Face Detection, Hierarchical Image Analysis, Motion Analysis by Image Differencing, Template Matching, SSD, NCC
Class Poll:
Which line equation is wrong?

A. \( y = mx + n \), where \( m = 1 \), \( n = 0 \)

B. \((-1,1)^T x - g = 0\), where \( g = \sqrt{2} \)

C. \(-x \sin \alpha + y \cos \alpha = 0\), where \( \alpha = 45 \) degrees

D. \((-\sin \pi/4, \cos \pi/4)^T x = 0\)
Finding the Head and its Movement by Detecting Pixels with Skin Color

Hope:
Largest skin color “blob” is face.

Fewer false positive skin pixels in background, e.g., wooden door.
Finding the Head and its Movement by Detecting Pixels with Skin Color

Common Trick in Computer Vision:
Use
“image pyramid” = input image at difference scale.
Here: 6 levels, reduction in x, y by ¼ (other schemes possible)
Then process result pyramid. Why?
Finding Movement by Detecting Pixels with Brightness Changes

- $\text{DifferenceImage}(x,y,t) = \text{Image}(x,y,t) - \text{Image}(x,y,t-1)$

- Or
  
  $\text{DifferenceImage}(x,y,t) = \text{Image}(x,y,t) - \text{Image}(x,y,t-k)$
  
  where $k > 1$, e.g., 10

- Or
  
  $\text{DifferenceImage}(x,y,t) = |\text{Image}(x,y,t) - \text{Image}(x,y,t-k)|$

Why absolute value?
Finding the Face and its Movement by Locating the Best Match of a Face Template

Better matches shown brighter
Best match: Blue pixel
Finding the Face and its Movement by Locating the Best Match of a Face Template

Use Jingbin’s face as a template

Visualization of Match Values

How can we compute a match?
Template Matching with Sum-Squared Difference (SSD)

- Scene subimage $s$, template image $m$
- same size images = $n$ pixels
- $s_i = ith$ pixel in subimage of scene
- $m_i = ith$ pixel in template image $m$

- \[ SSD = \sum_{i=1}^{n} (s_i - m_i)^2 \]

- Template matching = exhaustive search algorithm for position of scene subimage that best matches the template (where SSD is smallest)
Finding the Face and its Movement by Locating the Best Match of a Face Template

Used average face as a template

Visualization of Match Values
Normalized Correlation Coefficient (NCC)

Paired pixels in image X and Image Y:

\[ \{(x_1, y_1), \ldots, (x_n, y_n)\} \]

Definition of NNC:

\[
\rho_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}}
\]

where the mean for the image X pixel values is

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]

The mean for Y is defined similarly.

The NCC is also called “Pearson coefficient.” Pearson was not the inventor. He is known for eugenics and scientific racism, so we will not use his name to describe the NCC in CS 585.
Template Matching via with Normalized Correlation

- Scene subimage $s$, template image $m$
- Normalized correlation coefficient
  \[ r = \frac{1}{n} \sum_i ((s_i - \text{mean}(s)) \times (m_i - \text{mean}(m))}{\sqrt{\text{mean}(s) \times \text{mean}(m)}} \]
  where $s_i$ and $m_i$ are respective brightness values of the $i$th pixel
  $\text{mean}(m)$ and $\sigma_m$ are mean and standard deviation of all pixels in the template
  $\text{mean}(s)$ and $\sigma_s$ are mean and standard deviation of all pixels in the subimage of the scene
- Template matching = exhaustive search for position of subimage that produces highest $r$
- $r$ can be between -1 and 1
Finding the Face and its Movement by Locating the Best Match of a Face Template

Used average face as a template

Visualization of Normalized Correlation Coefficient Match Values
Finding the Face with Template Matching & the Normalized Correlation Coefficient

(a) Input

(d) Correlation
Multi-Resolution Matching

Normalized correlation coefficient over multi-resolution search space:

\[ r = \frac{1}{n} \sum_i (s_i - \text{mean}(s)) (m_i - \text{mean}(m)) \]

\[ \frac{(\sigma_s \sigma_m)}{(\sigma_s \sigma_m)} \]
You can apply template matching to a small version of your input image and use that search result to start searching for a match in the 2nd smallest images. Repeat until the original size is processed.

(a) Input  (d) Correlation
Multi-scale Pyramids

Combine the results of color and motion detection to mask the regions of interest for correlation-based template matching.
Face Detection

Data Variability

Large Face  Small Face

Shadows  Cluttered background
Algorithm: Multi-scale Face Detection

Video Input

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Color & Motion Analysis

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Mask Input Pyramids

↓

Face Tracking: Template Correlation Over Pyramid

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Output: Face Location and Scale
Face Detection Interface
Max Score: 193; Scale: 6; Location: (160, 120)
Learning Objectives

Can explain and apply to image analysis problems:

- Detection by Color Analysis
- Hierarchical Image Analysis
- Motion Analysis by Image Differencing
- Sum-squared Difference (SSD)
- Normalized Correlation Coefficient (NCC)
- Template Matching with SSD or NCC