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# Introduction to Biometrics

## Deep Learning in Biometrics

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Academic year 2018/2019

### Summary

- Basic concepts on biometrics
- Biometric recognition
- Performance evaluation of biometric systems
- Fingerprint
- Face
- Iris
- Voice
- Research trends



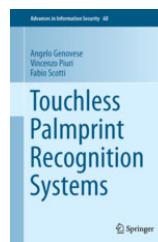
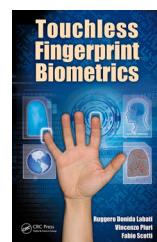
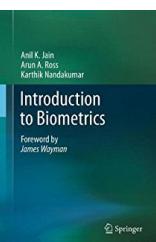
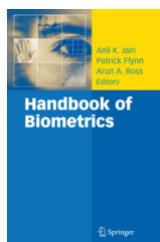
## Basic concepts on biometrics



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## Biometrics

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



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## Biometric traits

- Traditional recognition methods:  
key, password, smartcard, token

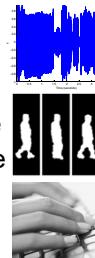
- Biometrics:

- physiological
  - fingerprint
  - iris
  - hand geometry
  - palmprint
  - palmevein
  - ear
  - ECG
  - DNA



- behavioral

- voice
- gait
- signature
- keystroke



## 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

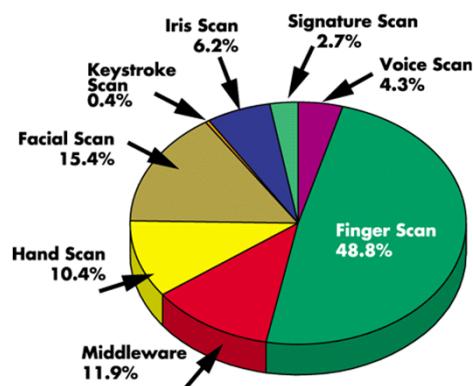
Trait	Univ.	Uniq.	Perm.	Coll.	Perf.	Acc.	Circ.
Face	H	L	M	H	L	H	L
Fingerprint	M	H	H	M	H	M	H
Hand geometry	M	M	M	H	M	M	M
Keystrokes	L	L	L	M	L	M	M
Hand vein	M	M	M	M	M	M	H
Iris	H	H	H	M	H	L	H
Retinal scan	H	H	M	L	H	L	H
Signature	L	L	L	H	L	H	L
Voice	M	L	L	M	L	H	L
Facethermograms	H	H	L	H	M	H	H
Odor	H	H	H	L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



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## Biometric traits in real applications



International Biometric Group, New York, NY; 1.212



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## Applications (1/3)



Border control



Disney world



2004 Summer Olympics

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## Applications (2/3)



Shops

\* Type ID  
\* Swipe ID  
\* Select payment  
-OR-  
\* Pay cashier  
Cred. Debit EBT |



ATM



Surveillance

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## Applications (3/3)



**LiveGrip™**  
Advanced Biometrics, Inc



Smartphones



**Hitachi - grip-type finger vein authentication**

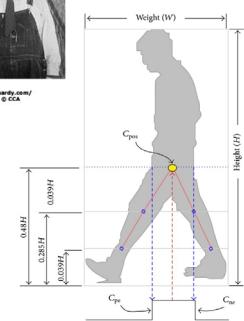
<http://www.hitachi.com>



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## Soft biometrics

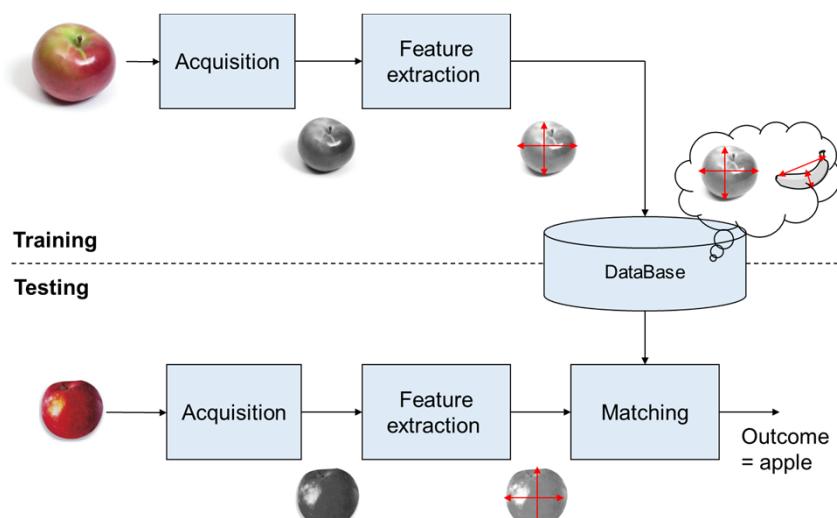
- Soft biometric traits are characteristics that provide some information about the individual, but lack the distinctiveness and permanence to sufficiently differentiate any two individuals
- Continuous or discrete



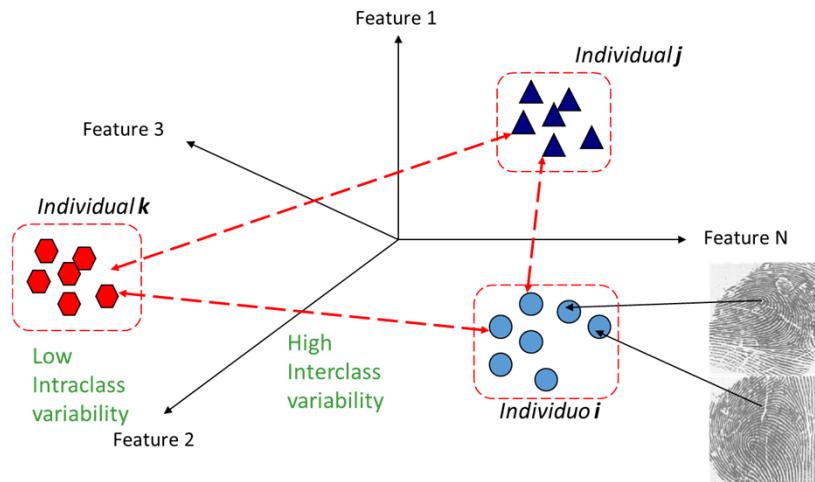
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## Biometric recognition

### Patter recognition systems



## Patter recognition and biometrics



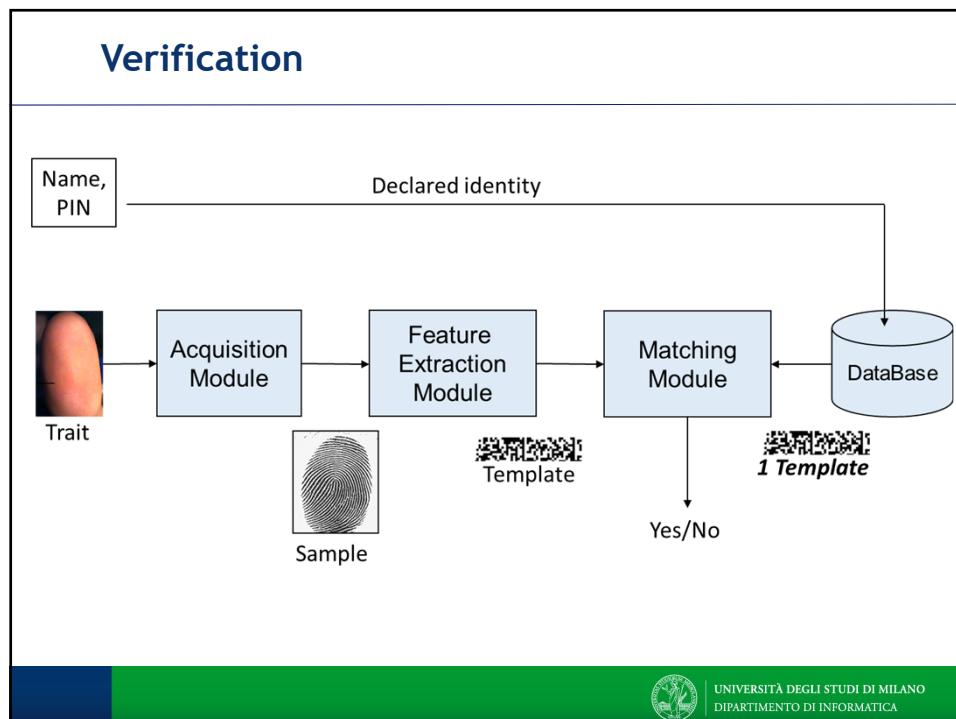
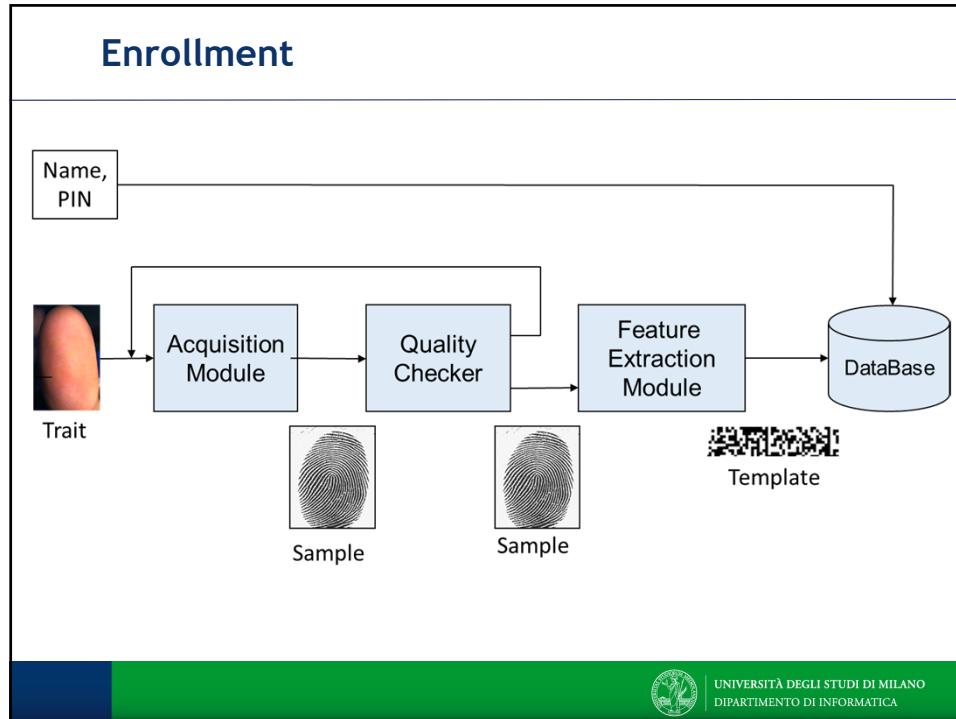
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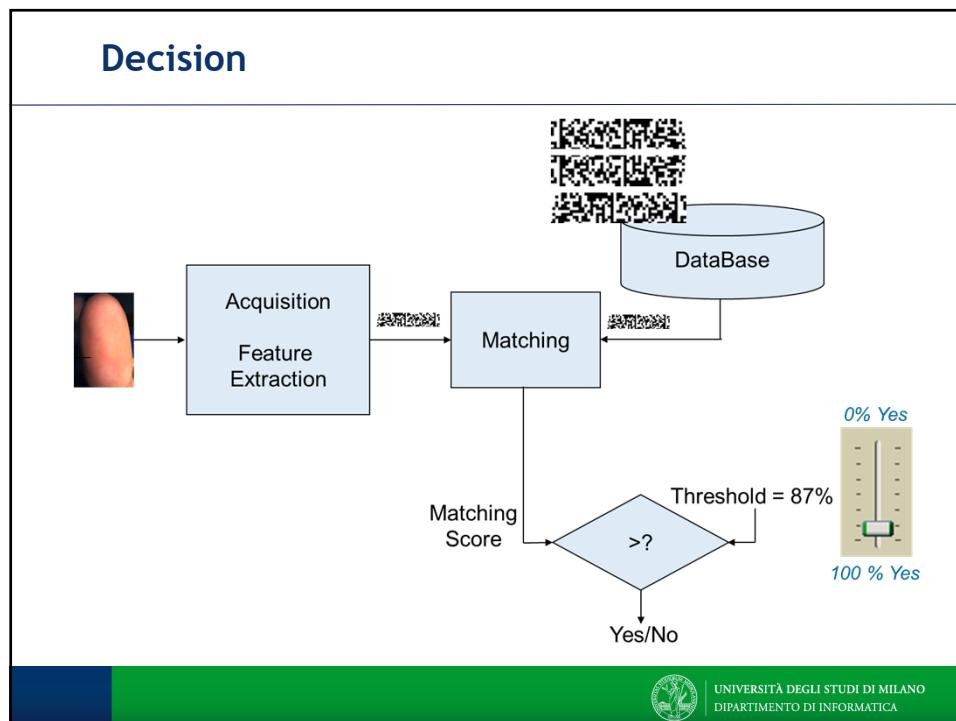
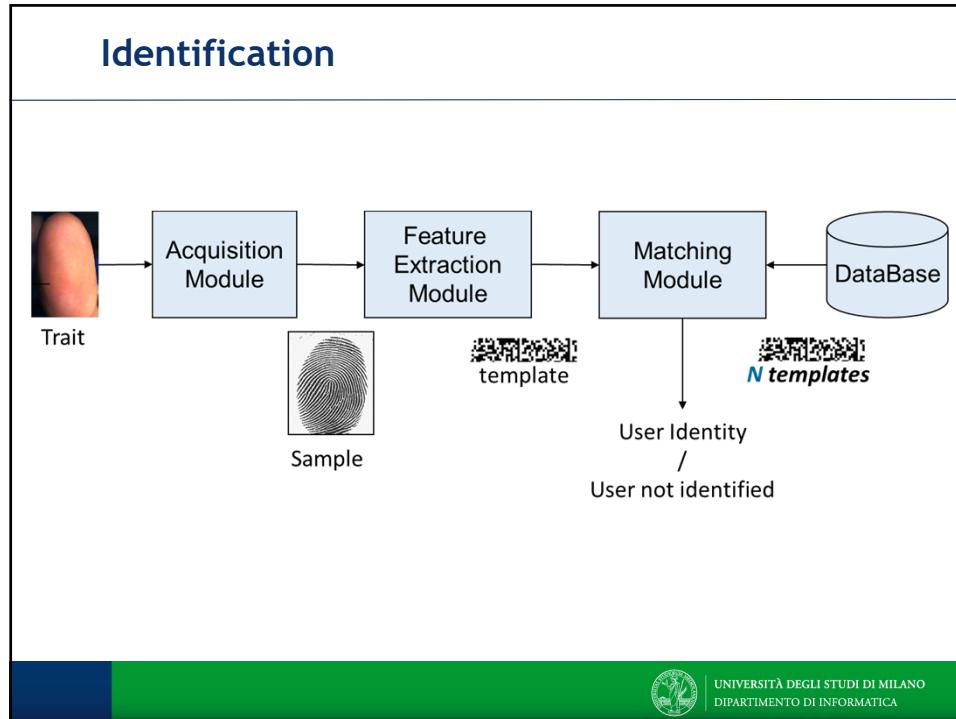
## Verification / Identification

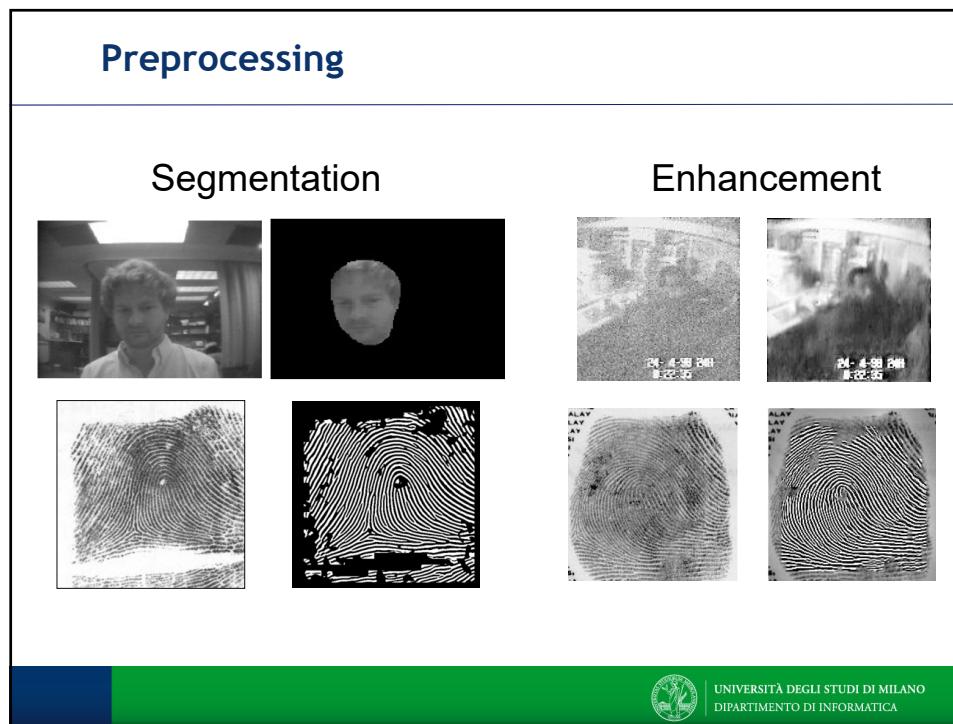
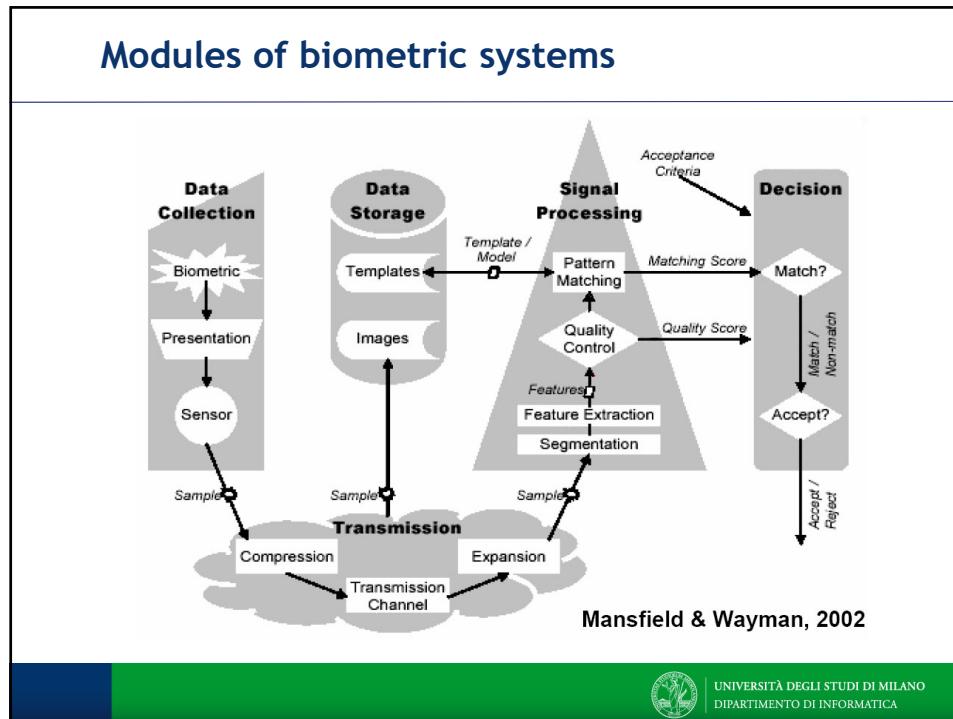
- Verification
  - The verification involves confirming or denying a person's claimed identity
- Identification
  - In the identification mode, the biometric system has to establish a person's identity by comparing the acquired biometric data with the information related to a set of individuals, performing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



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## Evaluation of biometric systems



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## Evaluation strategies

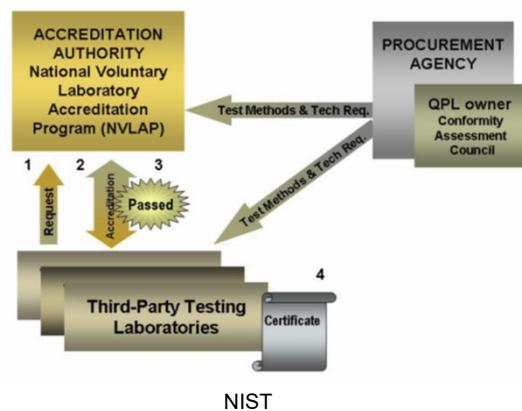
Technology



Scenario

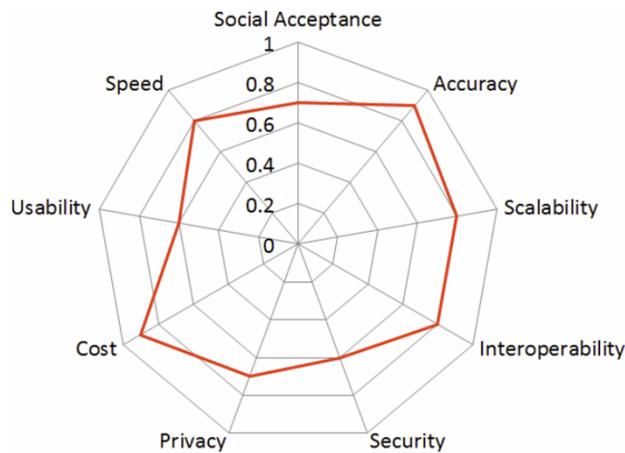


Operational



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## Aspects to be evaluated



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## Accuracy evaluation: genuine and impostor comparisons (1/2)

Genuine comparison



Impostor comparison



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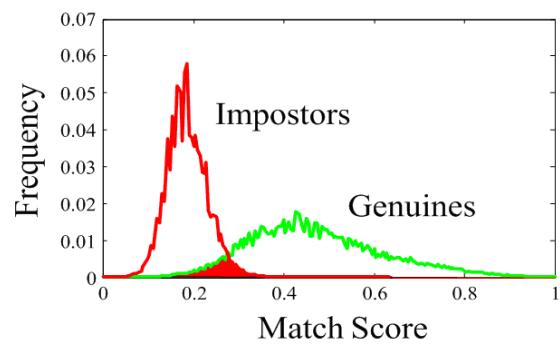
## Accuracy evaluation: genuine and impostor comparisons (2/2)

Genuine scores

$$\begin{aligned} S(X_{1\_1}, X_{1\_2}) &= 0.7 \\ S(X_{1\_1}, X_{1\_3}) &= 0.8 \\ S(X_{2\_1}, X_{2\_2}) &= 0.4 \\ S(X_{2\_1}, X_{2\_3}) &= 0.5 \end{aligned}$$

Impostor scores

$$\begin{aligned} S(X_{1\_1}, X_{3\_2}) &= 0.11 \\ S(X_{4\_1}, X_{3\_1}) &= 0.21 \\ S(X_{5\_2}, X_{1\_2}) &= 0.001 \\ S(X_{2\_2}, X_{1\_2}) &= 0.19 \end{aligned}$$



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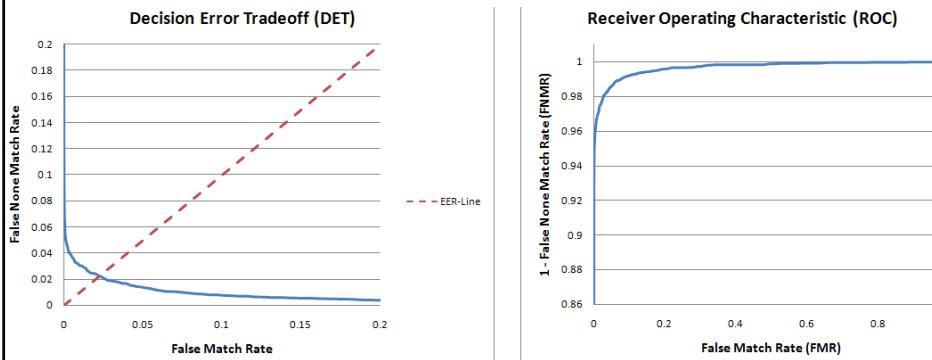
## Accuracy evaluation: FMR and FNMR

- **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*



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## Accuracy evaluation: DET and ROC



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## Accuracy evaluation: other figures of merit

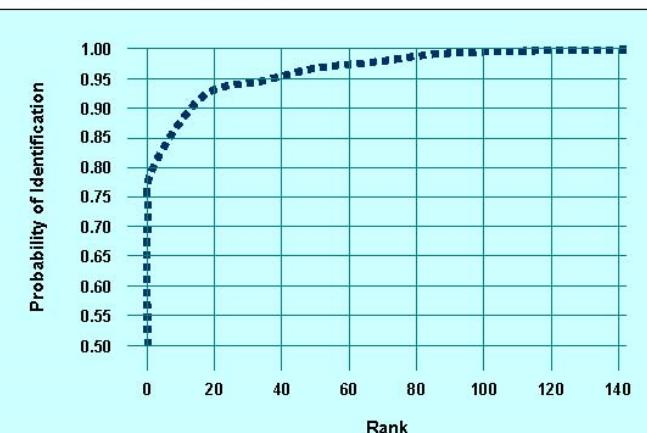
- **Failure to acquire (FTA)**
- **Failure to enroll (FTE)**
- **False acceptance rate (FAR)**: similar to FMR, but used for the complete biometric system (not only the algorithms)
- **False rejection rate (FRR)**: similar to FNMR, but used for the complete biometric system (not only the algorithms)
- **Equal error rate (EER)**: the ideal point in which  $FMR = FNMR$



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## Accuracy evaluation: identification

Cumulative Match Characteristic



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## Fingerprint



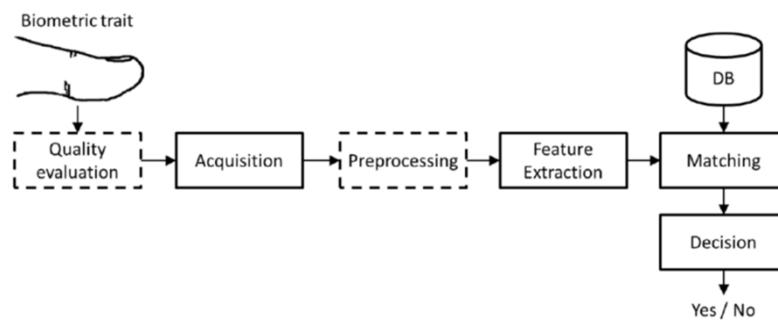
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## Fingerprint

- 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



## The biometric recognition process



## Acquisition

The slide displays three examples of fingerprint acquisition:

- Latent:** A dark, grainy image of a fingerprint impression.
- Inked and rolled:** A high-contrast, black-and-white image of a fingerprint impression.
- Live scan:** A high-resolution, grayscale image of a live fingerprint being scanned.

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## Live acquisitions

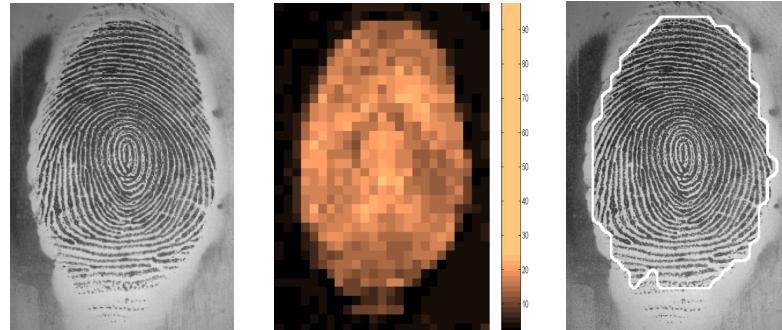
The slide displays six types of live fingerprint acquisition methods:

- Optical scanner:** A grayscale image of a fingerprint.
- Capacitive scanner:** A grayscale image of a fingerprint.
- Piezoelectric scanner:** A grayscale image of a fingerprint.
- Thermal (Sweeping):** An image showing a finger being swept over a thermal sensor array.
- Thermal scanner:** A grayscale image of a fingerprint.
- Inked impression:** A grayscale image of a fingerprint impression with handwritten text "04" and "S. L. THURBER" visible.
- Latent fingerprint:** A grayscale image of a latent fingerprint impression.
- 3dimensional:** A 3D surface plot of a fingerprint.

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## Preprocessing: segmentation

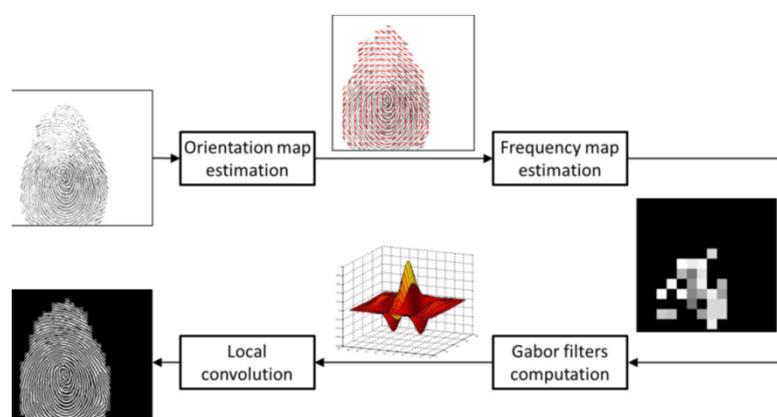
- Local standard deviation (16 X 16 pixels)



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## Preprocessing: enhancement

- Contextual filtering



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## Levels of analysis

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



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

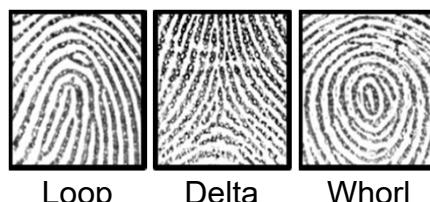


- **Level 3:** ultra-thin details, such as pores and local peculiarities of the ridge edges



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## Level 1: singular regions



Loop      Delta      Whorl

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



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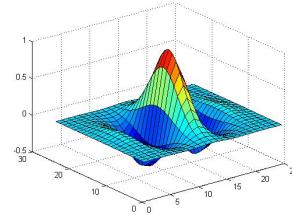
## Level 1: Gabor filters (1/2)

The even-symmetric Gabor filter has the general form

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

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

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

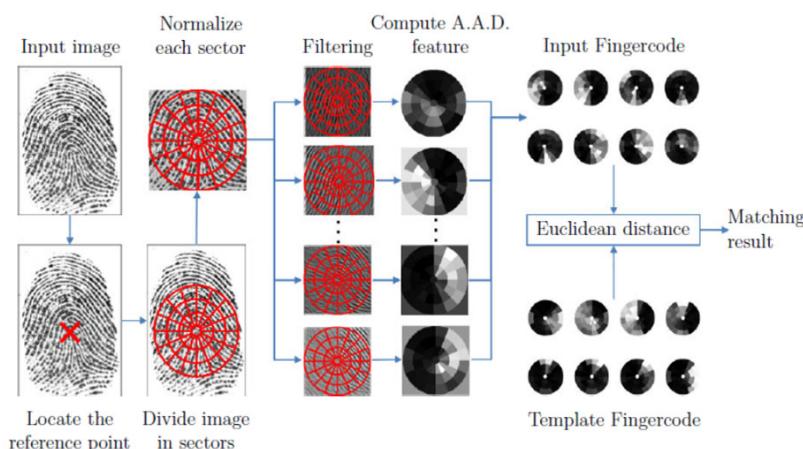


where  $\Phi$  is the orientation of the Gabor filter,  $f$  is the frequency of a sinusoidal plane wave, and  $\sigma_x$  and  $\sigma_y$  are the space constants of the Gaussian envelope along  $x$  and  $y$  axes, respectively.

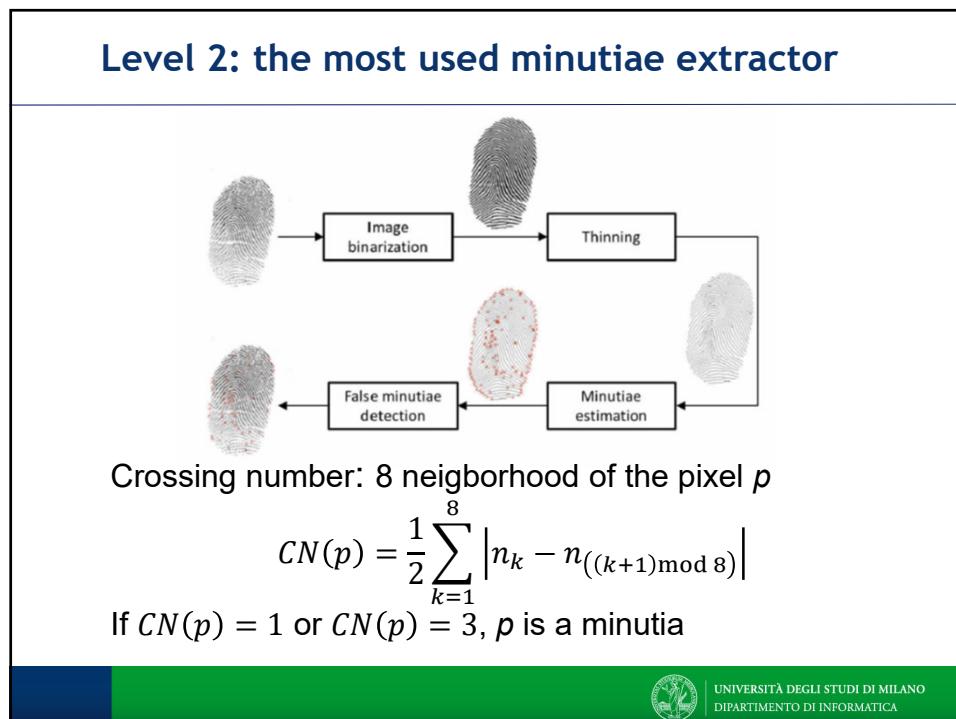
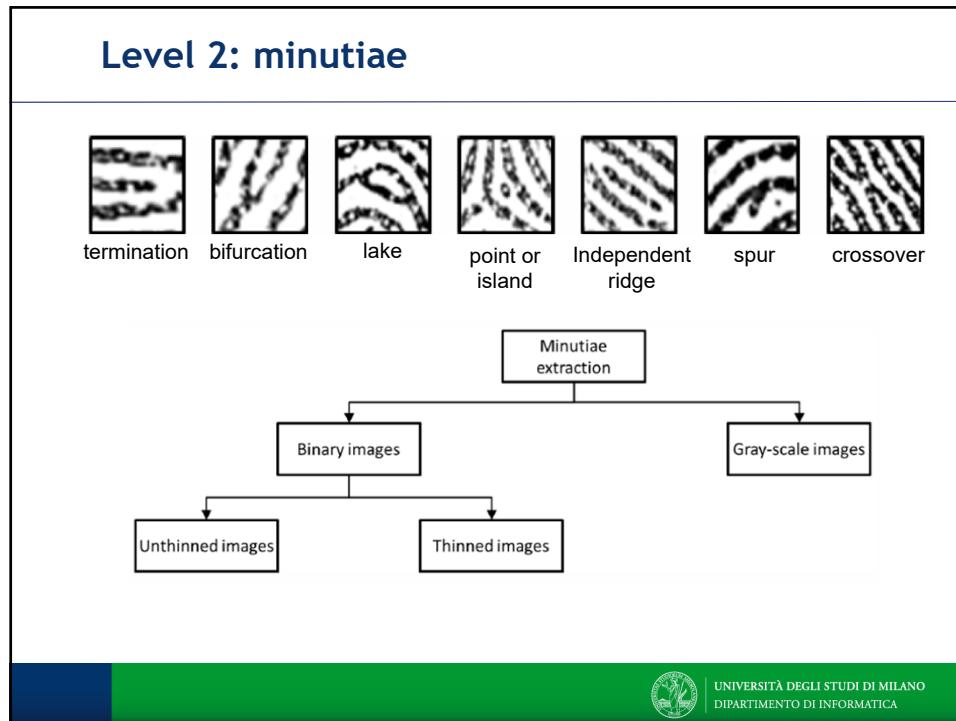


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## Level 1: Gabor filters (2/2)



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## Level 2: minutia patterns

1. Ridge Ending  
(appearing)



2. Ridge Ending  
(disappearing)



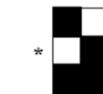
3. Bifurcation  
(disappearing)



4. Bifurcation  
(appearing)



5. Bifurcation  
(disappearing)



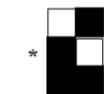
6. Bifurcation  
(disappearing)



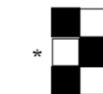
7. Bifurcation  
(appearing)



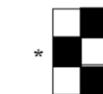
8. Bifurcation  
(appearing)



9. Bifurcation  
(disappearing)



10. Bifurcation  
(appearing)



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## Minutiae-based matching

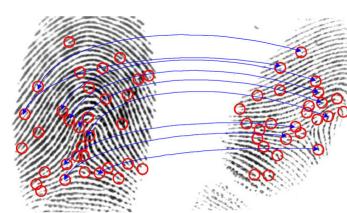
- Two minutiae are considered as correspondent if their spatial distance  $s_d$  and direction difference  $d_d$  are less than fixed thresholds

$$s_d(m'_j, m_i) = \sqrt{(x'_j - x_i)^2 + (y'_j - y_i)^2}$$

$$d_d(m'_j, m_i) = \min(|\theta'_j - \theta_i|, (360 - |\theta'_j - \theta_i|))$$



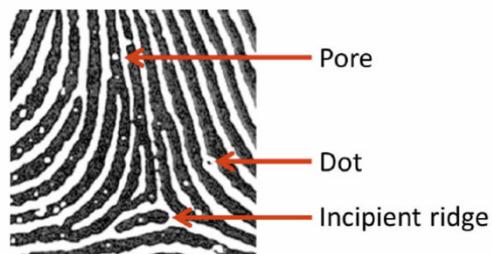
- Non-exact point pattern matching
  - Roto-translations
  - Non-linear distortions
  - False minutiae
  - Missed minutiae
  - Non constant number of minutiae



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### Level 3

- Minimum resolution of 800 DPI



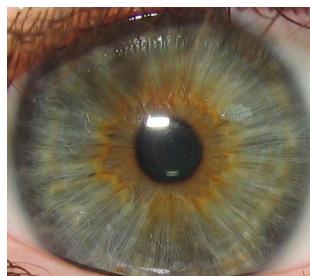
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Iris

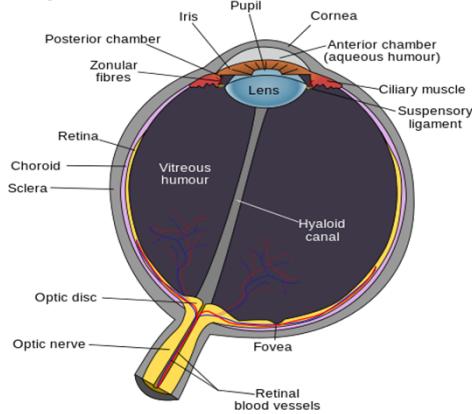


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## Iris biometric trait



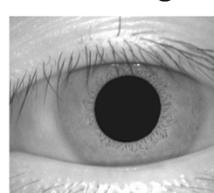
The colored ring around the pupil of the eye is called the Iris



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## How iris recognition works

Iris Image



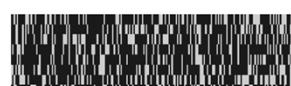
Preprocessing

Segmented Iris



Polar Transform

Feature Extraction



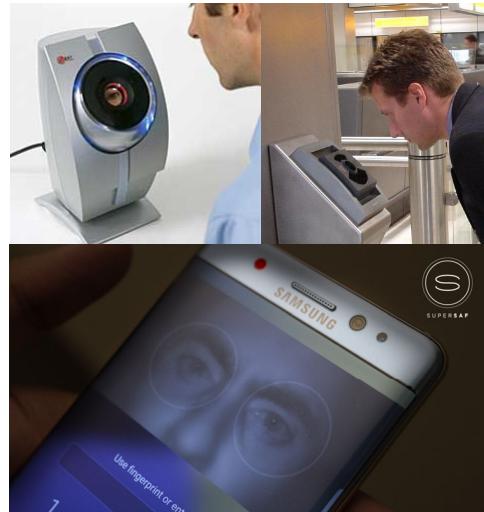
IrisCode

Iris in Polar Coordinates



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## Iris scanners



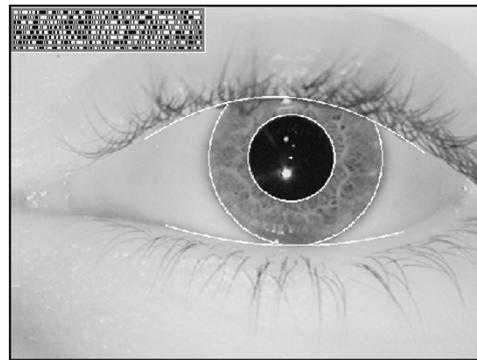
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## Iris segmentation using Hough transform



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## Iris segmentation using Daugman's method

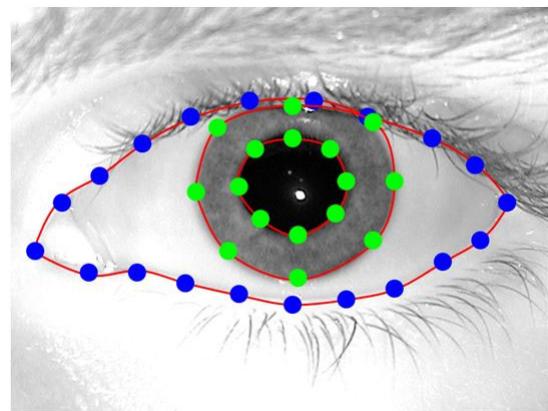

$$\max_{(r, \varphi_0, y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{\varphi_0, y_0} \frac{I(x, y)}{2\pi r} ds \right|$$

Localizing iris boundaries by differential operators



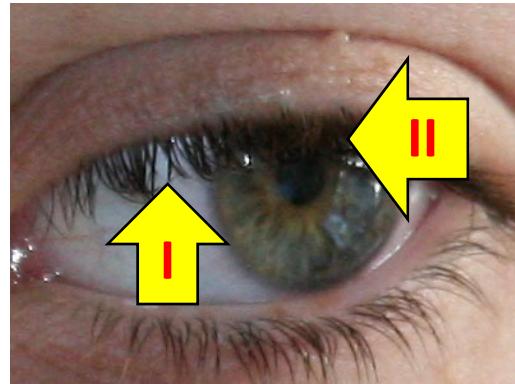
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## Iris segmentation using active contours



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## Eyelids and eyelashes



I = separable eyelashes

II = not-separable eyelashes

## Iris normalization: motivation

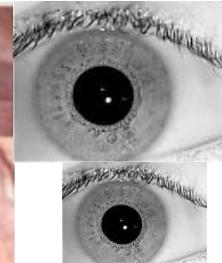
Pupil dilation



Gaze deviation



Resolution



## Iris normalization: Rubber sheet model

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

with

$$\alpha = \sigma_x^2 + \sigma_y^2$$

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

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## Iriscode (1/2)

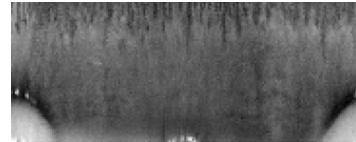
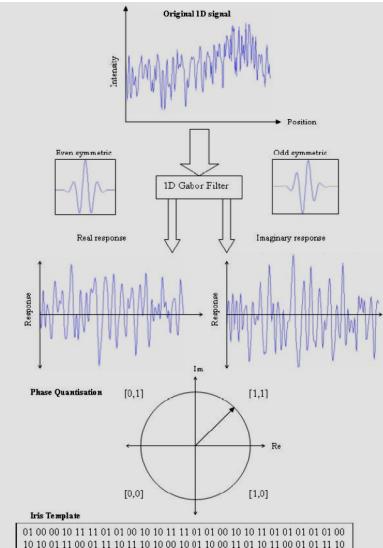
$$h_{\{Re,Im\}} = \text{sgn}_{\{Re,Im\}} \int_{\rho} \int_{\phi} I(\rho, \phi) e^{-i\omega(\theta_0 - \phi)} \\ \cdot e^{-(r_0 - \rho)^2/\alpha^2} e^{-(\theta_0 - \phi)^2/\beta^2} \rho d\rho d\phi$$

"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"

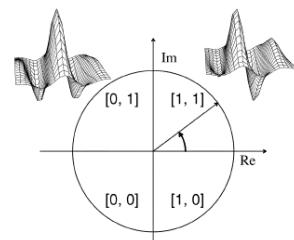
J. Dougman

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## Iriscode (2/2)



Phase-Quadrant Demodulation Code

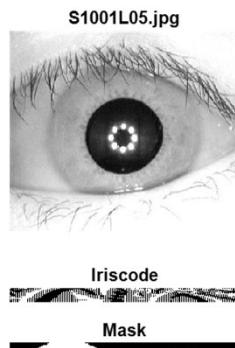
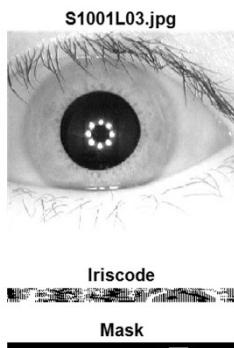


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## Iriscode matching

$$\text{HD} = \frac{\|(codeA \otimes codeB) \cap maskA \cap maskB\|}{\|maskA \cap maskB\|}$$

Matching Score = 0.26848



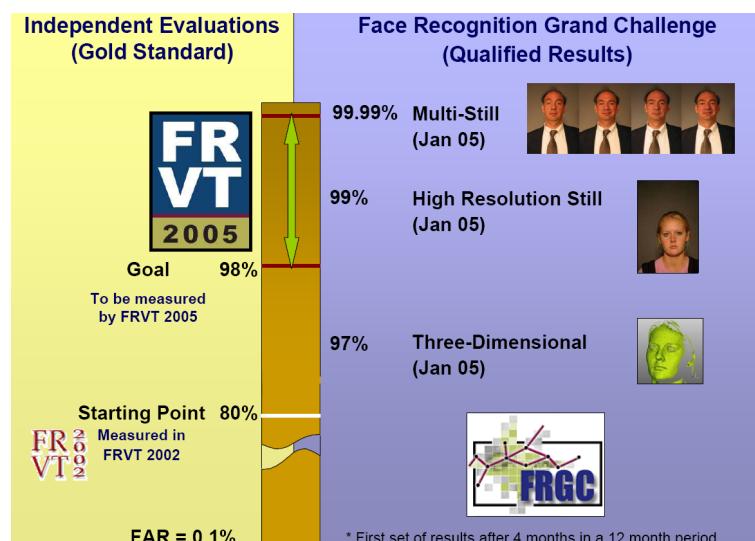
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## Face



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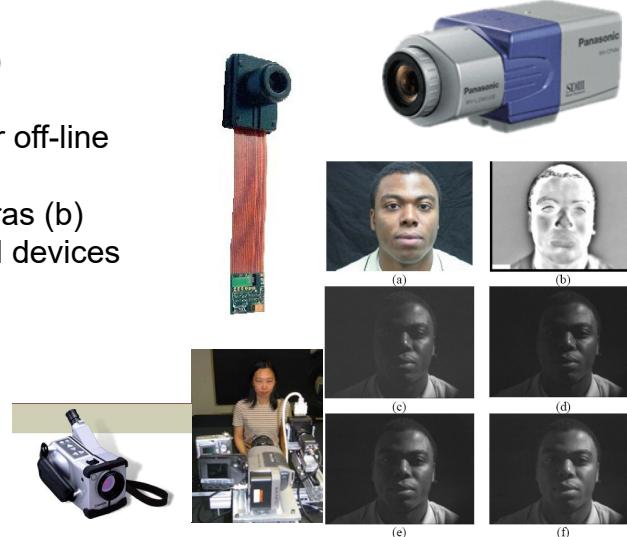
### Face recognition using still images



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## Face acquisition sensors

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



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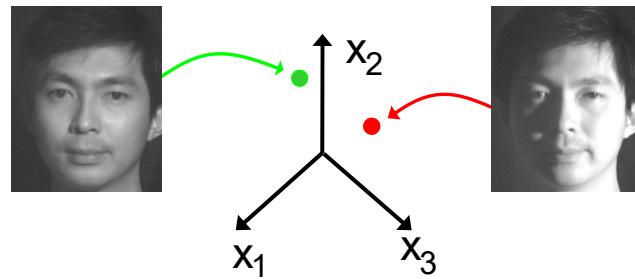
## Face detection

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



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## Images as features

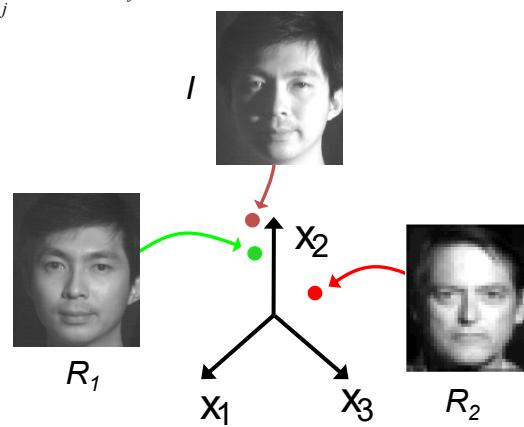


- Consider an  $n$ -pixel image to be a point in an  $n$ -dimensional space,  $\mathbf{x} \in \mathbb{R}^n$ .
- Each pixel value is a coordinate of  $\mathbf{x}$ .

## Nearest Neighbor Classifier

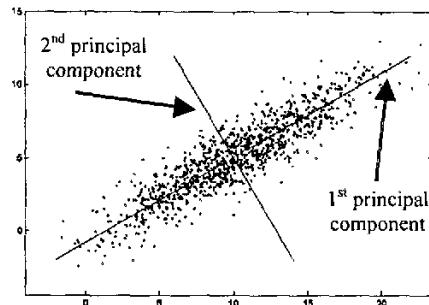
$\{R_j\}$  are set of training images.

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



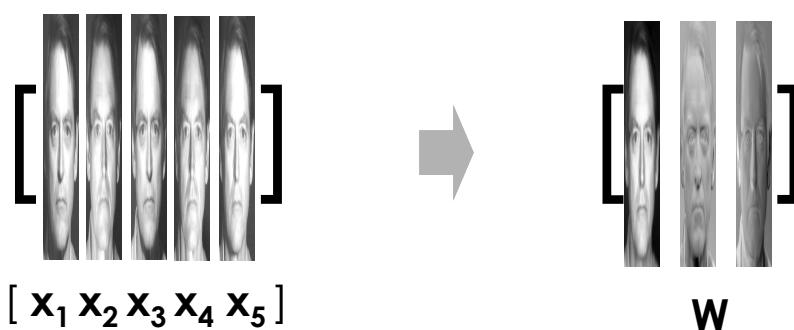
## Eigenfaces

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



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## Eigenfaces (2)



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



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## 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

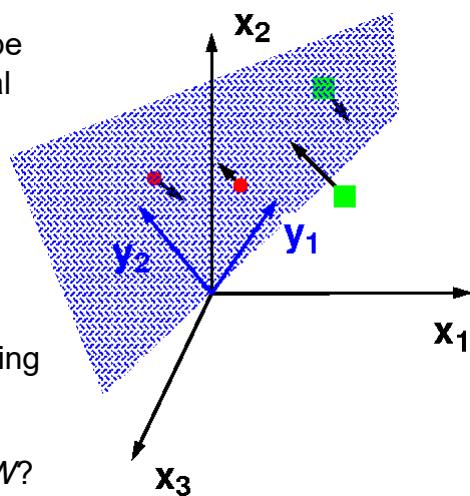
## Fisherfaces

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

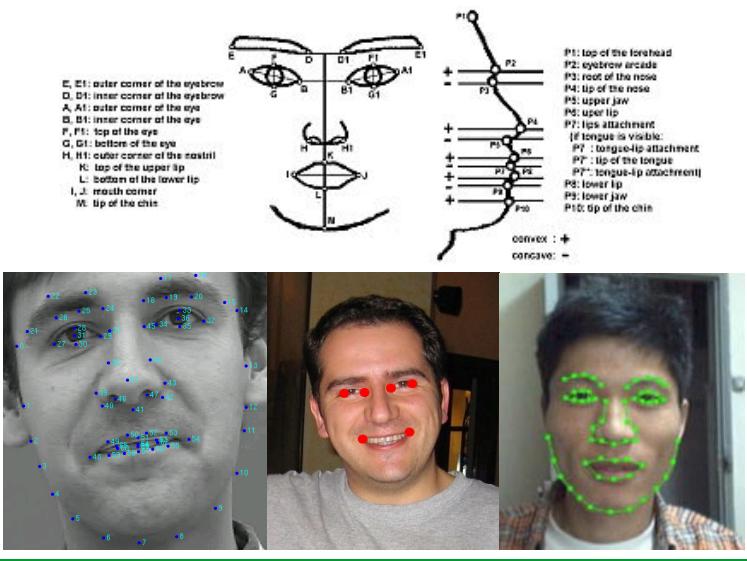
$$\mathbf{y} = \mathbf{W}\mathbf{x}$$

where  $\mathbf{W}$  is an  $n$  by  $m$  matrix.

- Recognition is performed using nearest neighbor in  $\mathbb{R}^m$ .
- How do we choose a good  $\mathbf{W}$ ?



## Face recognition based on fiducial points



The diagram illustrates the locations of 14 fiducial points on a face:

- E, E1: outer corner of the eyebrow
- D, D1: inner corner of the eyebrow
- A, A1: outer corner of the eye
- B, B1: inner corner of the eye
- F, F1: top of the eye
- G, G1: bottom of the eye
- H, H1: outer corner of the nostril
- K: top of the upper lip
- L: bottom of the lower lip
- I, J: mouth corner
- M: tip of the chin

Below the diagram are three images showing detected features:

- The first image shows a grayscale face with numerous blue dots representing detected landmarks.
- The second image shows a man's face with red dots at the detected landmarks.
- The third image shows a person's face with a green convex hull drawn around the detected landmarks.

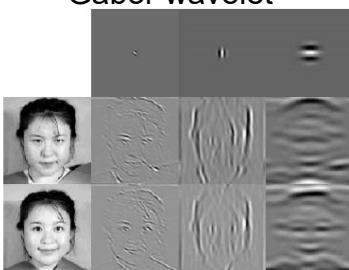
P1: top of the forehead  
 P2: eyebrow arcade  
 P3: rest of the nose  
 P4: tip of the nose  
 P5: upper lip  
 P6: lower lip  
 P7: lips attachment  
 If tongue is visible:  
 P8: tongue-lip attachment  
 P9: tip of the tongue  
 P10: chin-lip attachment  
 P11: lower lip  
 P12: lower jaw  
 P13: tip of the chin

convex : +  
concave : -

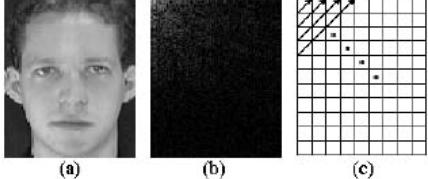
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## Examples of other features

**Gabor wavelet**



**Discrete cosine transform**



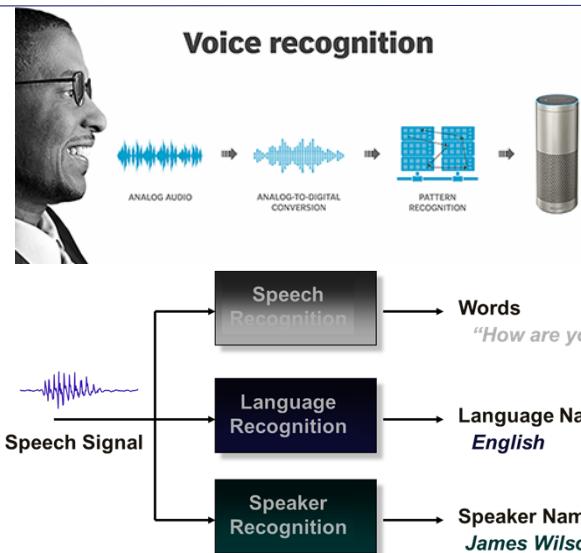
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# Voice



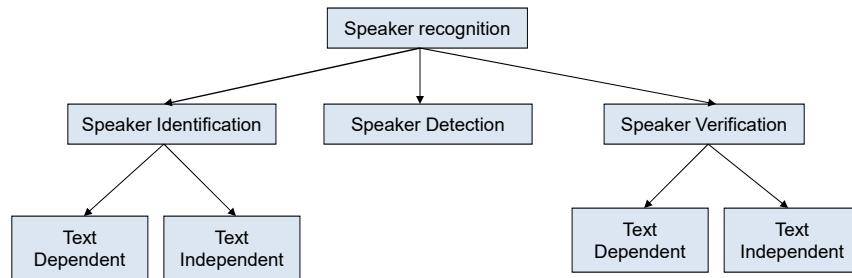
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## Voice recognition



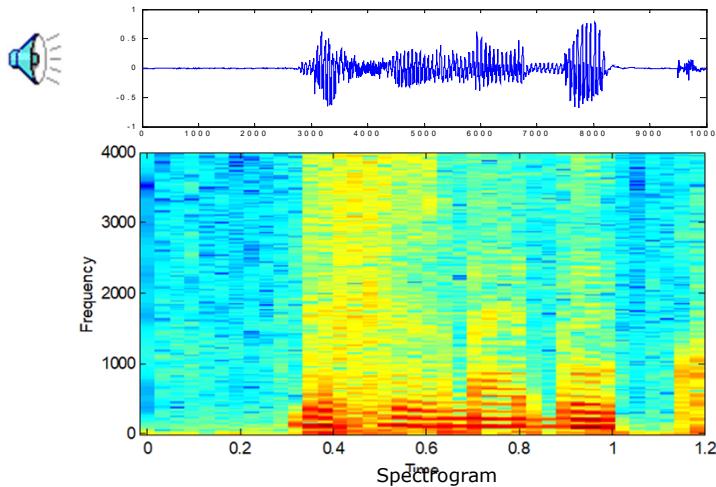
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## Speaker recognition



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## Nature of speech



A spectrogram is a visual representation of the spectrum of frequencies of sound or other signal as they vary with time.



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## How to build a system

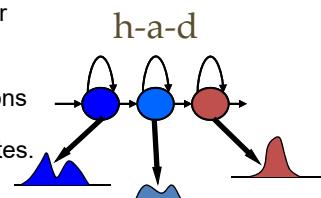
- Feature choices:
  - low level (MFCC, PLP, LPC, F0, ...) and high level (words, phones, prosody, ...)
- Types of models:
  - HMM, GMM, Support Vector Machines (SVM), DTW, Nearest Neighbor, Neural Nets
- Making decisions: Log Likelihood Thresholds, threshold setting for desired operating point
- Other issues: normalization (znorm, tnorm), optimal data selection to match expected conditions, channel variability, noise, etc.



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## Speaker Models -- HMM

- Speaker models (voiceprints) represent voice biometric in compact and generalizable form
- Modern speaker verification systems use **Hidden Markov Models (HMMs)**
  - HMMs are statistical models of how a speaker produces sounds
  - HMMs represent underlying statistical variations in the speech state (e.g., phoneme) and temporal changes of speech between the states.
  - Fast training algorithms (EM) exist for HMMs with guaranteed convergence properties.



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## Speaker models: HMMs / GMMs

Form of HMM depends on the application

**Fixed Phrase** → Word/phrase models

"Open sesame"



**Prompted phrases/passwords** → Phoneme models

/s/      /i/      /x/



**Text-independent** → single state HMM

General speech



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## Research trends



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## Research trends

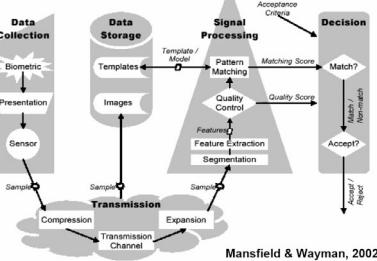
- Increase the accuracy
- Multimodal and multibiometric systems
- Reduce the sensor costs
- Less-cooperative acquisition techniques
- Increase the usability and user's acceptance
- Increase of the distances from the sensors
- Continuous authentication
- Adaptive biometrics
- Security and privacy
- New biometric traits



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## Increase the accuracy

- Enhancement
- Segmentation
- Feature extraction
- Matching
- Classification methods
- Deep learning



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## Multimodal systems

**Advantages**

- Accuracy
  - FNMR, FMR
- Enrollment
  - FTE
  - Universal registration requirements
- Anti-Spoofing

## Multimodal systems: examples

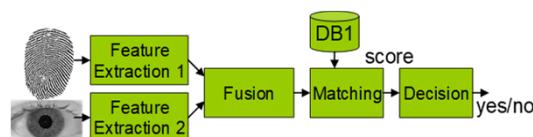
The bottom right corner features the University of Milan logo and the text 'UNIVERSITÀ DEGLI STUDI DI MILANO DIPARTIMENTO DI INFORMATICA'.

## Multimodal systems: fusion levels

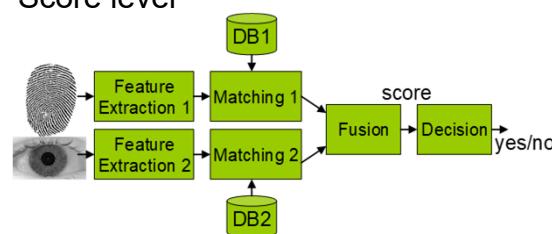
- Data Fusion Level of Fusion
  - Fusion at Sensor level
  - Fusion at Feature level
  - Fusion at Opinion level
  - Fusion at Decision level

## Multimodal systems: the most diffused methods

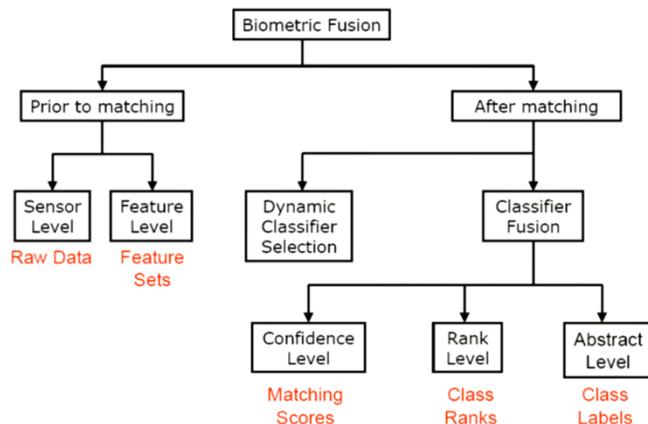
### Feature level



### Score level



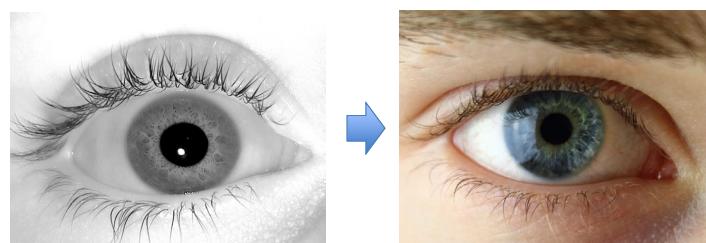
## Multimodal systems: data fusion



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## Reduce the sensor costs

- New application scenarios
- Wider diffusion of the technology



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## Less-cooperative acquisition techniques



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## Increase the usability and user's acceptance

- ISO 9241-11: The usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use
- User acceptance: subjective



Figure 17 Tall Participant Struggling at 99.1 cm (39 in.) and 30°

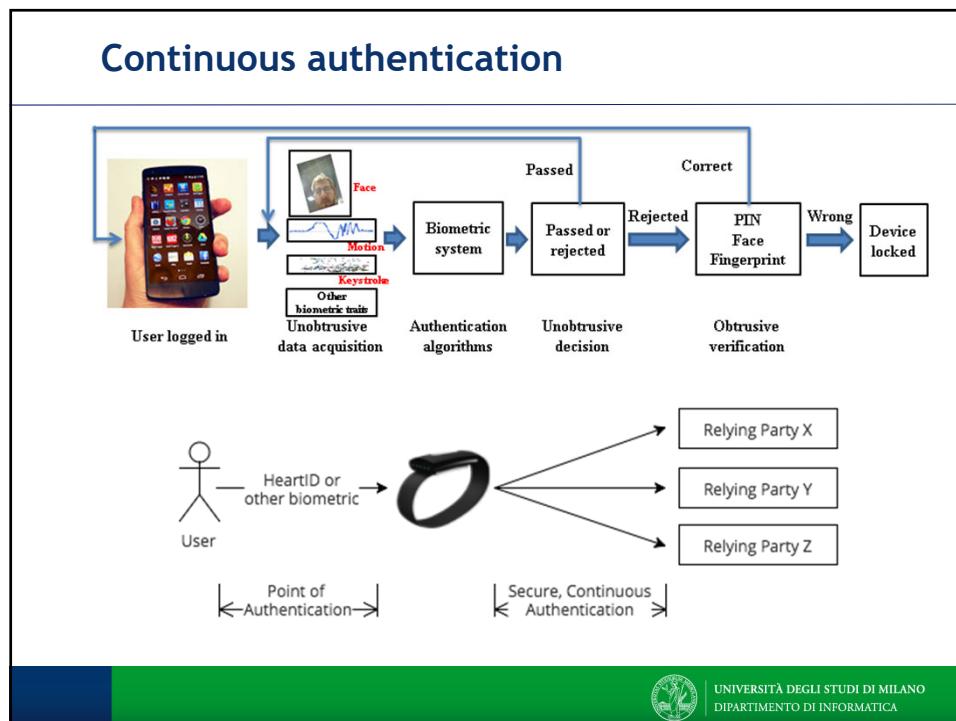
- <https://www.nist.gov/sites/default/files/nistir-7504-height-angle.pdf>

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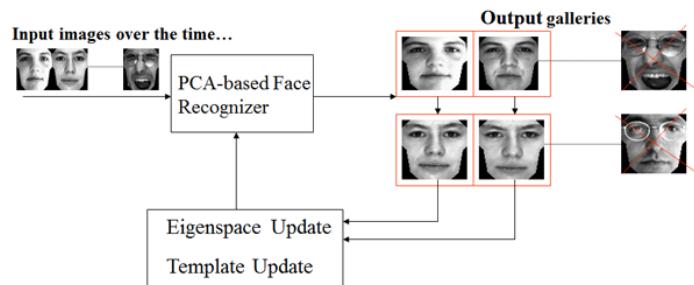
## Increase of the distances from the sensors

The top part of the image shows a physical checkpoint area with multiple sensors mounted on poles, labeled "CHECKPOINT" and "Exit". A small inset window titled "Iris at a distance" provides a detailed technical description of the system. The bottom part is a screenshot of the "Morpho IAD Demo" software interface, showing three camera feeds: a close-up of an eye, another eye, and a person's face. Below the feeds, it says "3.6 seconds" and "Pierre Bonjour" with a green checkmark. The software interface includes buttons for "SEARCH" and "IMAGE".

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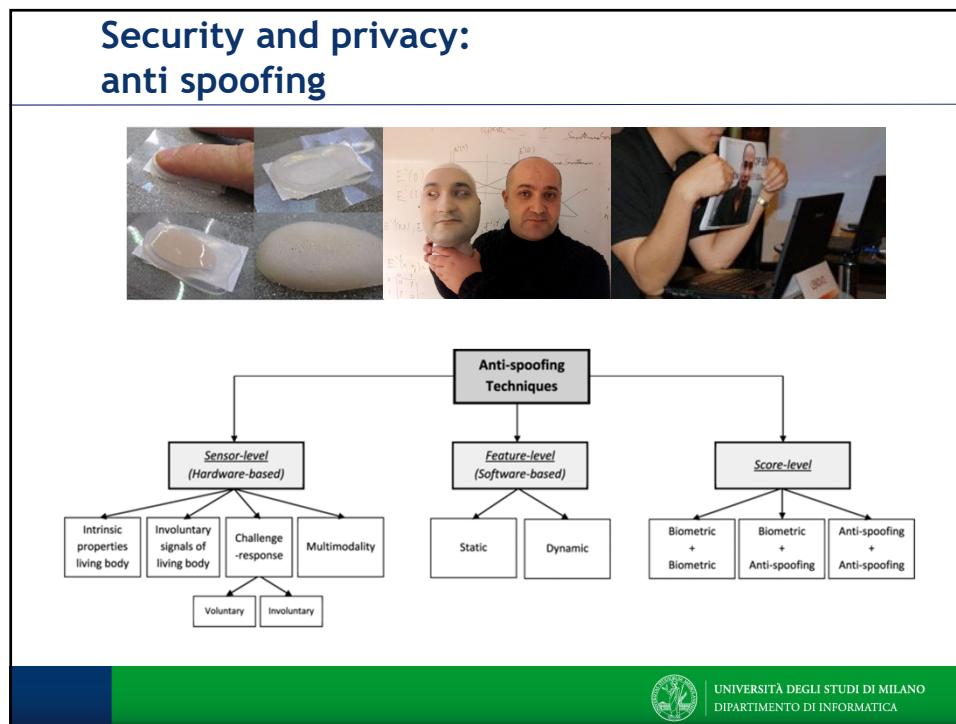
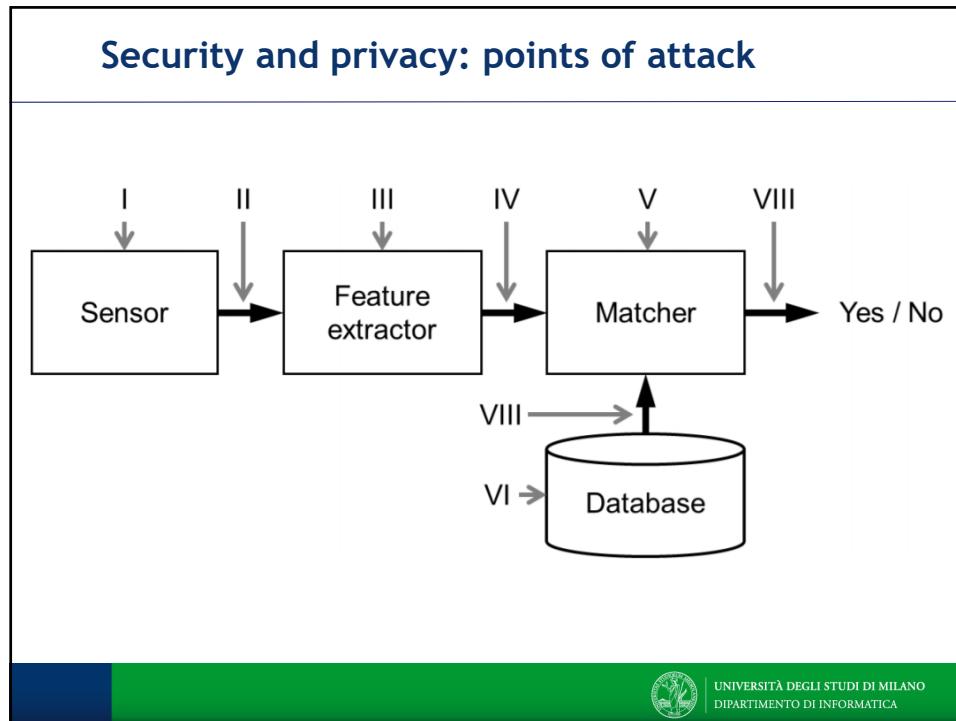
## Adaptive biometrics



## Security and privacy

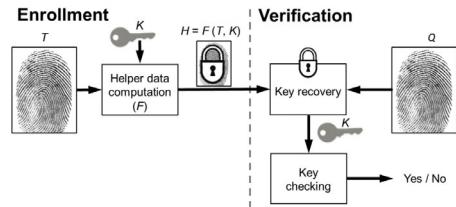
- Security: authentication, data integrity, confidentiality, and non-repudiation
- Privacy: security, data protection



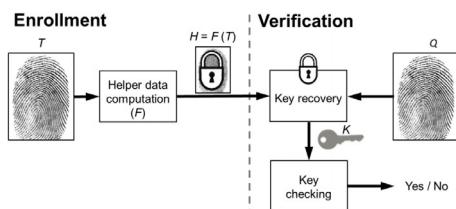


## Security and privacy: template protection (1/2)

### Key-binding biometric cryptosystem

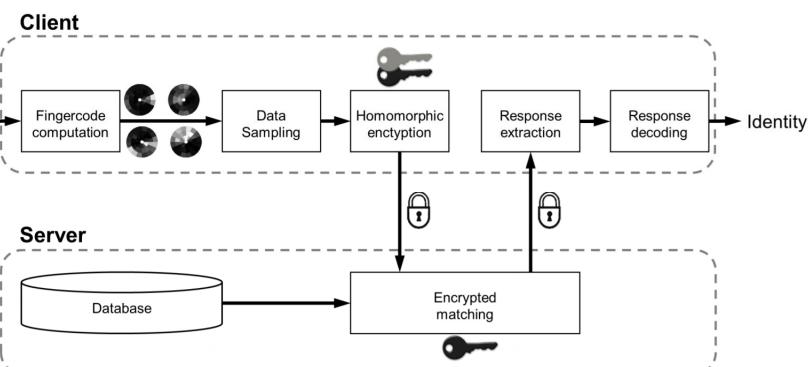


### Key generating biometric cryptosystem



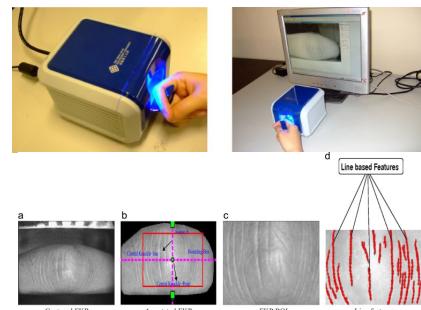
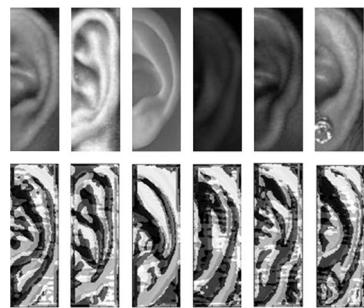
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## Security and privacy: template protection (2/2)



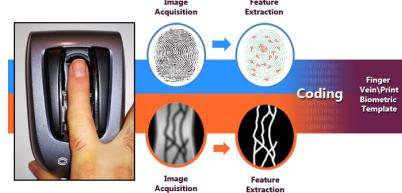
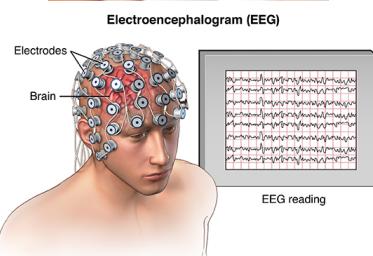
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## New biometric traits (1/3)



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## New biometric traits (2/3)



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### New biometric traits (3/3)



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