UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI INFORMATICA

Introduction to Biometrics

Deep Learning in Biometrics

Ruggero Donida Labati

Academic year 2020/2021

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Content

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1. Introduction to the Course

Program

1) Date: Tuesday, November 24, 2020
   Time: 10:00-13:00
   Introduction to Biometrics
2) Date: Thursday, November 26, 2020
   Time: 10:00-13:00
   Machine Learning in Biometrics
3) Date: Tuesday, December 1, 2020
   Time: 11:00-13:00
   Deep Learning in Biometrics
4) Date: Tuesday, December 1, 2020
   Time: 14:00-16:00
   Deep Learning in Biometrics

Contacts

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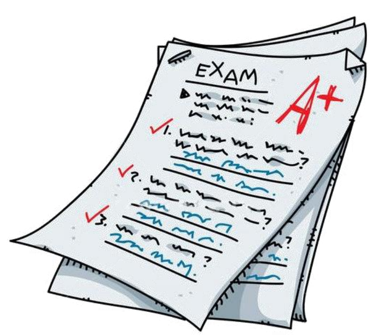
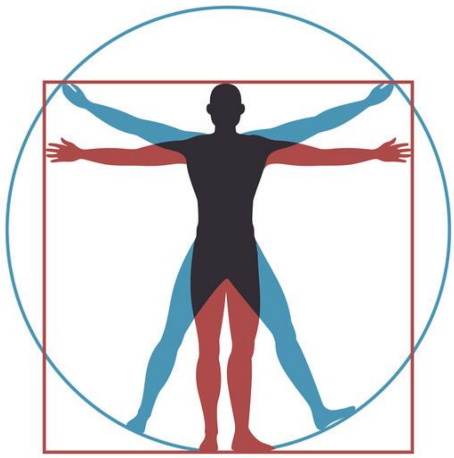
ruggero.donida@unimi.it

Exam

- Project or literature survey on a topic of the course
- The topic must be decided with the teacher of this course



2. Basic concepts on biometrics

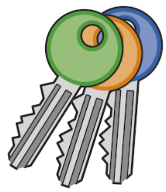


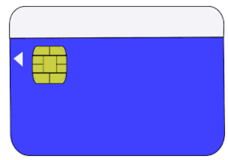
Biometrics

Biometrics is defined by the International Organization for Standardization (ISO) as **"the automated recognition of individuals based on their behavioral and biological characteristics"**

Traditional Identity Recognition Methods

Objects

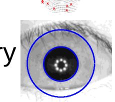


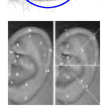


Knowledge

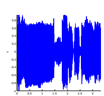
Biometric Traits

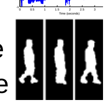
- Biometrics:
  - physiological
    - fingerprint
    - iris
    - hang geometry
    - palmprint
    - palmevein
    - ear
    - ECG
    - DNA

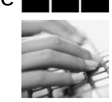




  - behavioral
    - voice
    - gait
    - signature
    - keystroke







Applications (1/3)

Border control

Disney world

2004 Summer Olympics

Applications (2/3)

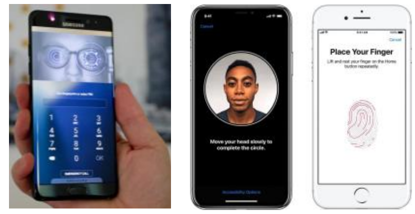
Shops

ATM

Surveillance

Applications (3/3)

LiveGrip^{TM}
Advanced Biometrics, Inc

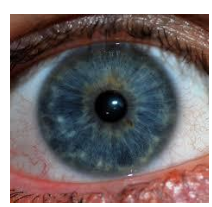


Smartphones

Hitachi - grip-type finger vein authentication
http://www.hitachi.com

Characteristics of Biometric Traits

- Human characteristic
  1. Universality
  2. Distinctiveness
  3. Permanence
  4. Collectability



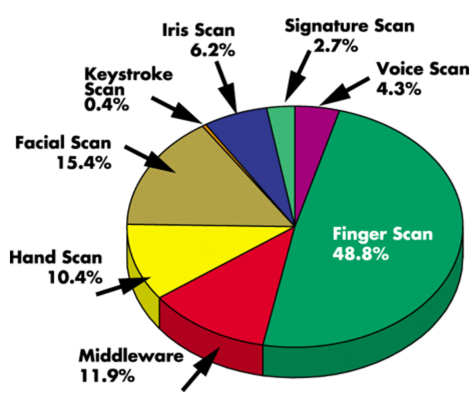
- Technology
  1. Performance
  2. Acceptability
  3. Circumvention

Qualitative Evaluation of Biometric Traits

Trait	Univ.	Uniq.	Perm.	Coll.	Perf.	Acc.	Circ.
Face	H	L	M	H	L	H	L
Fingerprint	M	H	H	M	H	M	H
Hand geometry	M	M	M	H	M	M	M
Keystrokes	L	L	L	M	L	M	M
Hand vein	M	M	M	M	M	M	H
Iris	H	H	H	M	H	L	H
Retinal scan	H	H	M	L	H	L	H
Signature	L	L	L	H	L	H	L
Voice	M	L	L	M	L	H	L
Facethermograms	H	H	L	H	M	H	H
Odor	H	H	H	L	L	M	L
DNA	H	H	H	L	H	L	L
Gate	M	L	L	H	L	H	M
Ear	M	M	H	M	M	H	M

A. Jain, A. Ross, and S. Prabhakar, “An introduction to biometric recognition,” IEEE Trans. on Circuits and Systems for Video Technology, vol. 14, no. 1, pp. 4 –20, Jan. 2004.

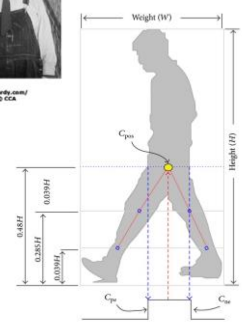
Biometric Traits in Real Applications



International Biometric Group, New York, NY; 1.212

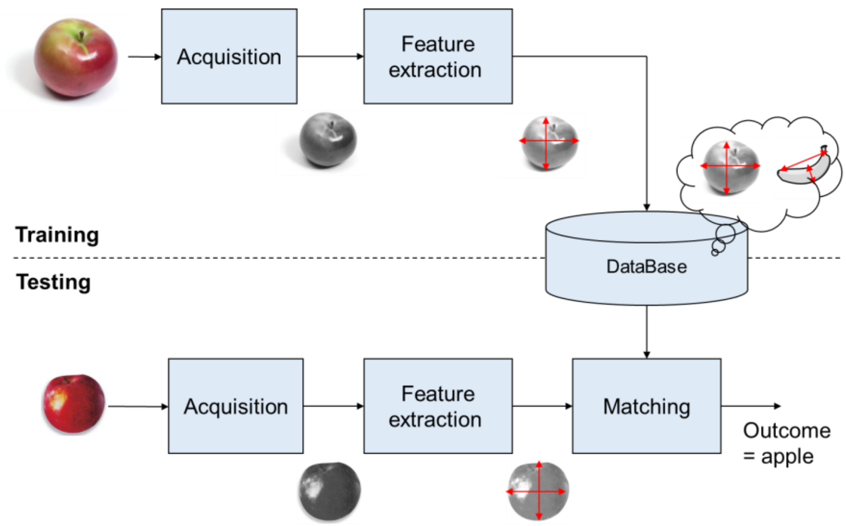
Soft Biometrics

- Soft biometric traits are characteristics that provide some information about the individual, but lack the distinctiveness and permanence to sufficiently differentiate any two individuals
- Continuous or discrete

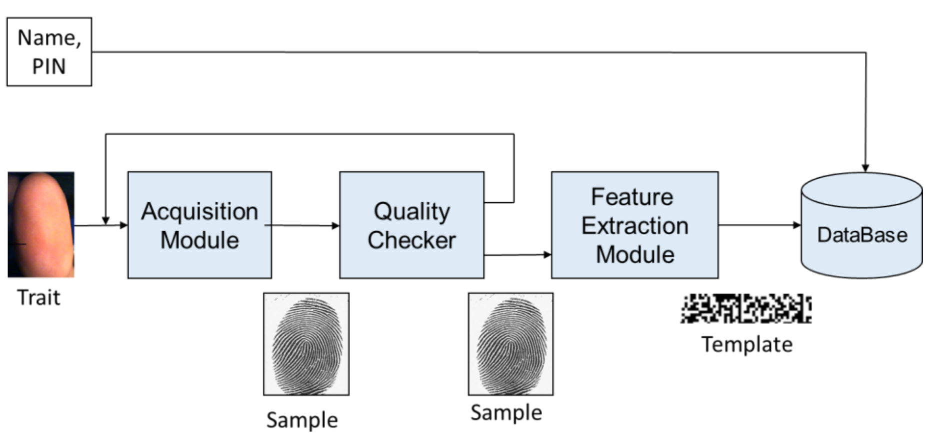


3. Biometric Recognition Process

Pattern Recognition Systems



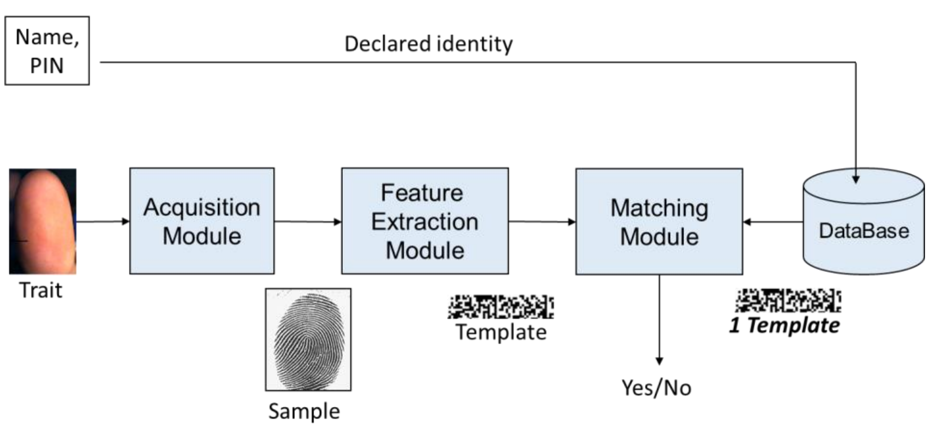
Enrollment



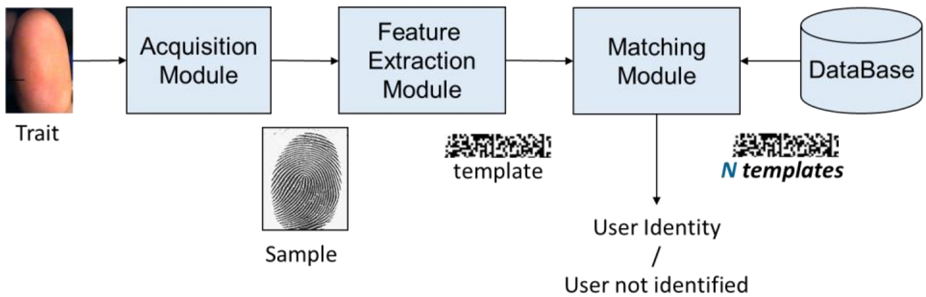
Verification / Identification

- Verification
  - The verification involves confirming or denying a person's claimed identity
- Identification
  - In the identification mode, the biometric system has to establish a person's identity by comparing the acquired biometric data with the information related to a set of individuals, performing a one-to-many comparison
  - Positive
  - Negative

Verification

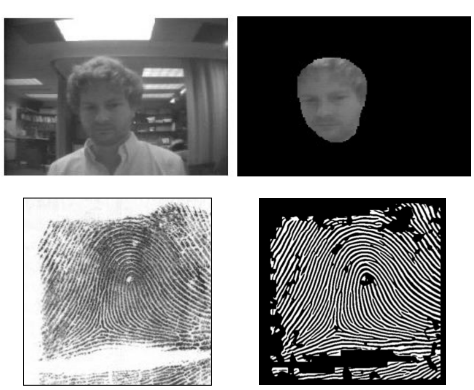


Identification

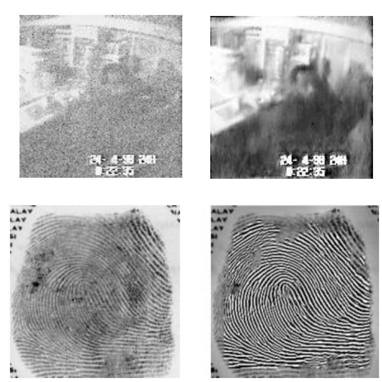


Preprocessing

Segmentation



Enhancement



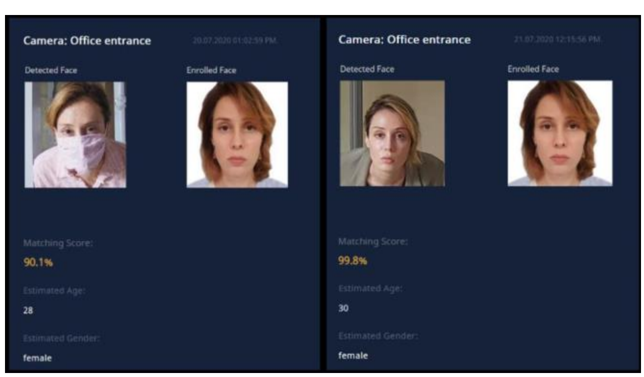
Feature Extraction

- Different Methods
  - biometric trait
  - biometric system
  - local / global

- Computes a **template** from a **sample**
  - Sample = input multidimensional signal
    - One-dimensional signal
    - Image
    - 3D model
    - Video
  - Template = abstract and compact representation of the distinctive characteristics of the sample

Matching

- Computes **the matching score** between two templates
  - Distance
  - Similitude

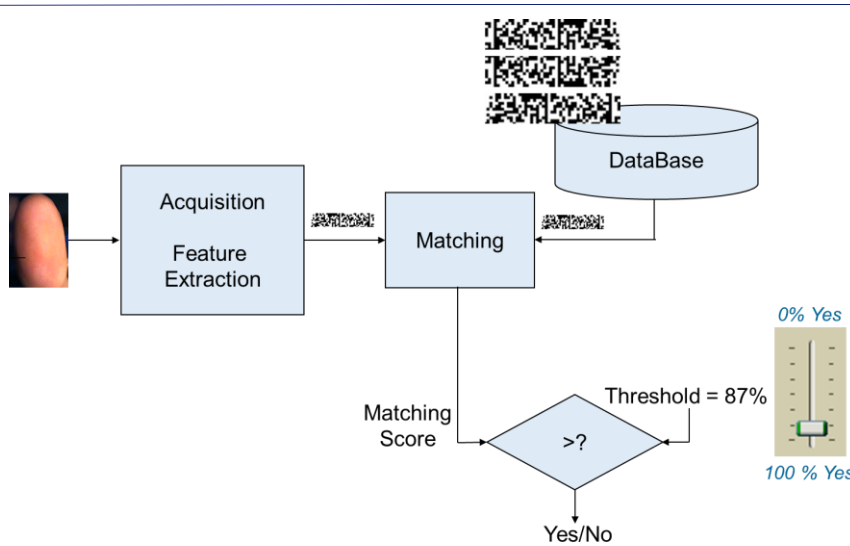


Genuine and Impostor Comparisons

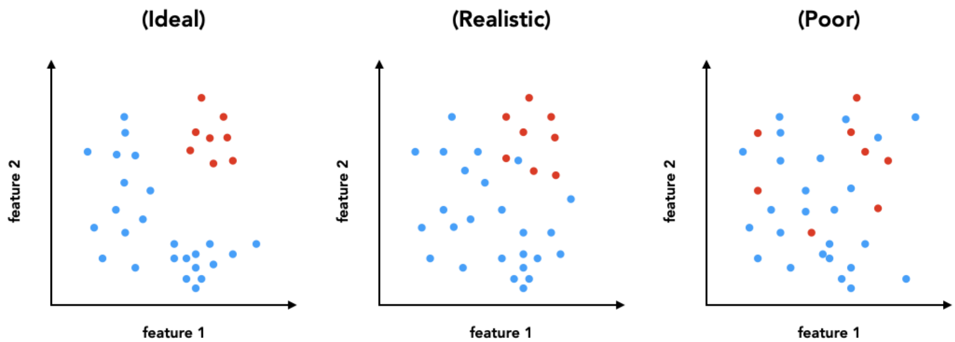
Genuine comparison

Impostor comparison

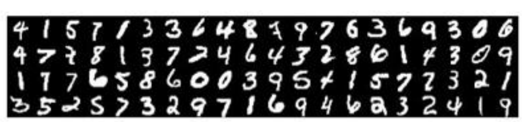
Decision

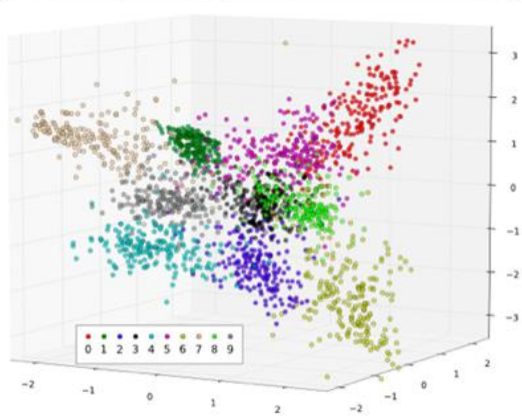


Pattern Recognition: 2D Feature Space



Pattern Recognition: 3D Feature Space



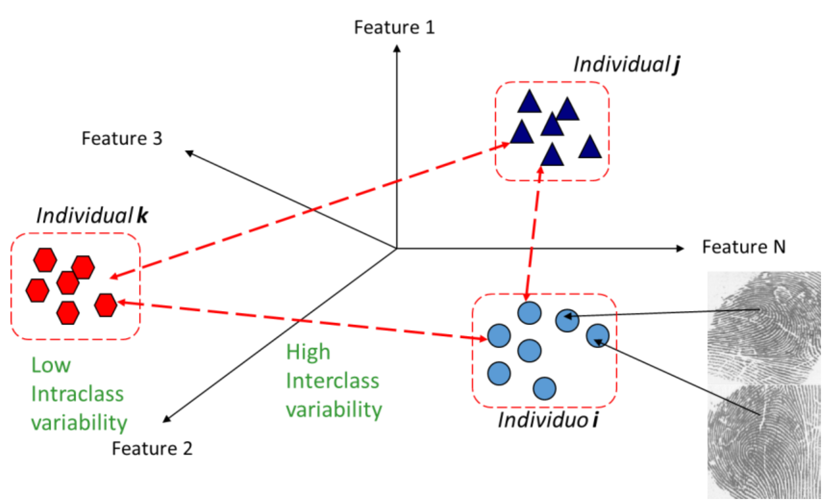


Interclass Similitude and Intraclass Variability

Interclass similitude

intraclass variability

Patter Recognition and Biometrics



Ruggero Donida Labati - Deep Learning in Biometrics - 2020-201
Ph.D. degree in Computer Science, Università degli Studi di Milano
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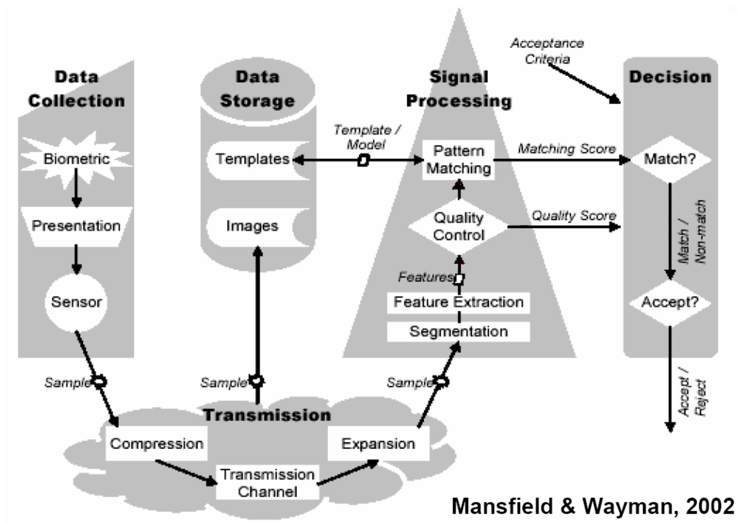
Modules of Biometric Systems



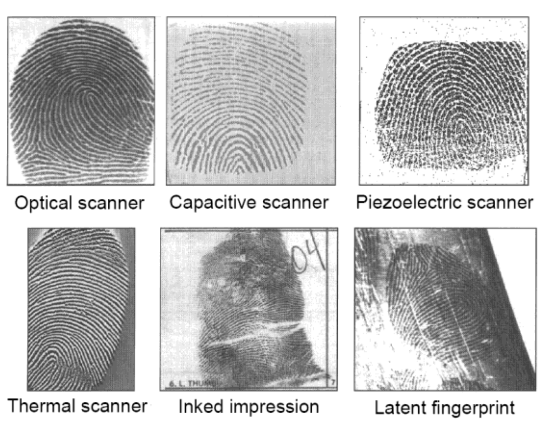
4. Fingerprint

Fingerprint

- A fingerprint in its narrow sense is an impression left by the friction ridges of a human finger
- One of the most used traits in biometric applications
  - High durability
  - High distinctivity
- The more mature biometric trait

Fingerprint Images

Sensors

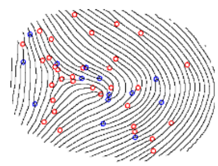


Finger placements

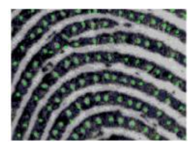
Levels of Analysis

- **Level 1:** the overall global ridge flow pattern

- **Level 2:** points of the ridges, called minutiae points



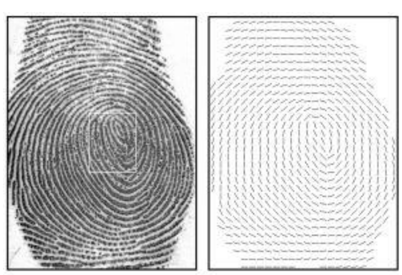
- **Level 3:** ultra-thin details, such as pores and local peculiarities of the ridge edges



Level 1: Local Ridge Orientation

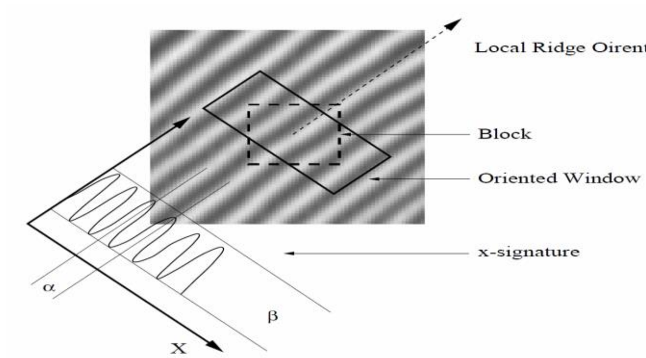
- Usually from 0° to 180°
- Evaluation of the gradient orientation in squared regions

  For each local region, the ridge orientation is considered as the mean of the angular values of the pixels

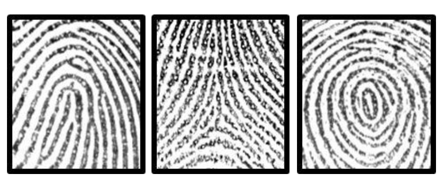


Level 1: Local Ridge Frequency

- Global or map
- x-signature



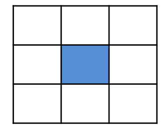
Level 1: Singular Regions



- Pointcaré algorithm
- The northern loop is usually considered as the core point

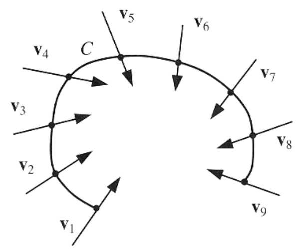
Level 1: Pointcaré Algorithm

- Let *G* is be a vector field and *C* be a curve immersed in *G,* then the Poicaré index $P_{G,C}$ is defined as the total rotation of the vectors of G along *C*
- Considering eight near elements d_k (k = 0… 7)

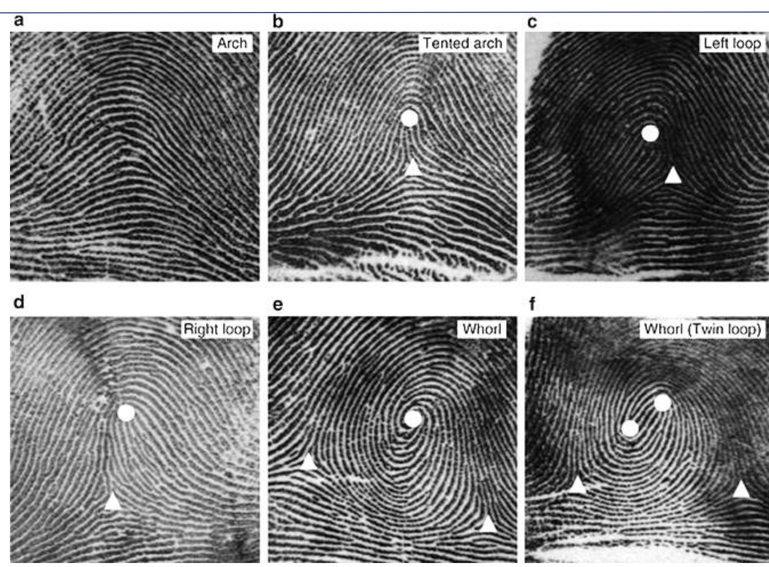


$$P_{G,C}\,(i,j) = \sum_{k=0\cdots 7} angle\left(d_k, d_{(k+1)mod8}\right)$$

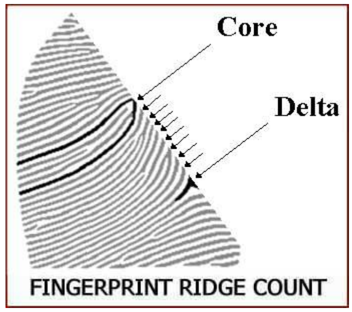
- Classification
  - 0° = the point is not a singular point;
  - 360° = whorl region;
  - 180° = core point;
  - -180° = delta point.



Level 1: Classification of the Ridge Pattern

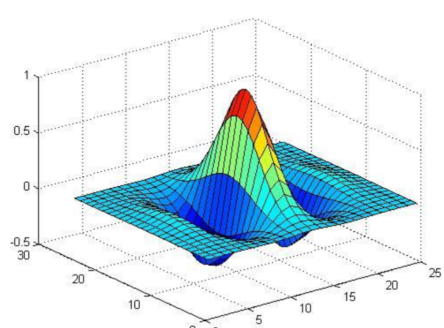


Level 1: Ridge Count



Level 1: Gabor Filters (1/2)

- Evaluates both frequency and space



Level 1: Gabor Filters (2/2)

The even-symmetric Gabor filter has the general form

$$h(x, y : \phi, f) = \exp\left\{-\frac{1}{2}\left[\frac{x_\phi^2}{\sigma_x^2} + \frac{y_\phi^2}{\sigma_y^2}\right]\right\}\cos(2\pi f x_\phi),$$

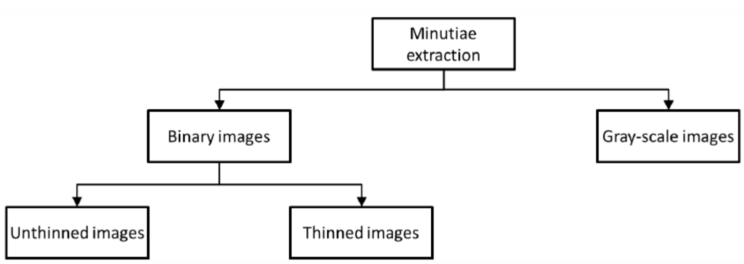
$$x_\phi = x\cos(\phi) + y\sin(\phi)$$

$$y_\phi = -x\cos(\phi) + y\sin(\phi)$$

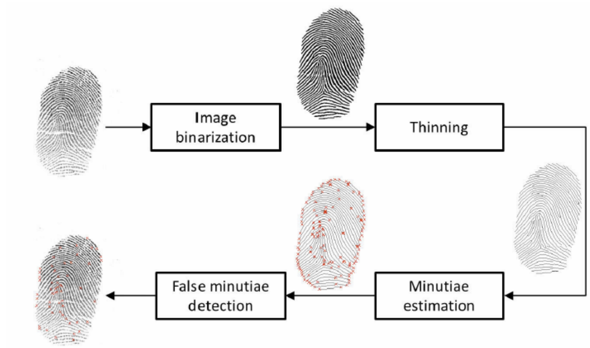
where Φ is the orientation of the Gabor filter, *f* is the frequency of a sinusoidal plane wave, and σ_x and σ_y are the space constants of the Gaussian envelope along *x* and *y* axes, respectively.

Level 2: Minutiae

termination | bifurcation | lake | point or island | Independent ridge | spur | crossover



Level 2: Minutiae Extractor

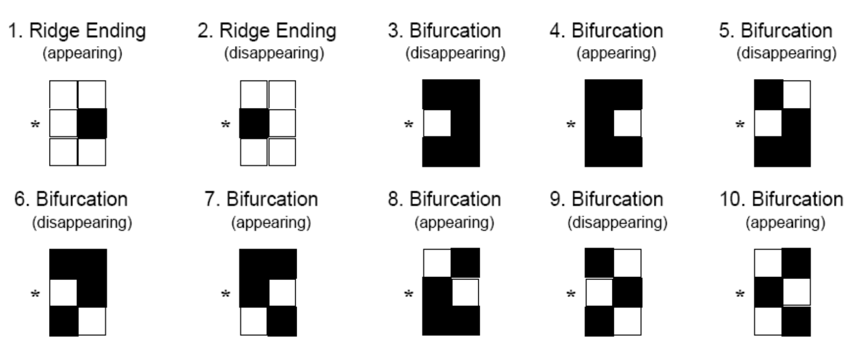


Crossing number: 8 neigborhood of the pixel *p*

$$CN(p) = \frac{1}{2}\sum_{k=1}^{8}\left|n_k - n_{((k+1)\mathrm{mod}\ 8)}\right|$$

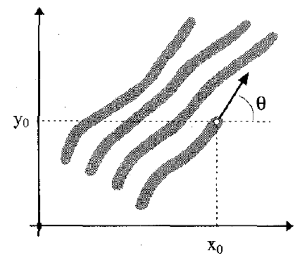
If $CN(p) = 1$ or $CN(p) = 3$, *p* is a minutia

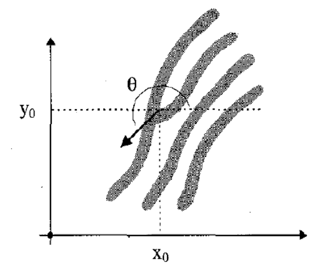
Level 2: Minutia Patterns



Level 2: Ridge Following

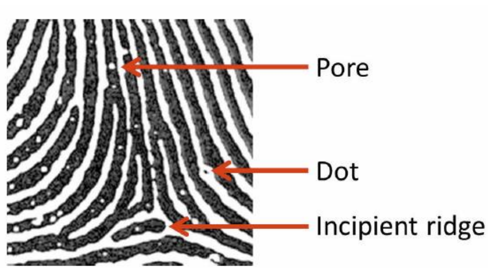
```
find minutia ( i_s, j_s )
  { esc := false ;
    (i_c, j_c) := nearest ridge line maximum
      (i_s, j_s) ;
    if ((i_c, j_c) ∈ discovered ridge lines
      (T)) then esc := true ;
    if (¬ esc )
      {φ_c := tangent direction in (i_c, j_c) ;
        ridge line following (i_c, j_c, φ_c) ;
        if (termination ∨ excessive
          bending) then
          { // termination minutia has
            been found
            store termination minutia ;   }
        if  (intersection) then
          { // bifurcation minutia may
            exist
            if  (intersection point is
              valid) then
              store bifurcation minutia
            else delete false termination
              minutia ;
          }
        store polygonal ( T );
        // Perform similar operations in
          direction φ_c + π ;
        ridge line following (i_c, j_c, φ_c + π)
;
        ....
      }
  }
```



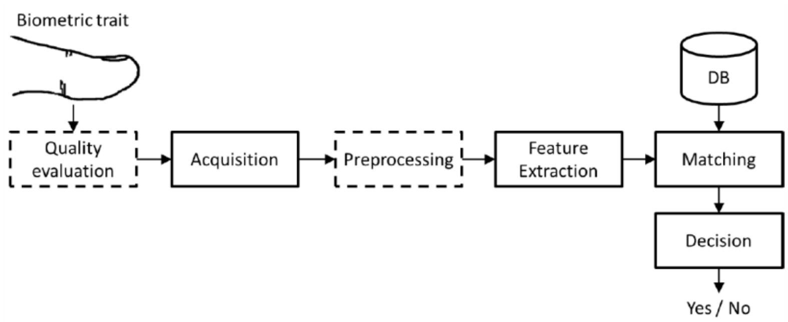


Level 3

- Minimum resolution of 800 DPI



The Biometric Recognition Process



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Acquisition

Latent

Inked and rolled

Live scan

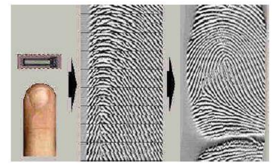
52

Images


Optical scanner

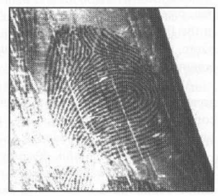

Capacitive scanner

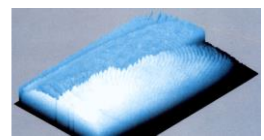

Piezoelectric scanner


Thermal (Sweeping)


Thermal scanner

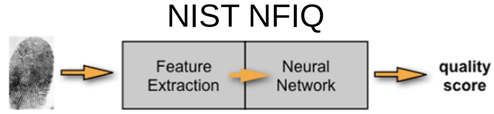

Inked impression

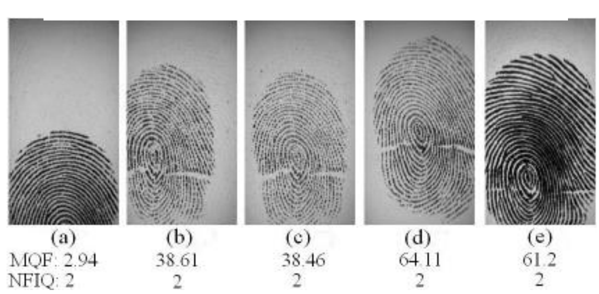

Latent fingerprint


3dimensional

Quality Evaluation (1/2)

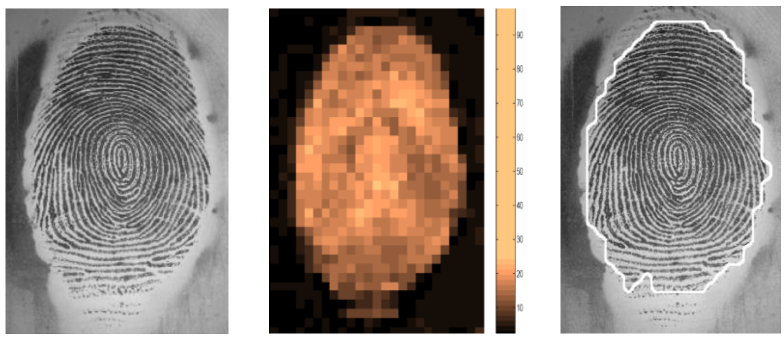
NIST NFIQ





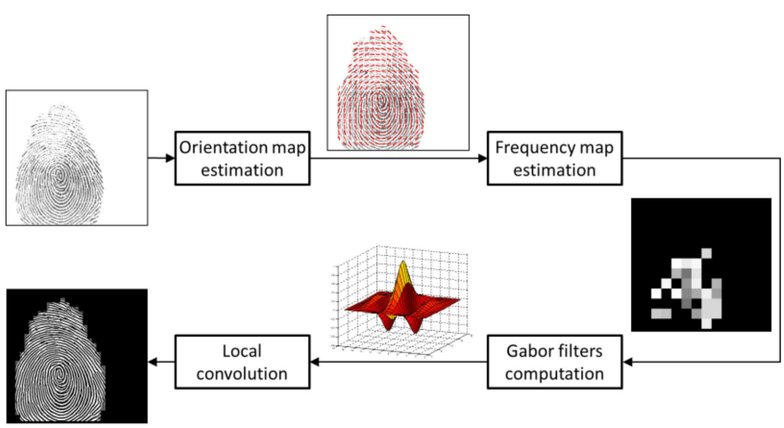
Preprocessing: Segmentation

- Local standard deviation (16 X 16 pixels)



Preprocessing: Enhancement

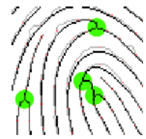
- Contextual filtering



Minutiae-based Matching

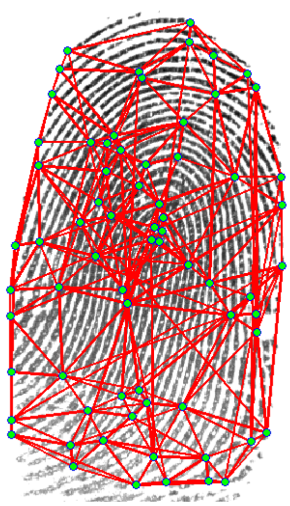
- Two minutiae are considered as correspondent if their spatial distance s_d and direction difference d_d are less than fixed thresholds

$$s_d(m'_j, m_i) = \sqrt{(x'_j - x_i)^2 + (y'_j - y_i)^2}$$
$$d_d(m'_j, m_i) = \min(|\theta'_j - \theta_i|, (360 - |\theta'_j - \theta_i|))$$



- Non-exact point pattern matching
  - Roto-translations
  - Non-linear distortions
  - False minutiae
  - Missed minutiae
  - Non constant number of minutiae

Minutiae-based Matching: Delaunay Triangulation



- Features
  - Side lengths of th triangles

$$L(i,1) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$
$$L(i,2) = \sqrt{(x_1 - x_3)^2 + (y_1 - y_3)^2}$$
$$L(i,3) = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2}$$

  - Greater angles

$$\alpha(i,1) = \frac{L(i,1)^2 + L(i,2)^2 - L(i,3)^2}{2 \cdot L(i,1) \cdot L(i,2)}$$

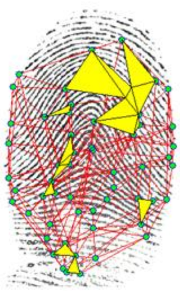
  - Incenters
  - Minutiae features (x, y, θ)

Minutiae-based Matching: Delaunay Triangulation (1/2)

- Method A

$$|L_B(j) - L_A(i)| < s_L,$$

$$|\vartheta_B(j) - \vartheta_A(i)| < s_O,$$

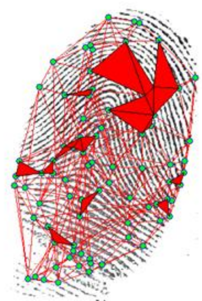


a)

- Method B

$$|L_B(j) - L_A(i)| < s_L,$$

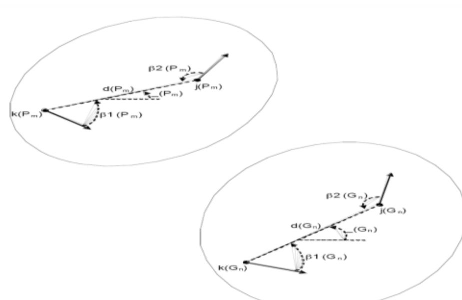
$$|\vartheta_B(j) - \vartheta_A(i)| < s_O,$$



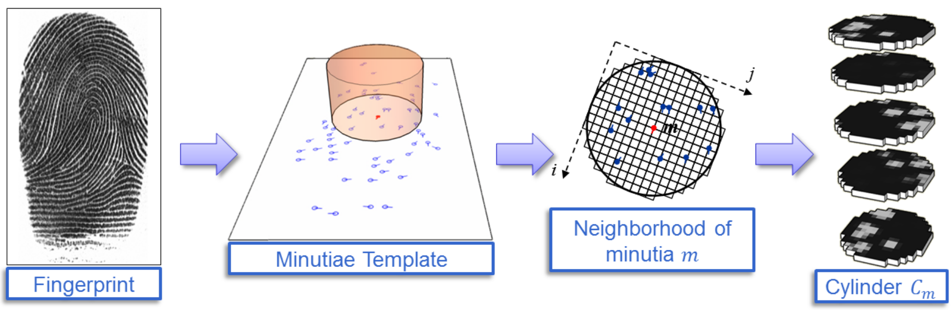
b)

Minutiae-based Matching: NIST Bozhorth 3

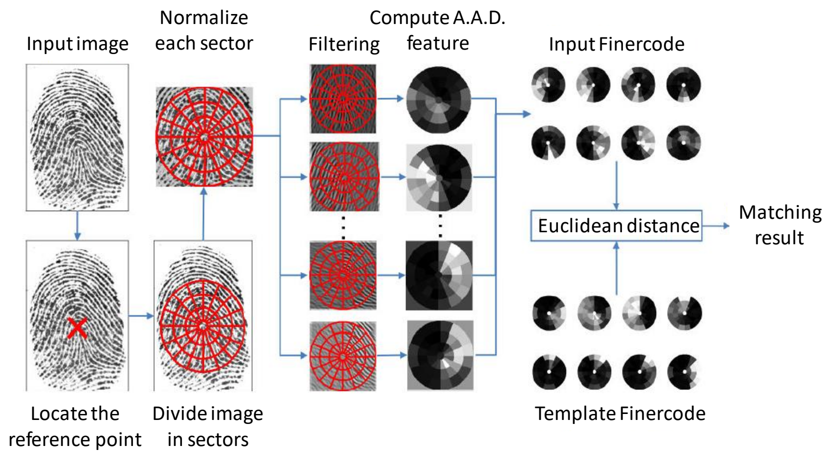
- Step 1: Construction of Intra-Fingerprint Minutiae Comparison Tables
- Step 2: Construction of Inter-Fingerprint Compatibility Table
  Step 3: Traverse Inter-Fingerprint Compatibility Table constructed in second step



Other Minutiae-based Recognition Methods: Cylindercode



Other Recognition Methods: Fingercode

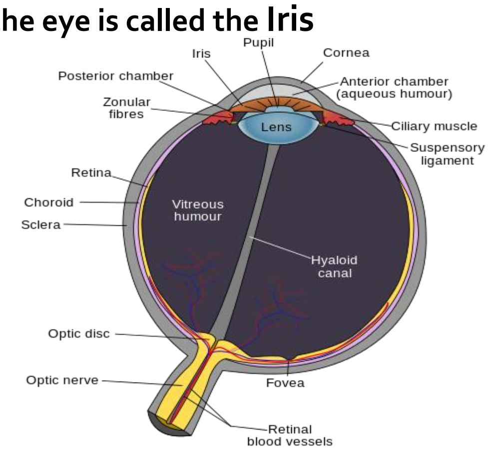


[1] A. K. Jain, et al., "Filterbank-based fingerprint matching," IEEE Transactions on Image Processing, 2000.

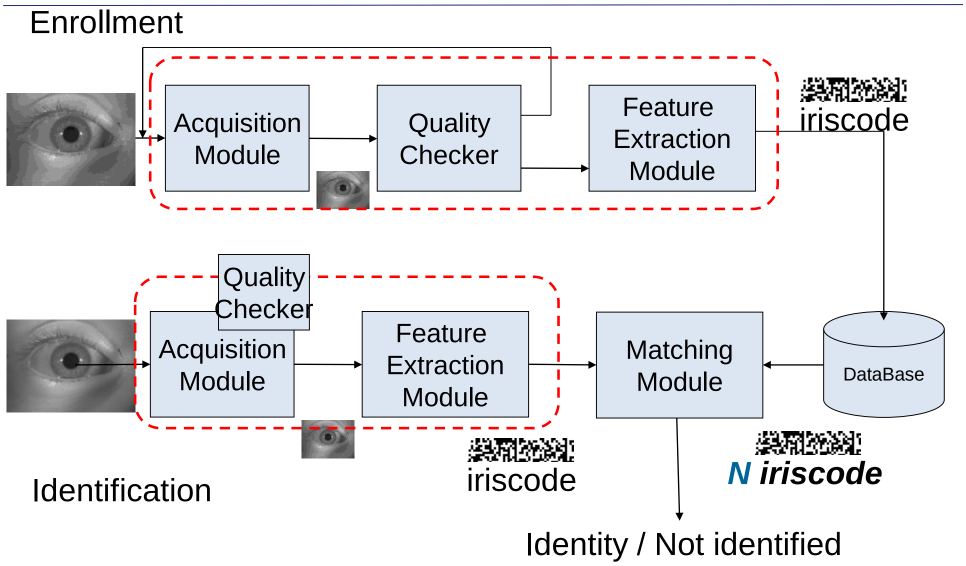
5. Iris

Iris Biometric Trait

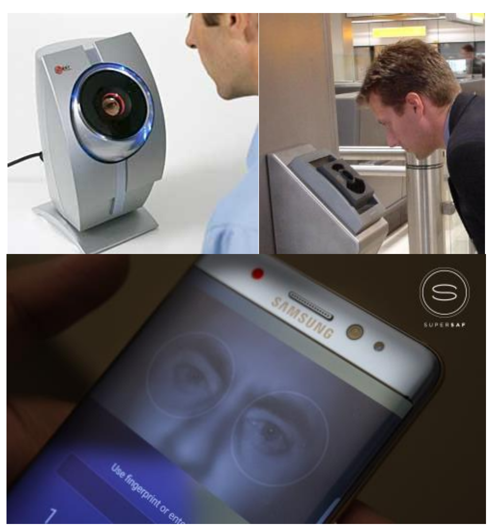
The colored ring around the pupil of the eye is called the **Iris**



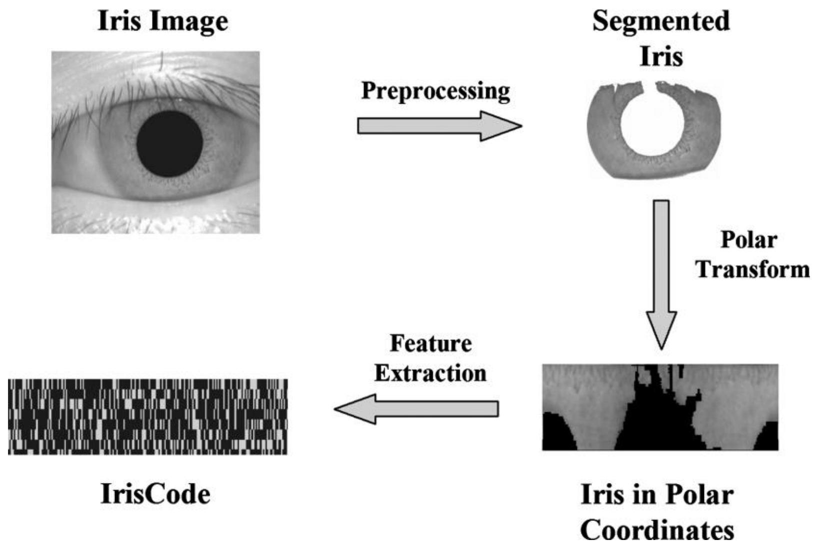
Iris-based Identification



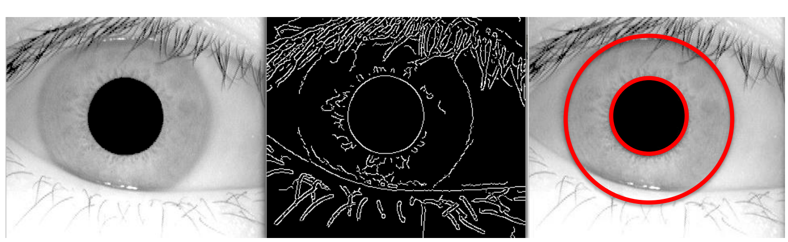
Iris Scanners



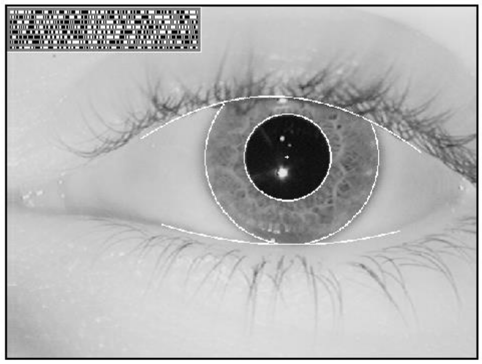
How Iris Recognition Works



Iris Segmentation Using Hough Transform



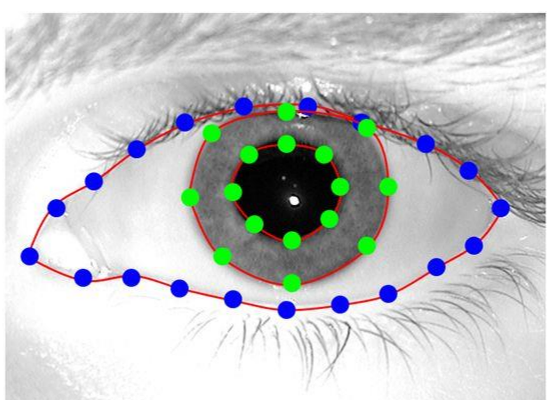
Iris Segmentation Using Daugman's Method



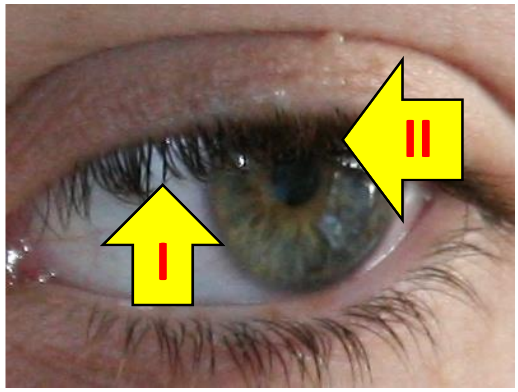
$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi r} ds \right|$$

Localizing iris boundaries by differential operators

Iris Segmentation Using Active Contours



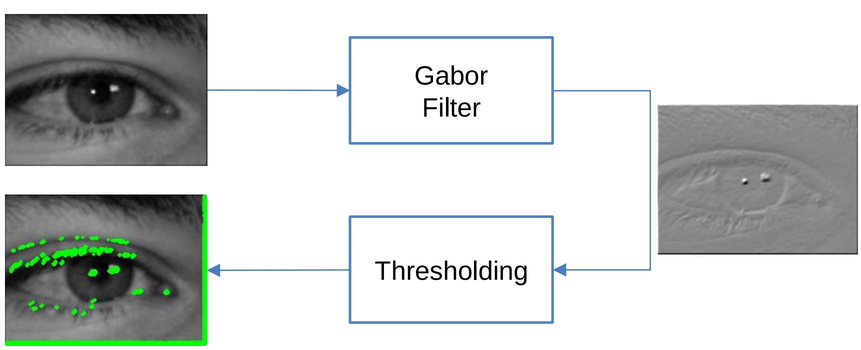
Eyelids and Eyelashes



I = separable eyelashes

II = not-separable eyelashes

Separable Eyelashes



$$g(x,y) = K \exp\big(-\pi(a^2(x-x_0)^2 + b^2(y-y_0)^2)\big) \exp\big(j(2\pi F_0\,(x\cos\omega_0 + y\,\sin\omega_0) + P)\big)$$

$$L_1\,(x,y) = \begin{cases} 1 & \text{if } \big|I(x,y) * \mathcal{R}e\big(g(x,y)\big)\big| > t_3 \\ 0 & \text{else} \end{cases}$$

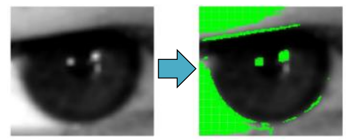
$$t_3 = k \max(|I_r(x,y) * \, g(x,y)|)$$

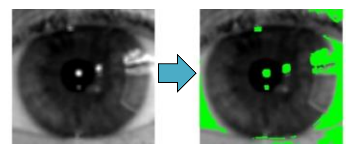
Non-separable Eyelashes and Reflections

1) $L_2\,(x,y) = \begin{cases} 1 & \text{if } \operatorname{var}(I(x,y)) > t_4 \\ 0 & \text{else} \end{cases}$
2) $L_3\,(x,y) = \operatorname{erode}(L_2(x,y), S\,)$
3) $L_4\,(x,y) = \begin{cases} 1 & \text{if } I(x,y) > t_5 \\ 0 & \text{else} \end{cases}$
4) $L_5 = L_3 \text{ OR } L_4$
5) Starting from an initial set of points L_5, we apply an iterative region growing technique based on the following

   $\mu + \beta\sigma < I(x,y)$

   where μ and σ are the local mean and standard deviation of $I(x,y)$ processed in a 3×3 matrix centered in the point x,y and β is a fixed threshold .





Iris Normalization: Motivation

Pupil dilation | Gaze deviation | Resolution

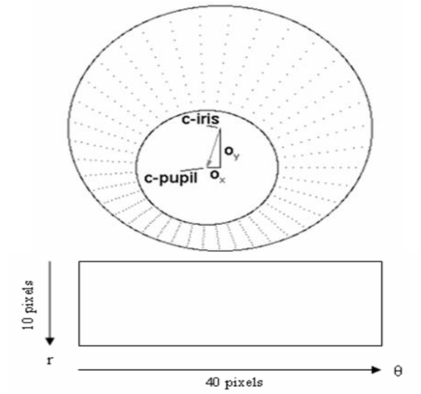
Iris Normalization: Rubber Sheet Model

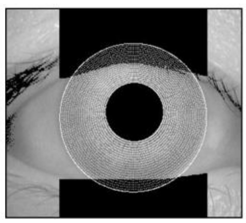
$$r' = \sqrt{\alpha}\beta \pm \sqrt{\alpha\beta^2 - \alpha - r_I^2}$$

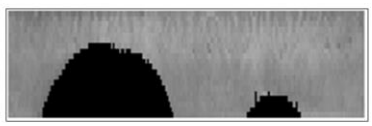
with

$$\alpha = o_x^2 + o_y^2$$

$$\beta = \cos\left(\pi - \arctan\left(\frac{o_y}{o_x}\right) - \theta\right)$$





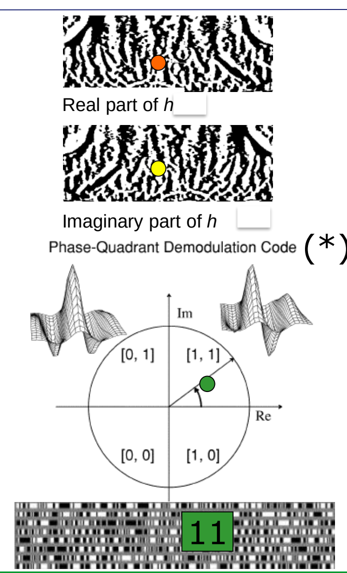


Iriscode (1/2)

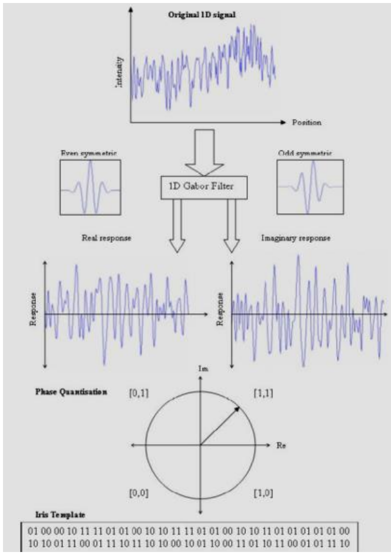
$$h_{\{\mathrm{Re},\mathrm{Im}\}} = \mathrm{sgn}_{\{Re,Im\}} \int_\rho \int_\phi I(\rho,\phi) e^{-i\omega(\theta_0-\phi)} \cdot e^{-(r_0-\rho)^2/\alpha^2} e^{-(\theta_0-\phi)^2/\beta^2} \rho d\rho d\phi$$

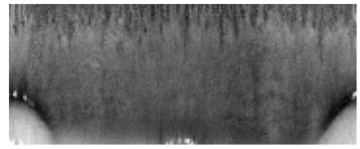
"The detailed iris pattern is encoded into a 256-byte "IrisCode" by demodulating it with 2D Gabor wavelets, which represent the texture by phasors in the complex plane. Each phasor angle (Figure) is quantized into just the quadrant in which it lies for each local element of the iris pattern, and this operation is repeated all across the iris, at many different scales of analysis"*

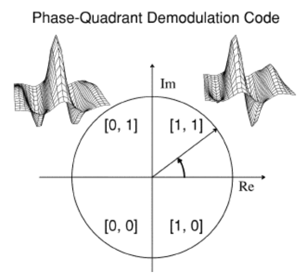
J. Dougman



Iriscode (2/2)







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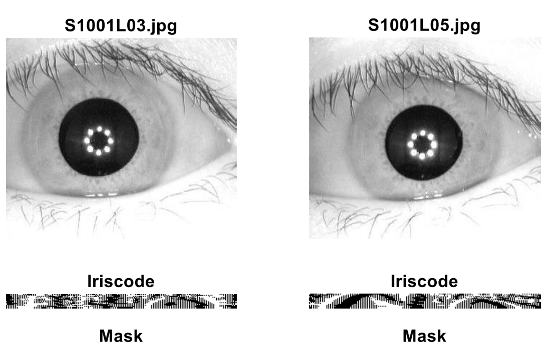
Iriscode Matching

$$\mathrm{HD} = \frac{\|(codeA \otimes codeB) \bigcap maskA \bigcap maskB\|}{\|maskA \bigcap maskB\|}$$

Matching Score = 0.26848



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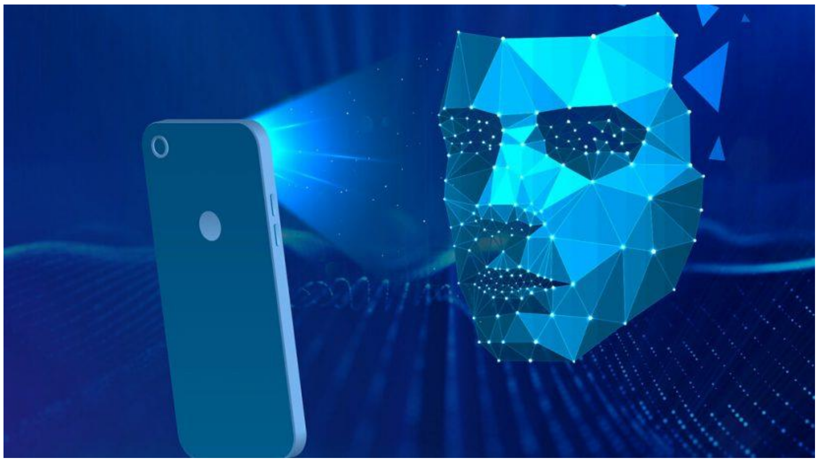
6. Face



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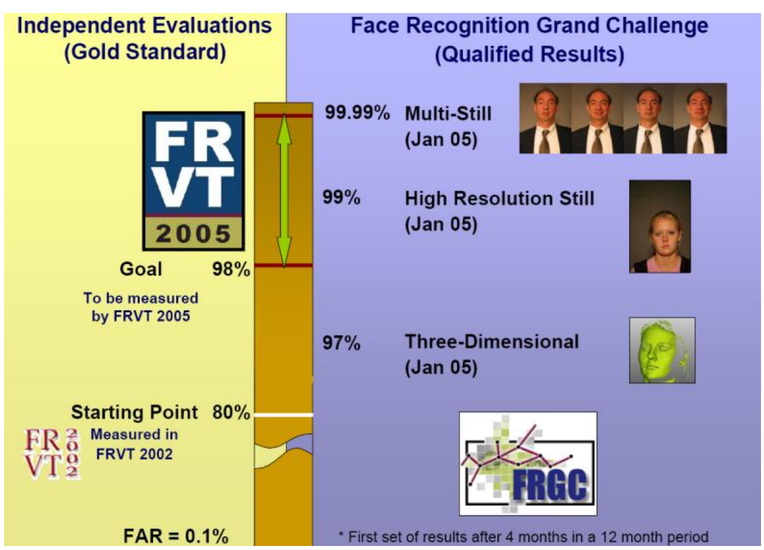
Face Recognition Using Still Images



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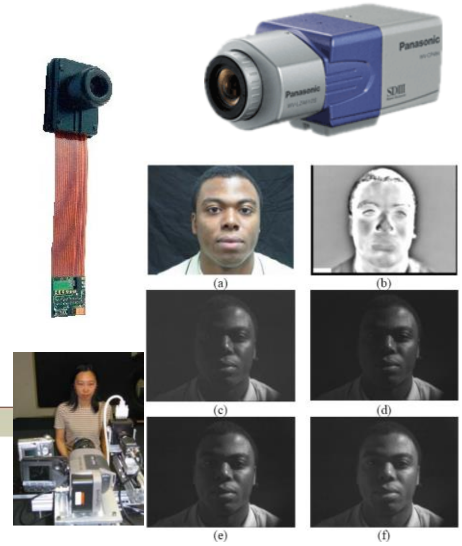
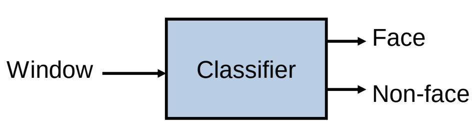
Face Acquisition Sensors

- Cameras (a)
- Webcams
- Scanners for off-line acquisitions
- Termocameras (b)
- Multispectral devices (c,d,e,f)

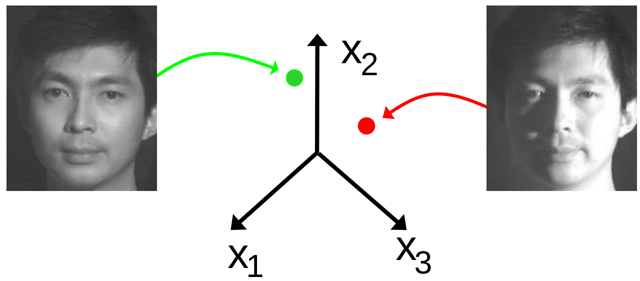


Face Detection

- Scan window over image
- Classify window as either:
  - Face
  - Non-face



Images as Features

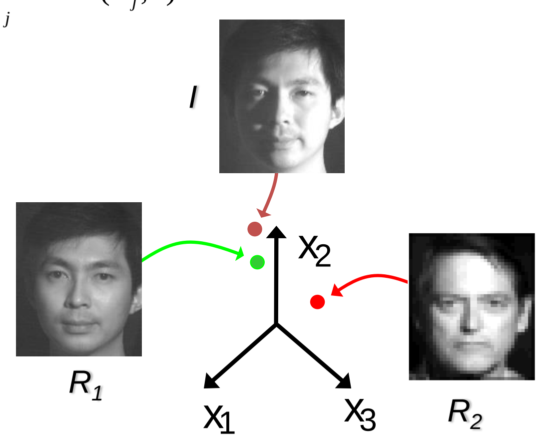


- Consider an n-pixel image to be a point in an n-dimensional space, $\mathbf{x} \in \mathbf{R}^n$.
- Each pixel value is a coordinate of $\mathbf{x}$.

Nearest Neighbor Classifier

$\{ R_j \}$ are set of training images.

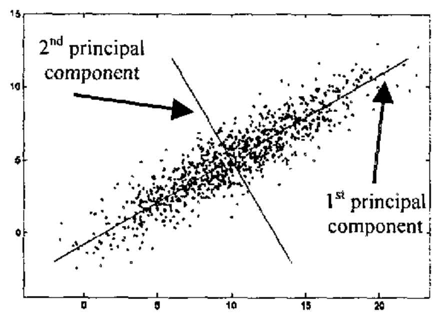
$$ID = \arg\min_j \; dist(R_j, I)$$



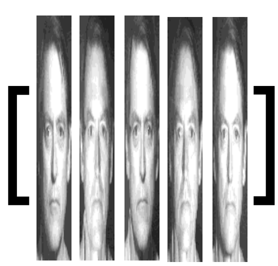
Ruggero Donida Labati - Deep Learning in Biometrics - 2020-201
Ph.D. degree in Computer Science, Università degli Studi di Milano
UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI INFORMATICA

Eigenfaces

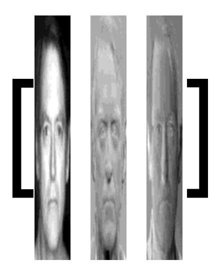
- Use Principle Component Analysis (PCA) to reduce the dimsionality



Eigenfaces (2)



$[\, x_1\ x_2\ x_3\ x_4\ x_5 \,]$



W

- Construct data matrix by stacking vectorized images and then apply Singular Value Decomposition (SVD)

Eigenfaces (2)

- Modeling
  - Given a collection of n labeled training images
    - Compute mean image and covariance matrix
    - Compute k Eigenvectors (note that these are images) of covariance matrix corresponding to k largest Eigenvalues
    - Project the training images to the k-dimensional Eigenspace
- Recognition
  - Given a test image, project to Eigenspace
    - Perform classification to the projected training images

Problems of PCA

- Projection may suppress important detail
  - smallest variance directions may not be unimportant
- Method does not take discriminative task into account
  - typically, we wish to compute features that allow good discrimination
  - not the same as largest variance

Fisherfaces

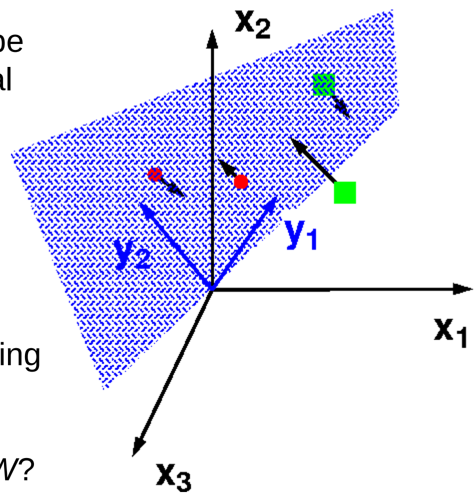
• An n-pixel image $\boldsymbol{x} \in \mathbf{R}^n$ can be projected to a low-dimensional feature space $\boldsymbol{y} \in \mathbf{R}^m$ by

$\boldsymbol{y} = W\boldsymbol{x}$

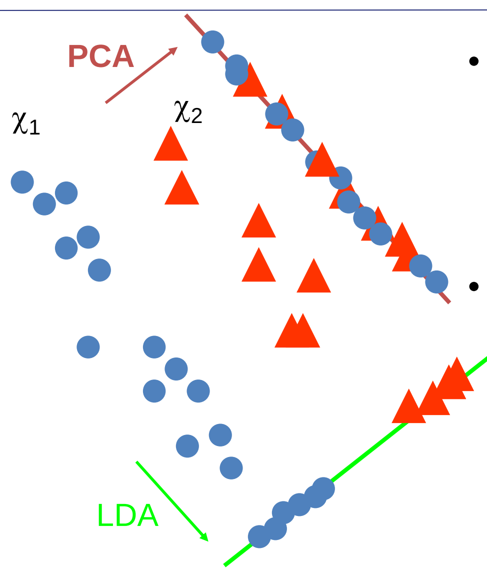
where W is an n by m matrix.

• Recognition is performed using nearest neighbor in $\mathbf{R}^m$.

• How do we choose a good W?



PCA and LDA



- PCA (Eigenfaces)

$$\boxed{W_{PCA} = \arg\max_{W} \left| W^T S_T W \right|}$$

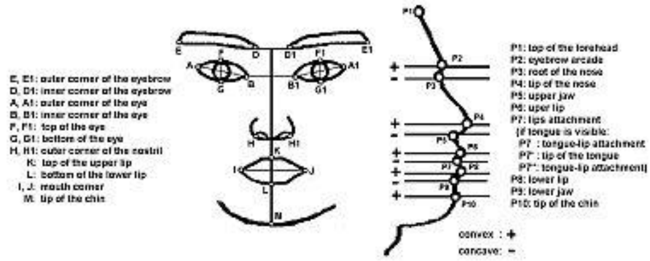
Maximizes projected total scatter

- Fisher's Linear Discriminant

$$\boxed{W_{fld} = \arg\max_{W} \frac{\left| W^T S_B W \right|}{\left| W^T S_W W \right|}}$$

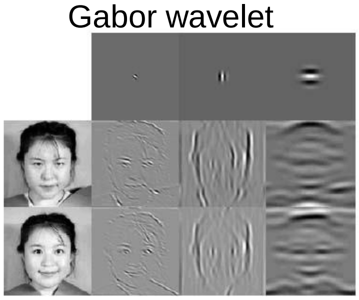
Maximizes ratio of projected between-class to projected within-class scatter

Face Recognition Based on Fiducial Points

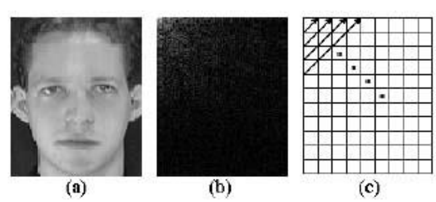


Examples of Other Features

Gabor wavelet



Discrete cosine transform



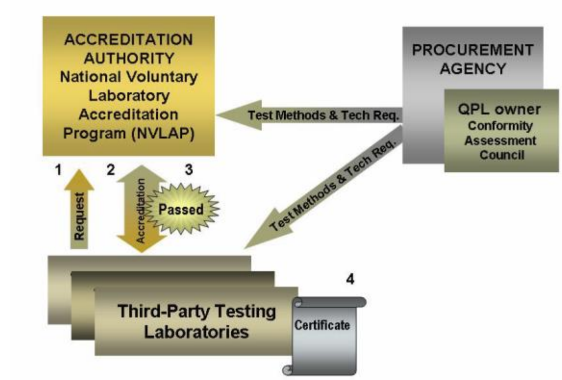
7. Evaluation of biometric systems

Evaluation Strategies

Technology

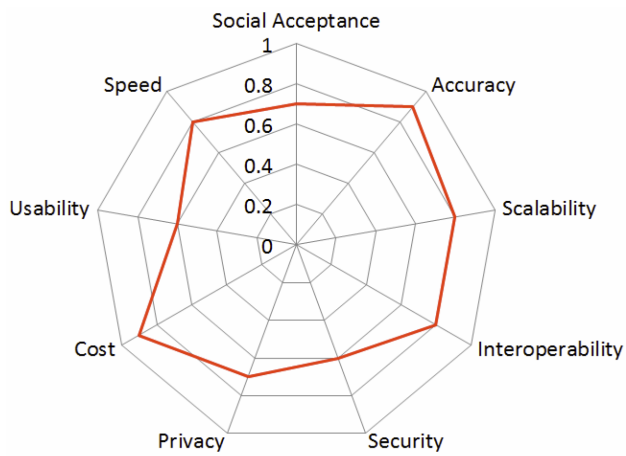
Scenario

Operational



NIST

Aspects to be Evaluated



Accuracy Evaluation: Genuine and Impostor Scores

Genuine scores

$S(X_{1\_1}, X_{1\_2}) = 0.7$

$S(X_{1\_1}, X_{1\_3}) = 0.8$

$S(X_{2\_1}, X_{2\_2}) = 0.4$

$S(X_{2\_1}, X_{2\_3}) = 0.5$

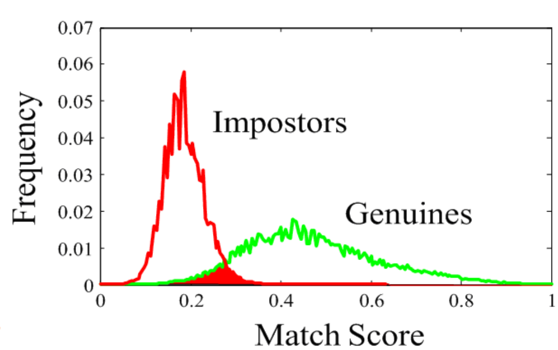
Impostor scores

$S(X_{1\_1}, X_{3\_2}) = 0.11$

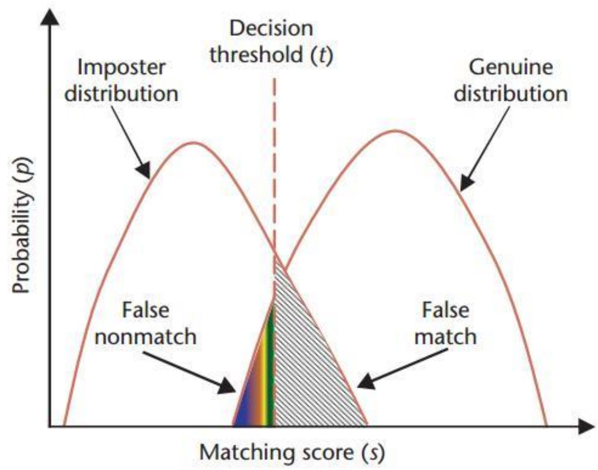
$S(X_{4\_1}, X_{3\_1}) = 0.21$

$S(X_{5\_2}, X_{1\_2}) = 0.001$

$S(X_{2\_2}, X_{1\_2}) = 0.19$



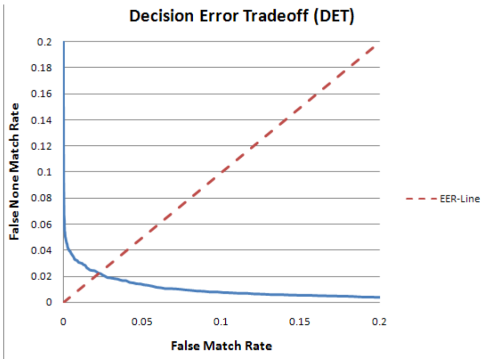
Decision Threshold

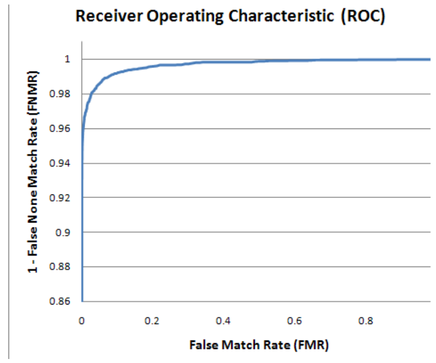


Accuracy evaluation: FMR and FNMR

- **False match rate (FMR)**: the probability that the system incorrectly matches the input pattern to a non-matching template in the database. It measures the percent of invalid inputs that are incorrectly accepted.
  Type 1 error
- **False non-match rate (FNMR)**: the probability that the system fails to detect a match between the input pattern and a matching template in the database. It measures the percent of valid inputs that are incorrectly rejected.
  Type 2 error

Accuracy Evaluation: DET and ROC





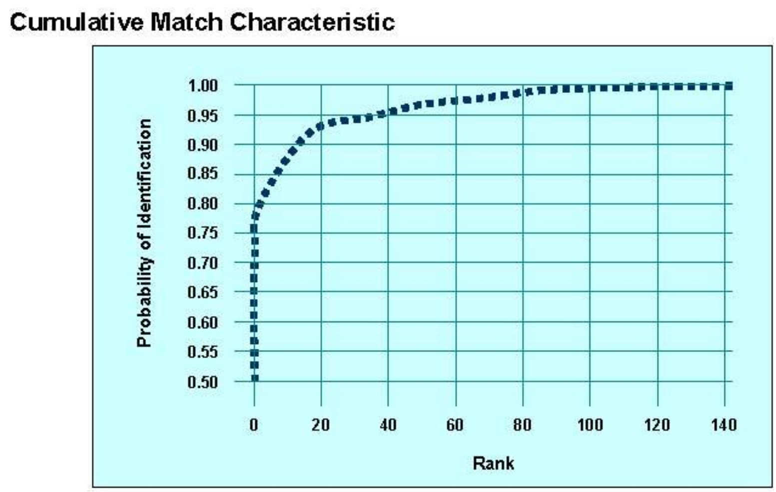
Accuracy Evaluation: Other Figures of Merit

- **Equal error rate (EER):** the ideal point in which FMR = FNMR

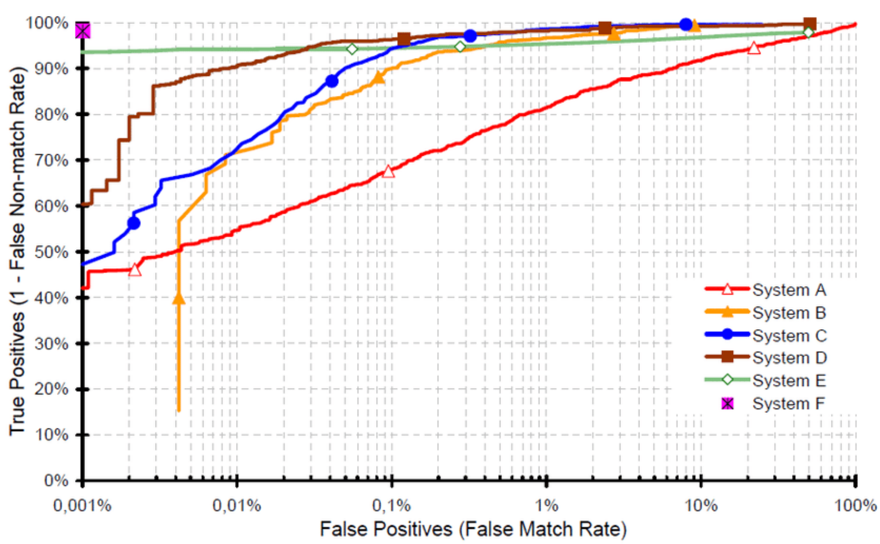
- **False acceptance rate (FAR)**: similar to FMR, but used for the complete biometric system (not only the algorithms)
- **False rejection rate (FRR)**: similar to FNMR, but used for the complete biometric system (not only the algorithms)

- **Failure to acquire (FTA)**
- **Failure to enroll (FTE)**

Accuracy Evaluation: Identification



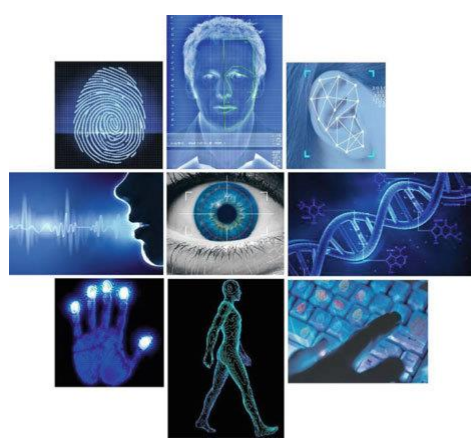
Accuracy Evaluation: Selection of the Best Method



8. Preview of the next lecture

Research trends

- Accuracy
- Robustness
- Security
- Etc.



Machine learning

- Introduction
- Feedforward neural networks
- Overfitting
- Introduction to deep learning

9. Summary

Summary

1. Introduction to the course
2. Basic concepts on biometrics
3. Biometric recognition process
4. Fingerprint
5. Face
6. Iris
7. Performance evaluation of biometric systems
8. Preview of the next lecture

Thank you!