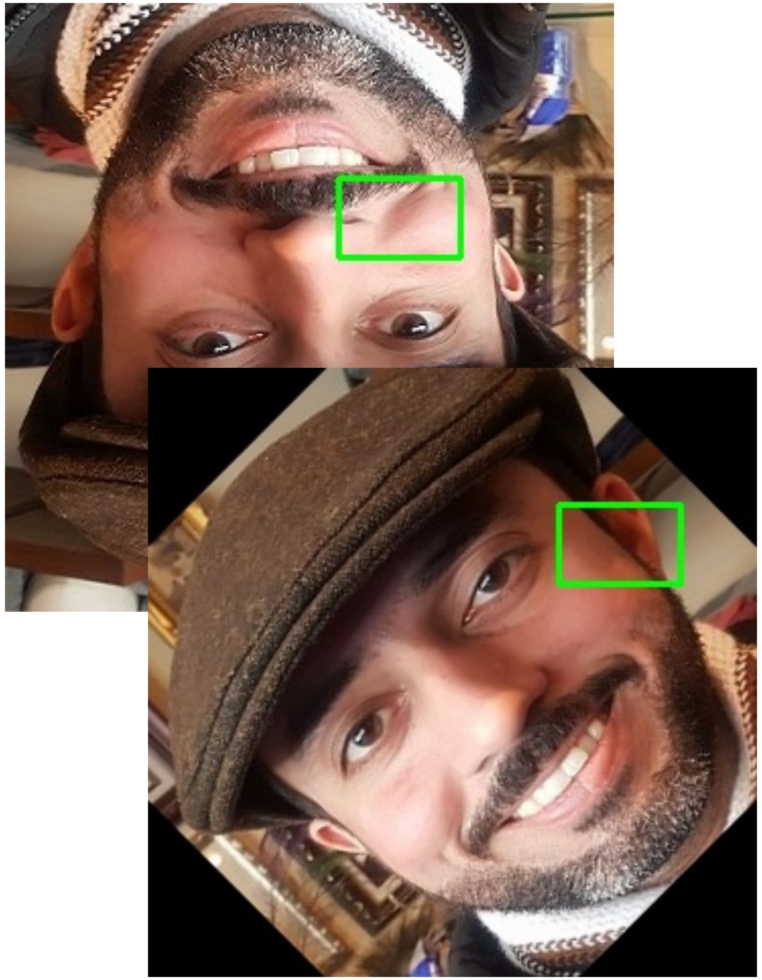
- Unfortunately, these approaches will fail if there is a significant difference in

  illumination, object color, viewpoint, etc.

Credit: Longin Jan Latecki, Temple University

Template Matching Metrics in OpenCV

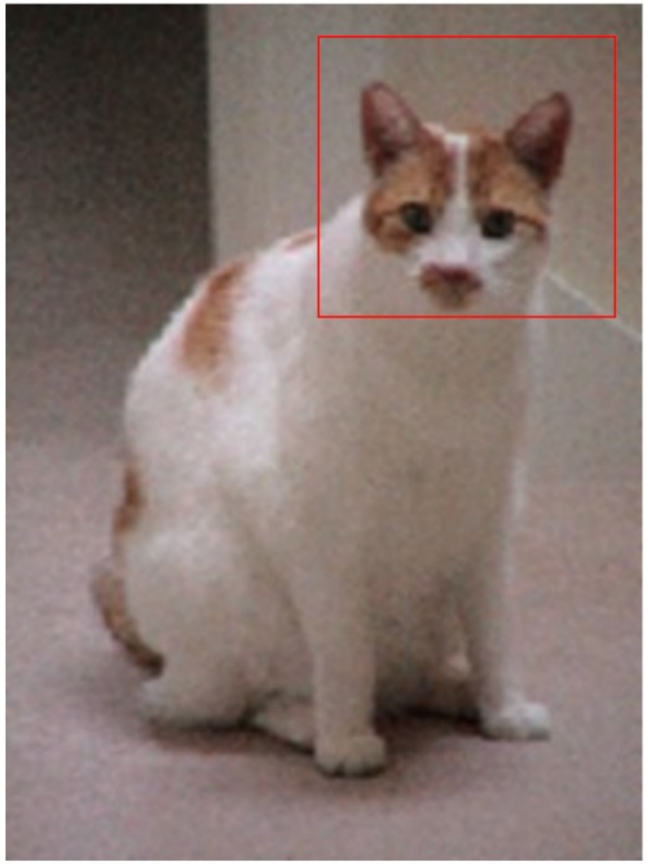
cv2.TM_SQDIFF



cv2.TM_CCORR

cv2.TM_CCOEFF

Appearance-based Matching: problem



? =

? =

Frontal faces are fairly easy to find (and sometimes classify)

However, changes to lighting and background cause problems.

Credit: Olsen, TemplateMatching, University of Washington

Edge Matching

Changes in lighting and color usually don't have much effect on image edges.

Credit: Olsen, TemplateMatching, University of Washington

Edge Matching

Strategy:

- Detect edges in template and image
- Compare edge images to find the template
- Must consider range of possible template positions

Credit: Olsen, TemplateMatching, University of Washington

Edge Matching: Measures

What measure should we use to compare edge images?

Can count number of overlapping edges. → It uses the maximum value location from the template matching result.

Not robust to changes in shape

Better: count number of template edge pixels with some distance of an edge in the search image. → It counts the number of template edge pixels that are close to edges in the search image.

Best:

- Determine probability distribution of distance to nearest edge in search image (if template at correct position)
- Estimate likelihood of each template position generating image

→ It calculates the average distance to the nearest edge in the search image for the template edge pixels.

Gradient Matching

One way to be robust to illumination changes, but not throw away as much information is to compare image gradients.

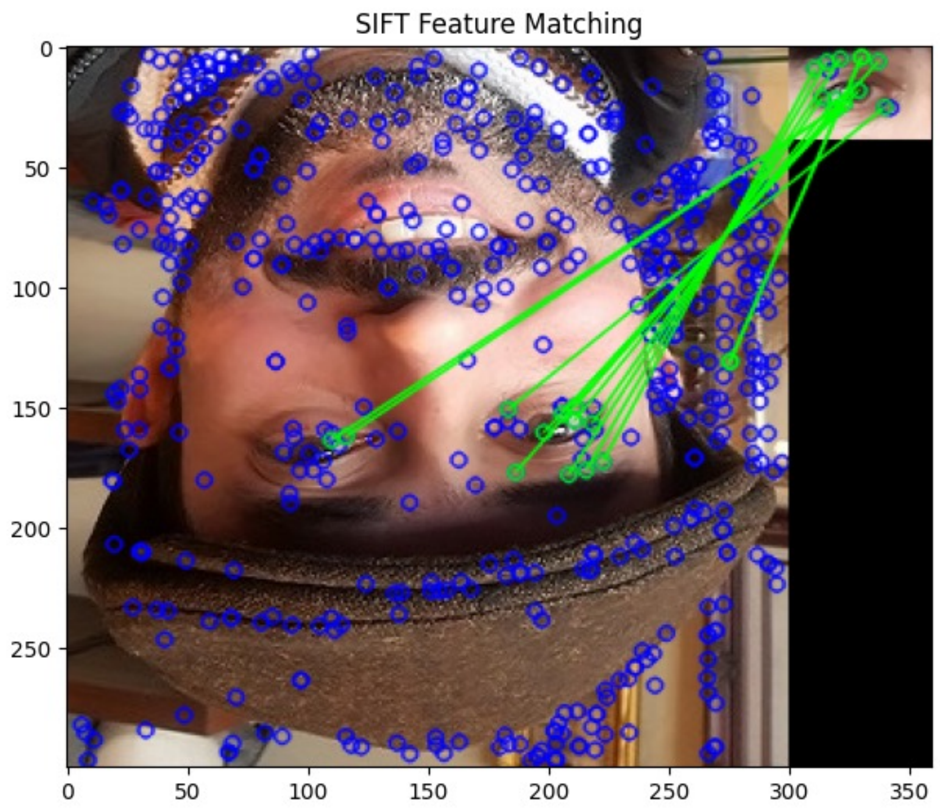
Matching is performed like matching greyscale images.

Simple alternative: use (normalized) correlation.

Robust TM to Rotation and Mirroring

Use a combination of techniques, such as feature matching and orientation estimation.

One approach: SIFT (Scale-Invariant Feature Transform) algorithm for feature extraction and matching. SIFT is invariant to scale, rotation, and partially invariant to affine transformations.



Note: SIFT is a patented algorithm in 2022, it might not be available in some OpenCV distributions due to patent restrictions.