EEE-6561 Fundamentals of Biometric Identification

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Lecture #7 Face Recognition

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Part I: The Face

Faces are useful

- **Human face images are useful for many things:**
  - Person recognition
  - Gender, age, ethnicity, and emotional state of person (affect)
- **Face recognition has been studied extensively in computer vision**
- **Face is important biometric modality in may applications**
  - Law enforcement
  - Human-computer interaction
  - Surveillance

Face Perception by Humans

- Humans are good at recognizing faces that are familiar.
- The specific cognitive processes involved in face recognition are not well understood.
- Training a machine to recognition face similarly as humans do is a difficult task.

What is a face?

- It is the frontal portion of the human head, extending from the forehead to the chin and includes the mouth, nose, cheeks, and eyes.
- The face is considered the most commonly used biometric modality by humans.
- Hence, it has become a standard practice to incorporate face photographs in various authentication tokens such as ID cards, passports, and driver’s licenses.

What is Face Recognition

- Defined as establishing a person's identity based on facial characteristics
- In its simplest form, the problem of face recognition involves compare two face images and determining if they are of the same person.
- Humans are good at determining the similarity between two face images acquired under diverse conditions, while automated face recognition has several challenges.

Face Variations

- **Face images of a person my have variations in:**
  - Changes in appearance due to facial hair, make-up, or accessories (glasses, piercings)
  - Age, pose, illumination, and expressions
- **The specific neural and cognitive processes involved in humans for face recognition are still not completely known.**

Advantages of Using Face

- **Face can be captured at a longer standoff distance using non-contact sensors**
- **Face conveys identity and the emotion of a person as well as biographic information**
- **Large legacy face databases are available which can allow for the analysis of individuality and scalability**
- **Higher user acceptance**
  - People are more willing to share images of their face compared to other biometric traits such as fingerprint and iris.

Psychology of Face Recognition

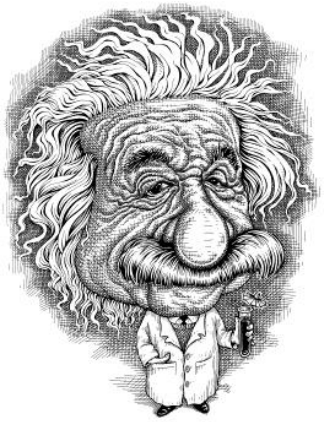
- **The underlying mechanism for face perception in humans has been studied for two purposes:**
  - To design machine recognition system that can mimic the human ability to recognize faces
  - To understand the neurological or psychological mechanisms of the brain functions for medical treatment
- **Because it is difficult to directly observe the brain functions related to face recognition, indirect observations are commonly made to understand the mechanism supporting human face recognition**

Psychology of Face Recognition (cont.)

- Based on the observations that humans can recognize caricatures and cartoon faces, it is inferred that humans perceive the face based on certain higher-level characteristics.
- Studies using advanced brain imaging techniques such as functional magnetic resonance image (fMRI) are expected to reveal the precise face processing mechanism in the human brain.

Cartoon Faces

Vincent Van Gogh



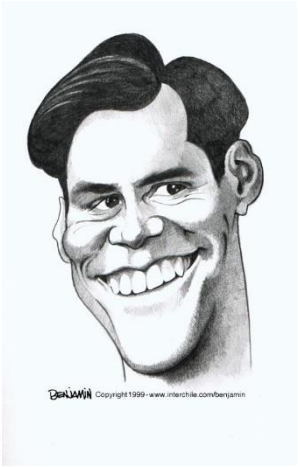
Albert Einstein

Bill Gates

- Humans can recognize caricatures and faces in cartoons
- Certain facial features are salient for each individual

Bill Cosby

Taylor Swift



Jim Carrey

www.magixl.com
www.pritchettcartoons.com
www.interchile.com/benjamin

http://www.tomrichmond.com/blog/wp-content/uploads/2008/11/swift.jpg

Margaret Thatcher Effect

Margaret Thatcher Effect

Facial Features: Three Levels

- **Level 1 Details**
  - Consist of gross facial characteristics that are easily observable
- **Examples**
  - The general geometry of the face and global skin color
- **Such features can be used to discriminate between**
  - Faces exhibiting male and female characteristics
  - Faces of different races
  - A short round face and an elongated thin face
- **These features can be extracted even from low resolution face images, e.g. < 30 interpupilary distance (IPD)**

Facial Features: Three Levels (cont.)

- **Level 2 Details**
  - Consists of localized face information such as the structure of the face components, the relationship between facial components, and the precise shape of the face
  - These features are essential for accurate face recognition, and they require a higher resolution face image (30 – 75 IPD). The characteristics of local regions of the face can be represented using geometric or texture descriptors.

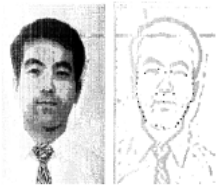
Facial Features: Three Levels (cont.)

- **Level 3 Details**
  - Consist of unstructured, micro level features on the face, which includes scars, freckles, skin discoloration, and moles
  - One challenging face recognition problem where level 3 details may be critical is the discrimination of identical twins.

Part II: Face as a Biometric

Face Recognition Milestones

1964
Woodrow Bledsoe
Face recognition

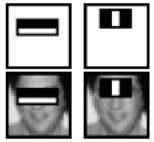


1973
Takeo Kanade
First FR thesis

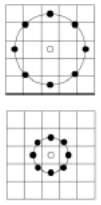
1991
Turk & Pentland
Eigenface

1997
Belhumeur et al.
Fisherface

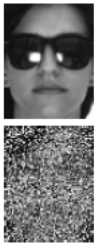
1999
Blanz & Vetter
Morphable face



2001
Viola & Jones
Face detector



2006
Ahonen et al.
LBP



2009
Wright et al.
Sparse rep.

1915
35mm still camera

1991
Kodak
Digital camera
1024p

1990s
Surveillance camera
480p @ 30fps

2000
Sharp
First camera phone
320p

2010-2013
Wearable camera
480P @ 30fps
Google Glass
720p @30fps

April 2013
Samsung Galaxy S4
1080p @ 30fps

Bledsoe, W. W. 1964. The Model Method in Facial Recognition, TR PRI 15, Panoramic Research, Inc., California.
Takeo Kanade, Picture Processing System by Computer Complex and Recognition of Human Faces, Kyoto Univ.,1973.
M. Turk and A. Pentland, Eigenfaces for recognition. Journal of Cognitive Neuroscience 3 (1): 71–86, 1991.
Belhumeur, P.N. et al., Eigenfaces vs. Fisherfaces: recognition using class specific linear projection, PAMI, 19-7, 1997.
V. Blanz and T. Vetter, A morphable model for the synthesis of 3D faces, SIGGRAPH 1999.
http://commons.wikimedia.org/wiki/File:Three_Surveillance_cameras.jpg
http://photodoto.com/camera-history-timeline/
Viola, Jones: Robust Real-time Object Detection, IJCV 2001.
Ahonen,et al. Face Description with Local Binary Patterns: Application to Face Recognition, *PAMI*, 2006.
J. Wright et al. Robust Face Recognition via Sparse Representation, PAMI, 31-2, 2009.
http://static7.businessinsider.com/image/4d013ea7cadcbb7033010000/looxcie-video-camera.jpg
http://www.techinasia.com/samsung-galaxy-s4-infographic/

Face Recognition

- Face is the most common biometric characteristic used by humans for recognition

- Applications range from static, mug-shot verification to a dynamic, uncontrolled face identification in a cluttered background

- Challenges: automatically locate the face and recognize the face from a general view point under different illumination conditions, facial expressions, and aging effects

Face Recognition

- Multiple faces, cluttered background

- Mug-shots

Inter-class Similarity

- Different persons may have very similar appearance

www.marykateandashley.com

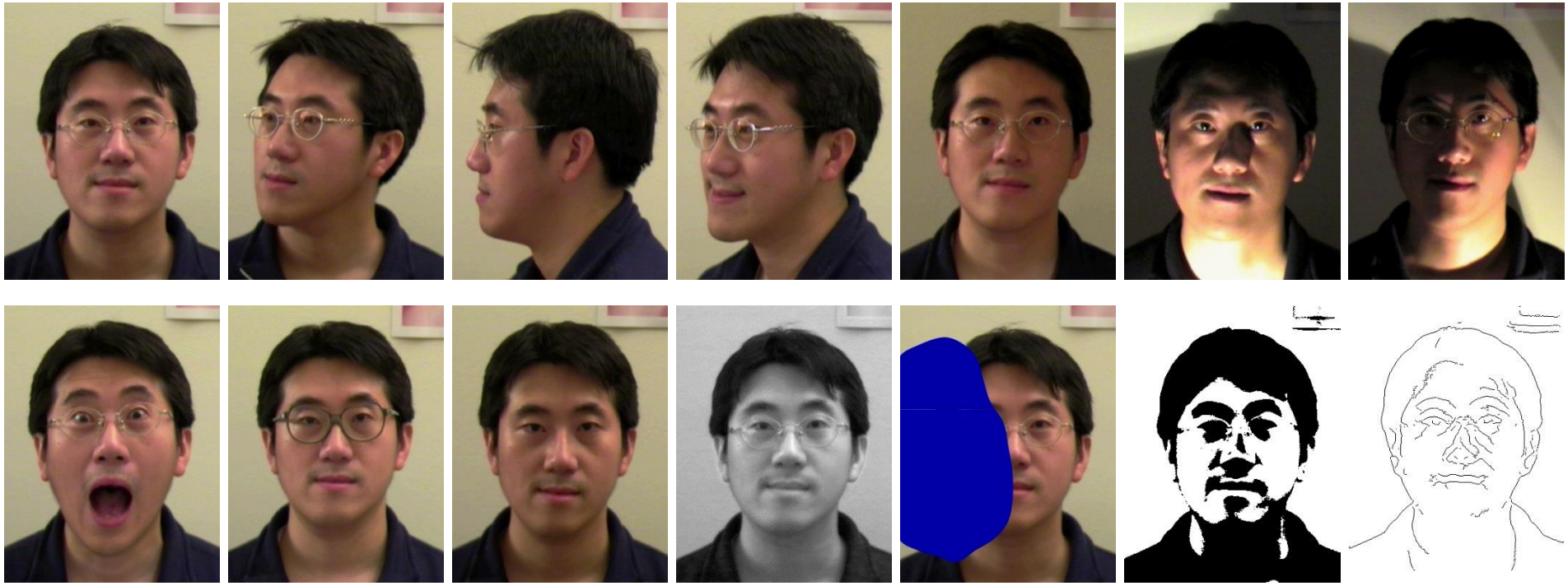
Twins

news.bbc.co.uk/hi/english/in_depth/americas/2000/us_elections

Father and son

Intra-class Variability

- Faces with intra-subject variations in pose, illumination, expression, accessories, color, occlusions, and brightness



Face Recognition: Advantages

- Public acceptance for this biometric identifier
- Face recognition systems are the least intrusive from a biometric sampling point of view, requiring no contact, nor even the awareness of the subject
- The biometric works, or at least works in theory, with legacy photograph data-bases, videotape, or other image sources
- Face recognition can, at least in theory, be used for screening of unwanted individuals in a crowd, in real time
- It is a fairly good biometric identifier for small-scale verification applications

Face Recognition: Disadvantages

- A face needs to be well lighted by controlled light sources in automated face authentication systems. This is only a first challenge in a long list of technical challenges that are associated with robust face authentication
- Face currently is a poor biometric for use in a pure identification protocol
- An obvious circumvention method is disguise
- There is some criminal association with face identifiers since this biometric has long been used by law enforcement agencies (‘mugshots’).

Psychophysics/Neuroscience Issues

- Face recognition is a dedicated process, which is sensitive to illumination and rotation.

- Features of faces
  - Both holistic and local features are important.
  - Hair, face outline, eyes and mouth are important; Nose is not important.
  - Upper part is more important than lower part
  - Attractive faces are more recognizable (smiling face is more recognizable?)

Psychophysics/Neuroscience Issues

Factors in face recognition

- *Distinctiveness* : atypical faces are more easy to be recognized, but are harder to be detected than typical ones.
- *Viewpoint* : face recognition is viewpoint-dependent
- *Illumination* : bottom light makes recognition harder.

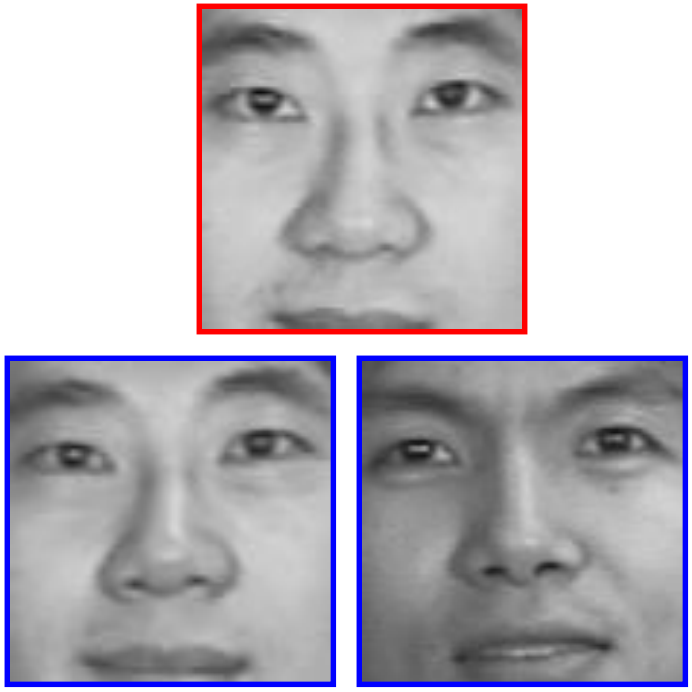
In the literature…

- **Appearance-based methods:** generate a compact representations of the entire face region in the acquired image by mapping the high dimensional face image to a lower dimensional subspace.
- **Texture-based methods:** use textural features to represent and detect facial patterns
- **Model-based methods:** attempt to build a 2D or 3D face models that facilitate matching of faces images in the presence of pose changes.

Appearance-Based Face Recognition

Appearance-based Techniques

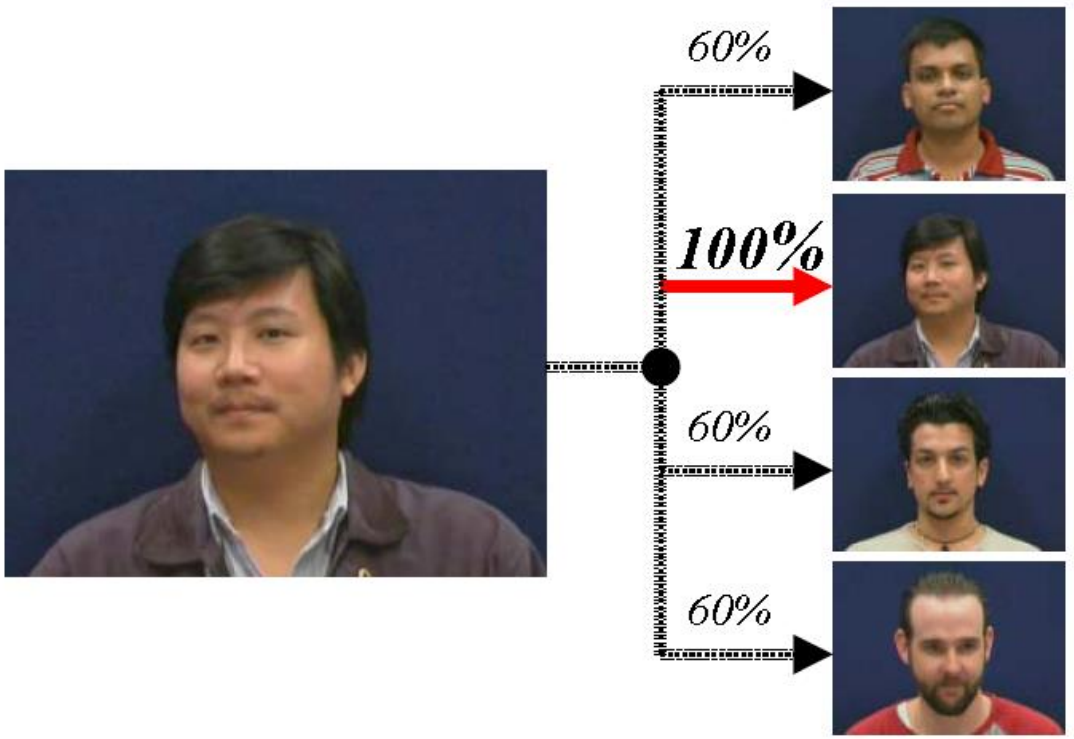
- Derive features based on the pixel values of the face image



Example:

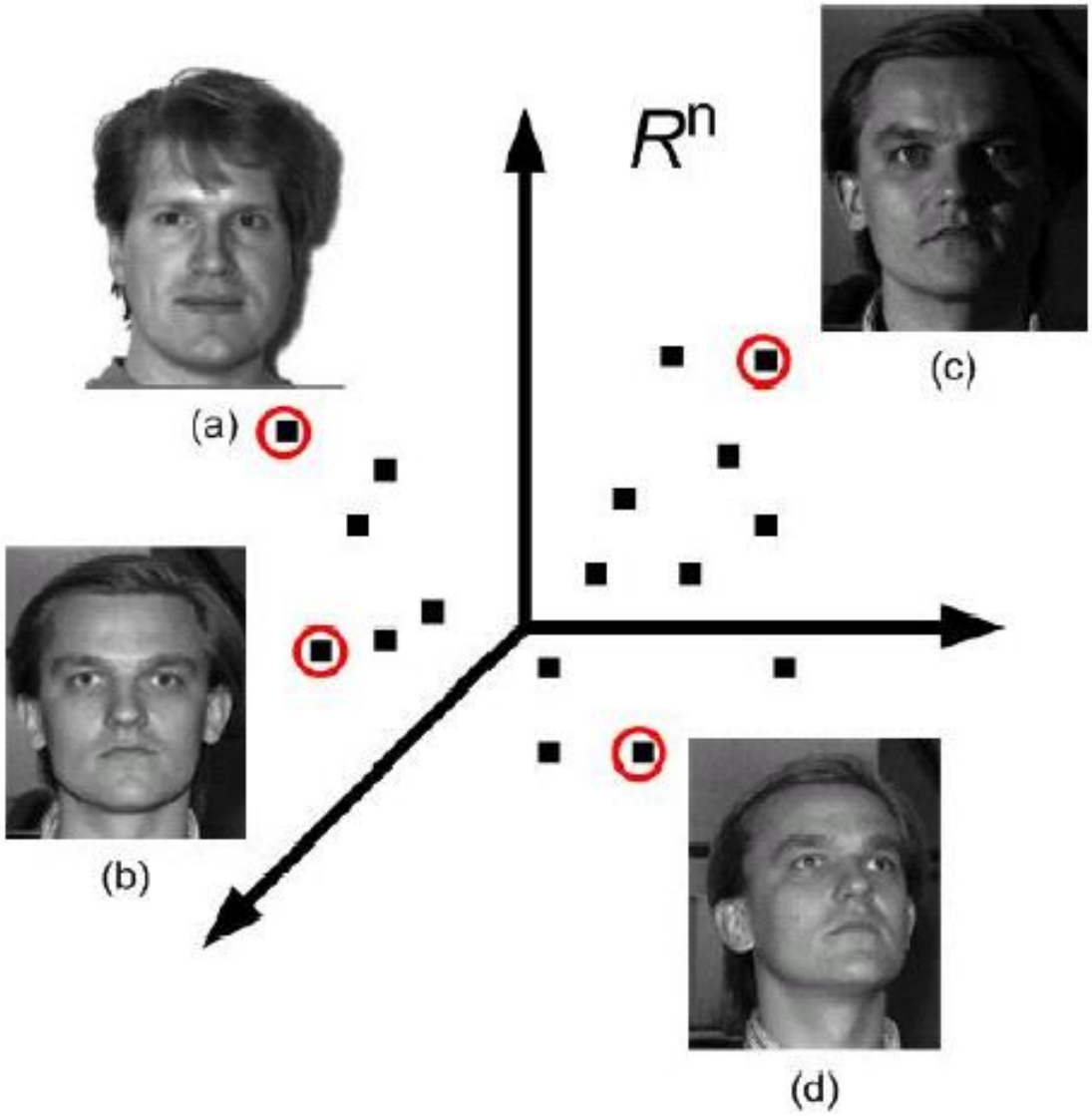
- Convert 2D pixel intensity values of the image into a 1D feature vector
- Transform this feature vector to a low-dimensional salient representation
- Face recognition involves comparing two such representations (feature vectors)

Appearance-Based: Correlation



Two images are superimposed and the correlation between corresponding pixels is computed for different alignments.

Appearance-based Techniques



- Assume that each image is of size 50x50
- Corresponding 1D feature vector is of size 2500
- Need dimensionality reduction

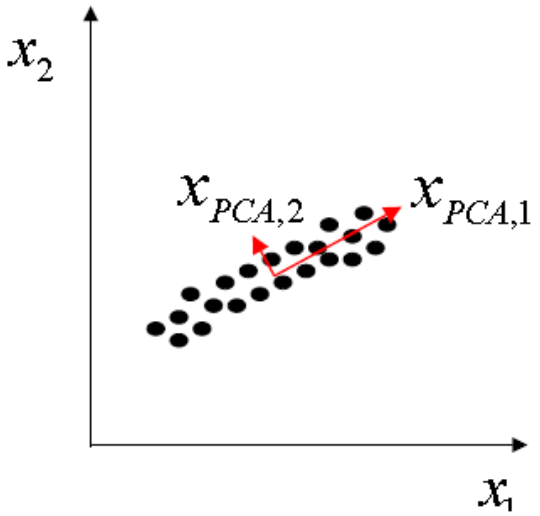
Dimensionality Reduction

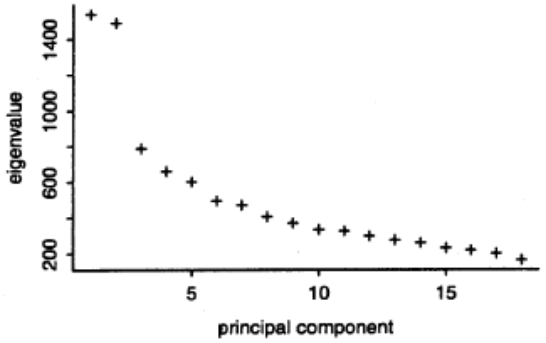
- Dimensionality reduction is commonly achieved through the use of two well-known linear transformations:
  - Principal Component Analysis (PCA)
  - Linear Discriminant Analysis (LDA)

1. *M. Turk and A. Pentland, "Eigenfaces for recognition," Journal of Cognitive Neuroscience, vol. 3, no. 1, pp. 71–86, Mar. 1991.*
2. *P. N. Belhumeur, J. P. Hespanha, and D. J. Kriegman, "Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection," IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 19, no. 7, pp. 711–720, Jul. 1997.*

Principal Component Analysis (PCA)

- A **face image** defines a point in the high-dimensional image space
- Different face images share a number of similarities with each other
- They can be described by a relatively low-dimensional subspace
- They can be projected into an appropriately chosen subspace of **eigenfaces** and classification can be performed by similarity computation (distance)





Eigen Faces

Input Face

Mean

MEF1

MEF2

MEF3

MEF4

MEF5

MEFm

w0 w1 w2 w3 w4 w5 wm

Reconstructed Face

(Weighted sum)

Fisher Faces (LDA-based)

- Unlike PCA, this technique utilizes class-specific information
- Two types of scatter matrices (covariances) are used:
  - S_w (within-class scatter matrix)
  - S_B (between-class scatter matrix)
- Compute the eigen vectors (eigen values) of the matrix ($S_w^{-1}S_B$); the eigen vectors corresponding to the top M eigen-values are used to define the basis vectors
- A 2-dimensional representation of the basis vectors is known as fisher faces
- An arbitrary face image is represented by projecting it onto the subspace spanned by the M basis vectors

PCA and LDA

PCA

LDA

- The PCA-based and LDA-based approaches make use of a set of orthogonal basis images
- Both provide a compact and global representation of face images

Texture-Based Facial Recognition

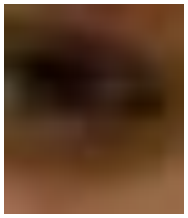
Local Binary Patterns (LBP)

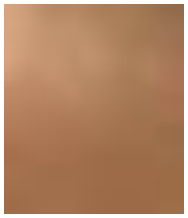
Motivation:

2-D surface texture is a two-dimensional phenomenon characterized by:

1. Spatial Structure (pattern)

2. Contrast (amount of texture)

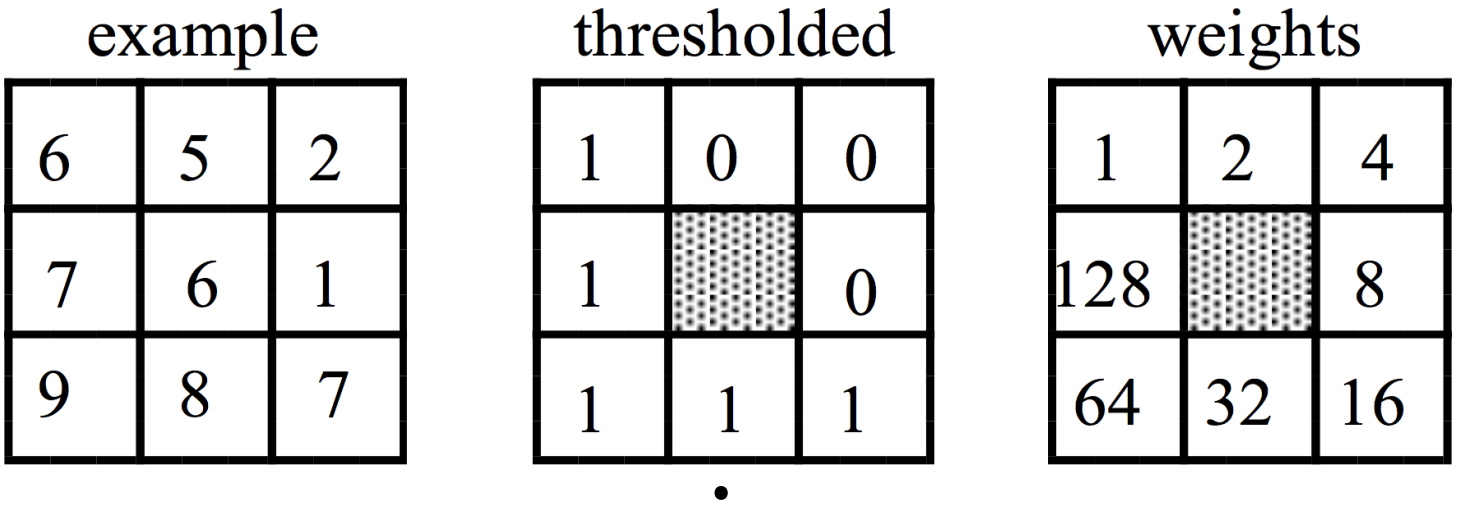




Adapted from notes by M. Pietikäinen and G. Zhao

Computing the LBP Descriptor

3x3 neighborhood

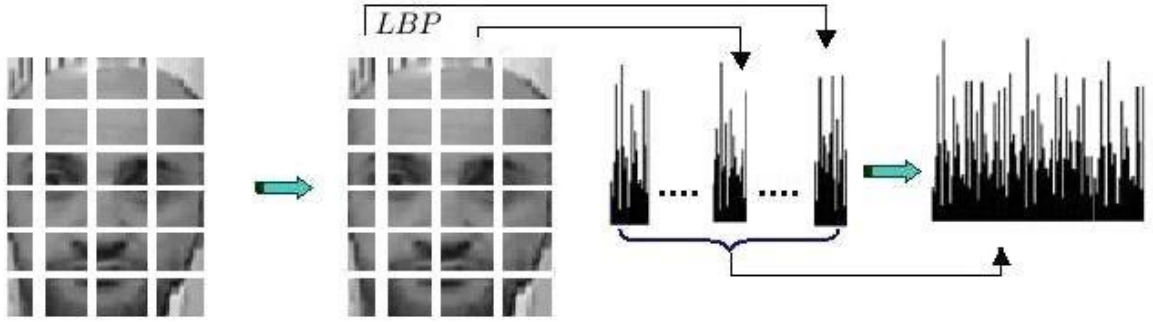


Pattern = 11110001

LBP = 1 + 16 + 32 + 64 + 128 = 241

LBP for Face Recognition

T. Ahonen et al. IEEE T-PAMI 2006



SVM or other supervised learning for classification

LBP for Face Recognition

Region weighting

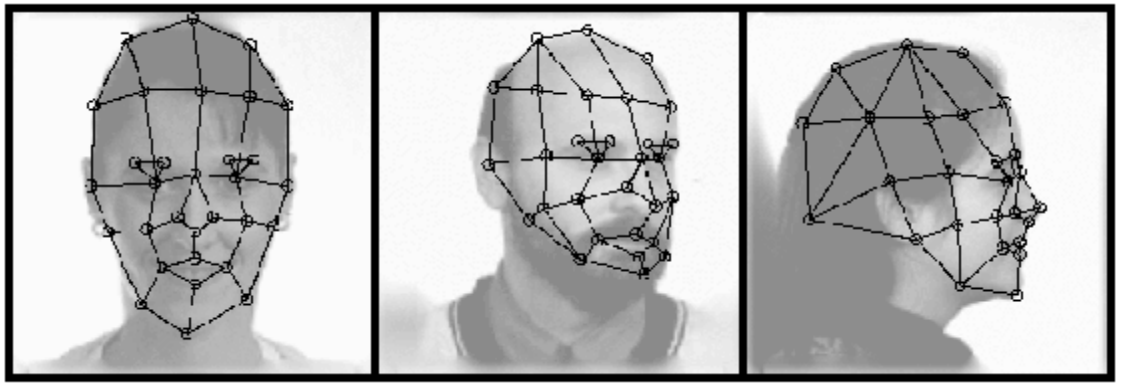
(a) (b)

Black squares = 0
Dark gray = 1
Light gray = 2
White = 4

Model-Based Facial Recognition

Elastic Bunch Graph Matching (EBGM)

Face Graph



- The EBGM-based approach constructs a face bunch graph, whose nodes are associated with a set of wavelet coefficients (called jets)
- It uses local features (extracted using Gabor wavelets) as well as global face shape (represented as a graph)

Limitations of 2D- Based Face Recognition

- A 2D face image is merely the projection of a 3D object; it can be thought of as a 2D texture image consisting of eyes, nose and mouth
- Very sensitive to changes in pose, face tilt, expression, etc.
- Multiple templates (face profiles) of a user have to be stored in order to account for variations in pose
- The side profile of a face is typically not used
- 2D representations do not capture the structure of the face

Challenges in Face Recognition

- Change in 3D head pose and tilt
- Varying illumination
- Different facial expressions
- Effects of aging
- Facial accessories
- Partial or occluded face in surveillance systems

Face Recognition Facts/Lessons

- Reached a significant level but still far away from the capability of human perception
- Take advantage of domain knowledge
- How big should be the face image size?
- Accurate feature localizations are critical
- Face recognition is probably not unique compared to other object recognition (psychology <=> engineering)
- Comparing different systems is important but difficult
- Choose appropriate systems based on particular applications
- Still face recognition techniques can be used as building blocks for video-based methods

Face Recognition: Open Issues

- Addressing the issue of recognition being too sensitive to inaccurate facial feature localization

- Robustly recognizing faces
  - Small and/or noisy images
  - Images acquired years apart
  - Outdoor acquisition: lighting, pose

- What is the limit on the number of faces that can be distinguished?

- What is the principal and optimal way to combine local features and global features

Questions?