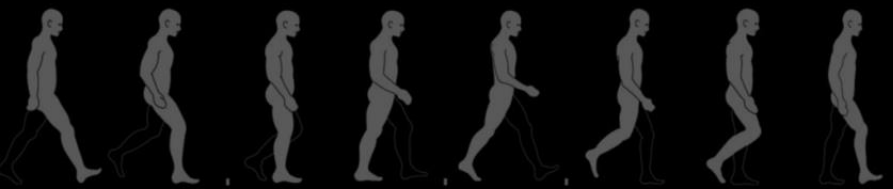
Biometric Authentication Systems

Chapter 8:

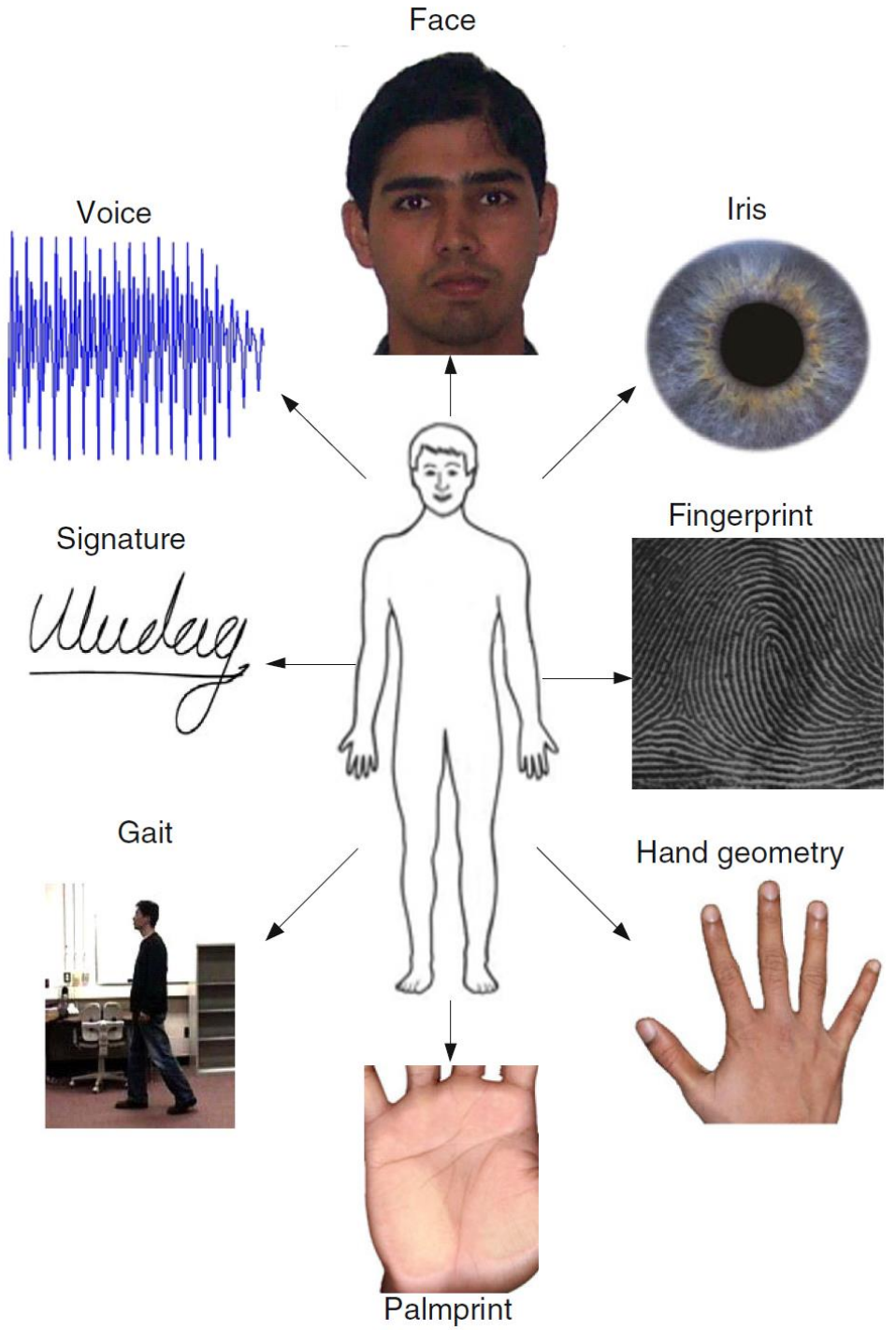
Fingerprint

Ngo Thanh Trung



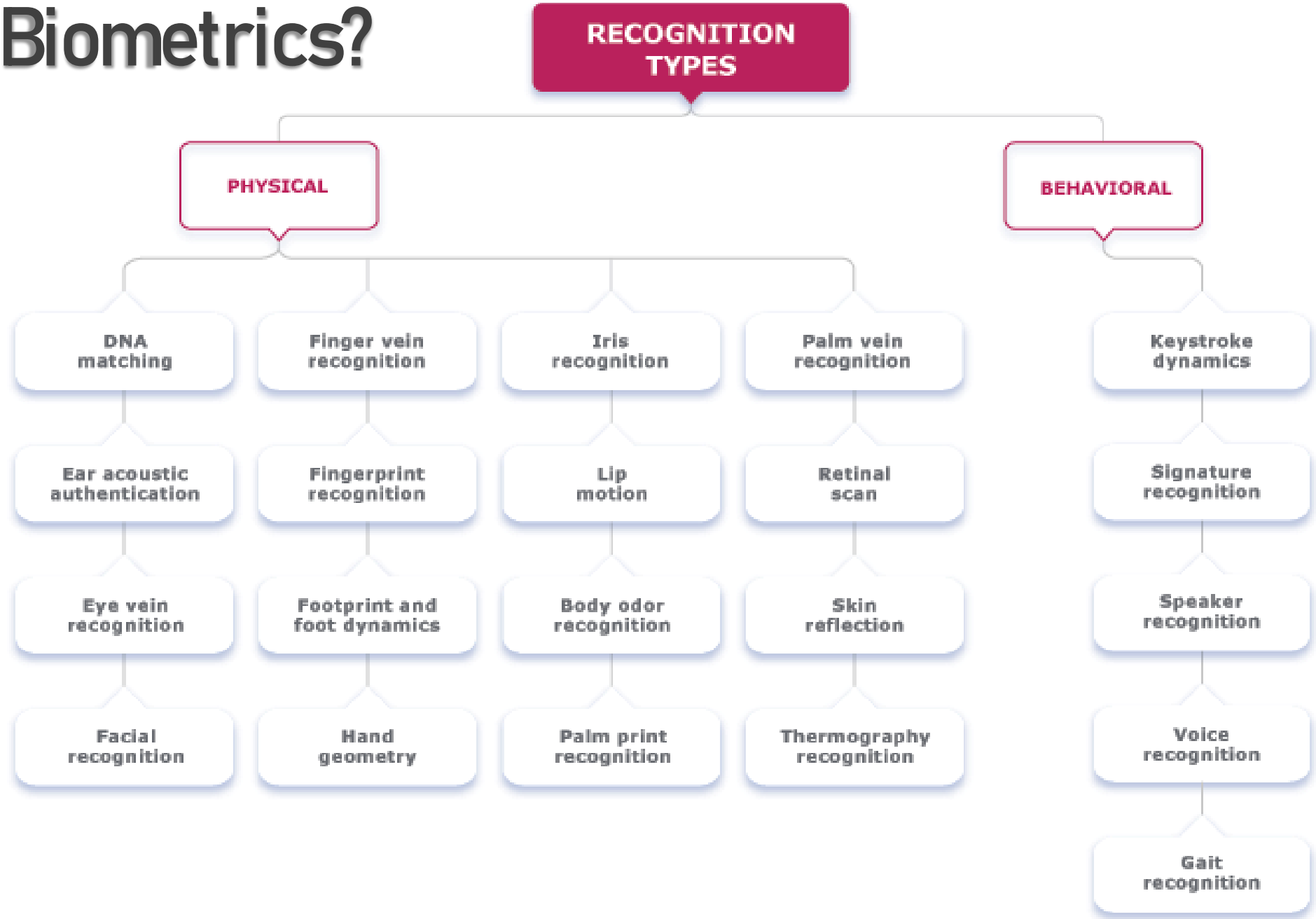
1-What is biometrics?

- A measurable **physical characteristic** or **personal behavioral trait** used to recognize the identity, or verify the claimed identity, of an applicant.

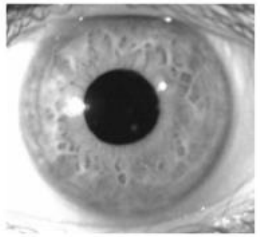
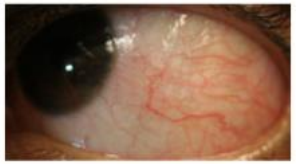


2- Types of Biometrics?

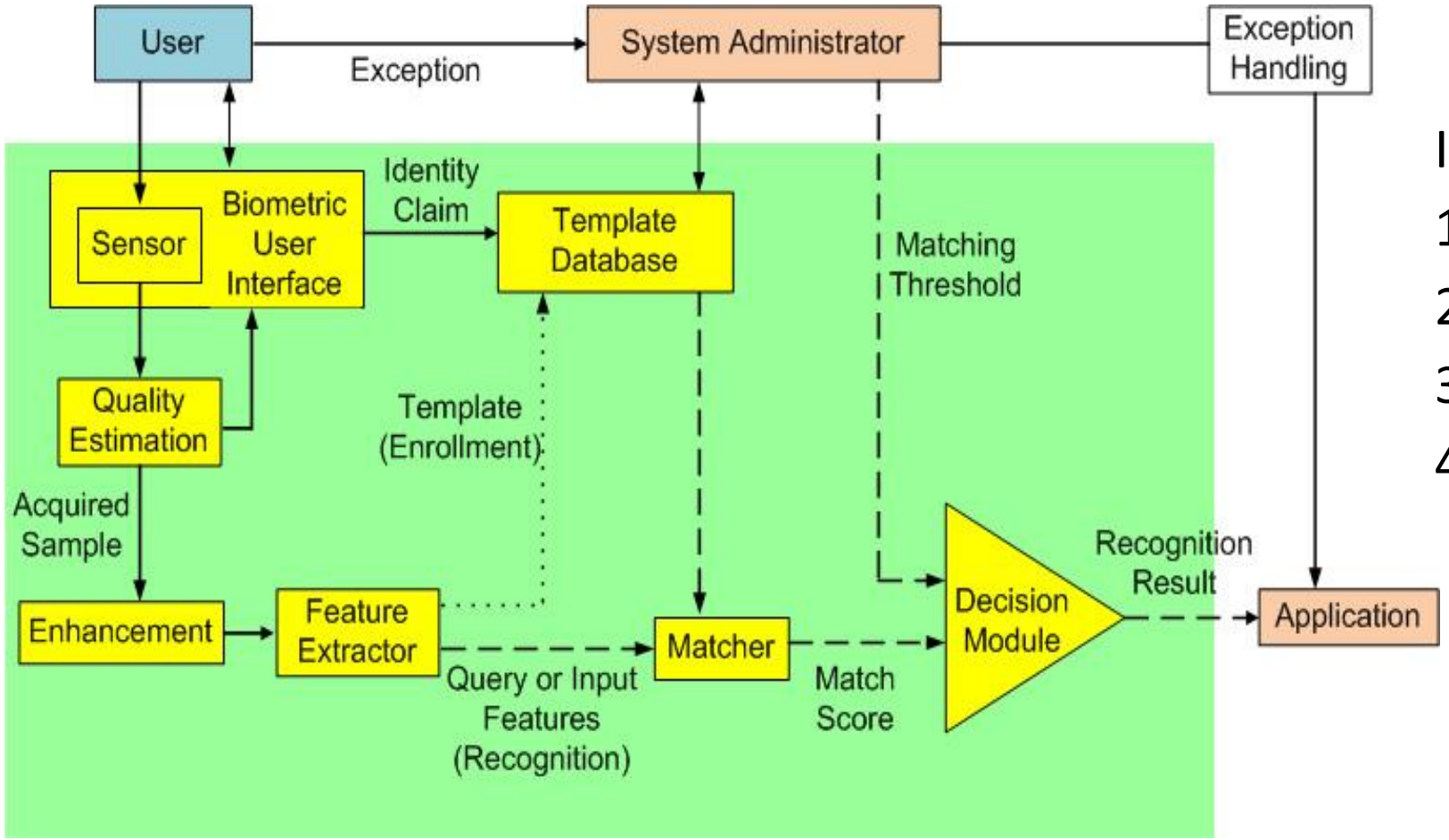
- **Physical**
- **Behavioral**



2- Types of Biometrics?

 Fingerprint	 Face	 Iris	 Retina	 Ear
 Palm print	 Hand geometry	 Periocular	 Conjunctival vasculature	 Key stroke dynamics
 Anthropometry	 Signature	 Facial thermogram	 Hand thermogram	 Gait

3-Biometric Systems



Important Biometric Subsystems

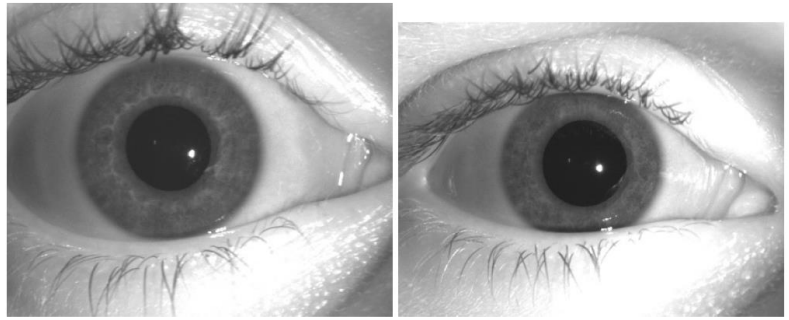
1. Biometric enrollment
2. Feature extractors
3. Template database
4. Feature Matchers

4- Types of Biometric Recognition?

- A standard biometric system has two functionalities
  - Verification or Authentication
  - Identification
    - Positive identification
    - Negative identification

5. Biometric System Errors

- Science of biometric recognition is based on two fundamental premises with a biometric trait:
  - Uniqueness
  - Permanence



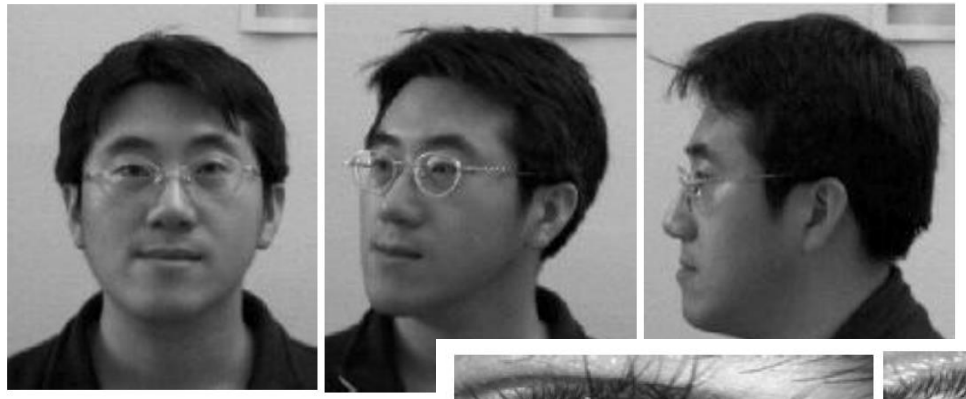
Biometrics of twins

5. Biometric System Errors

- However, these two premises are seldom true.
- Because
  - Physical trait may not be unique
  - Biometrics may change overtime

Variation of biometric traits

- Intra-user variations (or intra-class variations). This is due to reasons:
  - Imperfect sensing conditions (eg., noise, system errors)
  - Alteration in biometric characteristics
  - Changes in ambient conditions (eg., inconsistent illumination)
  - Variations in the interaction with the sensor,….



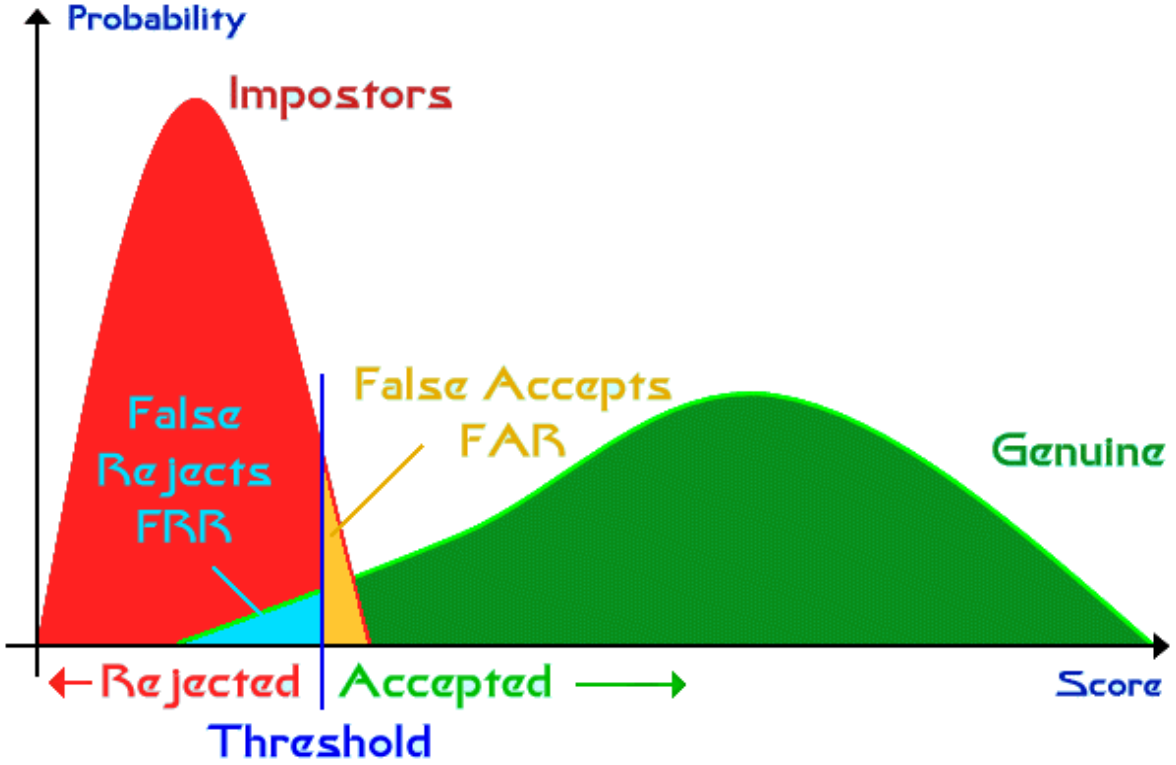
viewpoint variation

light intensity variation

6. Performance measures

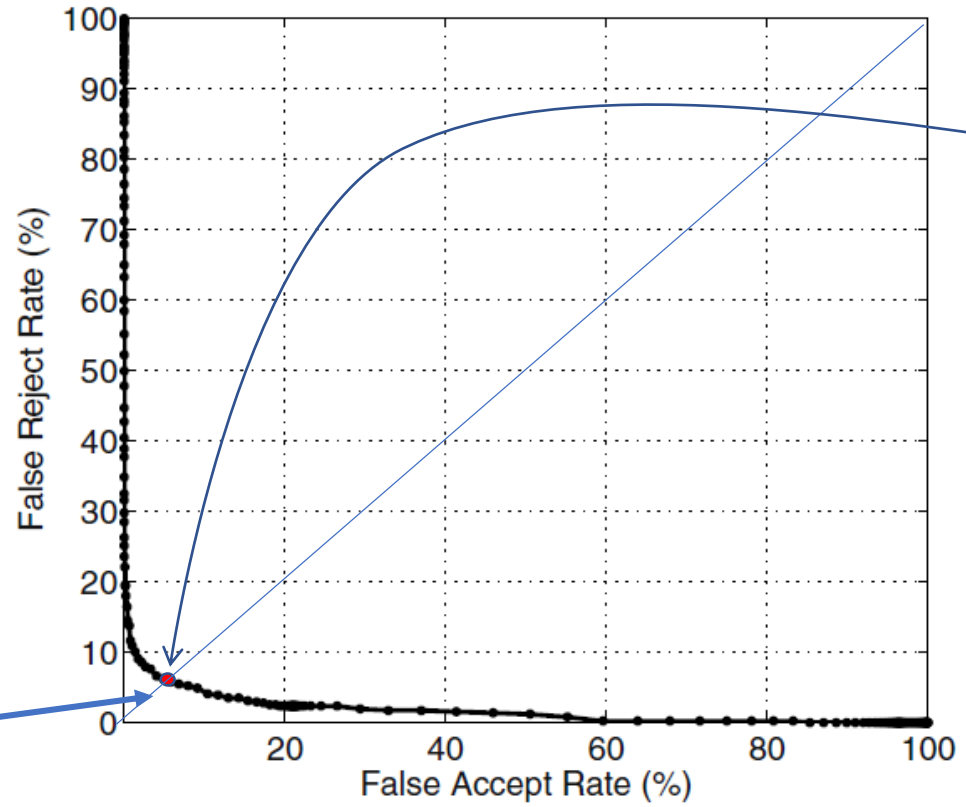
- In biometric verification, there are two popular metrics
  - False Rejection Rate (FRR) and False Acceptance Rate (FAR), also
  - False Non-match Rate (FNMR) and False Match Rate (FMR)

  which are computed based on the genuine and imposter match score distribution



6. Performance measures

- When changing the threshold η, we have variation of FAR(η) and FRR(η)



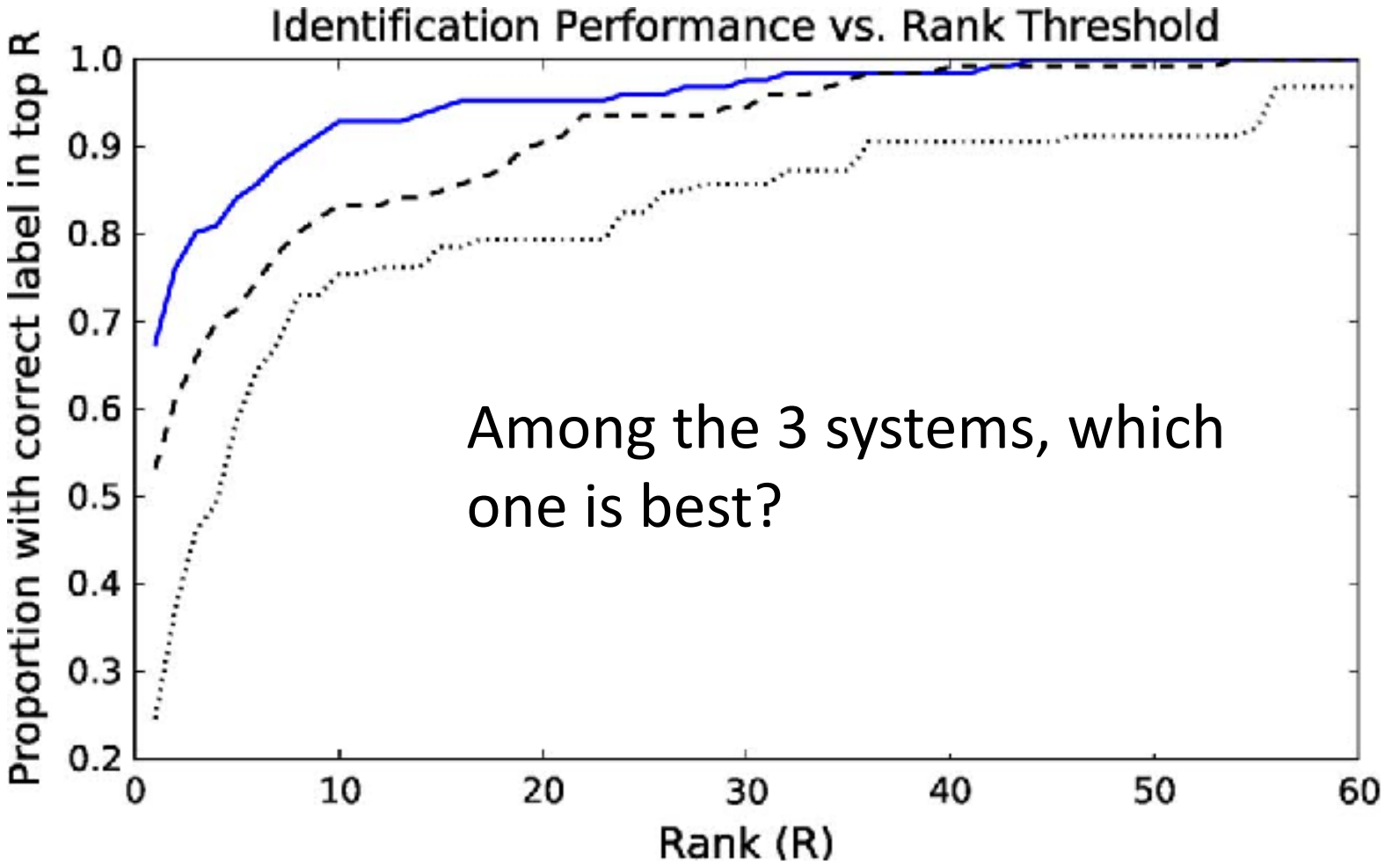
Equal error rate (EER)

Area under curve (AUC)

Detection Error Tradeoff (DET) curve

6. Performance measures

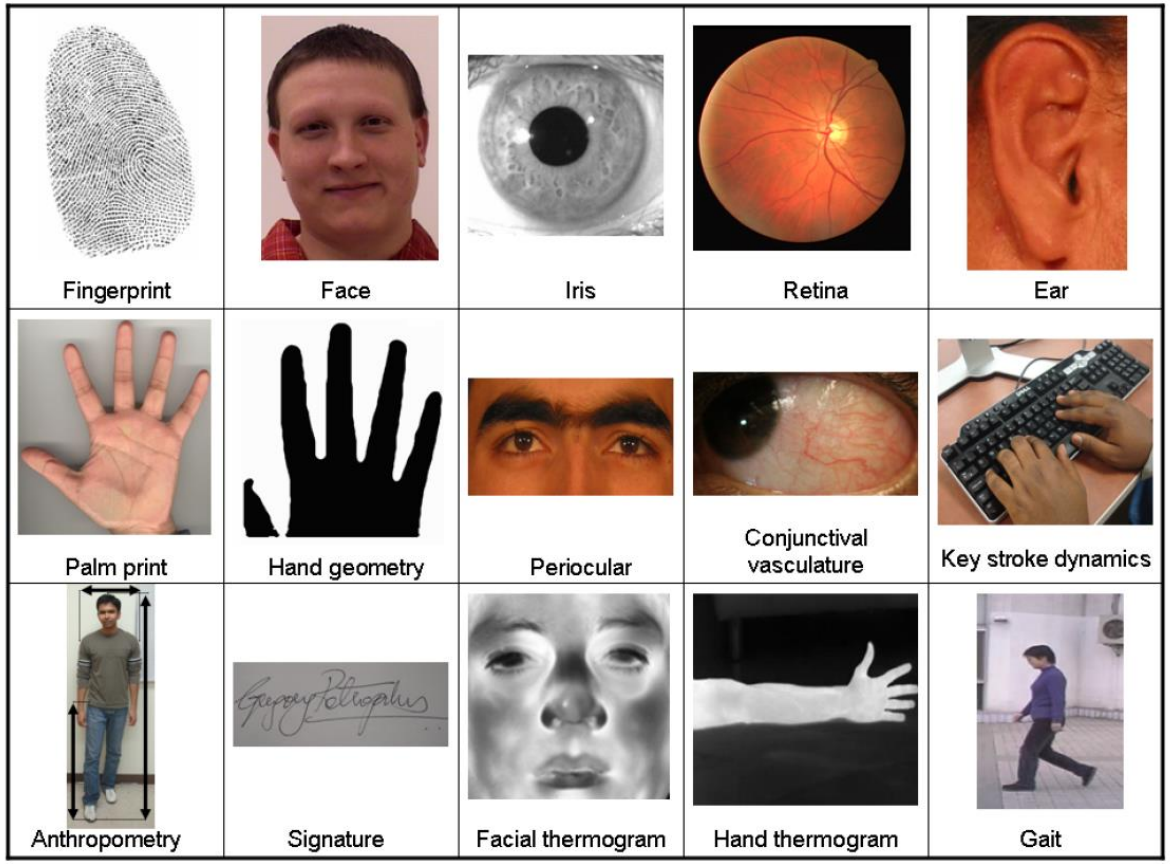
- Identification system



Among the 3 systems, which one is best?

7. Choice of biometric traits

- Number of biometric traits are being used in real applications. Each trait has its pros and cons.
- In general 7 factors should be considered:
  - **Universality**
  - **Uniqueness**
  - **Permanence**
  - **Measurability**
  - **Performance**
  - **Acceptability**
  - **Circumvention**



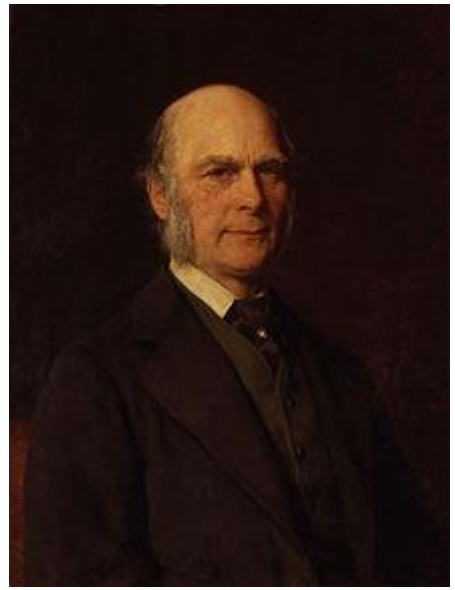
Today Outline

1. Introduction of Fingerprint?
2. Ridge pattern
3. Fingerprint acquisition
4. Feature extraction
5. Matching

1- Introduction of Fingerprint

- *"Perhaps the most **beautiful** and **characteristic** of all superficial marks are the small furrows with the intervening ridges and their pores that are disposed in a singularly complex yet even order on the under surfaces of the hands and the feet."*

  Francis Galton, *Nature*, June 28, 1888.



Fingerprint

Fingerprint in macro - friction ridge skin

Smooth skin

Galton was Charles Darwin's half-cousin

1- Introduction of Fingerprint

- A typical young male has, on an average, 20.7 ridges/cm^2
- While a female has 23.4 ridges /cm^2
- Biometric characteristics
  - Unique (even for twins)
  - Immutable

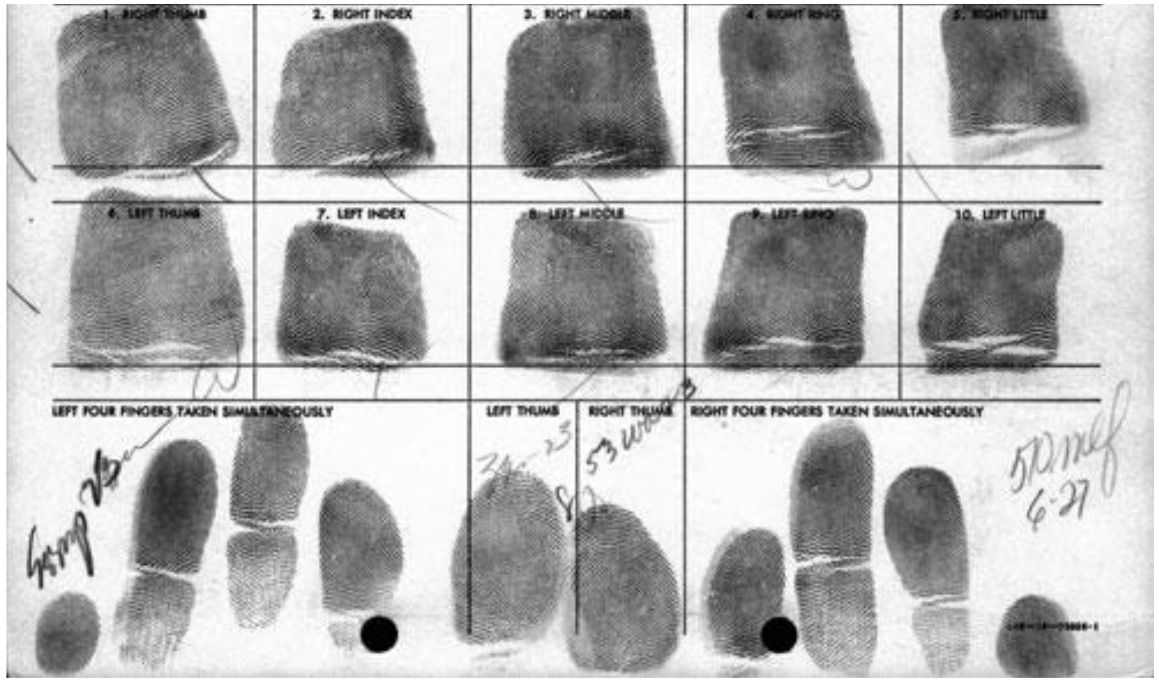
Fingerprint

Fingerprint in macro - friction ridge skin

Smooth skin

1- Introduction of Fingerprint

- Historical use of fingerprint
  - About thousand year ago, it was used as unique identifiers
  - 20th century, it is used systematically with 10 fingers



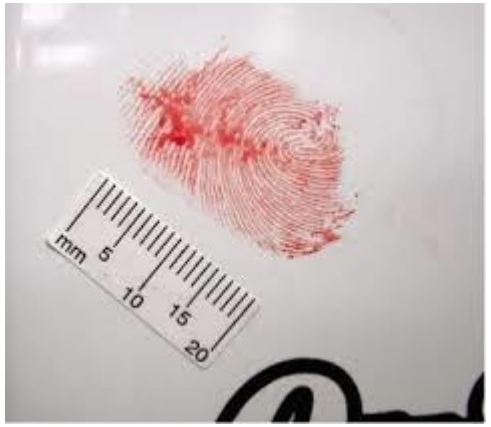
A tenprint card

rolled fingerprints

plain fingerprints

1- Introduction of Fingerprint

- Fingerprints on criminal scene



patent fingerprint

visible marks by transferring materials such as blood, dirt, ink, grease

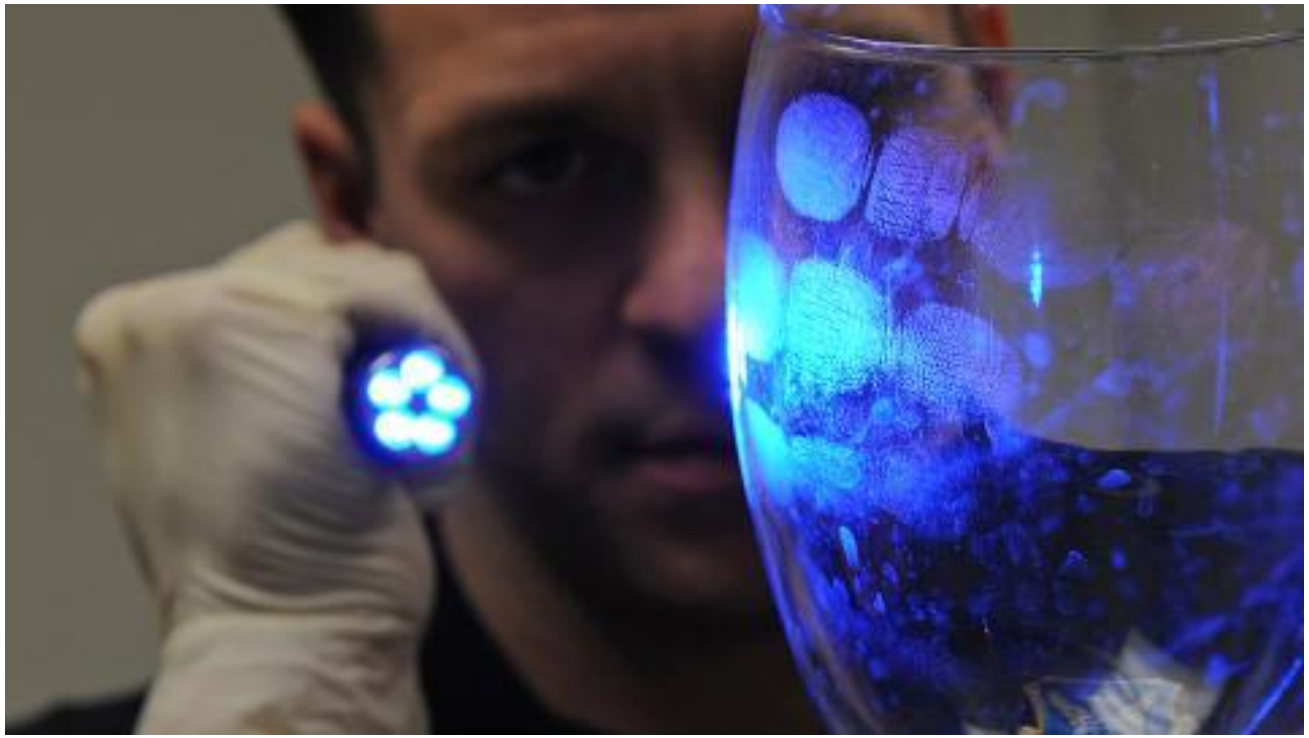
plastic fingerprint

formed by fingers leaving three-dimensional impressions in materials such as wet paint, tar, soap, or wax

latent fingerprint

sweat and oil on the skin's surface

1- Introduction of Fingerprint

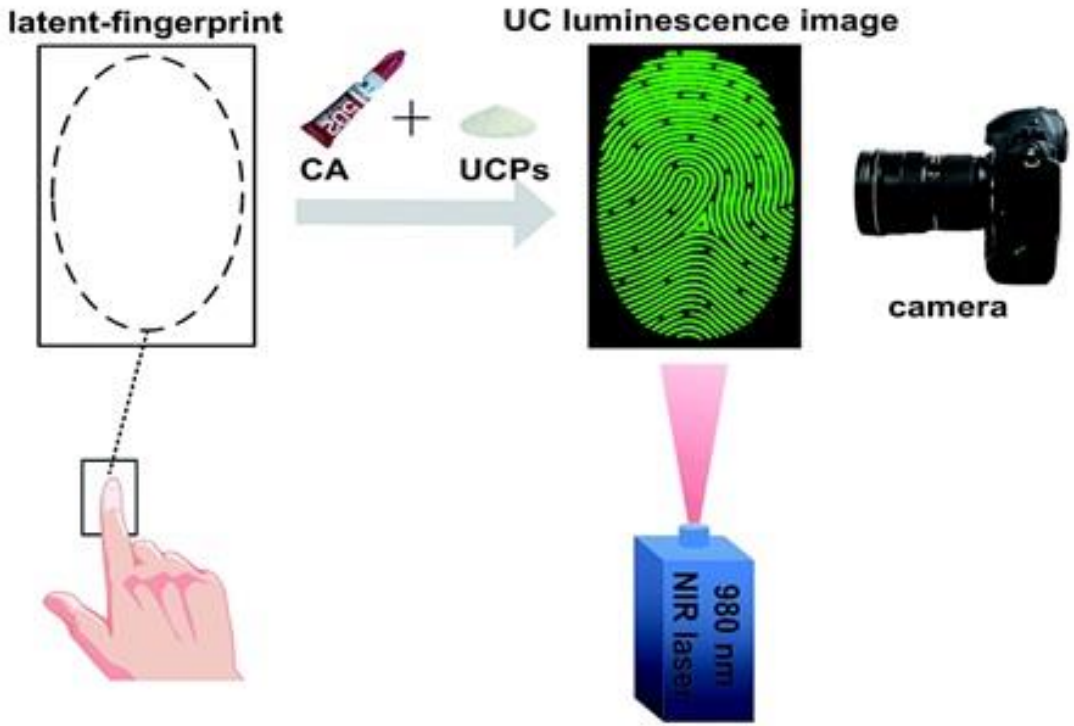


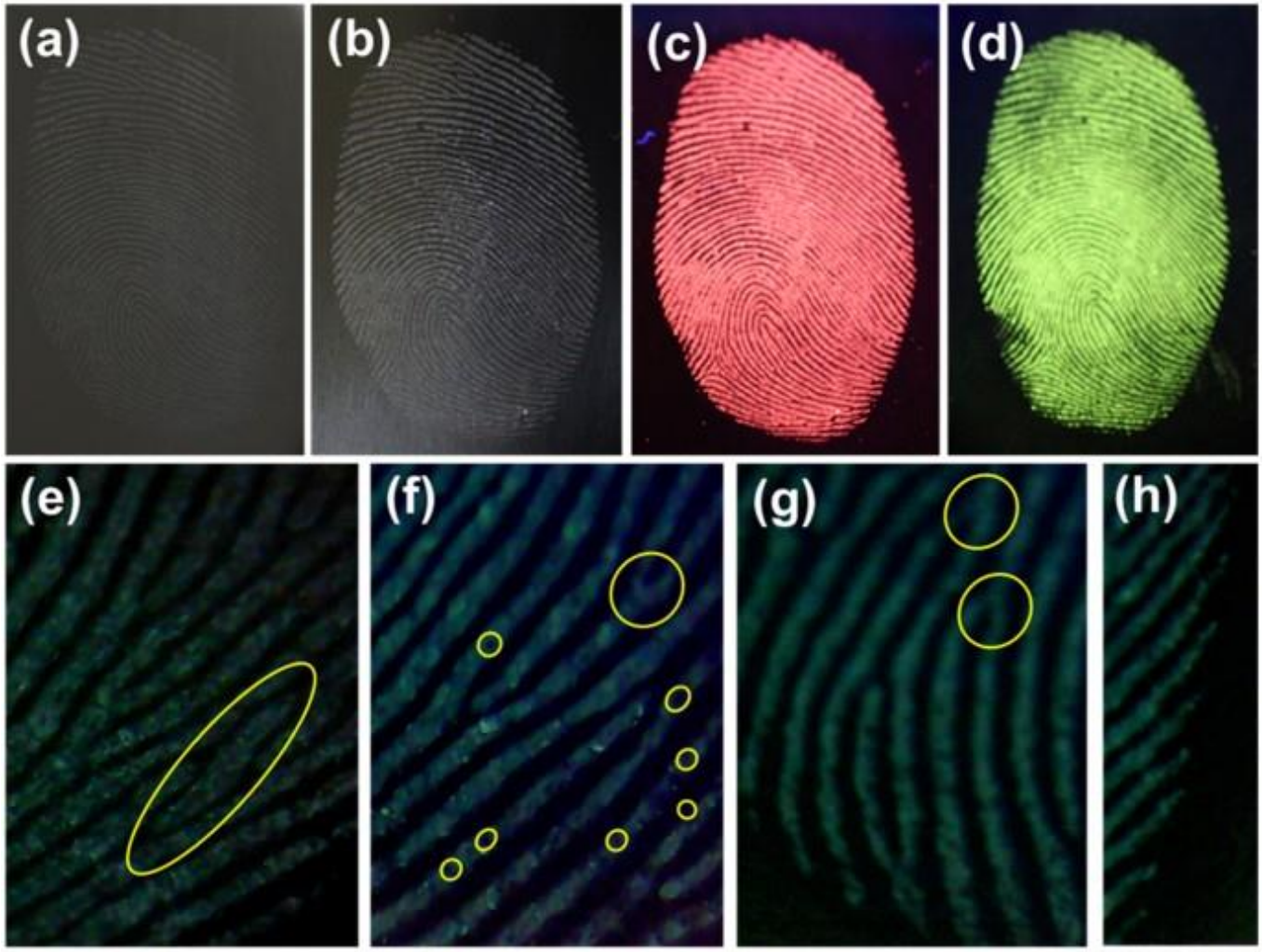
Examining latent fingerprint with light

Enhancing latent fingerprints in criminal scene

1- Introduction of Fingerprint

- Enhancing latent fingerprint





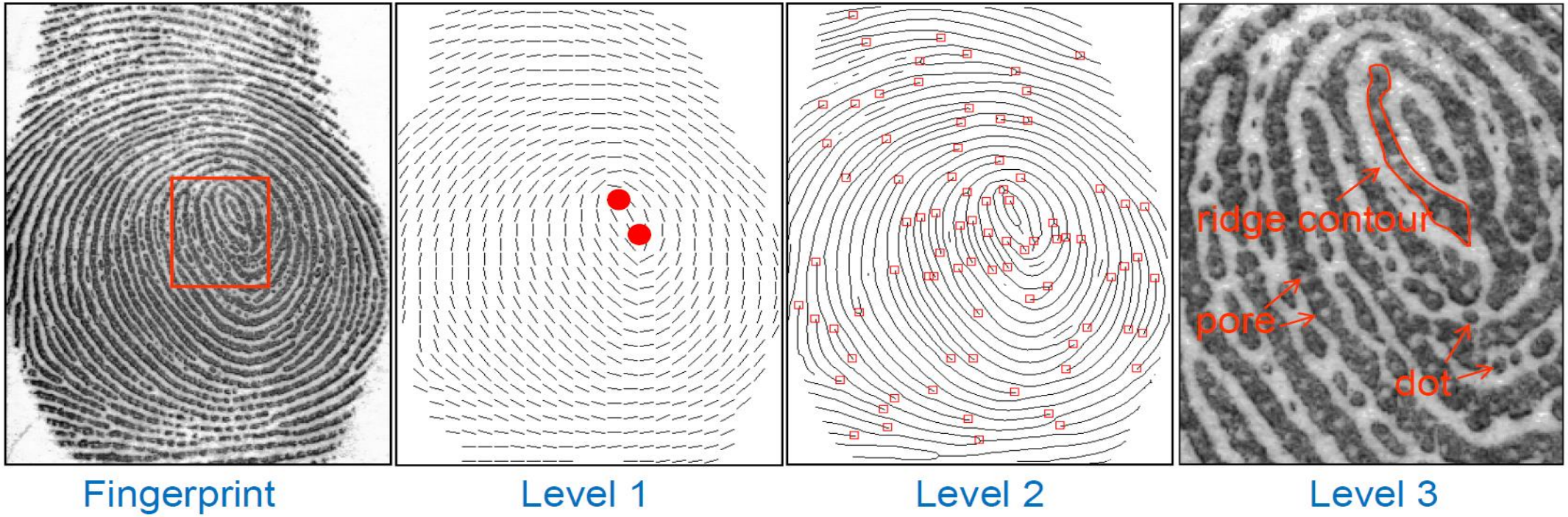
(**a**) Bare image, (**b**) powdered image, (**c**,**d**) fluorescent images and (**e**–**f**) high-magnification images of the latent fingerprints under UV light irradiation, which were obtained from the surface of stainless steel cup.

1- Introduction of Fingerprint

- Which pair of fingerprint is a match?
- It can be recognized
  - By experts
  - Automatically by machine

2- Friction Ridge Pattern

- Most fingerprint recognition method are feature-based
- Features
  - Different levels: coarse to fine



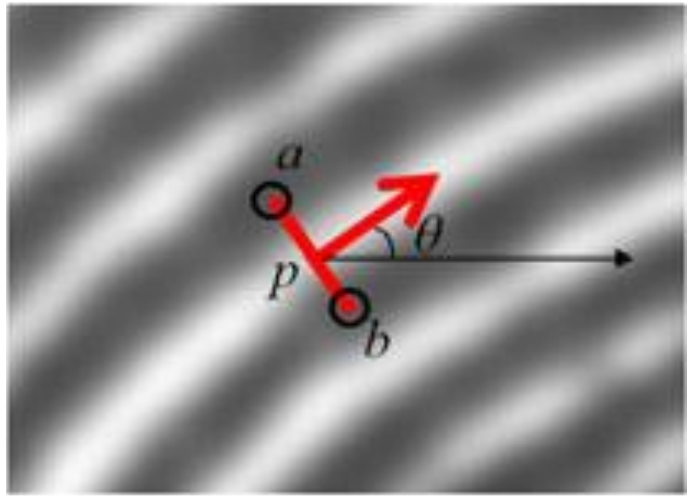
Features at three different levels in a fingerprint. (a) Grayscale, (b) Level 1 feature (orientation field or ridge flow and singular points), (c) Level 2 feature (ridge skeleton), and (d) Level 3 features (ridge contour, pore, and dot).

Level 1 (coarsest) feature

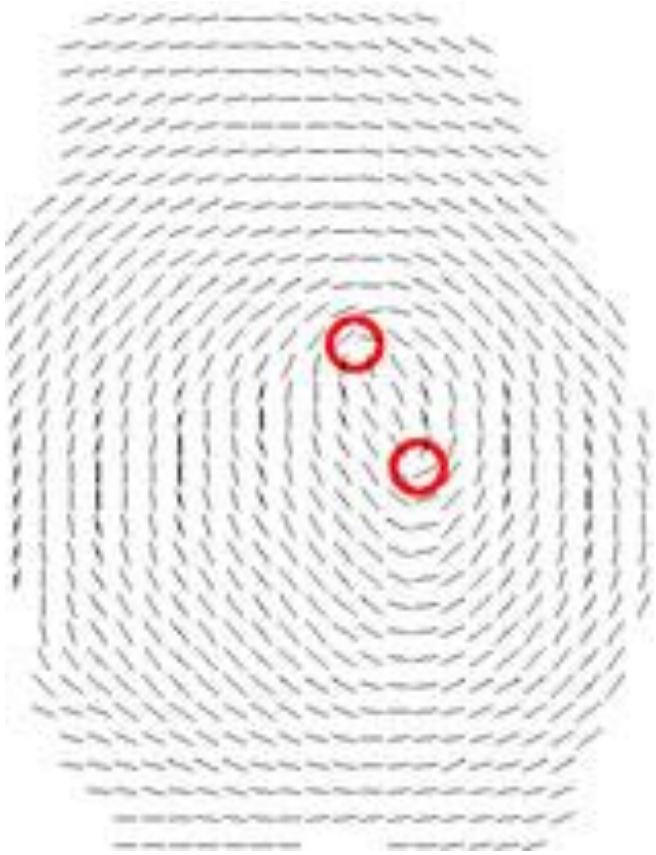
- Ridge orientation map
- Local ridge frequency (density)
- exact location and dimensional details are ignored

➔ oriented texture pattern

➔ Can be employed at a low resolution



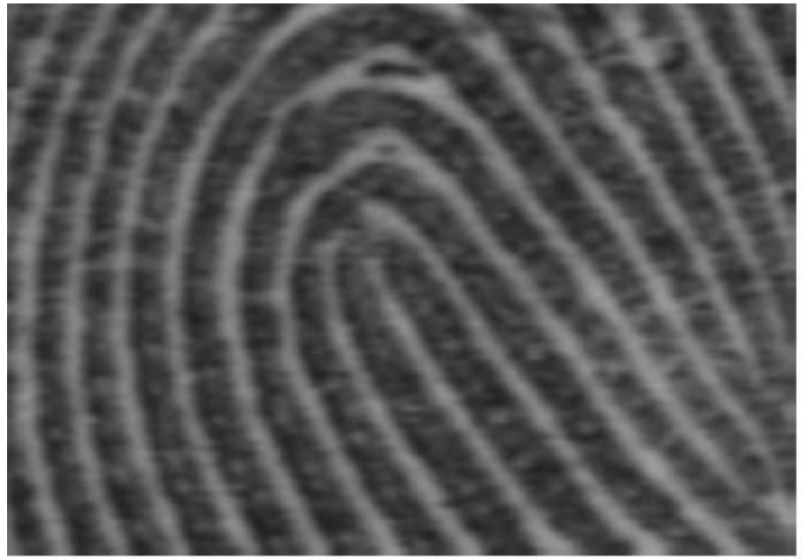
Ridge orientation



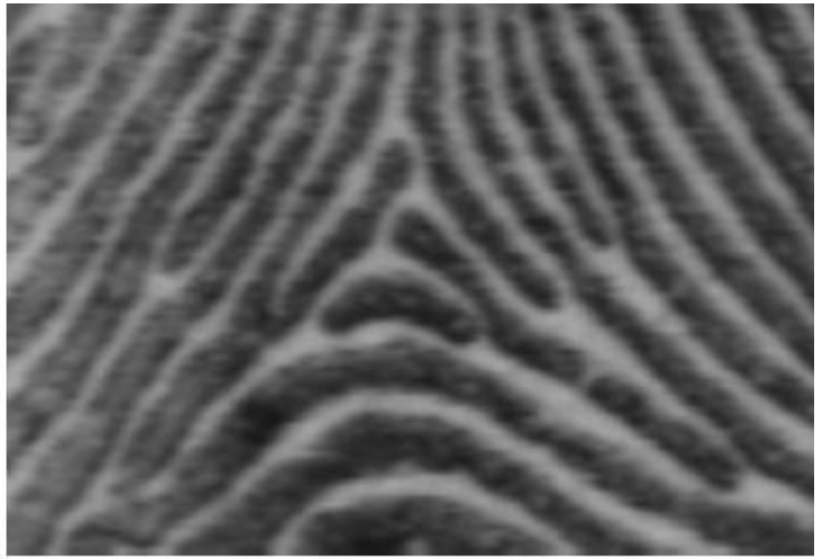
Ridge orientation map

Level 1 (coarsest) feature

- Salient locations where ridge orientation change abruptly
  - Loop and Delta ➔ Singular points

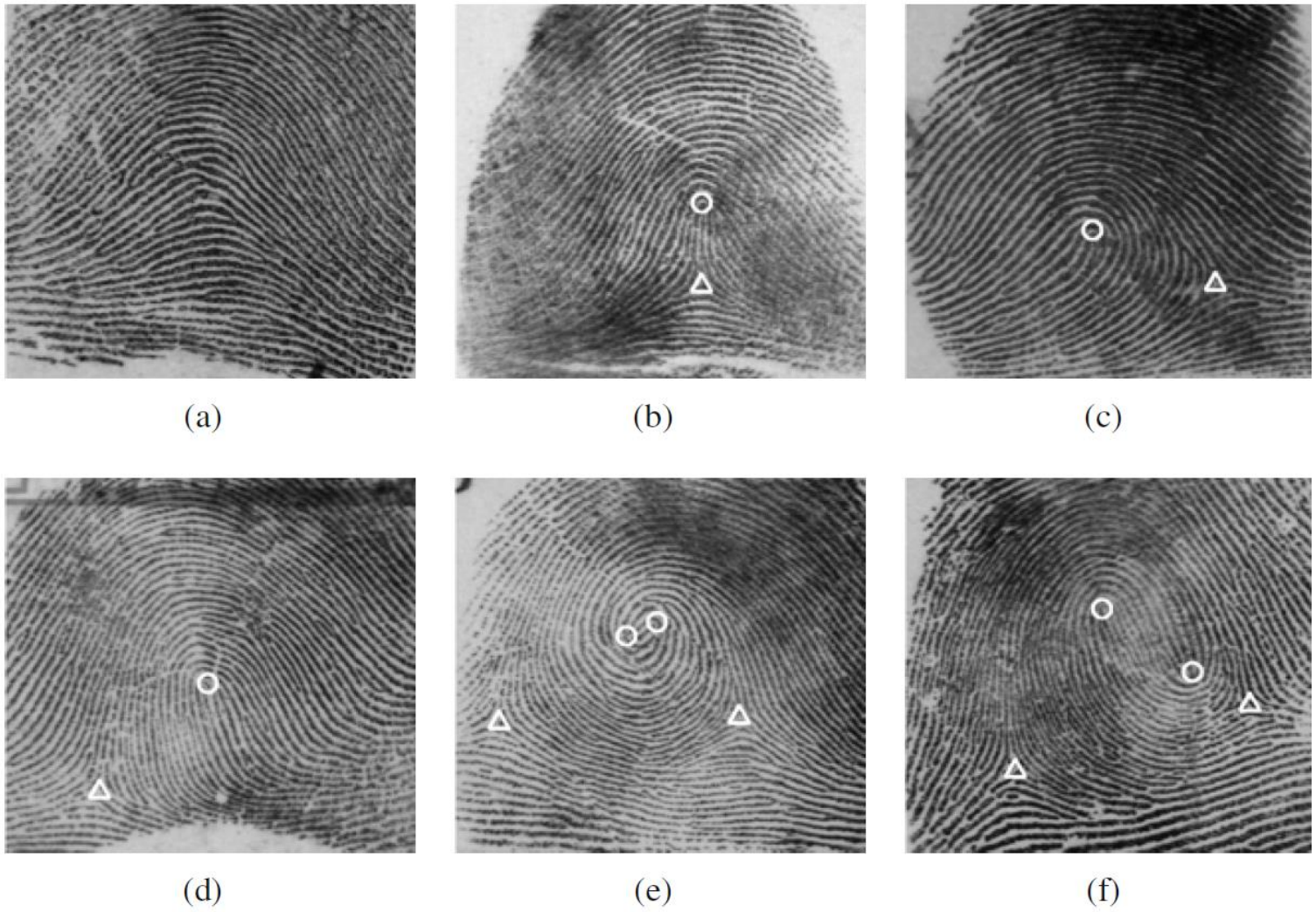


Loop-type singularity (also core)
- set of ridges enters and exits in the same direction



Delta-type singularity (also core)
- 3 sets of ridges meet

Level 1 feature: major fingerprint pattern types



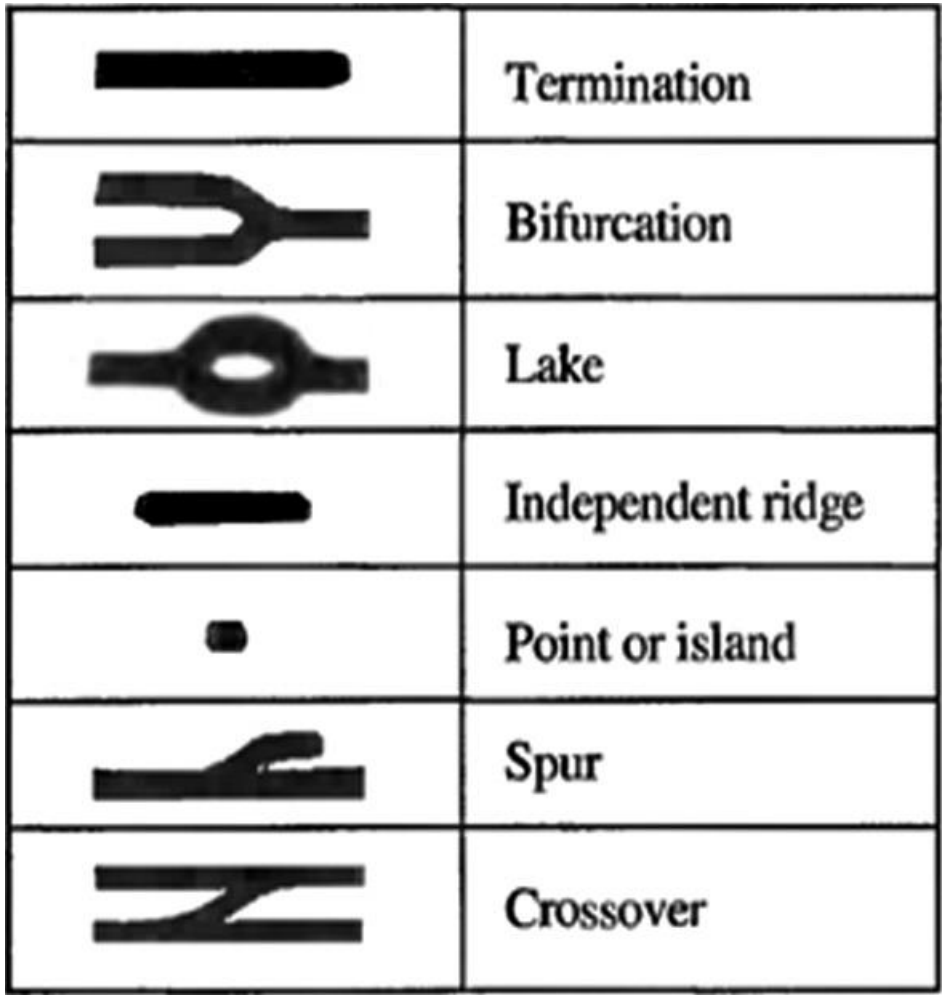
Major fingerprint pattern types:

(a) Plain arch,
(b) tented arch,
(c) left loop,
(d) right loop,
(e) whorl, and
(f) twin loop.

A loop is denoted by a circle and a delta is denoted by a triangle. Loop and whorl-type of fingerprints are found most commonly; about 65% of fingerprints belong to loop type, and 24% are whorl-type

Level 2 features

- Ridges at this level are represented as skeletons
- Geometric and dimensional details are ignored!
- Minutiae (ridge characteristics) is where ridges emerges, ends, splits, or merges:



Types of minutia

Level 2 features

- Feature map:
  - Location
  - Direction
  - Type

Level 2 features: examples

Level 3 features

- At high resolution of image
  - Inner holes (pores)
  - Dot: very short ridge
  - Incipient ridge: immature thin ridge

Other features

- Not inherent or universal, limited use
- They are abnormalities such as:
  - creases,
  - cuts, and
  - scars

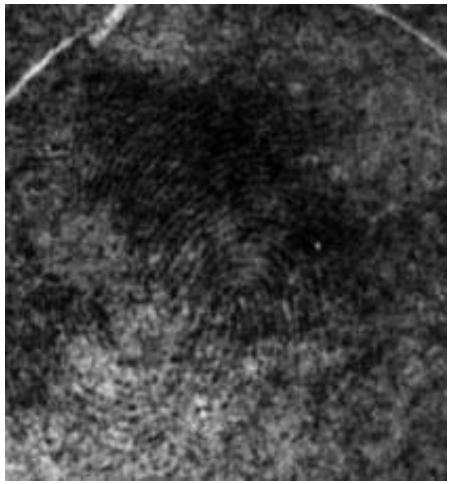
3- Fingerprint Acquisition

- Traditional method: ink-on-paper

3.1 Sensing techniques

- Offline
  - on paper
  - latent fingerprint
- Online

on paper



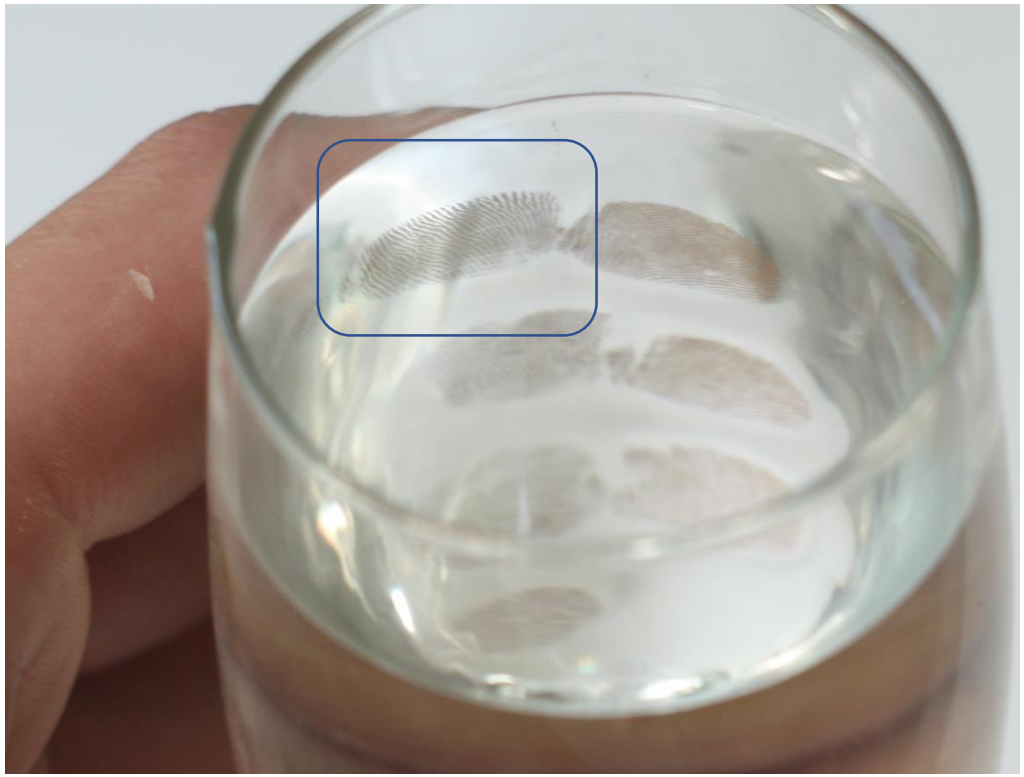
latent fingerprint at criminal scene

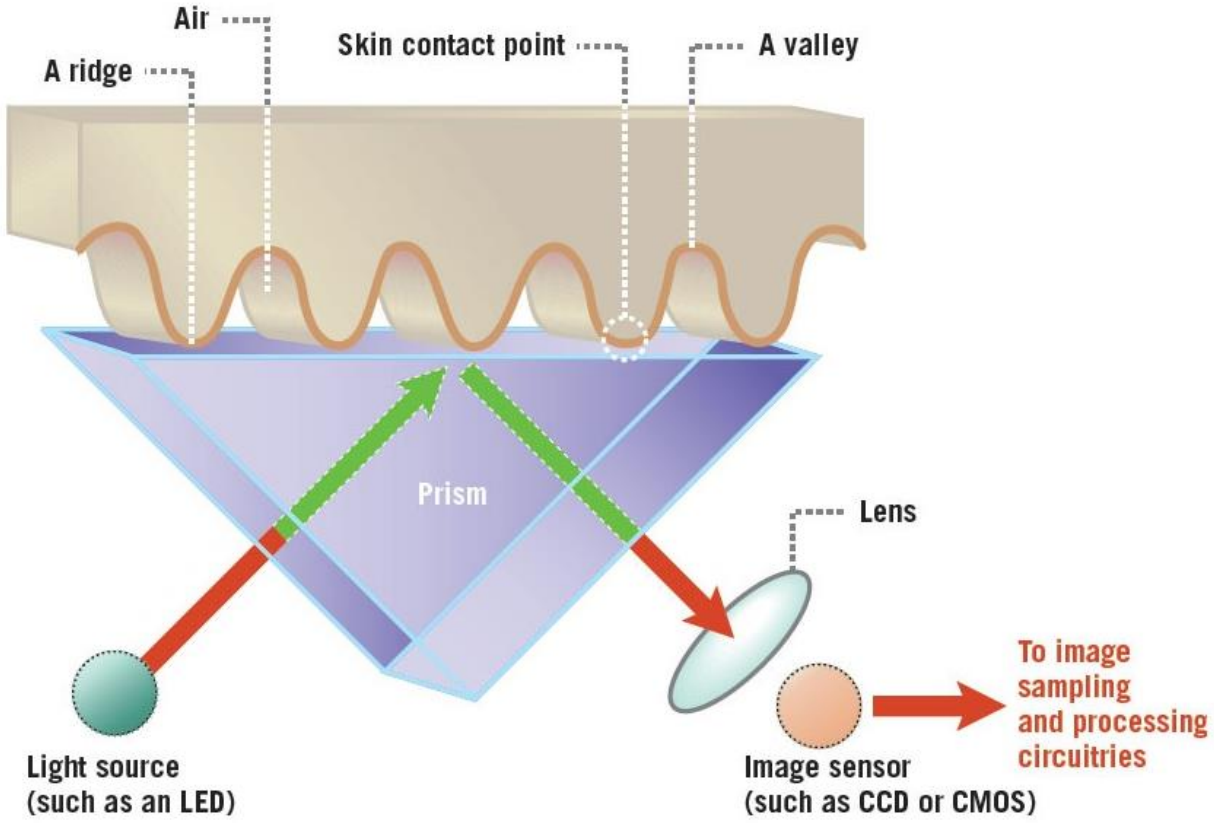
Sensor

3.1 Sensing techniques

Optical Frustrated Total Internal Reflection (FTIR)

- Totally reflected on the valleys
- Randomly scattered on the ridges





3.1 Sensing techniques

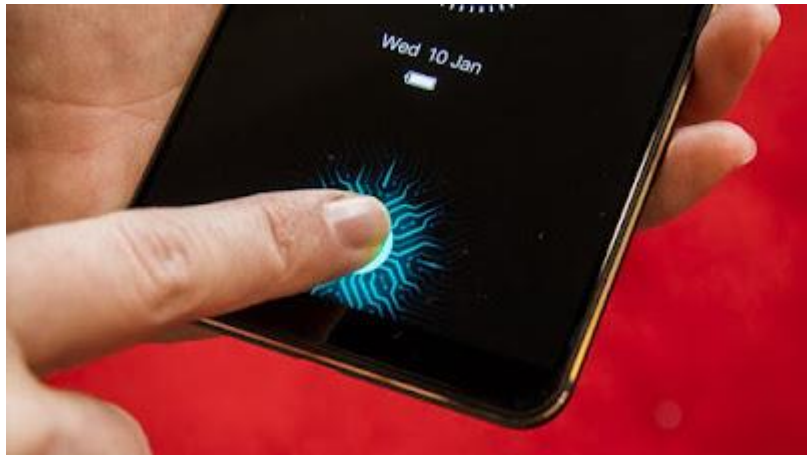
Capacitance

- Small, seen in laptop computers, mobile phones,…

3.1 Sensing techniques

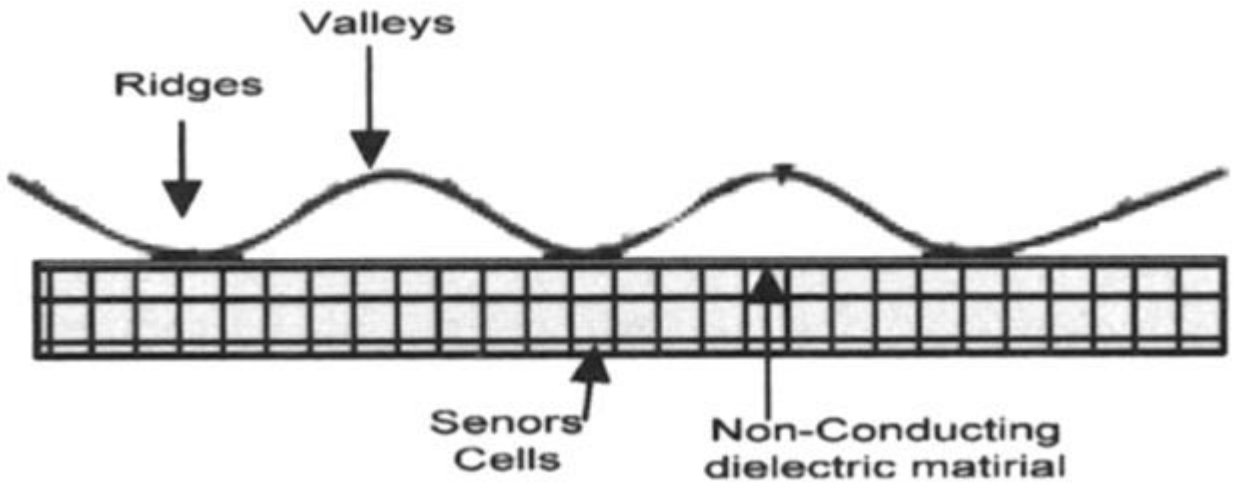
Ultrasound Reflection

- On-screen fingerprint reader



3.1 Sensing techniques

Piezoelectric Effect - Pressure-sensitive sensors



3.1 Sensing techniques

Temperature Differential

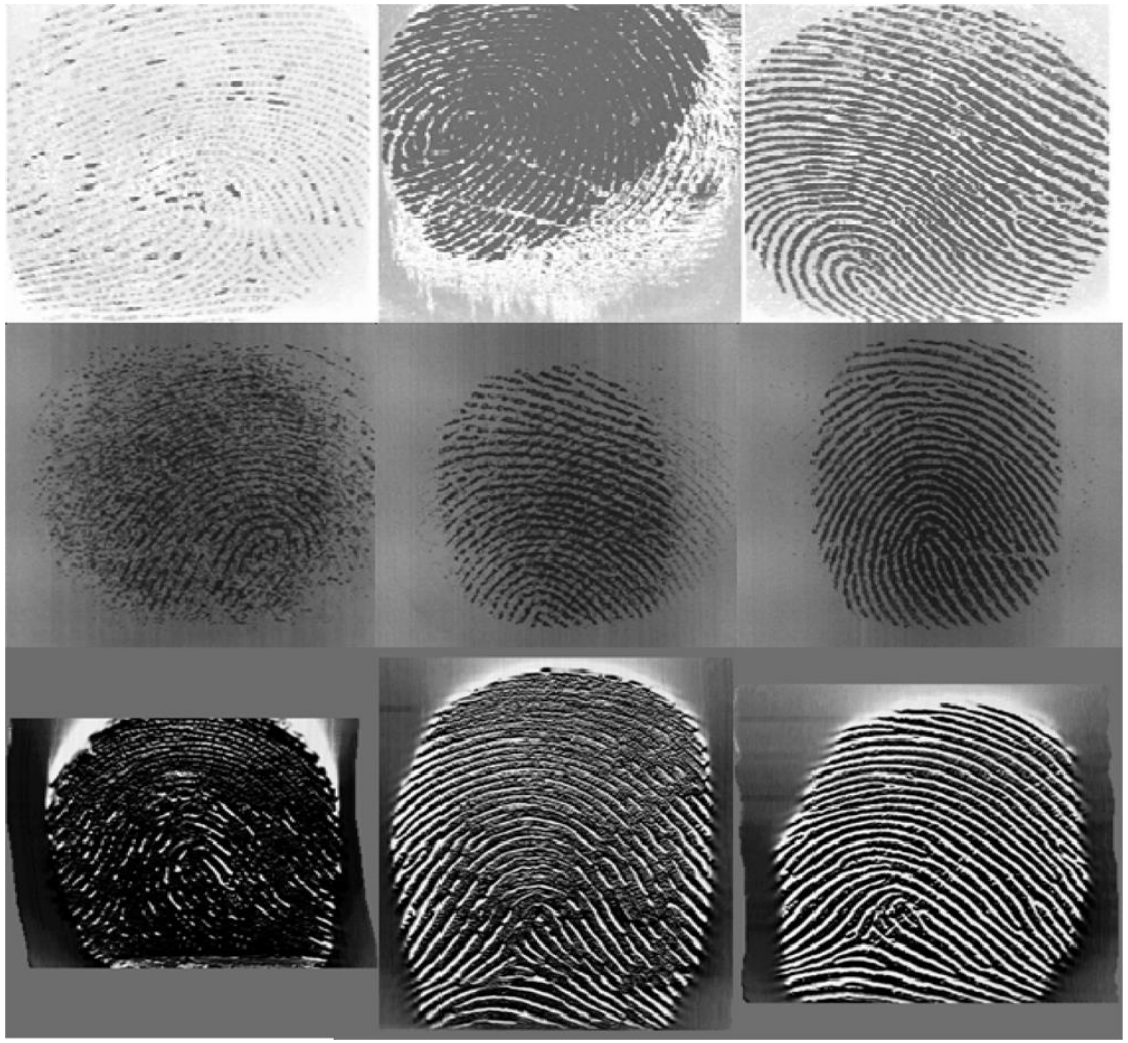
- Sense the temperature differences on the contact surface, in between fingerprint ridges and valleys.
- Generates a current based on temperature differentials

3.1 Sensing techniques: example

a)

b)

c)



Fingerprint images from different capture sensors:
(a) optical sensor,
(b) capacitive sensor and
(c) thermal sensor.

3.2 Image quality

- Important factors:
  - Resolution: more than 500ppi
  - Finger area
  - clarity of ridge pattern

(a)

plain fingerprint

(b)

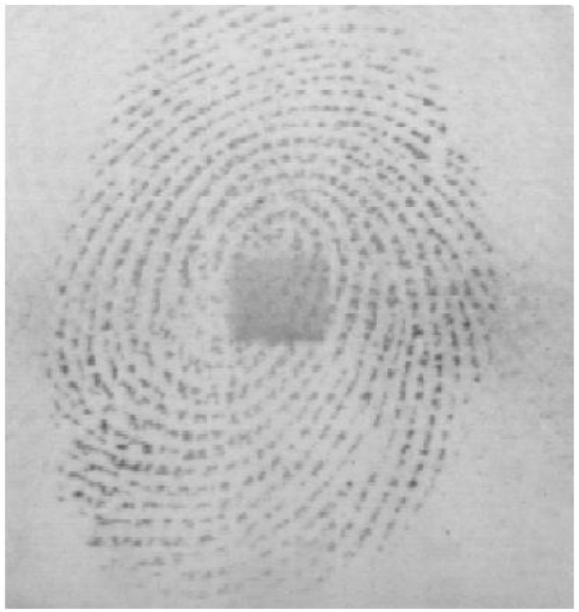
rolled fingerprint

(c)

sweep fingerprint

3.2 Image quality

- Important factors:
  - Resolution: more than 500ppi
  - Finger area
  - clarity of ridge pattern



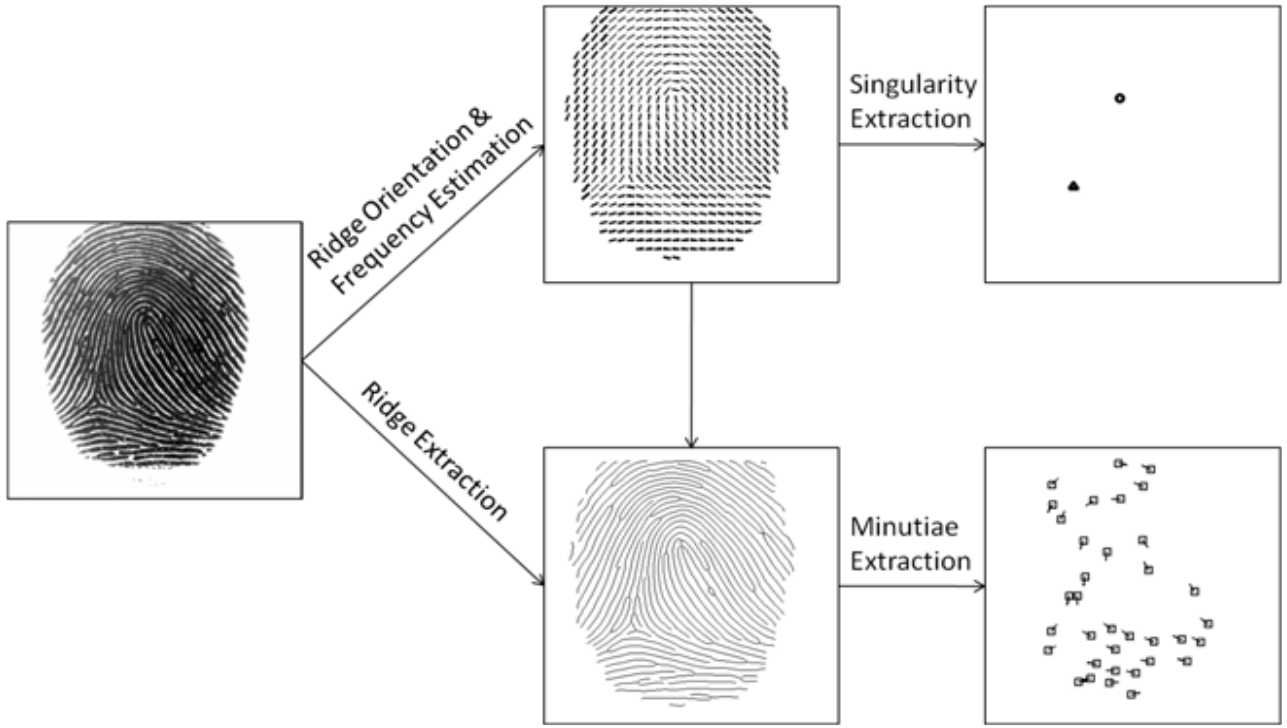
(a)
dry finger

(b)
wet finger

(c)
finger with many creases

4. Feature extraction

- Ridge orientation & frequency estimation

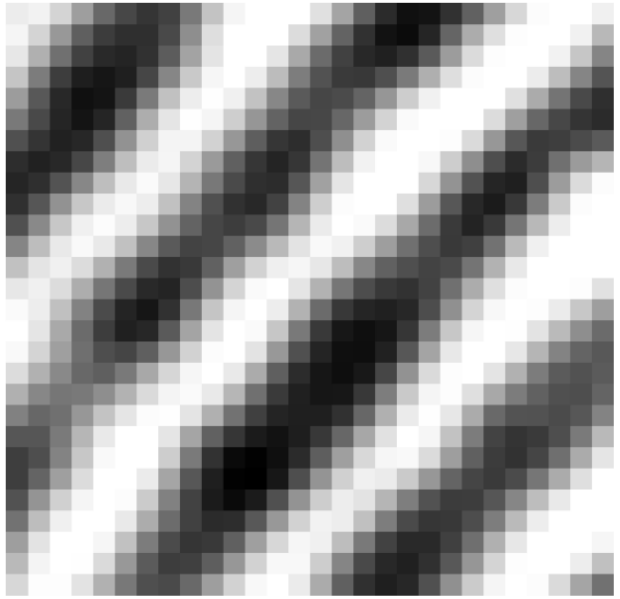


4.1 Ridge orientation and frequency estimation

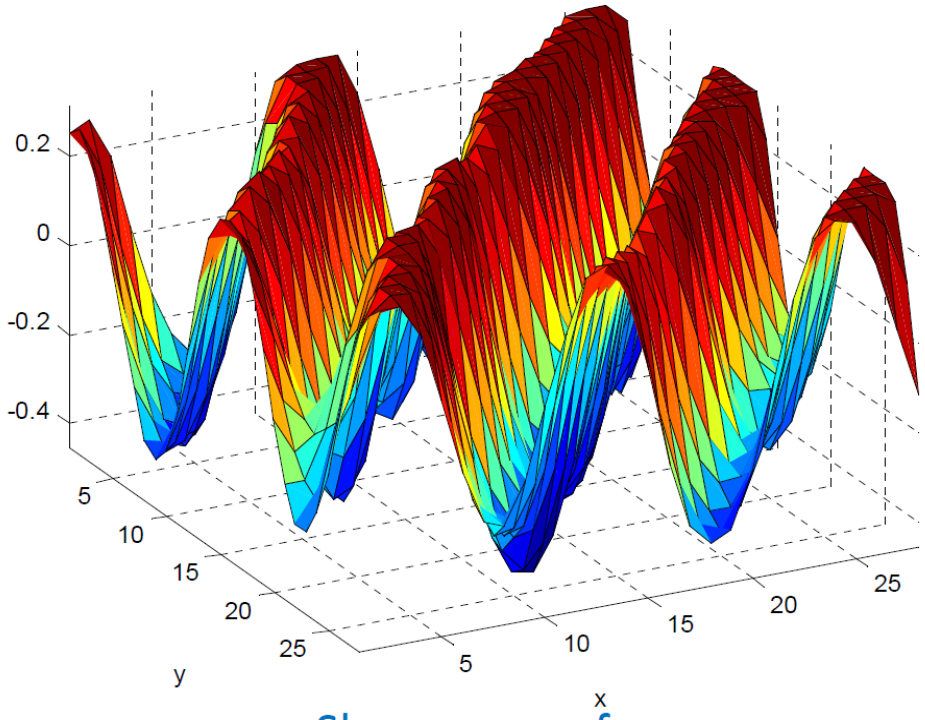
Ridge pattern in a local area of a fingerprint can be approximated by a cosine wave

$$w(x,y) = A\cos\left(2\pi f\left(x\cos\theta + y\sin\theta\right)\right)$$

amplitude frequency orientation



Local fingerprint region



Shown as surface

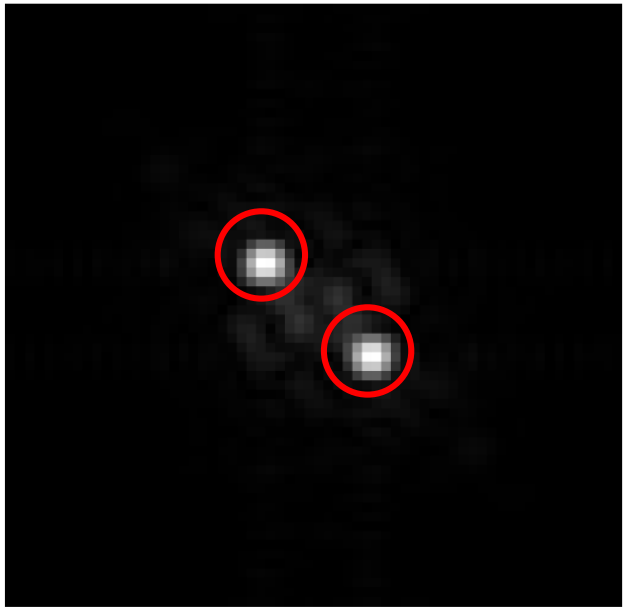
4.1 Ridge orientation and frequency estimation

2D Fourier transform of cosine wave

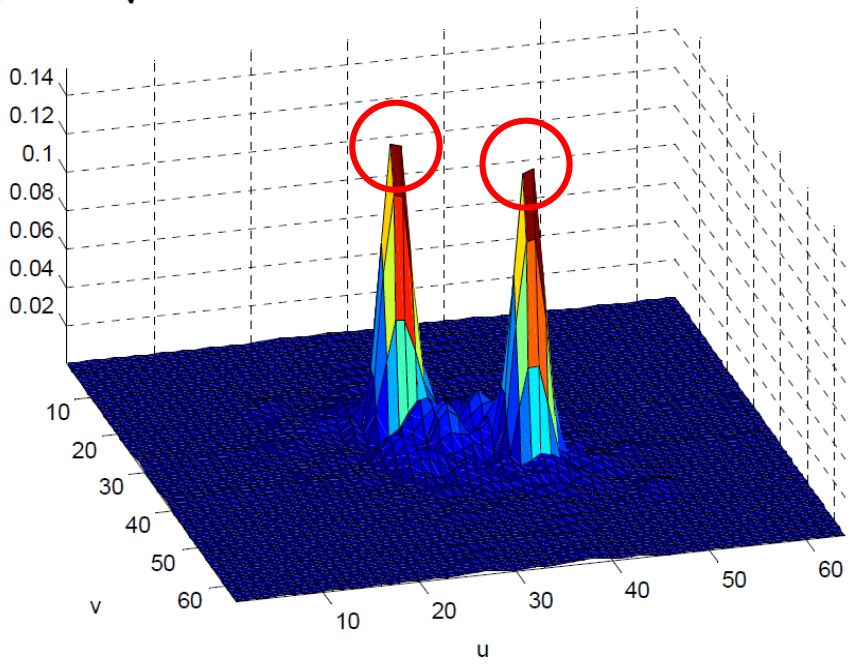
$$W(u,v) = \frac{A}{2}[\delta(u - f\cos\theta, v - f\sin\theta) + \delta(u + f\cos\theta, v + f\sin\theta)]$$

Let $(\hat{u}, \hat{v})$ denote the location of the maximum magnitude, then

$$\hat{\theta} = \arctan\left(\frac{\hat{u}}{\hat{v}}\right), \hat{f} = \sqrt{\hat{u}^2 + \hat{v}^2}$$



Magnitude spectrum

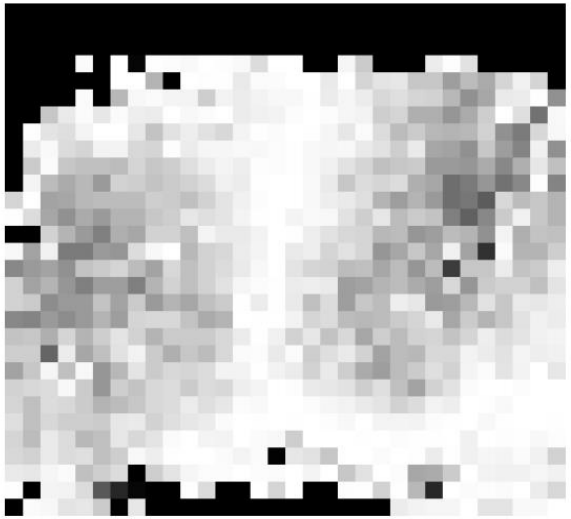


Magnitude spectrum shown as surface

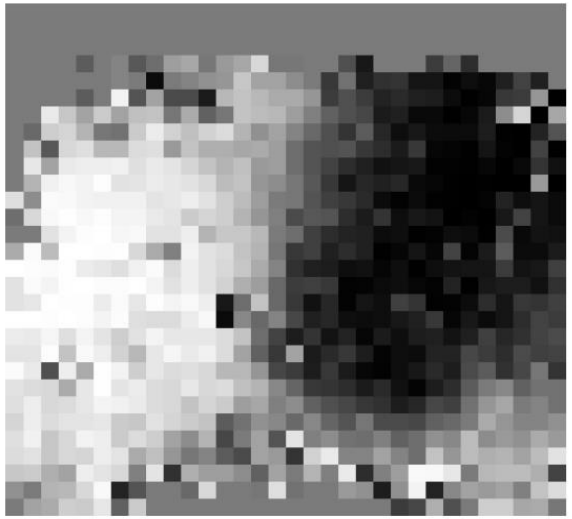
4.1 Ridge orientation and frequency estimation

Smoothing of orientation field

Initial OF, θ



$V_x = \cos(2\theta)$

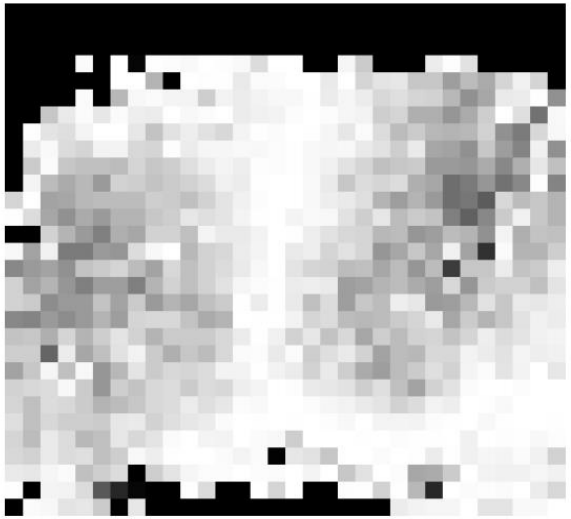


$V_y = \sin(2\theta)$

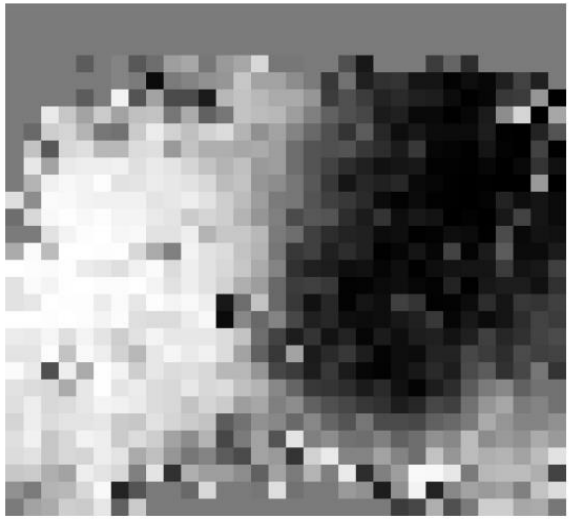
4.1 Ridge orientation and frequency estimation

Smoothing of orientation field

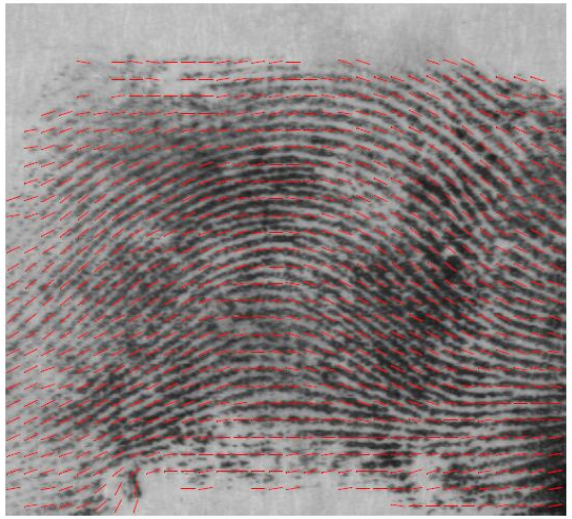
Initial OF, θ



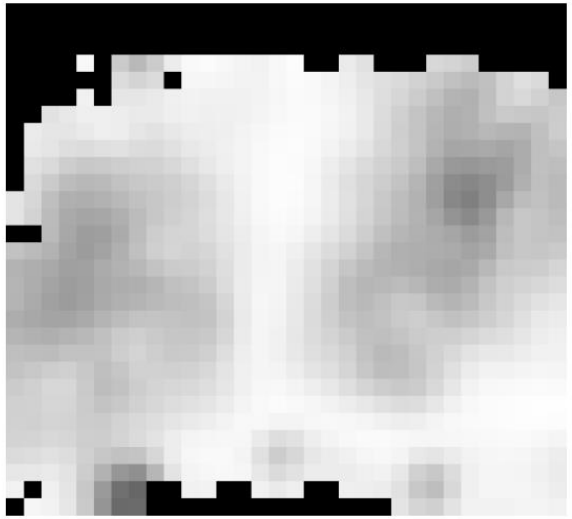
$V_x = \cos(2\theta)$



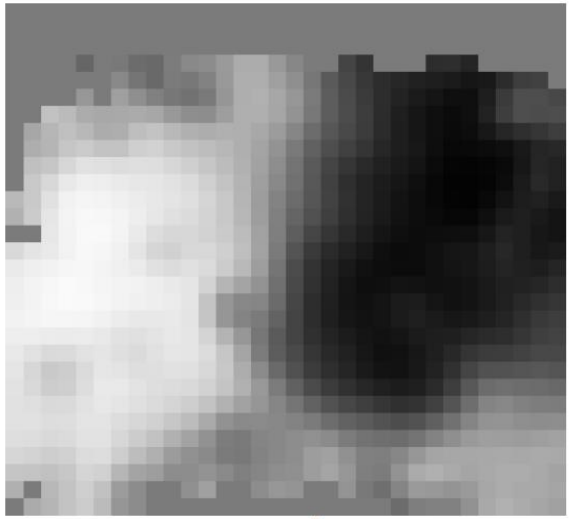
$V_y = \sin(2\theta)$



Smoothed OF, θ'



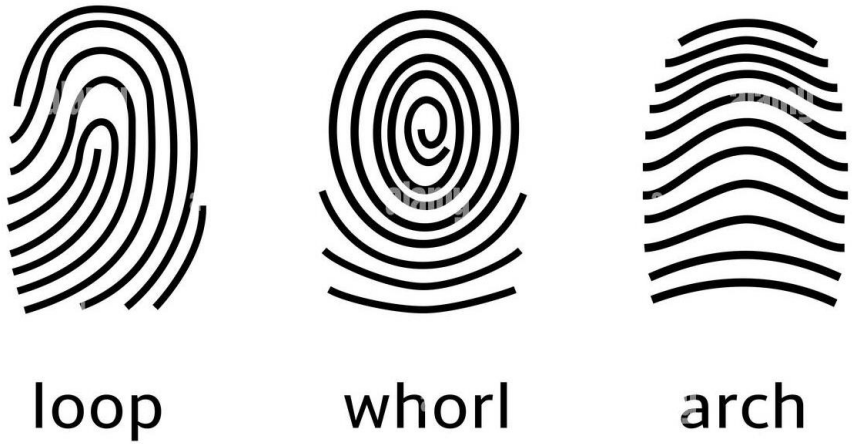
$V_x{}'$

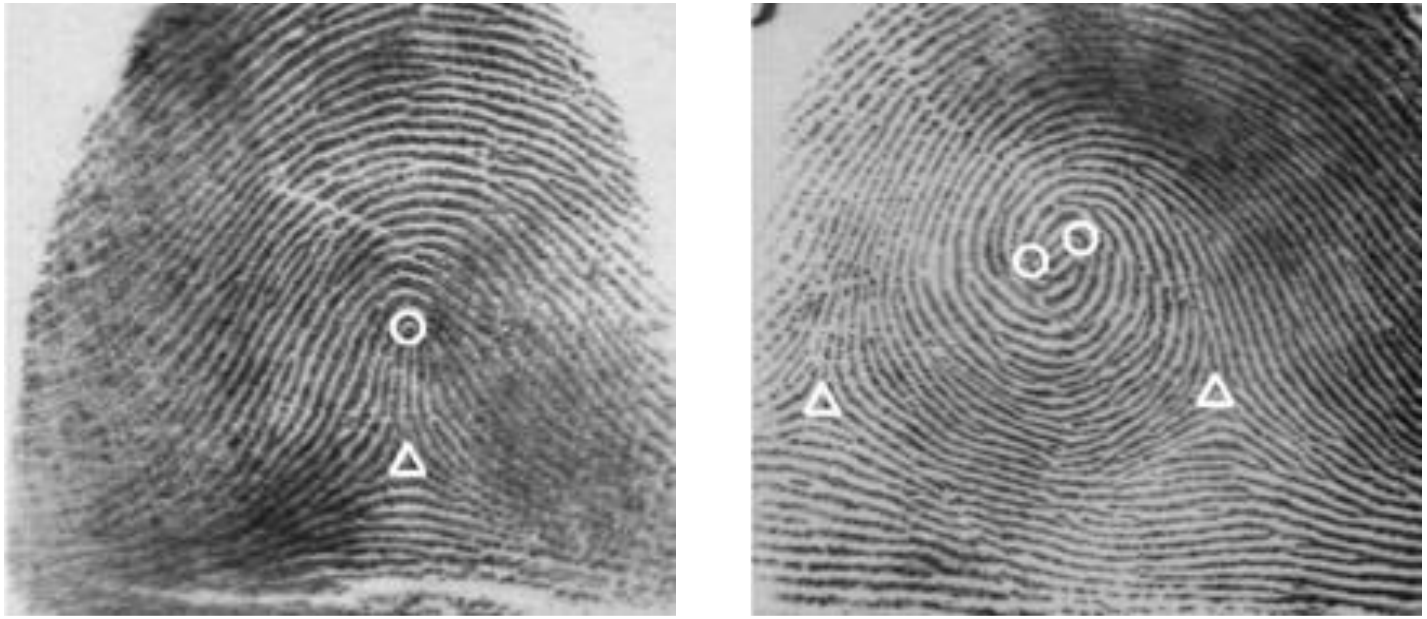


$V_y{}'$

4.2 Singularity extraction

- Loop
- Delta
- Whorl





Loop, delta, and whorl

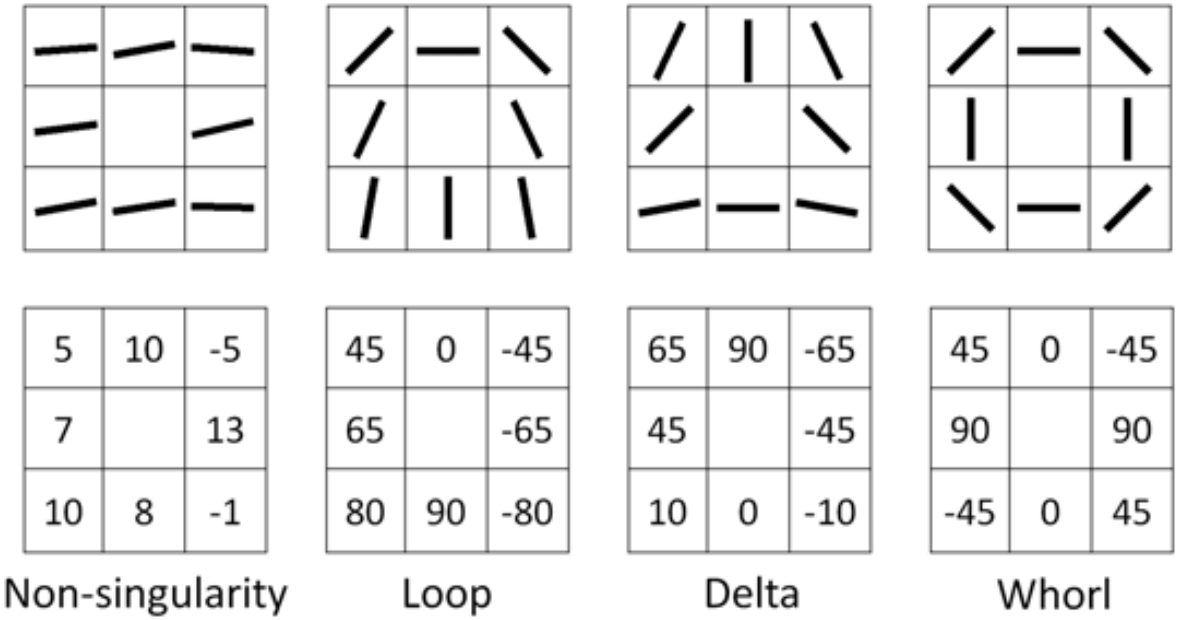
4.2 Singularity extraction: location

- How to detect singularity?
- Poincaré index (PI):
  - Based on orientation field O[i]
  - PI:

$$PI = \frac{1}{\pi}\sum_{i=0}^{7}\delta\left(O[(i+1)_{\bmod 8}] - O[i]\right)$$

$$\delta(\theta) = \begin{cases} \theta - \pi, \text{ if } \theta > \pi/2 \\ \theta, \text{ if } -\pi/2 \le \theta \le \pi/2 \\ \theta + \pi, \text{ if } \theta < -\pi/2. \end{cases}$$

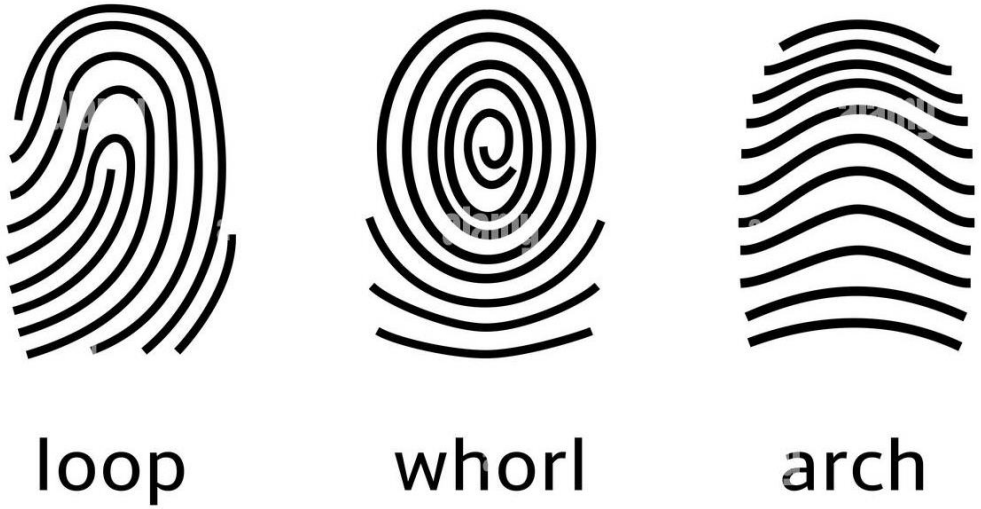
O[i]



PI	0	1	-1	2

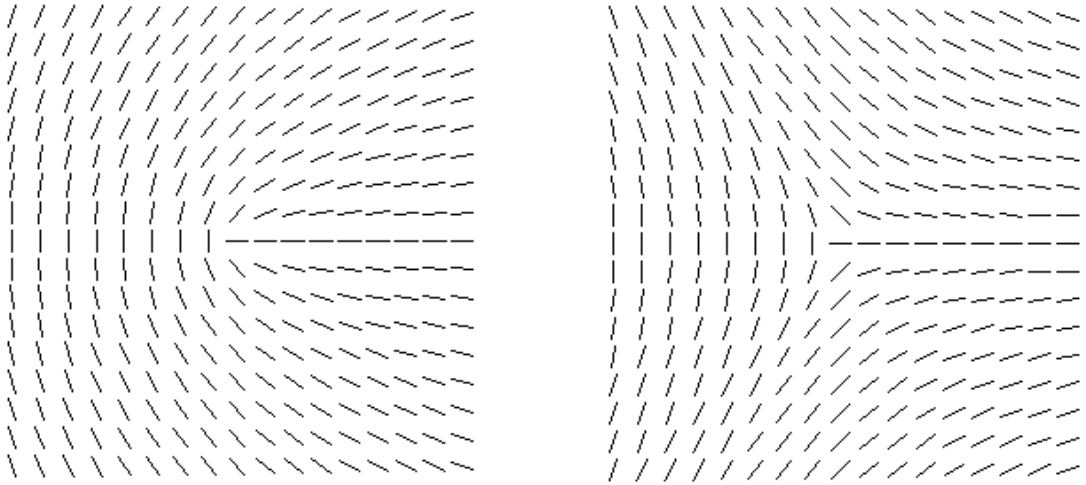
4.2 Singularity extraction: direction

- Loop: has direction
- Delta: has direction
- Whorl: no clear direction



4.2 Singularity extraction: direction

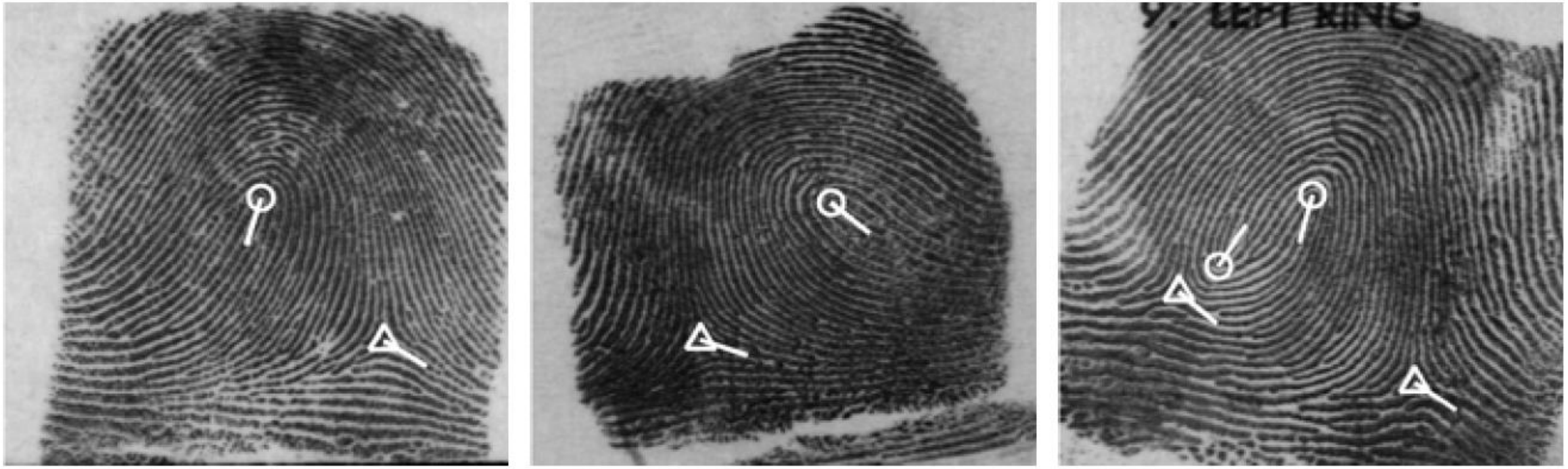
Singularity direction: orientation of singular points



$RO_{\{l,d\}}(x,y)$

Reference for orientation fields of **loop** and **delta**

4.2 Singularity extraction: direction



Directions of delta and loop singular points: (a) Left loop, (b) right loop, and (c) twin loop

4.3 Ridge extraction

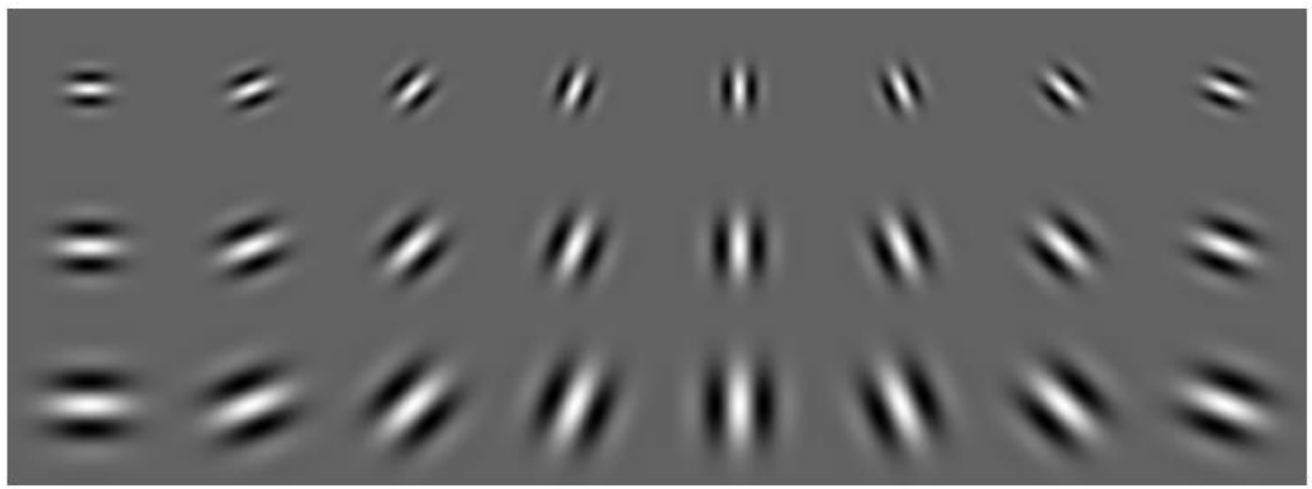
- A straightforward method is binarization.
- Problems:
  - Sweat pores on ridges are brighter than the surrounding pixels;
  - ridges can be broken due to cuts or creases;
  - adjacent ridges may appear to be joined due to wet skin or large pressure.
- Countermeasure: fingerprint enhancement.
- General purpose image enhancement is not effective for fingerprint.
- A successful fingerprint enhancement method is contextual filtering, such as Gabor filtering.

2D Gabor filters

2D Gabor wavelet:

$$G(x,y) = e^{-\pi[(x-x_0)^2/\alpha^2+(y-y_0)^2/\beta^2]}e^{-2\pi i[u_0(x-x_0)+v_0(y-y_0)]}$$

where (x_0, y_0) denote the position in the image, (α, β) denote the effective width and length, and (u_0, v_0) denote the wave direction with a spatial frequency $\omega_0 = \sqrt{{u_0}^2 + {v_0}^2}$.

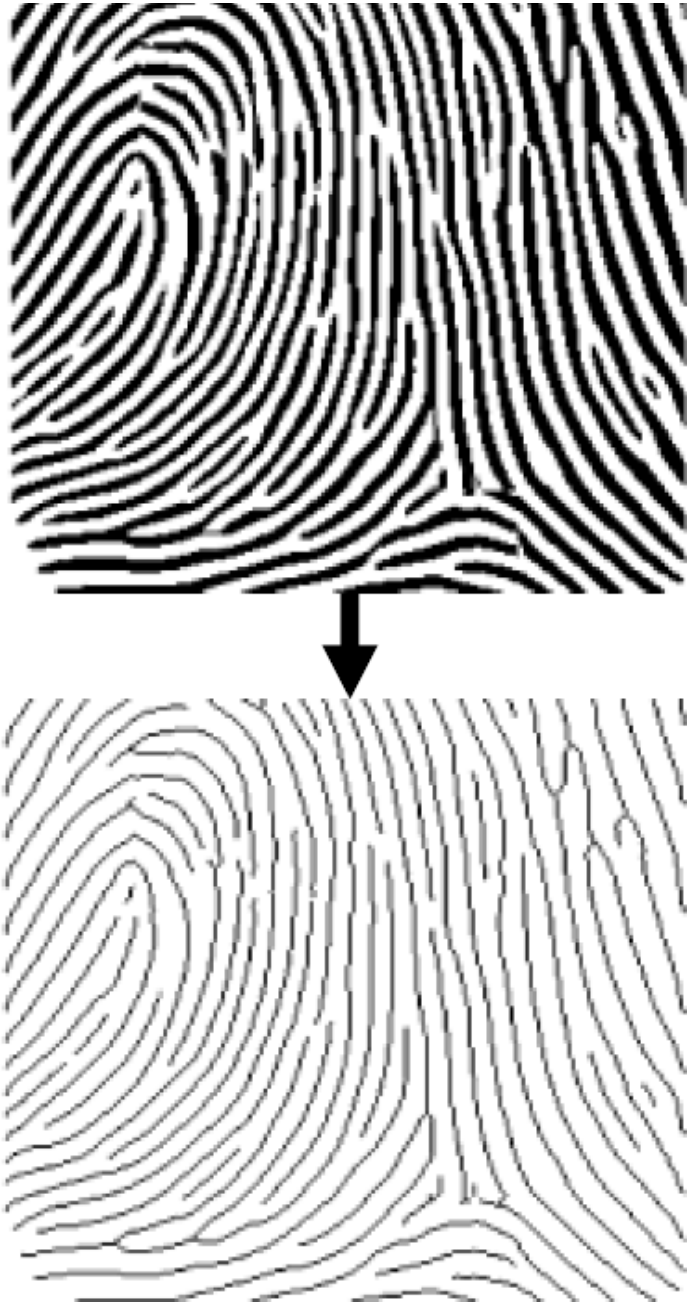


Real parts of Gabor filters (8 orientations and 3 scales)

Effect of Gabor filtering

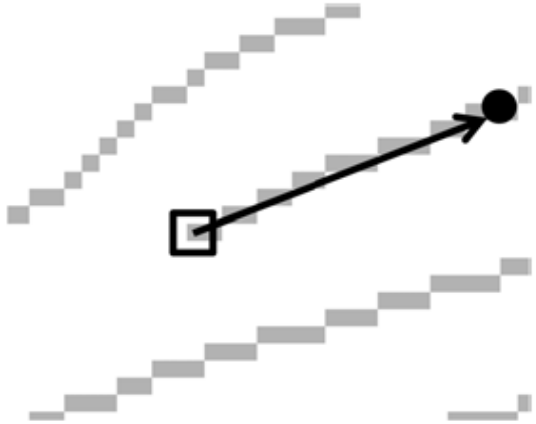
Ridge extraction

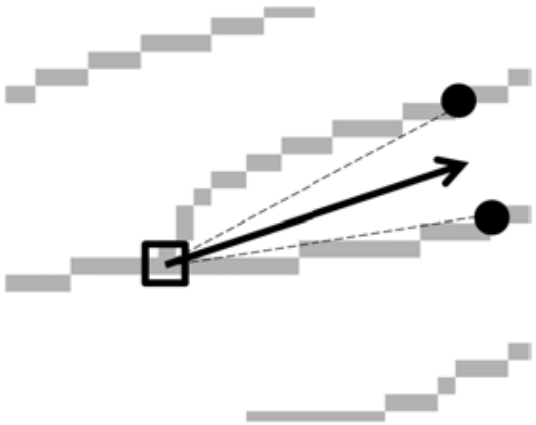
- Enhanced image can be converted into a binary image by comparing to hresholds (e.g. local mean).
- A morphological operation, thinning, is used to obtain the skeleton image.
- Thinning is a common technique in image processing, which involves iteratively removing outer ridge pixels.



4.4 Minutiae extraction

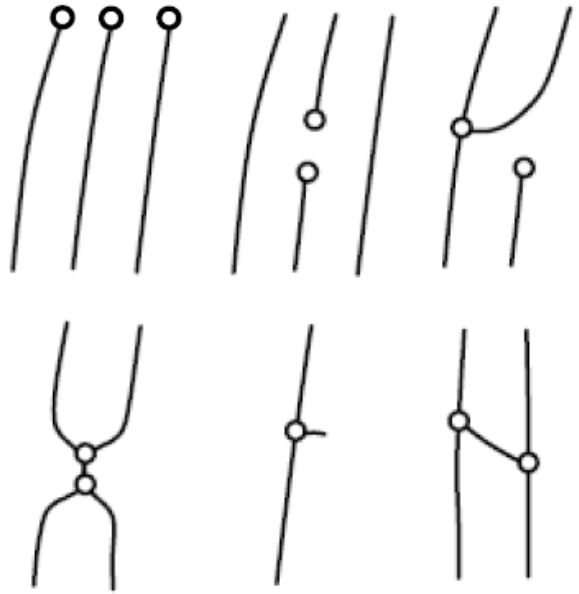
- Minutiae are special points on ridges:
  - ridge bifurcation (3 neighbors are black)
  - ridge ending (1 neighbor is black)
- Direction of a ridge ending:
  - Trace the associated ridge with a fixed distance (say 10 pixels) from $\boldsymbol{x}$ to $\boldsymbol{a}$. The direction $\boldsymbol{xa}$ is the minutia direction.
- Direction of a bifurcation:
  - Trace the ridges to get three directions. The direction is the mean of the two smallest different directions.



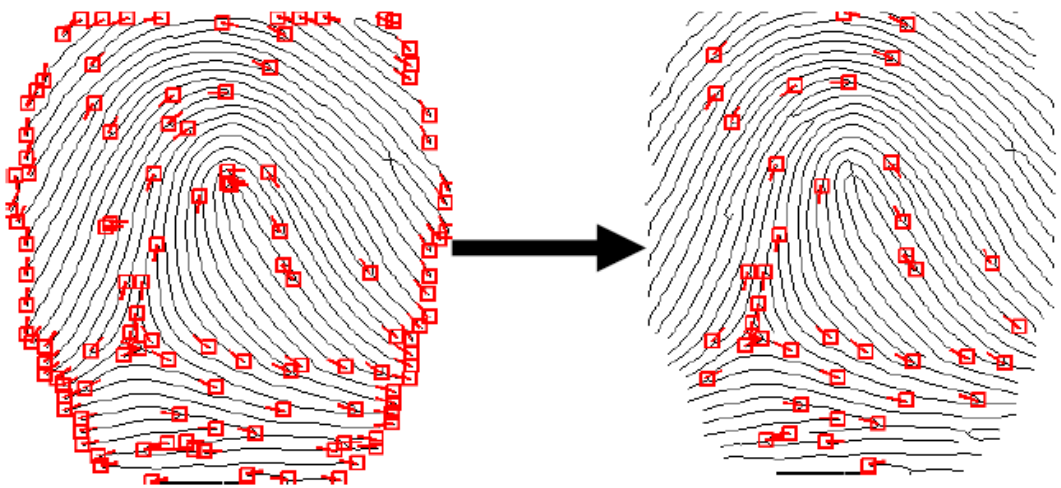


4.4 Minutiae verification

- That method considers only 3×3 window, producing false minutiae due to:
  - artifacts in image processing
  - noise in a fingerprint
- A minutia is classified as false if it meets any of the following conditions:
  - have no adjacent ridge on either side
  - be close in location and opposite in direction
  - too many minutiae in a small neighborhood

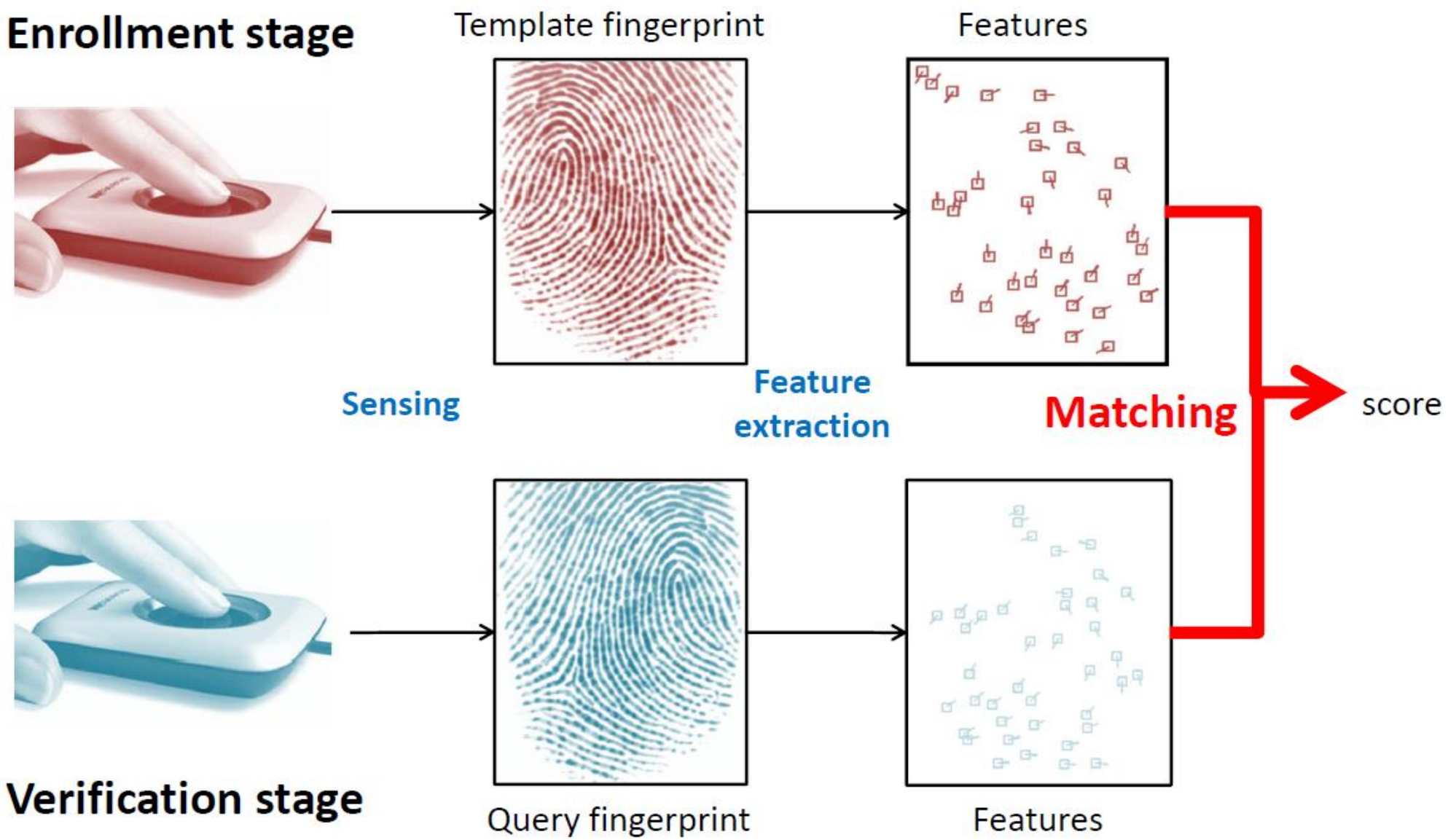


Handbook of fingerprint recognition



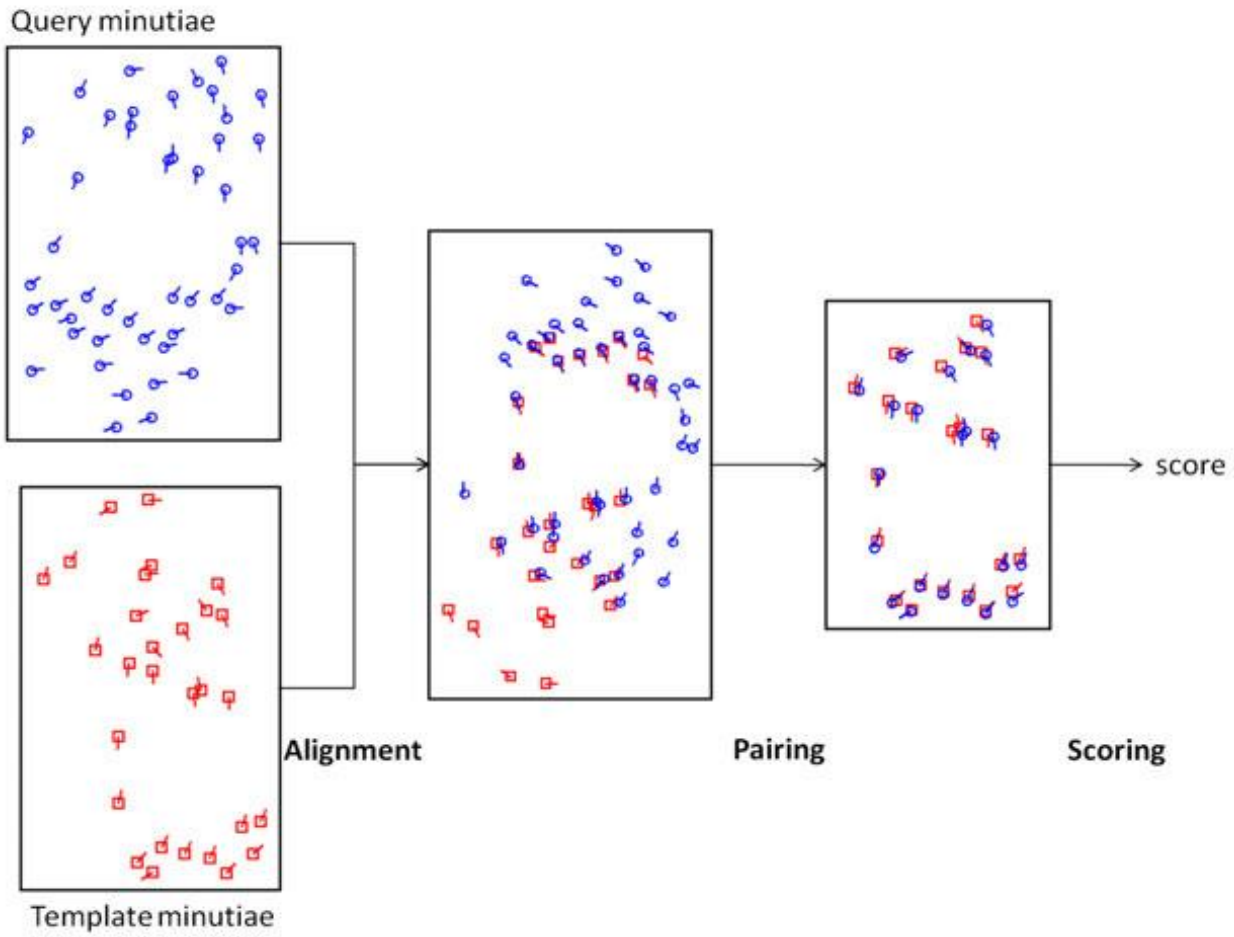
5 Fingerprint Recognition

Flowchart of fingerprint recognition

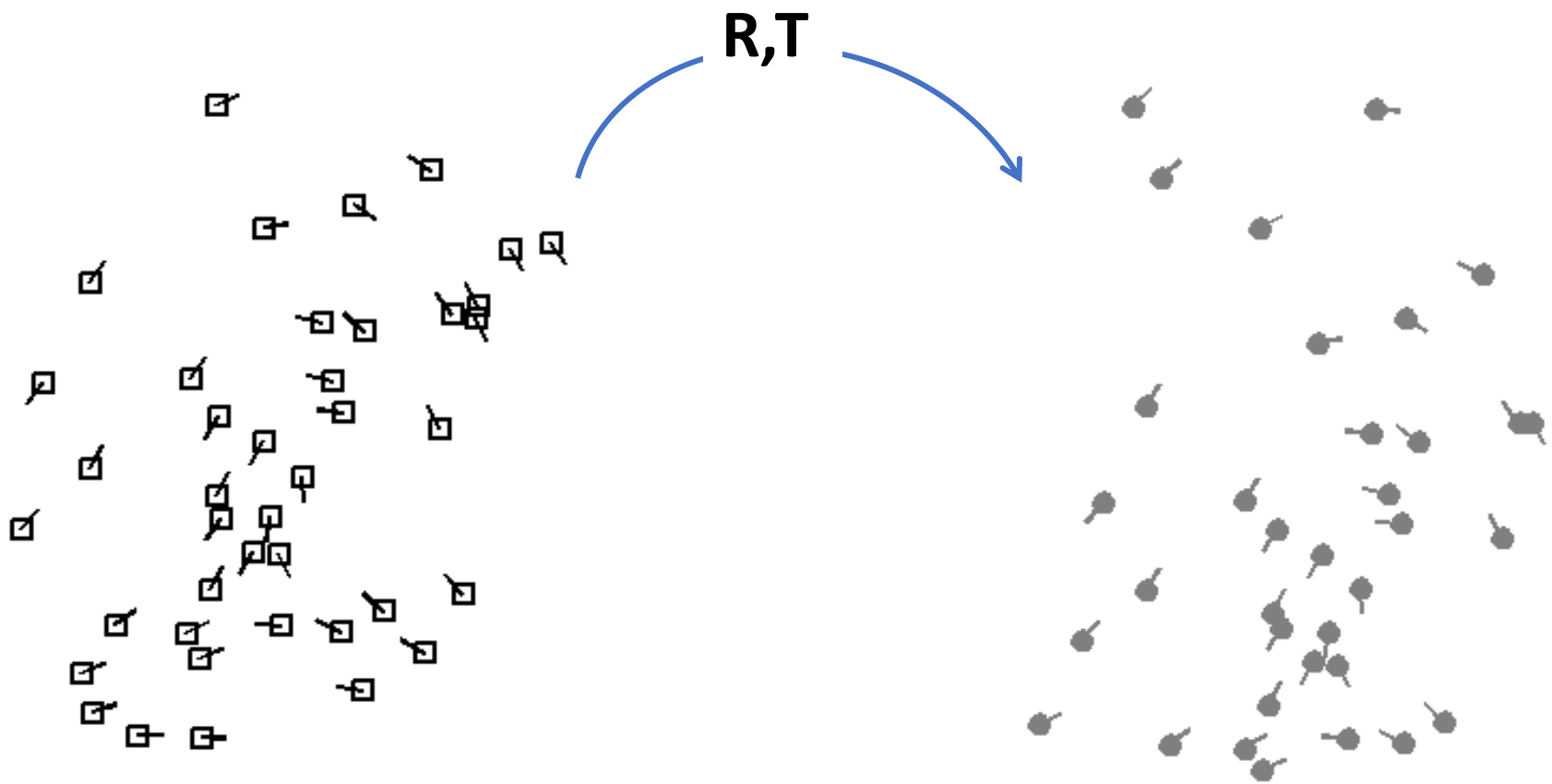


Minutiae matching

- Almost all fingerprint matchers are based on minutiae matching.



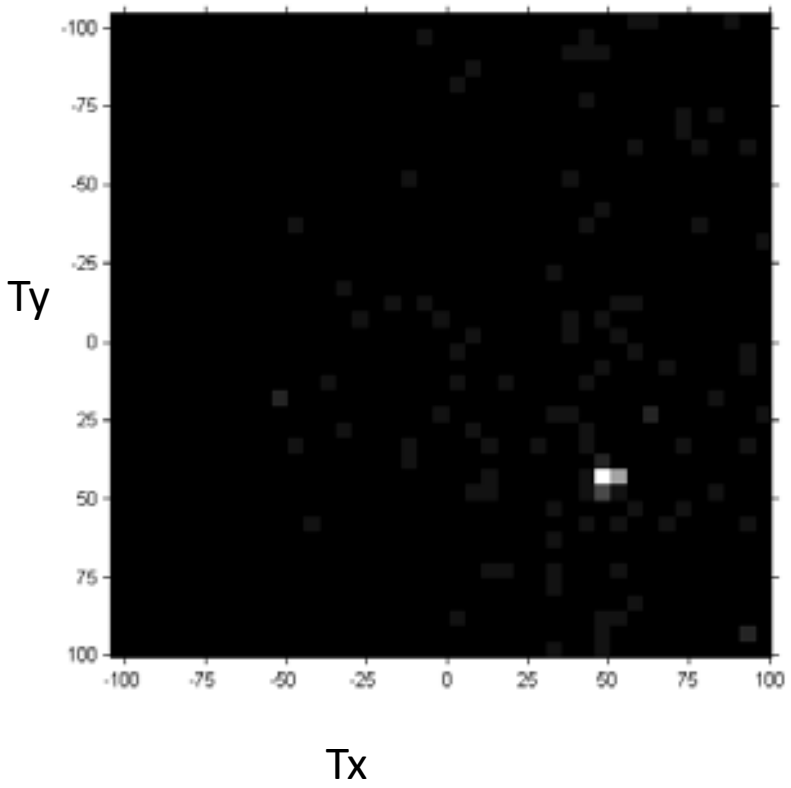
Generalized Hough transform: purpose



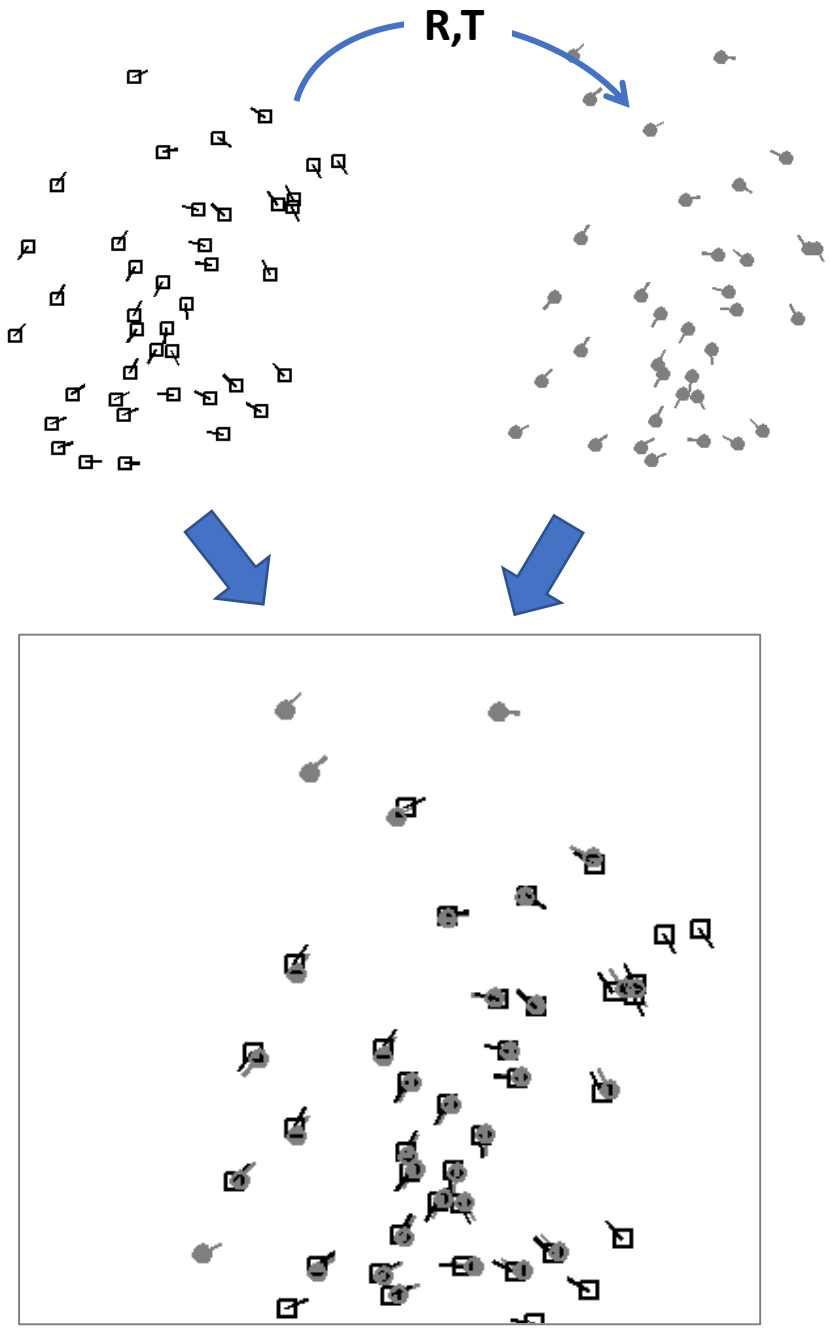
Query minutiae

Template minutiae

Generalized Hough transform:

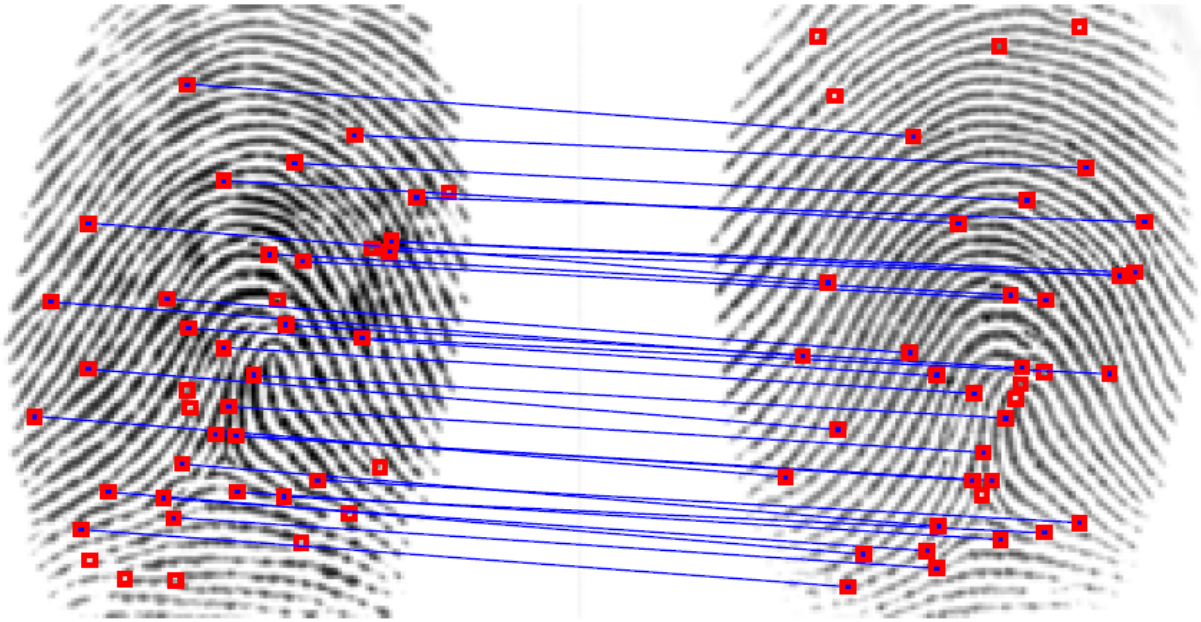


Hough searching space for translation only T=(Tx,Ty)

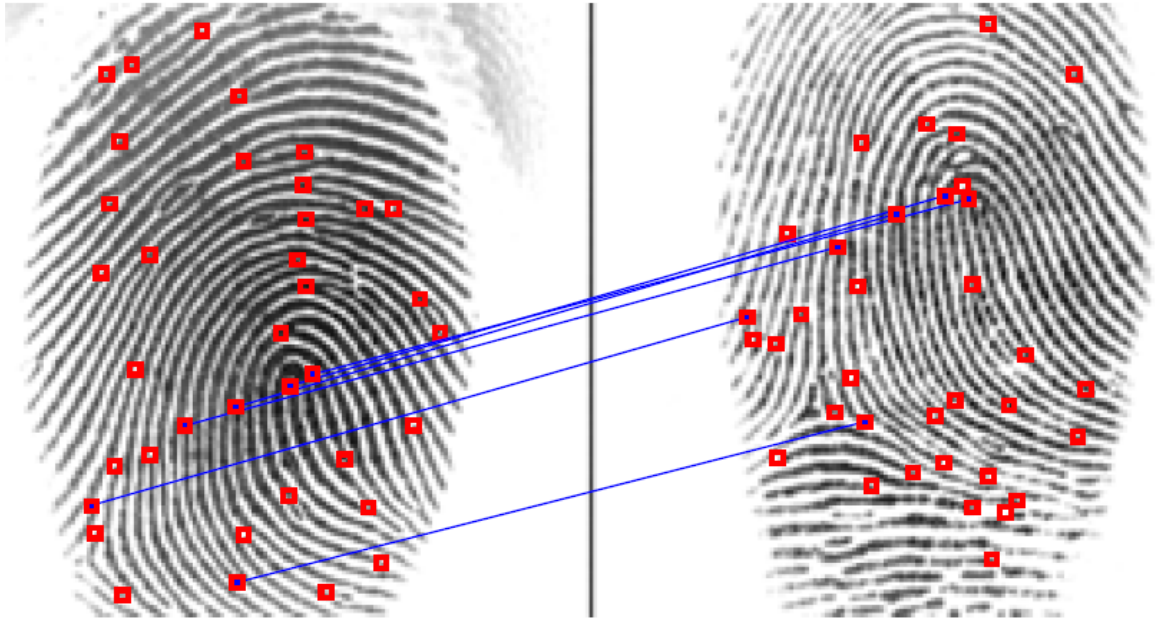


Aligned minutiae sets

Pairing minutiae and matching score



(a) Match score = 614



(b) Match score = 7

Thank you for your attention!